Seed Potato Tuber Production and Dissemination

Experiences, Challenges and Prospects

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Glossary

AARC	Adet Agricultural Research Center
ADC	Agricultural Development Cooperation
ADCS	Adigrat Dissociate Catholic Service
AI	Adoption Index
ANRS	Amhara National Regional State
ARARI	Amhara Regional Agricultural Research Institute
BoARD	Bureau of Agriculture and Rural Development
BPBLP	Better Potato for a Better Life Project
BW	Bacterial Wilt
CCF	Christian Children's Fund
CFC	Common Fund for Commodity
CIP	International Potato Center
CRD	Completely Randomized Design
CSA	Central Statistics Authority
DA	Development Agents
DLS	Diffused Light Store
DRMFSS	Disaster Risk Management and Food Security Sector
EIAR	Ethiopian Institute of Agricultural Research
FAO	Food and Agriculture Organisation of the United Nations
FG	Field Generations
FREG	Farmers-Research-Extension Group
FRG	Farmers' Research Group
HaARC	Hawassa Agricultural Research Center
HARC	Holetta Agricultural Research Center
HI	Harvest index
IAR	Institute of Agricultural Research
IAs	Investment Areas
LB	Late Blight
LER	Land Equivalent Ratio
MoA	Ministry of Agriculture
MRR	Marginal Rate of Return
MYAP	Multi Year Assistance Program
NARIs	National Agricultural Research Institutes
NARS	National Agricultural Research System
NGO	Non-Government Organizations
OoARD	Office of Agriculture and Rural Development
PAR	Photosynthetically Active Radiation

PLRV	Potato Leaf Roll Virus
PPP	Public-Private Partnerships
PRA	Participatory Rural Appraisal
PS	Positive Selected
PSNP	Productive Safety Net Project
PVS	Participatory Varietal Selection
PVY	Potato Virus Y
QDPM	Quality Declared Planting Material
QDS	Quality Declared Seed
RCB	Rotating Credit Base
RCBD	Randomized Complete Block Design
REST	Relief Society of Tigray
RMT	Rapid Multiplication Technique
RS	Revolving Seed
SARI	Southern Agricultural Research Institute
SMS	Subject Matter Specialists
SNNPR	Southern Nations Nationalities and Peoples Region
SPS	Sanitary and Phytosanitary
SPSNP	Support for Productive Safety Net Program
SSA	Sub-Saharan Africa
TAMPA	Tigray Agricultural Marketing Promotion Agency
TARI	Tigray Agricultural Research Institute
TMV	Total Monetary Value
UNSPPA	Uganda National Seed Potato Producers Association
WVE	World Vision Ethiopia
WOREDA	District, administrative unit

Preface

Potato is the world's top non-grain food commodity. Global production over the past two decades has expanded from 267 to 375 million tons, and market opportunities are emerging to respond to the potato as a popular source of affordable food for growing urban populations. A highly dependable food security crop, potato offers important advantages over major food grains. Potato produces more food per unit area than the other major food crop. It generates more employment in the farm economy than other crops and serves as a source of cash income for low-income farm households through access to higher value markets along the potato value chain. Finally yet importantly, potato is not prone to speculative commodities trading on global markets, instead, prices are more likely set by local supply-and-demand conditions.

Yet, potato has long been regarded as a lowly subsistence crop and is still one of the underexploited food crops with a huge unrealized potential to improve food security, income and human nutrition. Ethiopia is one of the countries where the potential of this crop is increasingly being realized as witnessed by growing interest in this crop by private investors and policy makers. However, national average yields are still far below attainable yields and ample opportunities exist to unleash this crop's potential for increased food security and income generation.

It is in this context, that the Ethiopian Institute of Agricultural Research (EIAR) the Amhara Agricultural Research Institute (ARARI), , and the International Potato Center (CIP) with greatly appreciated financial support from USAID, FAO and Sasakawa Global 2000 organized a National Workshop on Seed Potato Production and Dissemination in Bahir Dar on 12 to 14 March 2012. The workshop provided a platform for public and private value chain stakeholders to discuss current activities and future potato research and development priorities. The workshop aimed at sharing and documenting of seed potato production and dissemination experiences: evaluating the current state of national potato seed systems, identification of their constraints and opportunities for improvements: and strengthening public-private partnerships for further development of the potato sub-sector.

This book documents the papers presented during the workshop. It is divided into six sections, covering the following topics: General papers, Rapid multiplication techniques, Seed agronomy, Participatory seed potato production, Crop protection, and Socio-economic aspects. While most of the papers were from Ethiopia, three papers are dealing with aspects of potato production in Eastern Africa and Kenya. Given the fact that farmer access to quality seed still constitutes the main bottleneck to increased potato productivity in Ethiopia and the region in general, the main thrust is on seed potatoes; presenting and discussing research and development topics covering the entire seed potato value chain. The book is the first of its kind to collect and analyze potato seed research and provides the reader with a comprehensive overview of the current state of seed potato production. It presents recent research findings, describes ongoing development activities, and outlines future directions for potato, especially seed potato, research and development in Ethiopia and the region. It is also believed to benefit development actors engaged in the promotion of the crops.

The editors would like to acknowledge the organizers of the conference. We are grateful to Dr. Derege Gorfu for reviewing the papers. We would also like to extend our appreciations to all those who presented papers and the participants of the workshop/conference for their valuable and critical contribution

Welcome Speech

Fentahun Mengistu
Director General
Amhara Regional Agricultural Research Institute

On behalf of the Amhara Agricultural Research Institute, I would like to express my most sincere welcome to you all to Bahir Dar and to the national workshop on *"Seed Potato Tuber Production and Dissemination."*

Because of the importance of potato in this part of the Country, ARARI (through its Adet Research Center) has been given a national mandate to coordinate potato research program since 2006. As part of this task we have taken the initiative and jointly organized this important national workshop with EIAR and CIP which is a great honor of ours to host it here at ARARI premise. Of course, ARARI had also organized Amhara region- level workshop on potato in December 2008 on which various institutions and stakeholders had participated.

This gathering of scientific minds is held at a time when the country's 5 years GTP is on its second year of implementation. The GTP is believed to help the country lay a foundation for transforming from agriculture - to industry-led economy, extricate from poverty and turn to a new rosy chapter of achieving a level of a middle-income economy. Along this path several development targets are set; one is to put an end to food insecurity in this country. Hence, this workshop discussing on potato, one of the important food security crops, is very timely and the proceeds can be turned out a useful input to the realization of food security target, which is very close to the Ethiopian hearts.

As most of you might know, Ethiopia has a very high potential for potato production as its 70 % arable land or >6m ha is located in the mid and high altitudes, which is suitable for potato production. Close to half of the country's potato production comes from Amhara region. Potato is an important food security and a hunger reliever crop in Amhara region and in several other parts of the country by virtue of its ability to mature in advance of most other crops at the time of critical food need. In recent years, the production of this crop is expanding because of availability of improved technologies, expansion of irrigation culture, increased market value, production systems diversification—produced under rainy season, irrigation, residual moisture, short rains and recessed land.

For about four decades now the National Potato Research Program of Ethiopia in collaboration with CIP and other stakeholders have been carrying out various research activities on potato and has made great stride in improved technologies generation. Worth mentioning, among other technologies, is the release of more than 25 potato varieties that has made possible a quantum leap in potato productivity from a mere 8t/ha or less with the use of late blight susceptible local varieties to a yield order of as high as 45 tons/ha. Despite this success and a high demand by the growers, however, improved varieties did not reach to most of our potato growers yet. Reason: simply because of failure to adequately multiply and disseminate their seeds. Potato is perhaps one of the few rewarding crops that has a high demand but failed to appeal much to seed companies and thus overlooked in the formal seed system. Consequently, the informal seed system reigns in much of the country. Although, the latter is an important technology transfer mechanism due to the gap in seed quality control mechanism, the incidence of diseases as bacterial wilt and late blight are becoming serious, in some areas, to the extent of deferring potato production.

On its part, the research system has been trying to hasten adoption of improved potato technologies through extensive demonstration, multiplication, and supply of starter seeds including establishment of TC laboratory for speedy and healthy potato planting material supply, and organize seed grower farmers. Nonetheless, because of the seed multiplication missing link quality planting material of adequate quantity is in serious shortage and remains a major impediment for potato production. This needs to be tackled through a concerted effort among actors in the value chain. This is why the need for organizing this workshop.

This workshop, which is attended by several major actors of the potato value chain including Ministry/Bureaus of Agriculture, the research system (CIP, federal and regional) including senior scientists who made the start of potato research and those earnestly served and is serving the EARS in various capacities. Agricultural Universities, projects working on potato, public and private seed companies, seed producer cooperatives and unions, potato growers and other relevant stakeholders, is expected to serve the purpose I mentioned above.

Therefore, by having such a diversified group of people, bringing our knowledge and experiences to the table, I hope we will share precious ideas and experiences one another and learn better about the challenges that are faced now and those lie ahead on seed potato research and development.

We shall also transcend our perspectives in identifying solutions for strengthened potato seed system through the active public-private partnership, march together toward increasing potato productivity, and contribute to the battle against food insecurity and poverty.

Finally, I would like to express my sincere thanks to the organizing committee and the different institutions that rendered financial, material and technical support for the realization of the workshop.

I thank all of you who have made it to this important workshop again, welcome and wish you a pleasant stay in Bahir Dar.

Thank you!

Opening Speech

Teshome Walle
Deputy Head of Amhara Region Bureau of Agriculture

It is a great pleasure and honor for me to get this opportunity to welcome you all to this very important national workshop on potato seed production and dissemination on behalf of the Bureau of Agriculture and me.

In a country with dominating agrarian economy like Ethiopia, alleviating food security is one of the most important objectives to be attained by the agriculture system.

At present, our developmental government has adopted comprehensive and well thought out policies to promote agriculture and rural development. As a result, we have achieved a double-digit economic growth for the last eight consecutive years. However, our economic growth could not be sustained unless we intensively work on the introduction and promotion of new, adaptable and high productive technologies to the smallholder farmers.

As you might know, Ethiopia has possibly the highest potential for potato production of any country in Africa. An estimated seventy percent of the country's arable land is potentially suitable to potato cultivation. To this end, the livelihood of thousands of highland farmer’s in the country in general and Amhara region, in particular rely on potato production. However, In spite of its growing importance to Ethiopia's food security, the introduction of new technologies and infrastructural development to increase the production and productivity of this crop remains very low.

In our region, potatoes are often grown in rotation with other crops such as maize, rapeseed, and faba beans during the *meher* (main cropping) season. Now, the crop is rapidly expanding to irrigable areas. For instance, in Koga irrigation project, out of the total 5,060 ha of land covered by different crops so far, 2042 ha (41%) is entirely covered by potatoes and we are expecting around 40,000 tons of potato’s production.

Although, potato is an important crop towards to food self sufficiency, the attention given by the policy makers, extension workers, and researchers is found at lower level. At present, our smallholder potato growers face two serious problems: production and market problems.

Sustainable development could not be achieved without the active participation of all actors including GOs, NGOs, and the community. Hence, we appreciate and acknowledge FAO, USAID, CIP, EIAR, and ARARI for their initiative to organize this very important and symbolic national workshop on the experiences, challenges, and future prospects of potato seed tuber production and dissemination. On this workshop, prominent professionals, researches and policy advisors both from the country and abroad are taking part. I hope and believe this workshop will be a revelation for our region as the invited guests are quite experienced and know how to transfer skill and knowledge to the rest of us. Thus, unquestionably, we could benefit a lot from you and the regional bureau of agriculture will be more than pleased to realize the output of this workshop to the interest of our poor rural potato growers.

Please, accept, once more our thanks and appreciation to you for coming here to share your rich experiences in the area of this economically very important crop, potato and we look forward to working with you on this matter effectively and efficiently.

With this remark, I declare this national workshop is officially opened and wish you all fruitful deliberations.

Thank you!

Opportunities and Challenges for Commercial Seed Potato Production in Ethiopia

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Introduction

Quality of potato seed is a key factor in profitable potato production. Globally, commercial setting of a private sector seems to be a prerequisite for a sustainable seed system resulting in a permanent supply of high quality seeds. Ethiopia is well on the way to support and facilitate the emerging private sector in this key issue of profitable agriculture. Always this crucial link of a single cash crop should be considered in relation to the complex reality of the farmers.

The seed enterprise Solagrow PLC, from Dutch origin, was established in 2007 in Ethiopia, having its headquarters at Hidi, Debre Zeit, and Oromia Regional State. It defined its vision as "to contribute to food production and food security of Ethiopia by providing seeds, expertise, and technology to the farmers on a sound commercial basis, re-investing its dividends into the ongoing development of the agro-economic sector." The primary focus was the potato crop. To produce quality seeds for the perennial potato production in Ethiopia, Solagrow needs to get suitable land at two altitudes: highland farms (< 2,400 m.a.s.l.) to produce healthy seed during the warm spring season (January-May) and midland farms (1,500-2,000 m) to produce healthy seed during the cold autumn season (October-January). In 2010 and 2011, the company acquired two highland farms at Haro Wenchi (Woliso, West-Shoa, and Oromia) and Doba (Bekoji, Arsi, Oromia). Currently the company is urgently looking for good locations for its midland farms in the other regions to be able to grow potato seed in the autumn season.

Commercial Seed Potato Production

To further improve the Ethiopian potato sector, a number of critical prerequisites are to be met: improved varieties, quality seed of those varieties, application of improved cropping practices and access to proper markets to sell potatoes produced.

Solagrow got the chance to register three early-maturing Dutch-varieties and owned by HZPC Holland BV, after having them tested in six locations in the Ethiopian highlands. The initial elite seed lots were imported by reefer containers to get the seed production started. Although potato seeds from The Netherlands meet the highest available phytosanitary levels worldwide, still the disease spectrum of Europe and East-Africa are different. To prevent the risk of introducing new pathogens or strains, Solagrow decided to stop the import of field-grown seeds and to establish its own minituber-production of the Dutch varieties. This enables the company to produce huge amounts of quality seeds at the lowest risks, preventing the further enrichment of the yet abundant pallet of potato diseases in Ethiopia and East-Africa. This minituber facility will also be used to produce the basic stocks of the proven Ethiopian varieties. Currently a new set of Dutch varieties is tested to find candidate varieties with high processing qualities.

In close collaboration with the Ethiopian farmers, the company is developing a cropping strategy in which the timing of crops and varieties comply with the different seasons and requirements of the market. Finally, attention is paid to address the seed and ware potato markets to ensure that the efforts of farmers to produce quality potatoes will be paid off by the consumer market, via retail, processing, or export.

Farmers' reality

Many times the position of the small farmers is described in terms of "poor peasants that need our continuous help to survive." In addition, most of the time, this third party of poor farmers is not represented at the meetings and workshops and many interventions showed only temporary effects. As to our short-term experience in Ethiopia, the Ethiopian farmers are not that much different compared to their colleagues elsewhere. Although many of them are poor, still most of them understand quite well what input, output and profit means.

The major interest of all farmers, whether small or big, is the profit to be gained from his crop. Of course, they are happy to see a huge pile of potatoes behind their hut, but if no merchant pays its price, the farmer will lose. Final profit counts the income of the farmer needed to keep the family economics running. This exactly is one of the reasons why farmers are not interested to grow seed potatoes, as their limited tuber weight is not covered by an equivalent higher price per kilogram.

Furthermore, the farmers usually possess limited resources. Even relatively small investments on seeds, fertilizer, mechanization, irrigation, pesticides, and labour are a financial burden for most of the farmers and they tend to minimize those costs. At the same time, many farmers are lacking the required expertise and knowledge level to produce. This combination results in low production levels. Furthermore, traders and intermediaries dominate the connection between farmers and consumers in Ethiopia. The farmers are lacking the actual market data and usually they will only get a low price for their products. Those intermediates also will play around with the numerous lots, trying to increase their profits by blending different qualities and transporting to far-away destinations.

I would propose to consider our farmers as being commercial farmers, or small investors. Almost every farmer is selling part of his crop and this “production for profit” deserves the label “commercial”. This also demonstrates the need of skills with respect to the basic farm economics. Every farmer should understand the balance between input, output, and profit. The second aspect is the evaluation of the different qualities of inputs, enabling the farmer to decide about the purchase of local seed versus certified seed, to apply the recommended rates of fertilizer and to choose the right time of marketing his products. Inputs with added value then will be accepted by farmers as long as their value addition is higher than it higher purchase price. This basal mechanism will determine the success of any introduction of new varieties and new technology. When it pays off at normal risks, it will serve the farmer and he will accept and implement the profitable novelty.

One other skill to be developed at farmer’s level is to make reservations out of the cash income of the crop. This partial saving should serve to enable the farmer to invest in his next crop, to pay his next investments from his current profit. Poor farmers then just need for one or two times financial credits to get started and after that he will earn his own investment capital for the subsequent crops.

Pillars of company strategy

To meet the real needs of our farmers, the approach of our commercial seed company is based on the next four pillars

To address the whole potato chain from ‘field to fork’, ultimately to ensure the success of our seed link;

To pay equal attention to the rotation crops as potato is just one crop of the farmer;

To support farmers and outgrowers by a demonstration farm in their region to give them access to the latest knowledge and technology; and

To link education and extension institutes to the farmers practice that may ensure the continuous experience sharing between scientists and extensionists and students and farmers.

Whole potato chain: Breeding to eating, from forceps to fork

The success of the potato chain is determined by the success of the weakest link. To ensure the profitability and thus the continuity of each link, we cannot afford to limit our scope to just our part of the chain. Thus, Solagrow is involved in at least the following links: variety selection – minituber production – outgrowers training - basic seed production – seed certification - seed trade – ware potato growing – processing – wholesale and retail. Since most links of the potato chain in Ethiopia are still immature, we are obliged to pay attention to all preceding and subsequent links of 'seed production', waiting for the time when other private partners are taking over parts of this multiple task.

Potato focus versus Crop Rotation

A normal and balanced farm applies crop rotation and diversification. In addition, most of the smaller farms are integrated farms possessing dairy animals. Therefore, a farmer is not just positioned to one link in the potato chain, but is one central link in many value chains. Our farmers are embedded in a *value web*. In approaching farmers, we must consider this and in supporting the development of the farm, we cannot neglect this reality. To our experience, farmers tend to move to mono cropping when they once get good profit from a specific crop. We can prevent this negative trend by creating awareness on this topic of rotation and by offering other alternative crops to the farmers. For our company this has resulted in major investments in other rotation crops, as linseed, vegetables, and malting barley, to make seeds, expertise and (export) markets available to the farmers. The major advantage of this approach is the continuous collaboration with our farmers and the spreading of risks by growing complementary crops.

Demonstration farms in midst of outgrowers and technology sharing center

When we started in 2007, we expected to be able to organize the farmers and outgrowers out of one main office in Debre Zeit. Soon we learned that the only way to establish a strong and direct relationship with farmers is by being their neighbor. Therefore, we are aiming to get a 200 hectare nucleus farm with 30-50 ha of potatoes in each prominent region. This nucleus farm will serve as demonstration site to show the improved practices of the full crop rotation as well as the performance of the improved varieties. It also provides the opportunity to offer the neighboring farmers the service of renting adequate machinery, whereas the investment and maintenance of those assets can be centralized and shared.

Links to research and extension and education

Finally yet importantly, Solagrow is aware that just one company never can cover all the needs of the farmers. Therefore, our enterprise tries to establish long-term collaborations with research and extension institutes and services. The involvement of lecturers and students provides the opportunity to demonstrate the newest achievement to the new generation of farmers and entrepreneurs.

All-round support to farmers as provisional solution

The company development since 2007 shows the stepwise involvement into all the links of the farmer's value web. This encompasses the risk of getting lost in too many aspects of the sector development. On the other hand, neglecting problems and shortcomings in the contiguous links of your value chain will adversely affect your link as well. Therefore Solagrow prefers to focus on its core objectives and to stimulate other partners to get involved in the adjacent links, as defined as follows:

Core objectives:

- Improved potato varieties;
- Production of minitubers and basic seed generations;
- Quality seed production by commercial outgrowers;
- Coaching of those farmers by training and demonstration; and
- Market development for potato seed

Supportive objectives:

- Value chain of rotation crops: variety-seed-cropping-market;
- Micro-credits for first investments;
- Rental of machinery; and
- Market development of products up to the consumers

Finally, the establishment of strong producers associations and direct links to the major markets will warrant the ultimate goal of potato production: bringing profit to the farmer.

Conclusion

Contributing to the sustainable development of potato farmers in Ethiopia, requests a strong focus on your own link of the potato value chain. Dedication and specialization is required to overcome the numerous challenges of this still immature agro-sector. But as the potato value chain cannot be separated from the daily farmer's practice, at the same time we have to recognize and be involved in the parallel value chains of rotational crops. As long no other strong stakeholders are present to address those links, it requires a transitional involved and contribution of Solagrow PLC to all links in this network of chains, the farmers' value web. The marketing mix is often defined in terms of the 5 P's. To my understanding the approach of sustainable support to the Ethiopian farmers can also be defined in terms of P's, describing the core actors in this farmers' value web. Adequate support to bring sustainable and profitable value chains are:

- Requested by Peasants;
- Done by Private;
- Facilitated by Public, and
- Paid by Profits

In this way our farmers, as being commercial investors, are the leading players who determine and perform the daily development of cropping and marketing. The farmers determine the process of development and as being private investors, they produce the crop. The supply of required inputs, technology, and finance to those private farmers is done by the private input suppliers as well as by the receiving market partners.

Governmental bodies and institutes together with NGO's facilitate this development process by laws and regulations and by providing the socio-economic knowledge.

The whole process is paid by the profits that our farmers are gaining by producing good amount of marketable food products. Finally the humble potato pays!

Pest Risk Analysis for Potato Importation into Ethiopia: A Case of Four Source Countries

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Introduction

The potato improvement program in Ethiopia imports and utilizes many potato germplasm and early breeding materials from external sources, and thus, thousands of potato samples were imported from different countries that include Kenya, Uganda, Peru, the Netherlands, etc. in the past. Presently, Ethiopia imports 25 to 40 potato planting materials every year. In addition to these, potato planting materials (particularly registered varieties) could be imported through technology shopping programs for adaptation test and subsequent registration or even for direct planting during seed shortage periods.

Quarantine precaution against inadvertent importation of pests during germplasm and technology exchange was an important topic in the world since many years. Accordingly, in Ethiopia periodic reviews of quarantine information were published (Awgechew *et al.*, 1985; Awgechew, 1993; Merid *et al.*, 2008) to increase awareness on quarantine pests of the country. In addition, plant quarantine guideline for Agricultural Research was published by EIAR (Dereje, 2006) to be used by the National Agricultural Research System (NARS) to support the risk management operations at national level. As a result, during plant importation for research, regular inspection was carried out at Holetta Agricultural Research Center (HARC) of the EIAR for freedom of pests that include arthropods, nematodes, pathogens causing diseases and weed seeds. Results indicate that until 2006 alone many shipments were destroyed with appropriate methods due to infestation with serious and risky pests (Merid *et al.* 2008). Additionally in accordance with our inspection guidelines and procedures (Dereje, 2006), many germplasm materials imported into the country were subjected to meticulous post-entry quarantine to safeguard the country from alien pests of quarantine concern.

At present, however, importation of plant materials (including potato) into a country necessitate to consider recent developments in regulatory sciences for sound biological, economic, social and policy decisions. This trend in quarantine inspection and post-entry follow-up for any plant commodity demanded to consider guidelines and procedures outlined by the sanitary and phytosanitary (SPS) standards that provides terms of the International Plant Protection Convention, rectified by Ethiopia. To be effective in this important regulatory pest management undertaking, this review attempts to provide a concerted approach for effecting pre- and post-entry regulatory measures for potato importation into Ethiopia based on pest risk analysis (PRA).

Accordingly, this paper describes quarantine precautions in the import control scenarios and presents pest risk analysis (PRA) based on pathway analysis for importing potato into Ethiopia from four source-countries including the Netherlands, Peru, Kenya, and Uganda. It also provides protocols for preliminary inspection and detection, and phytosanitary measures of potentially risky pests to safeguard the country. Finally, it forwards a list of important considerations for the future.

Mechanism of Import Control

Mechanism of plant quarantine operates under five set of guiding principles and procedures comprising embargoes, inspection and certification, disinfection, special permits, and unrestricted shipments. In order to be effective, both pre- and post-entry quarantine measures are very important and complementary. In case of potato importation into Ethiopia, pre-entry quarantine measures may include importing from pest-free areas, field inspection at the country of origin, and laboratory tests and then carrying out appropriate treatments at the country of origin. This is carried out based on the results of PRA, in which potato tubers are major import item. Sprouted tubers could have stems, leaves, and sometimes roots that may harbor primary inocula of pathogens or juveniles or even eggs. After entry into the country (post-entry) on the other hand, follow-ups may include closed quarantine, production of pest-free tubers (tuberlets and plantlets), field inspection, rouging and cleaning, laboratory testing, and treatment and disposal of risky samples. Since the scope of this paper is limited to experimental materials, embargoes and unrestricted shipments are of little relevance hence are not considered for the time being. These could fairly fulfill the requirements of sound control mechanism for potato quarantine pests. The importation of potato into Ethiopia until now considers the prior approval of import permits by the regulatory body (MOA), each imported consignment was expected to be accompanied with world standard phytosanitary certificate of the source country based on inspections of competent experts. In the certificates, all prerequisites listed in the import permit should be fulfilled and hence samples should be treated accordingly during and after shipments. After verification and release for post-entry follow-up by

EIAR, all imported samples were subjected to series of inspection and detection procedures, although not adequate. Sorting and disinfection were carried out to salvage safe germplasm materials whenever possible and destroyed unsafe ones to avert associated risk are some of the measures usually taken. Even then, the number of intercepted pests increase from time to time warranting the need for still more strict quarantine measures based on sound biological data and PRA.

Pest Risk Analysis (PRA)

In actual practice, on a worldwide scale, issues of inadvertent importation of potentially hazardous pests into new areas arise in relation to several dimensions that include biological, economic, political, and social scopes (Kahn, 1979). These are factors determining the entry status of an item, in this specific case potato tubers (planting materials), and subsequent post-entry follow-up to minimize the chance of introducing alien pests that include arthropods, nematodes, disease causing pathogens, weed species, etc. are the issues under consideration. When only one of these factors, especially biological factor, is in use to determine the entry status of items, the activity ought to be based on PRA.

PRA is a thoughtful process whereby the entry status of potato plant, plant products, cargo, baggage, mail, common carriers, etc. is based on calculated risk of inadvertently introducing hazardous pests/pathogens with potato tubers as moved by man (Kahn, 1979; Merid *et al.*, 2008). Therefore, PRA is an indispensable process when intending to import planting materials into this country. The PRA is hence carried out for potato importation into Ethiopia from four possible source-countries using information from CABI Plant Protection Compendium (CABI, 2007) and current information on pests of potato in Ethiopia (Ferdu *et al.*, 2009; Mathias and Waga *et al.*, 2009; Mesfin, *et al.*, 2009). As a result, the pest spectrum of quarantine importance to Ethiopia is given in Table 1. Pest categories in order of importance include arthropods, nematodes, fungi, bacteria, and then weed species. This is mostly the order for potato, but when the origin is from the tropics and vector activities are expected to be high viruses would appear with nematodes.

Table 1: Number of pest species of quarantine importance when importing potato tubers into Ethiopia from the Netherlands, Peru, Kenya and Uganda

Pest category	**Netherlands**	**Peru**	**Kenya**	**Uganda**
Arthropods	25 (22)	17 (11)	10 (1)	9 (1)
Nematodes	18 (8)	11 (1)	11 (1)	8
Fungi	18 (9)	12 (3)	5	6
Bacteria	6(3)	3	4 (1)	1
Viruses	10 (4)	12 (7)	1	1
Weeds	21	11	9	18
Total	**98**	**66**	**40**	**43**

Values in parentheses are specific to the country of origin

Generally, PRA has three phases including initiation, risk assessment, and risk management. The initiation phase starts with the request of Import Permit to import potato plant materials from specific country of origin. At this stage, plant quarantine specialists initiate PRA with some details described in the request form. Since no specific pest species was a target, a pathway analysis of PRA option was perceptibly followed and the pathway details considered in this PRA are:

- Country of origin including the Netherlands, Peru, Kenya and Uganda;
- Importing country is Ethiopia;
- Crop is *Solanum tuberosum*; and
- Commodity types to import are tubers, stem, roots and leaves.

Risk assessment considers two areas of information that eventually determine the pest balance of the country. Pest balance is the list of pests that are present in the country of origin minus the list of pests widely distributed in the importing country. Up-to-date information on potato pests in Ethiopia includes arthropods (Ferdu *et al.*, 2009), diseases causing pathogens (Mesfin, *et al.*, 2009) and weed species (Mathias and Waga *et al.*, 2009) that are recently published while those in source countries could be obtained from CABI (2007). From this, two pest categories including those potentially requiring phytosanitary measures and those pests excluded from the risk assessment are determined. This information enables us to differentiate pests of quarantine concern to the country when importing potato tubers for planting (Tables 2, 3, 4, 5 and 6). Listing pests and determining the mode of transmission and dissemination from source to destination are important and useful tool to decide import permission or on the type and level post-entry follow-up. New pest records of all directions are essentially important to conduct a sound PRA. Pests recorded on the host plant, liable to be carried on the commodity and absent in the importing country are considered for phytosanitory measures while pests recorded and widely distributed in the importing country were excluded from risk assessment. Generally, the order of pests for potato in this PRA follows as arthropods, nematodes, fungus, bacteria, viruses, and weeds.

Excluding weed species, a total of 118 pests (including 45 arthropods, 25 nematodes, 23 fungi, 8 bacteria, and 17 viruses are of quarantine concern to Ethiopia when importing potato from four germplasm source counties considered in this risk assessment (Tables 2, 3, 4, 5 and 6). The number and species vary from country to country, because the pest index of each country is different. The highest being in the Netherlands consisting 77 pests, followed by Peru (55 pests), then Kenya (31 pests) and Uganda (25 pests). Risk elements considered for this analysis includes climate–host interaction, host-range, dispersal potential (population dynamic and epidemiology including variability), and plant parts imported, and possible economic and environmental impacts. Accordingly, importing in-vitro materials from temperate zone reduce the risk by 95% when compared with importing sprouted tubers from subtropical zones. To facilitate the risk management task, some detection protocols and phytosanitary measures are given for each pest category in the following sections.

Table 2: Arthropod pests associated with the pathway of importing potato tubers into Ethiopia from four major source counties and potentially requiring phytosanitary measures in Ethiopia

Arthropod species(common name)	**Netherlands**	**Peru**	**Kenya**	**Uganda**
Adelphocoris lineolatus (lucerne bug)	x			
Agriotes lineatus (wireworm)	x			
Agriotes obscurus (dusky wire worm)	x			
Araecerus fasciculatus (cocoa weevil)			x	x
Autographa gamma (silver-Y moth)	x			
Cacoecimorpha pronubana (carnation tortrix)	x			
Chrysodeixis chalcites (golden twin-spot moth)	x		x	x
Chrysodeixis includens (soybean looper)		x		
Cryptomyzus galeopsidis (currant, aphid, black)	x			
Diabrotica speciosa (cucurbit beetle)		x		
Dysmicoccus brevipes (pineapple mealybug)		x	x	x
Empoasca vitis (smaller green leafhopper)	x			
Frankliniella	x			
Gryllotalpa gryllotalpa (European mole cricket)	x			
Hyalopterus pruni (mealy plum aphid)	x			
Jacobiasca lybica (cotton jassid)			x	x
Leptinotarsa decemlineata (Colorado potato beetle)	x			
Liriomyza huidobrensis (serpentine leafminer)	x			
Loxostege sticticalis (beet webworm)	x			
Mamestra brassicae (cabbage moth)	x			
Manduca sexta (tobacco hornworm)		x		
Melolontha melolontha (white grub cockchafer)	x			
Naupactus leucoloma (white fringed weevil)		x		
Nesidiocoris tenuis (tomato bug)				x
Nipaecoccus viridis (spherical mealybug)		x	x	x
Orthezia insignis (greenhouse orthezia)		x	x	x
Ostrinia nubilalis (European maize borer)	x			
Pantomorus cervinus (rose beetle)		x		
Peridroma saucia (pearly underwing moth)	x	x		
Phenacoccus madeirensis (cassava mealybug)		x		
Philaenus spumarius (meadow froghopper)	x			
Premnotrypes spp. (weevil)		x		
Pseudococcus calceolariae (scarlet mealybug)	x			
Pseudococcus longispinus (long-tailed mealybug)	x	x	x	
Rhopalosiphum rufiabdominale (rice root aphid)		x	x	
Sminthurus viridis (lucerne flea)	x			
Spodoptera eridania (southern armyworm)		x		
Spodoptera frugiperda (fall armyworm)		x		
Symmetrischema tangolias (tomato stem borer)		x		
Thrips angusticeps (field thrips)	x			
Tipula paludosa (European crane fly)	x			
Trialeurodes ricini (castor bean whitefly)			x	x
Tetranychus cinnabarinus (carmine spider mite)		x		x
Tetranychus evansi (red spider mites)			x	
Xestia c-nigrum (spotted cutworm)	x			

Table 3: Nematodes associated with the pathway of importing potato into Ethiopia from four major source counties and potentially requiring phytosanitary measures in Ethiopia

Nematode species (disease)	**Netherlands**	**Peru**	**Kenya**	**Uganda**
Criconemella (ring nematode)		x	x	
Ditylenchus destructor (potato tuber nematode)	x	x		
Ditylenchus dipsaci (stem and bulb nematode)	x	x	x	
Globodera pallida (white potato cyst nematode)	x	x		
Globodera rostochiensis (yellow potato cyst nematode)	x	x		
Helicotylenchus dihystera (common spiral nematode)			x	
Helicotylenchus pseudorobustus (spiral nematode)	x		x	x
Heterodera trifolii (eelworm, Clover cyst)	x			
Longidorus (longidorids)	x		x	
Meloidogyne arenaria (peanut root-knot nematode)	x	x		x
Meloidogyne chitwoodi (columbia root-knot nematode)	x			
Meloidogyne fallax (false Columbia root-knot nematode)	x			
Meloidogyne hapla (root knot nematode)	x		x	x
Meliodogyne javanica (sugarcane eelworm)		x	x	x
Meloidogyne minor	x			
Nacobbus aberrans (false root-knot nematode)		x		
Pratylenchus brachyurus (root-lesion nematode)		x		x
Pratylenchus coffeae (banana root nematode)			x	x
Pratylenchus penetrans (northern root lesion)	x		x	
Pratylenchus thornei	x			
Rotylenchus parvus (reniform nematode)			x	x
Rotylenchus reniformis (reniform nematode)		x		x
Trichodorus (stubby root nematodes)	x	x	x	
Trichodorus viruliferus (stubby root nematode)	x			
Tylenchorhynchus claytoni (stunt nematode)	x			
Xiphinema diversicaudatum (dagger nematode)	x			

Table 4: Fungi associated with the pathway of importing potato tuber into Ethiopia from four major source counties and potentially requiring phytosanitary measures in Ethiopia

Fungi species (disease)	**Netherlands**	**Peru**	**Kenya**	**Uganda**
Alternaria radicina (black rot of carrots)	x			
Botryotinia fuckeliana (grey mould-rot)	x			
Chalara elegans (black root rot)	x	x		x
Cochliobolus lunatus (mould of grasses and sorghum)	x			
Didymella lycopersici (canker of tomato)	x			x
Geotrichum candidum (citrus sour rot)	x			
Gibberella baccata (collar rot of coffee)		x	x	
Gibberella zeae (headblight of maize)	x	x	x	
Golovinomyces orontii (powdery mildew)	x			
Helminthosporium solani (silver scurf)	x			
Phoma foveata (potato gangrene)	x	x		
Phytophthora cryptogea (tomato foot rot)	x			
Phytophthora erythroseptica (pink tuber rot)	x	x		
Phytophthora infestans (Phytophthora blight)	x	x	x	x
Pythium aphanidermatum (damping-off)	x	x	x	
Pythium ultimum (blackleg of seedlings)		x		
Pythium vexans (damping off)	x			x
Rosella bunodes (black root rot)		x		x
Septoria lycopersici (annular leaf spot of potato)		x		
Synchytrium endobioticum (wart disease of potato)	x			
Thacaphora solani (potato smut)		x		
Ulocladium atrum (Ulocladium blight of potato)	x			
Verticillium dahliae (verticillium wilt)	x	x	x	x

Table 5: Bacteria species associated with the pathway of importing potato into Ethiopia from four major source countries and potentially requiring phytosanitary measures in Ethiopia

Bacteria pathogens (disease)	**Netherlands**	**Peru**	**Kenya**	**Uganda**
Clavibacter michiganensis subsp. sepedonicus (Potato ring rot)	x			
Erwinia carotovora subsp. *atroseptica* (potato blackleg disease)	x	x		
Erwinia chrysanthemi (bacterial wilt of dahlia)	x	x	x	
Pectobacterium chrysanthemi (slow wilt)	x			
Pseudomonas syringae pv. *garcae* (bacterial blight of coffee)			x	
Pseudomonas syringae pv. *tabaci* (wildfire)			x	x
Ralstonia solanacearum race 3 (brown rot of potato)	x	x	x	
Streptomyces scabiei (potato scab)	x			

Table 6: Viruses associated with the pathway of importing potato into Ethiopia from four source countries and potentially requiring phytosanitary measures in Ethiopia

Virus (disease)	Netherlands	Peru	Kenya	Uganda
Andean potato mottle virus (Andean mottle of potato)		x		
Arracacha virus B		x		
Pepino mosaic virus	x	x		
Potato black ringspot virus (calico disease of potato)		x		
Potato leafroll virus	x	x		
Potato mop-top virus (potato mop-top)	x	x		
Potato virus M	x			
Potato virus S	x	x		
Potato virus T		x		
Potato yellow vein virus (yellow vein of potato)		x		
Potato yellowing virus		x		
Tobacco necrosis virus (augusta disease of tulip)	x			
Tobacco rattle virus (spraing of potato)	x			
Tobacco ringspot virus (annulus tabaci)		x		
Tobacco streak virus (stunt of asparagus)	x	x		
Tomato black ring virus (ring spot of beet)	x			
Tomato spotted wilt virus (tomato spotted wilt)	x		x	x

Protocols for Inspection and Detection

Direct inspection of potato tubers

Direct inspection of the imported potato tubers is the primary stem in the post-entry quarantine procedures. This is mainly carried out to examine the presence of infestation and visible infection by alien pests using PRA results (Tables 2, 3, 4, 5 and 6). All samples should pass through this direct inspection process. Usually, visual or aided examination of tubers, tuberlets, plantlets, roots, packaging materials, associated soil debris using magnifiers or binocular microscope that provide adequate vision on the presence of pest infestation or symptoms of tuber and other plant organs infection by any pathogen. Some pathogens and internal infestation by arthropods, however, need special detection methods to confirm pest infestation. In this case, appropriate detection methods should be specified for each specific pest considering its requirements and conditions.

Detection of arthropods

Forty-five arthropod pests are of quarantine concern for Ethiopia because of this PRA (Table 2). Inspection, as described above, is just enough to confirm external infestation. Internal infestation, however, needs further detection methods that include dissection, incubation, staining, or x-ray. For potato tubers, dissection and/or incubation method could provide adequate information and is dependable method although time taking. Specific conditions of the pest or group of pests determine the conditions of incubation, however. Although identification at species level is mostly difficult for general plant protectionists, the use of CABI Compendium (2007) could facilitates and may enables one to take appropriate measures against these arthropods in imported potato tubers.

Detection of nematodes

Twenty-five nematode species are of quarantine concern (Table 3). Extraction methods through inverted funnel, washing and incubation, dissecting plant tissues and staining could give reliable evidence for detecting plant parasitic nematodes. Like arthropods, identification aid could be the CABI Compendium (2007).

Detection of fungi

Twenty-three fungi species are of quarantine concern in imported potato tubers (Table 4). Moist chamber and agar plate methods could generate reliable data with reasonable cost. The former method is rather simple while the agar plat method utilizes general media such as Potato Dextrose Agar, Malt Extract Agar or any seed extract enriched dextrose-agar and incubated at temperature between 20 to 25^{O}C could serve the purpose.

Detection of bacteria

Eight bacteria species are of quarantine concern in imported potato (Table 5). Many workers (Vishunavat, 2007) recommended ELISA for detection of these bacteria. However, agar plate method could generate reliable data with reasonable cost. Specifically, the medium to be used should contain important nutritive substances and eventually incubated at 25^{O}C.

Inspection and detection of viruses

Seventeen viruses are of quarantine concern in imported potato tubers into Ethiopia (Table 6). Visual inspection could not help much for this group of agents. Thus, detection methods using specific Kits for potato viruses and other methods including grow-out test in the greenhouse and field inspection with rigorous rouging for cleaning could help in reducing the risk of establishment in potato crops.

Inspection of weed seeds and identification

Potato tubers should be free of any weed seed to avoid their establishment in the country. Visual and/or aided inspection of dry seeds using magnifiers or binocular microscope provides adequate information on presence of any weed seed, but identification of the weed species require growing weed seed under well-protected situations in the greenhouse. Weed species of quarantine concern to Ethiopia should be handled with great care and responsibility; as an example problem of *Parthinium* reaches high altitude.

Phytosanitary Measures Against Potato Pests of Quarantine Concern

Phytosanitary measures include all **risk management aspects** to safeguard the country from hazardous alien species that individual and/or groups operate at different levels.

- Specify appropriate tuber treatment that should utilize effective pesticides against pest of quarantine concern for Ethiopia in the Import Permit. Provide this information to your source before shipments are made at the origin;
- At arrival, inspect consignments (samples and containers) for pest infestation at entry ports (land, sea, or airport) and destroy infested parcels, bags and boxes with appropriate methods. The Animal and Plant Health Regulatory Directorate of the MOA, is responsible for supreme decision on these measures. However, all citizens (individually or in groups) have obligations to ensure the safety of their country and must cooperate for the success of this important measure involving common responsibility that may possibly ensures the safe importation potato planting materials into the country;
- After the release of consignments by MOA, inspect potato samples thoroughly and subject suspected samples to appropriate detection methods. Consider cleaning, sorting, physical and chemical treatment, etc. of suspected samples to salvage clean and safe potato materials. The results of PRA (Tables 2, 3, 4, 5 and 6) and a list of prohibited weed species and other articles given in the Plant Quarantine Regulation of the Council of Ministers 4/1992 in Ethiopia or in the Plant Quarantine for NARS (Dereje, 2006) are guiding tools. If salvaging through these methods does not seem to be feasible, then destroy the samples and containers using incinerators; and
- All samples imported for research should usually pass, as tradition through post-entry follow-ups depending on the situations (Dereje, 2006). Different measures and handling are specified for quarantine pests of potato in the following post-entry follow-ups section.

Post-entry Follow-ups

Receiving potato samples for post-entry follow-up instigates inspection and detection of pests of quarantine concern in potato tubers imported for planting. All samples are subjected to appropriate phytosanitary measures described above and post-entry measures described here after, depending on the specified conditions required. These measures and practices include:

Isolation, field inspection, and cleaning

Potato materials imported for research purposes are planted in the first season only in post-entry quarantine fields at Holetta Agricultural Research Center (EIAR) and Amhara Agricultural Research Center (ARARI), where plant protection specialists do field inspection and cleaning. At this stage, rigorous rouging and destruction of suspects, refuses or any strange plant in the nursery are important activities. Although viruses show mostly visible symptoms, complete cleaning is doubtful during field rouging due to latent infection. To be in the safest side, indexing plants may be appropriate and as a general procedure, cleaning potato from diseases using tissue culture method is necessary and this is possible at present with current capacity available at Holetta.

Growing-on test

Some samples might be very small and suspected for a bacterial wilt of potato. ELISA was the only recommended detection method for bacteria listed in Table 5. However, some laboratories use growing-on test, in which imported tubers are grown in the greenhouse with special care. In this case, samples are tested in the greenhouse under controlled conditions where tubers and mini-tubers from only healthy plants are released for planting in the next season. Presently, however, the Plant Biotechnology laboratory at Holetta has enormous capacity to clean viruses, which can be used for this purpose also.

Seedling symptom test

Some potato samples might be very small and suspected for bacterial or viral infections, could also be tested in the laboratory for seedling symptom observation. Special conditions could be provided in the lab to express symptoms for detection. Moreover, the, the plants are directly transferred to field and/or only clean mini-tubers produced from these plants are used in the subsequent planting.

Refuse management

Any refuse of imported material could carry small pest individuals that may initiate the establishment of a particular pest. Hence, all refuses of potato obtained from these inspections, detection, cleaning and treatment measures should be destroyed using appropriate incineration equipment or fire.

Future Considerations

- Potato importation into Ethiopia needs to sternly consider *in vitro* materials that are by far safer than tubers, tuberlets, or plantlets. When tubers are imported, however, consider strict regulatory measures at all levels by using the results of PRA. The PRA result should guide the phytosanitary steps and procedures before, during and after arrival of potato samples;
- Import very small number of materials as much as possible. Tubers usually harbor very many pests or pest-organs that perpetuates to full individuals, or even eggs thus minimize sprouted tuber during importation;
- Listing of pests, especially pathogens causing potato diseases should follow scientific method that eventually confirm its existence and depict its distribution in the country. CABI Compendium could assist the identification of pest but may not be the sole reference as a guiding material;
- Implement all aspects of risk management (phytosanitary measures) recommended/ suggested in this paper and consider post-entry quarantine as one and essential criteria of advancing imported potato into subsequent nursery stages;
- Involve plant protection specialists in the early growth stages and seek their subsequent follow-ups for at least two seasons of nursery management to reduce the risk of pest establishment;
- Produce pest free planting materials by using national diagnostic and cleaning capacity, particularly use the facility of the Plant Biotechnology Laboratory at Holetta;
- Adequately cooperate with National Quarantine System that provides guidance and authority to this important and shared responsibility to safeguard our agriculture and the environment; and
- Establish a network among scientists working in potato improvement and staff in the extension system to obtain timely pest assessment records and feedbacks on strange pests occurrences.

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Possibilities and Opportunities for Enhancing Availability of High Quality Seed Potato in Ethiopia: Lessons from the Successful 3G Project in Kenya

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Introduction

In Ethiopia, potato production could fill the gap in food supply during the "hungry months" of July to August before the grain crops are being harvested. Potato in Ethiopia is currently planted in around 164,146 hectares producing an estimated total tuber yield of 940,087 tons (CSA, 2002). This implies that average yield in the country reaches only 7 t/ha when the potential for small holder is around 25 t/ha. There are many factors that have been identified as the causes for this low yield in Ethiopia and most of the East African countries, but the lack of high quality seed seems to explain most of the differential with the potential yields of the existing potato varieties. Increasing the availability of high quality seed at affordable prices would be a priority in order to significantly increase potato yields in the region.

Following the crisis of world food price in 2008, a group of international and regional agricultural organizations led by the International Potato Center met in Nairobi, Kenya in order to propose immediate actions to respond to the critical situation in East Africa and the lack of enough high quality seed potato. From this meeting an initiative called the 3G revolution emerged and aimed to boost the production of high quality potato seed by involving different stakeholders from both the public and the private sector in Sub-Saharan countries.

This initiative was implemented successfully in Kenya, Uganda, and Rwanda between 2009 and 2011 showing very promising results. In Kenya, the availability of high quality seed increased from an average of 80-200 t/year to a total of 4,000 – 5,000 t /year after 2 years of intervention. More than 20,000 farmers have directly benefited from this experience creating various business opportunities for different potato value chain stakeholders (CIP, 2011). It was shown that large private farmers, medium scale seed multipliers, and small-scale ware producers increased their farm income and improved their food security (Labarta and Mulwa, 2011). Now the challenge is to scale up and out this experience and to bring this strategy to countries like Ethiopia where the production and consumption of potato continue to grow and where the potential for business opportunities and for generating impacts in poverty alleviation and food security improvement is huge. This paper discusses the opportunities and possibilities to implement the 3G strategy in Ethiopia.

The "3G" strategy and different business opportunities for producing high quality seed potato

The 3G strategy was conceived as an innovative response to the crisis increased on the unavailability of seed potato in East Africa. Encouraging the participation of different stakeholders from both public and private sectors, the 3G strategy aims to drastically lower the cost of production of pre-basic or starter seed and at the same time use extension mechanism to train smallholder potato growers in good on-farm seed management. This is because the strategy involves delivering low cost quality seed to growers in 3 generations of field multiplication, rather than the conventional 5 to 7 generations, the new seed potato strategy is widely known as "**3G**" system. The interventions that the 3G strategy proposes can be summarized as

- Increasing the capacity of National programs to produce and multiply mini-tubers at lower unit cost and reduced number of field generations;
- Encourage the participation of private sector in mini-tuber production and field multiplication;
- Promotion and distribution of clean seed to smallholder private seed multipliers and smallholder growers through voucher schemes, seed fairs and large scale distribution of small quantities of seed in trail packs;
- Promoting the diffusion and adoption of new high yielding and disease resistant varieties;
- Securing farm saved seed supplies at nationally significant scale through positive selection and farmer awareness campaigns; and

Promotion of diffused light stores and awareness rising in the importance of good seed storage.

In the next sub-sections we describe the different business opportunities that are related to the 3G strategy:

Rapid seed multiplication techniques: aeroponics

Technologies and techniques for rapid multiplication of sizeable amounts of quality seed of the best varieties now exist together with expertise. A typical seed potato production system starts with completely virus free plantlets coming from the tissue culture laboratories. These plantlets are planted in an insect -proof screen house to produce clean mini-tubers. Currently the production of mini-tubers plus the first 2-3 multiplication are done by the national public research institutes. The seed potatoes resulting from this are called starter seed potatoes, and are further multiplied by parastatal organizations or commercial seed potato farmers and grower organizations. The production of mini-tubers in soil or compost-based substrate is limited by the natural multiplication rate of the crop that is typically only about 6:1 as well as the increasing cost of energy needed to sterilize large quantities of substrate. Many National programs in Sub-Saharan, also face serious land constraints in providing enough land required to multiply high-grade input seed.

CIP scientists have successfully adapted a previously complex process of producing high quality mini-tubers in a specialized soil-less system known as “aeroponics” to become an affordable and low cost production technique. Experience in South America and in Kenya, Uganda and Rwanda are indicating that multiplication rates of 50:1 can be achieved per season at affordable cost of production. It has also been shown that up to 60,000 mini-tubers cab be produced in a single 15 by 5 m pilot scale screenhouse (compared with some 18 000 mini-tubers in a conventional system), the final amount varying by variety. This innovative system should allow producing mini-tubers at far lower cost, reducing the number of field generations required to multiply seed and thus reduce the impact of serious soil-borne disease constraints such as bacterial wilt.

Specialized high-grade seed producers: G1 and G2 seed production

The 3G strategy participates large-scale and specialized seed producers that would benefit from multiplying high quality mini-tubers (G1) into larger quantities of high quality seed potato (G2 and G3) that could be used to produce commercial ware potatoes or further multiply by other trained farmers for keeping the quality of seed potato and benefit for small-scale farming.

It is expected that mini-tubers harvested from aeroponics and conventional mini-tuber production cycle1, would be stored and multiplied in bacterial wilt free field for two generations (G1 and G2) (seasons 3 and 4). A balanced mixture of public, parastatal, and private partners that meets the requirements for being a high-grade seed producer (CIP, 2011) could carry out this enterprise. In countries where a certification system is in place, all G2 and G3 field multiplied seed would be certified by appropriate seed regulatory authorities and all fields would be tested pre-planting for freedom of bacterial wilt. Technical assistance for field multiplication of mini-tubers is a key element to guarantee the quality of the seed potato production and the good economic return of the investment in this enterprise.

A network of decentralized seed potato multipliers

The 3G strategy aims potato growers to become aware of available seed multipliers in their locality and catalogues of these seed suppliers will be produced as the scheme enlarges. The encouragement and training of more local specialist seed multipliers is a key component of the strategy. This training is targeted to local seed potato producers with minimum conditions to further multiply 3G or even certified potato seed. The objective would be to generate business opportunities for some local seed producers who would supply high quality seed to the large number of local ware potato producers in the country at large.

The secondary potato seed multipliers would demand high quality seed (G2 or G3) seed from specialized high-grade seed producers and further multiply these seed following good practices and standard for quality seed production. It is expected that these secondary multiplier would be located in different potato producing areas and would lead a decentralized seed potato multiplication next to where the majority of small potato growers are located, generating a business opportunity and increasing high quality seed availability across different potato growing areas.

Farm based seed maintenance: "select the best"

The innovative extension system known as "**Select the Best**" was developed by CIP and national partners in SSA. Through the training, potato producers learn how to maintain the quality of their potato seed for a longer period through positive selection. Furthermore, farmers become aware of the impact of seed potato quality on yield, and the need for regular replenishment of their seed stock with high quality seed from specialized seed growers. The process involves training farmers to recognize healthy plants, which are not showing symptoms of seed borne diseases such as virus and bacterial wilt infection. Healthy plants, representing about 10% of the crop, are marked and later harvested to provide next years' seed. The intervention is relatively low cost and requires less contact time than a conventional farmers' field school. Essential in the training curriculum is that the farmers plant a demonstration experiment in which they compare the yields through using their existing seed selection method, using positive selection, or buying seed from a specialist. This provides the farmers with options to improve their seed quality. Different evaluations of positive selection have shown a yield gain of over 30% after practicing it a single season (Gildemacher, 2009; Schulte-Geldermann, 2010).

Profitability of quality seed potato enterprises in Kenya

The profitability analysis for all seed enterprises compare production costs with financial benefits derived from each seed production process. The unit of analysis is standardized to screen house production for mini-tubers and to one hectare of land for field seed potato multiplication and for ware potato production. The analysis also contemplates different scenarios that account for the range of input and output prices and the range of rates of multiplication observed during the two years of the implementation of the 3G strategy in Kenya.

Profitability of the mini-tuber production though aeroponics and conventional methods

In Kenya, as in many countries in SSA, mini-tubers are traditionally produced using pots filled with sterilized soil and using one potato plantlet per pot. These are accommodated in standard screenhouses. The 3G strategy introduced the production of mini-tubers using aeroponics (CIP, 2010) in screen houses of 115 square meters with a capacity of using 1,366 plantlets of clean potatoes. In addition, CIP and Kenyan partners tested an alternative improve conventional system that consisted in using the same pot system but using two plantlets per pot and drip irrigation for mini-tuber production. The idea was to produce more mini-tubers in the same sterilized soil. In this section we present the profitability analysis of four alternative systems to produce mini-tubers: (1) the base conventional pot system, (2) the improved pot system, (3) the aeroponics using regular power supply and backup generator, and (4) the aeroponics using a solar power supply with backup generator. All of them produced mini-tubers of the same quality but using different levels of investment, variable cost and showing different multiplication rates of mini-tubers. For the profitability analysis we use the average multiplication rate found for the base conventional pot system (7 mini-tubers per plantlet), for the improved pot system (11 mini-tubers per plantlet) and for both aeroponics systems (26.4 mini-tubers per plantlet). It is important however to highlight that in some cases and for some potato varieties, the multiplication rate of mini-tubers exceeded the 50 mini-tubers per plantlet.

Table 1 summarizes the profitability analysis of the mini-tuber production under the 4 schemes considered. It presents the level of investment required and assumed to last for 10 seasons (5 years), the variable cost (that includes the cost of plantlets, substrates, nutrients, water, electricity, labor and soil sterilization when needed), the unit cost per mini-tuber, and gross and net benefits of the enterprises along with a benefit/cost ratio. For the benefits and the final ration two alternative scenarios are presented that reflects the current price per mini-tuber (0.31 USD) per mini-tuber) and the expected price (0.25 USD) that is likely to happen when more mini-tuber production would be in place.

The current pot system is financially unsustainable as it is producing negative net benefits and benefit/cost ratios (Table 1). Decreasing the market price of mini-tubers would only worsen the situation. In the public sector that uses commonly this mini-tuber production scheme, the initial investment is not accounted in the production cost and they can barely cover the variable cost that is highly driven by the cost of sterilizing the soil. The improved pot system seems to be a solution in the short term when other systems were not affordable or when trying to take advantage of current infrastructure. Under current conditions, the improved pot system is slightly profitable and reduces the unit cost of mini-tuber from 0.60 USD to 0.24 USD. However, in the end, this system is not attractive as a business; as it would only recover the initial investment and cover, the production cost during 10 seasons. On the other side, the aeroponics systems are showing encouraging financial results. Aeroponics are highly profitable under current conditions and will remain profitable even under reduced market price of the mini-tubers. Also the more efficient production of mini-tubers through aeroponics make the production cost per mini-tuber to be reduced as low as 0.10 USD. With a current price of 0.31 USD and even with an expected lower price of 0.25 USD the production of mini-tubers using aeroponics is very attractive. More stakeholders (from public and private) may have the incentive to enter into the business and increase significantly the production of mini-tubers. With the margins between the production cost and the market price, this enterprise would remain highly profitable.

Table 1: Profitability of mini-tuber production under four different production schemes (Values in USD)

	Base conventional pot	Improved pot system	Normal aeroponics w/backup	Aeroponics w/solar power and backup
Initial investment	31,053	16,970	27,310	32,841
Variable cost (season)	3,146	2,228	1,220	1,315
Discounted total cost	57,288	35,551	37,482	43,809
Unit cost per mini-tuber	0.60	0.24	0.10	0.12
Discounted Gross Benefit (price USD0.31)	24,920	39,160	92,646	92,646
Discounted Gross Benefit (price USD0.25)	19,936	31,828	74,117	74,117
Net benefit (price 0.31)	-32,368	3,609	55,164	48,837
Benefit/cost 1	-0.57	0.10	1.47	1.11
Net Benefit (price 0.25)	-37,352	-3723	36,635	30,308
Benefit cost 2	-0.65	-0.10	0.95	0.69

The initial investment seems to be the most important constraint for entering in to this business; however, the investment required for aeroponics is as high for the traditional pot system. Definitely, the variable cost is much lower in aeroponics due to the more efficient use of resources (like nutrient) and the no need for sterilized soil, which turns out to be a high variable cost (Labarta and Mulwa, 2011). There are difference between aeroponics that would depend on regular power supply and aeroponics that requires a solar power system. Both aeroponics systems would require a backup generator as in SSA, the power supply is not constant and the supply for solar systems are not enough for a 100% operations of the aeroponics unit. However, although an aeroponics using a solar power system is less financial attractive than aeroponics connected to the regular power supply, the first one is highly profitable and can produce a benefit/cost ratio of over 100% for a five years period. In areas where power supply is not present, the production of mini-tubers through aeroponics using solar power is a suitable alternative.

Profitability of the production of high-grade seed potato

Many countries in SSA have trained specialized seed potato producers over the years and also many large farmers specialized in other crops production have the capacity to start the production of high quality seed with the backstopping in the implementation of seed potato technologies. In Kenya, a combination of public organizations and a group of private initiatives have started the process of increasing the process of producing high quality seed potato in large quantities (CIP, 2010).

These specialized seed potato producers use the mini-tubers produced by aeroponics or conventional production to further multiply the seed on potato fields. The main reason for this enterprise is to increase significantly the quantity of high quality seed available, but also to reduce the cost of producing ware potato. If mini-tubers were used directly in ware potato production, it would be required 55,000 mini-tubers per hectare requiring an investment of around 17,000 USD per hectare, which is unaffordable and unprofitable for any potato grower. The specialized seed potato producers constitute the direct demand of the mini-tuber production. For analyzing the profitability of these high-grade seed producers, we consider the production of G2 and G3 seed that in Kenya have received certification by the governmental authorities (CIP, 2011). We start considering all production costs that include the cost of mini-tubers, the land cost, the cost of chemicals used and the labor cost. Finally, the total cost of producing one hectare of seed potato is determined along with the cost of one kg and one bag of 50Kg of high quality seed potato. For the estimation of the benefits, we consider two scenarios. In both scenarios, we use a conservative yield of 15 t/ha in G2 seed production and 25t/ha in G3 seed production, but we differentiate them with the traditional price of certified seed of 27.5 USD/bag of 50Kg and the lowest price that a high-grade multiplier managed to sell the seed (20 USD/bag of 50kg). The summary of the profitability analysis of G2 and G3 seed is summarized in Table 2.

Producing certified seed with just one multiplication (G2) of the mini-tubers is not a profitable enterprise. The cost of mini-tubers accounts almost for 83% of the production cost (USD 14,500) and the cost for producing one bag of 50 kg of high quality seed is around 58 USD while the market price does not exceed 27.5 USD per bag of 50 kg. Once the total cost of G2 is accounted for in the production of G3, the production of certified seed becomes a very profitable enterprise.

As shown in Table 2, producing certified seed by having two field multiplications of mini-tubers (G3) increases considerable the financial benefits of this enterprise. With the current market price (27.5 USD), a high-grade seed multiplier would be making profits of over 100% of their investment in just one season of 4 months. Even in the event of a market price drop (20 USD per 50 kg bag), the production of 3G seed would imply a profitability of 63% of the level of investment. It is important to highlight however, that in Kenya some high-grade seed producer’s already selling certified seed at 20 USD per 50kg bag had yields of over 30 t/ha. It implies that keeping a high profitability among high-grade seed producers would guarantee a constant demand for mini-tubers. At the same time these high-grade seed enterprise would depend on the profitability of large commercial ware producers and of decentralized secondary seed multipliers who would demand the certified seed

Table 2: Profitability of the production of high-grade seed (G2 and G3) in USD

	Production of G2 seed	Production of G3 seed
Variable cost (1 ha/season)	17,433	6,127
Unit cost per 50 kg bag	58	12
Gross Benefit (price USD 27.5)	8,250	13,750
Gross Benefit (price USD20)	6,000	10,000
Net benefit (price 27.5)	-9,183	7,623
Benefit/cost 1	-0.53	1.24
Net Benefit (price 20)	-11,433	3,873
Benefit cost 2	-0.66	0.63

Profitability of the production of high quality seed potato among secondary multipliers

The 3G strategy requires a network of secondary seed multipliers to be trained across different potato growing areas as the key link to keep the supply of high quality seed flowing towards the ware potato producers. The target is to have a network of decentralized seed supplier in different potato areas that can produce high quality seed and make it available to hundreds of potato growers that would require them. A key assumption of the 3G strategy is to have a profitable multiplication of quality seed from certified or 3G seed. The aim is for small seed multipliers to produce G4 or G5 that can be used in ware potato production producing high yields among the ware potato producers that invest in this high quality seed. Similar to the profitability of high-grade seed producers, for the secondary seed multipliers this analysis compares the total cost of production for one hectare of land with the total benefits produced in the same unit of land. It also estimates the cost of one bag of 50kg of quality seed potato. The yield information used in the analysis is the average yield of a group of more than 20 secondary seed multipliers in Kenya (14 t/ha for G4 and 13 t/ha for G5) using low inputs. Another important characteristic is that all this seed producers divided the production between seed and ware producers with an average of 50% each. This feature has been incorporated in the analysis that represents the nature of the dual-purpose potato production of these growers. The average market price of G4 and G5 was found to be similar to the G3 seed. Although it is of less quality G4 and G5 are produced locally which avoid the transport cost of bringing G3 seed that could double the market price for this G3 seed. Table 3 summarizes the profitability analysis of G4 and G5 seed potato that were produced by secondary seed multipliers.

Table 3: Profitability of the production of quality seed potato among secondary multipliers

	Production of G4 seed	Production of G5 seed
Variable cost (1 ha/season)	1,951	1,648
Unit cost per 50 kg bag	7.3	7.2
Gross Benefit (price USD27.5)	3,137	2,671
Net benefit (price 27.5)	1,186	1,023
Benefit/cost	61%	62%

The level of investment required for G4 and G5 seed potato production is much lower than the investment required for the production of high-grade seed. This characteristic makes this enterprise affordable for a large number of medium scale producers that are located in different potato areas. Both multiplication processes G4 and G5 seed potato are profitable providing a return of 61%-62% of the investment over a four-month period (Table 3). Depending on the location and the proximity to the source of G3 seed production, farmers may decide to combine the production of G3 and G4 seed. It is important to highlight that with the improvement of the seed management these farmers can get yields of around 15 t/ha to 20t/ha which would imply a much profitable enterprise that can attract a larger number of secondary seed multipliers and increase substantially the supply of high quality seed for the ware potato production.

Profitability of ware potato production and the use of positive selected seed

The overall 3G strategy would depend at the end on the profitability of the ware potato production that reflects the demand for table potato and from the potato industry. It can be stated that the higher the demand for potato consumption, the higher the price and the higher the probability of having a profitable enterprise that would require seed potato that offers greater productivity.

For the profitability analysis of the ware potato production, we consider the four options that Kenyan farmers were facing between 2009 and 2011. Most of the farmers were using their own seed to produce ware potatoes, a large number of farmers were using positive selected seed (CIP, 2011) and an increasing number of ware potato producers were using G4 and G5 seed produced by secondary seed multipliers. In general, the two key variables that changes across the four production options is the cost of the seed (increasing from the use of farmer seed towards the use of G4 seed) and the yields of the potato production (also increasing from farmer seed towards the use of G4 seed).

Table 4: Profitability of ware potato production suing different types of seed (values in USD)

	Ware potato using farmer seed	**Ware potato with positive selected seed**	**Ware potato using G5 seed**	**Ware potato using G4 seed**
Variable cost (1 ha)	951	1,072	1,320	1,320
Unit cost per 50 kg bag	4.4	4.4	4.7	4.2
Gross Benefit	1,815	2,088	2,648	2,956
Net benefit (price 27.5)	864	1,016	1,328	1,636
Benefit/cost	0.91	0.95	1.01	1.24

The information coming from a large number of farmers showed that positive selected seed yielded 20% more potatoes, the use of G5 around 40% more potatoes and the use of G4% over 50% of potatoes compared with the base scenario (use of farmer seed). The profitability analysis of ware potato production in Kenya is summarized in Table 4.

In general, the 3G project experience provided evidence that the production of ware potato is a highly profitable enterprise regardless the type of seed used (Table 4). The difference is that the better the quality of the seed used, the higher the profitability that a farmer can achieve and the higher the quantity of food that one hectare of land can produce. The use of higher quality of seed potato would therefore improve farm income and household food security. The analysis from Kenya show that the higher production cost of ware potato using G4 and G5 is largely compensated by the higher profits generated due to much better yields associated with the use of better quality of seed. Potato growers can double the net benefits produced per unit of land and can increase the profitability of this unit of land by almost 35% by using G4 seed instead of farmer seed in the production of ware potato. The high profitability of the ware potato enterprises would guarantee a large demand for high quality seed over the years.

The potential of the 3G strategy in Ethiopia

Ethiopia is a large country with around 165,000 hectares of land under potato cultivation and that has shown an increasing demand for potatoes from urban and rural markets and most recently for processing purposes. However, the yields per unit of land remain very low around 5.7 t/ha (CSA, 2002). The lack of quality seed potato has been also identified as one of the major constraints for not reaching the potential yields of over 20 t/ha. Currently the production of quality seed only reaches 800 t/year out of the 330,000 t that required annually in

Ethiopia. A strategy like the 3G would be suitable for Ethiopia. We discuss here the potential to implement successfully a 3G strategy that could enhance availability of quality seed in Ethiopia. We first start estimating the current demand for high quality seed in Ethiopia that may justify the implementation of 3G strategy and then discuss some ongoing experiences that may facilitate this implementation in Ethiopia.

Existing demand for high quality seed potato in Ethiopia

The estimation of the demand for seed potato starts from the annual requirement of seed needed to plant the total area devoted to potato production. To estimate this annual requirement we used the reported area of the last agricultural census (CSA, 2002). Secondly, it uses the average rate of seed used per ha in Ethiopia reported in two recent large household surveys (Obado, 2010b; 2010c). From the same farm level information, the paper estimated the percentage of farmers that replace their seed stock with off farm sources and the average numbers of seasons that the same seed is used before replacement (among those who replace seed). The next step is to estimate the annual demand for new seed in each country. This represents the total seed potato that is supplied by off-farm sources. We estimated the demand of new seed by multiplying the annual requirement of seed potato by the percentage of farmers that replace seed and by dividing this product by the number of years that takes to replace old seed with new seed (the number of seasons of seed use plus one is divided by two seasons). Although this annual demand of new seed may represent the maximum quantity of seed that can potentially be sourced with high quality seed, a better estimation of the lower bound of the demand for high quality seed is calculated using the average proportion of new seed that used high quality sources (form public sector, research institutes, or trained seed multipliers). This allows us to estimate the minimum quantity of high quality seed that would be expected to be demanded by potato producers in Ethiopia. Table 5 presents the estimation of the demand for high quality seed in Ethiopia.

With existing information and without considering awareness creation for the use of high quality seed performed by projects like CFC and Better potato for better life (CIP, 2011), we can estimate that the demand for high quality seed is at least 9,446 t per year.

Conclusion

The 3G strategy was proposed as a means to overcome the shortage of high quality seed potato in East Africa, aiming to increase significantly potato yields and to contribute to improve smallholder income and food security. The 3G strategy concentrates their efforts in producing large amount of high quality seed potato in 3 generations. It also contemplates parallel investments at the farm level in order to improve farmers' seed management and to generate a sustainable demand for high quality seed.

A critical assumption is that the production and distribution of high quality seed is a profitable demand at all levels of the value chain and that responds to a large demand for seed that allow to increase considerably the potato productivity and respond to the increasing demand for table potato and from the potato processing industry. This paper provides the evidence that all levels of the potato sub-sector have very profitable enterprises and that the production and distribution of high quality seed would be sustainable and supported by business opportunities for different stakeholders.

Ethiopia is a country where potato continues to increase its importance as a cash crop and a key contributor to food security of rural households. Ethiopia has a public sector that has updated its capacity and has some positive experiences from the private sector that makes this country suitable for the implementation of the 3G strategy. The objective would be to produce 10,000 t of high quality seed per year after 5 years of implementation of the 3G strategy expecting to have significant impacts on reducing poverty and improving food security of the rural poor.

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Potato Research and Development in Ethiopia: Achievements and Trends

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Introduction

In Ethiopia, potato production increased considerably through the twentieth century. However, potato cultivation declined in the early 1980s, due in part to widespread infestation by late blight (Tesafun et al., 1985).In 1975, the area of cultivation was estimated at 30,000 ha, with an average yield of approximately 5 tons/ha. By 2001, Ethiopia's potato area had grown to 160,000 ha, with average yields of around 8 tons/ha (Gebremedhin et al., 2001). Potato can still grow on 70% of the 10 million ha of arable land in the country (FAOSTAT, 2008).

In the last 10 years, potato productivity has progressed from 7 to 11 tons/ha. Nevertheless, the current area cropped with potato (about 0.16 million ha) is very small and the average yield is below 10 tons/ha—far below the country’s potential.

Diseases, the lack of improved varieties, poor crop management practices, use of inferior quality seed tubers of unknown origin, inappropriate storage structure, poor seed system, and poor research-extension linkage are among the key factors contributing to this low acreage and yield. The national potato research program has made great strides in overcoming these production constraints, and this paper aims to present major potato research achievements in the last three decades.

Major Achievements

Potato varieties

The local varieties, introduced earlier, may be of the same parentage (Haile-Michael, 1979), suggesting that the genetic base of local varieties in the country is most probably narrow. Improving the productivity of potato, which is a demanding process, has occurred by trying to widen the genetic base of potato. A selection program was started in 1973 at the College of Agriculture in Alemaya in cooperation with the Institute of Agricultural Research (IAR) and the International Potato Center (CIP) with a large number of seedling populations. A more coordinated improvement effort was started later in 1975. Introduction and evaluation of commercial varieties, germplasm, generation of local populations, and, more recently, introduction of advance materials were some of the strategies that have been followed to develop varieties by the National Potato Research Project (formerly known as the National Potato Improvement Program). A number of variety trials were conducted in different areas of the country to address problems of different agro-ecologies. As of 2010, 29 improved potato varieties with high-yielding potential, wide adaptation, and resistance/ tolerance to diseases and pests have been released (Berga et al., 1994) and are under production (Table 1).

Table 1: Potato varieties in Ethiopia from 1987 to 2010

Variety	Suitable altitude (m)	Yield (t/ha)		Year of release	Breeder/Center
		RM	FM		
Red scarlet	1800-2400	50	40	2010	Solagrow PLC
Belete	1600-2800	47.2	28-33.8	2009	Holetta ARC
Caesar	1900-2400	65	47.5	2009	Solagrow PLC
Mondial	1900-2400	65	50	2009	Solagrow PLC
Dancha	1700-2850	32	-	2009	AWARC
Kulumsa	2200-2750	28-31	20-25	2007	KARC
Hundee	2400-3350	21-51	28-54	2006	SARC
Ararssa	2400-3350	20-42	37-50	2006	SARC
Gudene	1600-2800	29	21	2006	HARC
Gabbisa	1700-2000	40	31	2005	HU
Shonkolla	1700-2700	31.5	29.10	2005	AwARC
Bulle	1700-2700	39.3	38.3	2005	AwARC
Challa	1700-2000	42	35	2005	HU
Mara-Charre	1700-2700	33.3	28.4	2005	AwARC
Gera	2200-3200	25.9	-	2003	DARC
Gorebella	2200-3200	30-52	26-30	2002	DARC
Guassa	2000-2800	24.4-33	22-25	2002	ADARC
Digemegn	1600-2800	30-37	25.7	2002	HARC
Jalene	1600-2800	40.3	29.10	2002	HARC
Zemen	1700-2000	37.2	-	2001	HU
Bedassa	1700-2000	40.6	-	2001	HU
Zengena	2000-3100	30-35	22.5-25	2001	ADARC
Chiro	1600-2000	32-40	25-35	1997/98	HU
Wochecha	1600-3000	27.5	17.5	1997	HARC
Tolicha	1600-3000	23.8	20.2	1993	HARC
Menagesha	>2400	27.00	-	1993	HARC
Awash	-	-	-	1991	HARC
Sisay	-	-		1991	HARC
AL-624	-	-	-	1987	HU

Source: *Ministry of Agriculture Crop variety registration bulletin (1987-2010); RM = under researchers' management, FM = under farmers' management.*

Crop management

The suboptimal agronomic techniques practiced by potato growers in Ethiopia are undoubtedly one of the contributing factors to the existing low average yield. Agronomic studies have been undertaken by different research centers to develop a package of optimum management practices, together with improved cultivars, which are briefly described in the following sections.

Time of planting

Planting time varies from place to place and from variety to variety. It influences tuber yield and LB incidence. For maximum yield, potato should be planted when favorable conditions prevail for better growth and development. Farmers in northwest Ethiopia plant potato earlier in the season to escape LB infection. However, this practice exposes the crop to moisture stress at early growth stage for which potato is very sensitive and subject to considerable loss. Tesfaye et al. (2008) reported that regardless of type of varieties, yield declined as planting date was delayed. Therefore, May 1–June 1 were recommended planting dates around Adet for potato cultivars and similar agro-ecologies that are LB susceptible and moderately tolerant/resistant. Similarly, early June was recommended for Emdiber (Gurage zone), Holetta (central Shewa), and other similar agro-ecological areas (Berga et al., 1994). Abdulwahab and Semagn (2008) recommended the last week of May to mid-June as an appropriate planting time for potato in the highlands of Ankober (North Shewa) and other similar agro-ecologies.

Seed tuber size and plant population

Seed tuber size and plant population density are among the major factors affecting the production and productivity of potato. According to Berga et al. (1994), spacing should depend on the intended use of the crop such as for seed or ware. Closer intra-row spacing of 10 or 20cm in rows 75cm apart would be beneficial for seed; larger seed tubers (45–55 mm) do better than the smaller ones. Wider intra-row spacing (30 or 40cm) were better, again on rows 75cm apart, for ware potato. Considering the amount of seed tuber required and type of output and synergy with other cultural practices, seed tuber size of 35–45 mm diameter, 60-cm inter-row spacing, and ridging once at 3–4 weeks of crop emergence were recommended for seed potato production. However, 35–45-mm diameter seed tuber, 75-cm inter-row spacing, and ridging once at 3–4 weeks from crop emergence was found to be optimum and recommended practices for ware potato production at Adet and its environs (Tesfaye et al.,2008).

Fertilizer rate

Potato is naturally a heavy feeder crop. Economically feasible fertilizer rate varies with soil type, fertility status, moisture amount, other climatic variables, variety, crop rotation, and crop management practices (Smith, 1977).Research results indicated that 108/69 and 81/69 kg/ha N/P2O5 were economically feasible and optimum rate for potato production in south Gondar and Gojam areas, respectively (Tesfaye et al., 2008). For optimum potato tuber yield in nitosols and light vertisols of the highland areas of north Shewa, 110 kg/ha nitrogen and 70.5kg/ha P_2O_5 kg/ha were recommended (Abdulwahab and Semagn, 2008). Berga et al. (1994) recommended 165/90 N/P_2O_5 as feasible rate for the central Shewa, and this recommendation is still in use as blanket recommendation throughout the country. In the same way, 146/138 N/P_2O_5 was recommended as economic and agronomic rate of fertilizer for the highlands of Hararghe (Teriessa, 1995). These recommendations may not work for the current market, soil fertility status, and other climatic variables. Therefore, detail soil test-based fertility studies should be carried out to provide appropriate local recommendations.

Intercropping

Intercropping of potato with maize is a common practice in northwest Amhara region. Consequently, an experiment was conducted at Adet for two consecutive years (1997–1998) to identify economically feasible intercropping systems. The result of experiment was statistically analyzed using total monetary value of the system and economic yield of each component crop. Moreover, the land equivalent ratio of each intercropping system was calculated. Intercropping of potato with maize in 2:1 and 1:1 (potato: maize) row arrangements were found superior and recommended for potato production around Adet (Tesfaye et al., 2008).

Harvesting Time

In the absence of storage technologies for ware and seed potato, farmers keep potato harvest in the ground for a long period in Ethiopia. This reduces tuber yield significantly. A study on extended harvesting period in Alemaya revealed that yield of marketable tubers was reduced by 60% when tubers were harvested at 210 days after planting as compared to a harvest at 120 days (Berga, 1984). Similarly, Gebremedhin (1987) reported significant yield reductions (70–100%) as harvesting was delayed from about 125 days to 230 days after planting at Holetta.

Crop Protection

Insect pest of potato

Numerous general insect pest surveys have been conducted in the last three decades (Crowe et al., 1977, as cited by Bayeh and Tadesse, 1994). The insect pests identified were the following: *Agrotis* spp. and *Euxoa* spp (cutworms), *Dorylus* spp (Gojam red ant), *Epilachanahirta* (potato epilacha), *Lagriavillosa* (metallic leaf beetle), *Phthoruimaea opercullela* (potato tuber moth), *Myzuspersicae* (green peach aphid), and *Macrosiphum euphorbiae* (potato aphids). Of these, potato tuber moth (PTM), cutworms, and aphids were the most important. Research has been made to inform management options against these economically important insect pests. Many survey reports indicated that PTM was known to damage potato only in the warmer areas, though major production areas mainly cover the highlands. Monitoring of PTM was conducted using PTM sex pheromone trap at Holetta. The result showed that the peak months were January, February, and June. Unlike the field situation, monitoring in the store showed no obvious peak record (Bayeh and Tadesse, 1994). Aphids in potato, though, were more important as vectors of virus diseases than as pests. Monitoring work was conducted using yellow water traps at Holetta, and during the monitoring different aphid species were recorded. The peak months were January, April, and November–December. The dominant species were Brassica aphids, green peach aphids, and potato aphids (Bayeh and Tadesse, 1994).In this work an attempt was made to correlate the population fluctuation with some abiotic factors, temperature, (minimum and maximum temperature in $^{\circ}$C), rainfall (mm), and wind speed (km/h). The result showed that rain fall and minimum temperature had negative effects, whereas the influence of the other two factors was non significant.

Potato diseases

Potato suffers from a wide range of leaf, stem, and tuber diseases. A number of pathological activities have been done in the last decades: since 1989, 11 fungal, three bacterial, six viral, and one mycoplasma diseases have been recorded. Among these, LB, followed by bacterial wilt (BW), potato leaf roll virus, and potato virus Y (PVY) were the most important diseases. LB was widely distributed where the crop is grown under rainfed conditions (Bekele and Yayinu, 1994). In this report, BW was detected and found restricted to the mid- and low altitudes. Currently, however, it has also been recorded in high altitudes (>2400 masl); virus diseases were more prevalent in the mid-altitudes than in higher. Studies on host-plant resistance, loss assessment, cultural control measures, and integrated management have been conducted on many diseases. Promising results have been obtained. Potato LB caused yield losses of 34–97.5% at Holetta. Race analysis of *Phytophothera infestans* was performed at Holetta and Race 1,2,3,4, and 6 were identified. However, R2 and R3 were found to be highly prevalent (Bekele and Yaynu, 1994). Race identification has been carried out for BW and only Race 3 was recorded from different farms (Yaynu and Korobko, 1986).

Results of chemical control trials indicated that a fungicide (Ridomil MZ 63.5% WP) containing Mancozeb and Metalaxyl was very effective in controlling LB (Bekele and Yayinu, 1994).

Seed Potato Production

Shortage of quality seed tubers of improved cultivars is one important limiting factor to potato productivity and production. Past research experiences indicated that there is a good prospect for producing better quality seed potato on farmers' field in collaboration with other stakeholders. Currently, few formal organizations are engaged in potato seed production as a business. However, informal seed multiplication programs conducted by different agricultural research centers and other partner organizations were effective in disseminating improved potato varieties to farmers covering about 22% (Hirpa et al., 2007).

To provide disease-free planting materials, a number of research activities have been conducted. Some rapid multiplication techniques (RMT, e.g., stem cutting and aeroponics) were evaluated under local conditions. Tuber yield increased with increasing number of stem cuttings per hill from 1 to 3 and with closer spacing. Results revealed that the rooting abilities of stem cuttings differed with cultivar and media; fine sand was found to be the best locally available medium (Berga et al., 1994).Currently, millions of minitubers are under rapid multiplication for experimental and for pre-basic in our tissue culture laboratories and aeroponics facilities at Bahirdar and Holetta (Fig. 1). The conventional multiplication rate (1:3) of potato was promoted to very high rate (1: 30) by RMT.

Figure 1: Potato minituber production under aeroponic system (HARC)

Potato Storage

Since potato tuber is a living botanical organ, it loses weight and quality during storage. Ethiopia lacks proper storage facilities, and farmers are forced to sell their potato harvest at low prices during harvesting and buy seed tubers at high prices during planting. However, farmers are aware of the new seed storage technology—that is, diffused light store (DLS) (Fig. 2). Practical training was given to farmers in different part of the country. Currently, 87% of the central part and 25% in the north and west are using DLS to store their improved potato variety seed (Agajie et al., 2008). Generally, better quality seed tubers are obtained with storage in DLS than in traditional dark storage, and as a result, productivity of potato in Ethiopia increases.

Figure 2: DLS constructed by a farmer

Demonstrations

Technology transfer is both a technical and nontechnical process, and it should be carried out in collaboration with stakeholders. The main objective of technology transfer is to improve peoples' welfare gradually and continuously. In Ethiopia, there are still some drawbacks of technology transfer such as inappropriate channels, applicability of the technology, and lack of integration. A number of potato technologies were promoted through participatory seed multiplication and scaling-up from production to utilization in different parts of the country. These promotional activities sought to facilitate the diffusion and adoption of potato technologies that will improve potato production. To transfer these new technologies, two phases of activities were facilitated.

In the first phase, participatory seed multiplication was conducted over the last 10 years. At this stage, researchers, Farmers' Research Groups (FRG), development agents, subject matter specialists, development project workers, nongovernmental organizations, and other stakeholders were involved in planning, monitoring, and evaluation. This was to promote awareness on better adoption of new technologies and quality seed for further dissemination. In the second phase, before launching the actual activity, an inception workshop was held with all stakeholders. Researchers played a catalytic role. On the basis of group consensus, the seed, which is maintained during the evaluation and seed multiplication phase, was distributed to all members of the FRG. In this way the potato technologies are diffusing to potato farmers. Currently, potato farmers are using almost all components of the potato production package. Throughout the whole process of evaluation, seed multiplication, and scaling-up of improved technologies, participation of farmers and stakeholders was useful to promote the diffusion and adoption of improved technologies, knowledge, and skill of quality seed production, and postharvest handling. This established the farmer-to-farmer seed exchange and information dissemination system. In the process, a number of field days were organized to demonstrate the production, postharvest handling, and utilization of potato (Fig. 3). In general, technical backstopping and creating good public-private partnership and technology transfer system are the most important issues that need more attention.

Figure 3: Field days to promote new potato technologies

Focuses of Future Research

- Characterization of potato production areas and systems;
- Introduction and screening of potato genotypes for different purposes, agro-ecologies, and production systems;
- Strengthening the generation of local populations to develop potato varieties;
- Identification of low-input and nutrient-efficient potato cultivars;
- Biofortification (increasing the nutritional values of varieties);
- In-depth investigation of soil fertility management such as fertilizer requirement, study on organic source of nutrients;
- Identification of the racial composition of LB and BW pathogens;
- Strengthening integrated management options for diseases and insect pests;
- Strengthening of the informal seed system and public-private partnership and establish the basis for formal potato seed system.

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Potato Variety Development Strategies and Methodologies in Ethiopia

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Background

Just like any other crop, potato's production is constrained by a wide range of factors that resulting in low yields. These factors include marginal soils, climatic limitation, inadequate seeds, deficient cultural practices, storage problems, unimproved varieties, high cost of farm inputs, and insect pests and diseases. National potato research programs in sub-Saharan Africa have continuously focused on selection of high-yielding varieties with resistance to late blight (LB) disease (E1-Bedewy et al., 2005).

With the understanding of constraints challenging the production and productivity of potato in Ethiopia, strategic research began in 1975. The research focused on the development of varieties that are high yielding, widely adaptable, and resistant to LB, which is caused by *Phytophthora infestans* (Mont) de Bary. The disease, as in most potato growing regions of the world, has been the most devastating throughout the country. The improvement also focused on evaluating and selecting for important traits valued by producers and consumers such as tuber shape, storability, cooking quality, and taste (Table 1).The improvement work has benefited from the global collaborative efforts in potato breeding. The major source of variation, upon which selection was practiced, has been generated by crossing of different genotypes and selfing the heterozygotes. The International Potato Center (CIP) in Peru, where genetic diversity of the crop is high, has carried out this work. Researchers usually obtained the germplasm for selection in the form of advanced clones, tuber families, and true potato seed (TPS) (Gebremedhin et al., 2008).

Most of the potato genotypes that have been developed and released in Eastern Africa before 2008 either have genes for vertical resistance to LB or have been developed for horizontal resistance to LB in the presence of unknown resistance (major R) genes, thus named population "A" clones (Landeo et al.,1997). A particular feature of this breeding population is that horizontal resistance was improved in the presence of undesired, unknown major (R) genes for vertical resistance (population A). Their presence, rather than contributing to the overall resistance, made the recognition of true horizontal resistance and effective gene frequency upgrading more difficult (Landeo et al., 1997). The concept of population improvement at CIP is used to the extent of ensuring the systematic upgrading of gene frequencies for desirable quantitatively inherited traits. This guarantees its genetic diversity and enhances recombination with other valuable crop protection traits, through genotypic recurrent selection breeding scheme (Landeo et al., 2000a, 2000b).

Table1: Characteristics to be considered in evaluation and selection of a potato variety

Characteristics	**Specifics**
Agronomy and yield	Maturity, bulking rate, marketable yield, number of tubers, tuber size, yield of tubers, plant height, number of stems
Tuber morphology	Eye depth, flesh color, growth cracks, hollow heart, secondary growth, shape
Quality	Dry matter, browning, skin color, taste, storage characteristics
Resistance	LB (foliage and tuber), viruses (PVX, PVY, and PLRV)

PVX = potato virus X, PVY = potato virus Y, PLRV = potato leaf roll virus,
Source: *Gebremedhin et al., 2008*

Breeding efforts on population A was stopped at CIP, and the emphasis shifted to the formation of a new population where horizontal resistance is improved in absence of major resistance (R) genes. The new population was then named as population"B". The main feature of this population is that testing and selection were mainly done for horizontal resistance to LB (unlike those applied for population A), which are simplified significantly in the absence of major (R) genes. Because of the elimination of the interference effect of major R genes, breeding material can be exposed readily to any local isolates in favorable environments and allow effective screening and selection for horizontal resistance (Landeo et al., 1997). Population B1 was developed through several recombination cycles of resistance sources of *Solanum andigena.* Population B2 was obtained from crosses between *S. andigena* and *S. tuberosum* sources of resistance. While population B3, the most advanced and recent ones, is currently under evaluation and selected from population A. B3 contains mostly *S.demmisum* derived horizontal resistance improved mainly from *S. tuberosum* germplasm background (Landeo et al., 1997). During the improvement process, suitable agronomic traits, tolerance to abiotic and biotic stresses, early tuberization and bulking, table and processing quality, as well as adaptation to a wide range of environments were taken into consideration (Landeo et al., 2000a, 2000b). An important feature of population B3 is that testing and selection for horizontal resistance to LB, unlike those previously applied to population A clones, were simplified significantly to the absence of major R genes.

Breeding Strategies and Methods

The overall potato breeding strategy focuses on developing varieties with high and stable yield with good levels of horizontal resistance to LB. The varieties are also sought to exhibit good traits like ware and processing qualities, adaptability, and resistance/tolerance to viruses and other important biotic stresses. The breeding procedure generally involves introducing resistance clones, clonal selection, stability studies, and verification tests for official release and dissemination of new varieties for production. In the past two decades, several resistance clones were introduced and tested (Gebremedhin et al., 2008).So far, 30 potato varieties are released by the research system. The clones with better performance in the nursery stages are replicated across three different environments in pre-national variety trial (PNVT) (Table 2) and evaluated for one season before they were promoted to the national variety trial (NVT). The clones selected from the PNVT stage are promoted to a replicated study across 16 different environments (8 locations for two years) under NVT (Tables 3 and 4). The purpose of this multi-environment test is to understand the response of advanced genotypes to different environmental settings that will help develop varieties stable across environments. The challenge in this approach has been the appropriateness of the weather in 2–3 consecutive years to represent the long-term climate at each site, even though the management in each year for all varieties across sites can be assumed uniform,. Moreover, the stability of clones across locations and years was evaluated to better understand the genotype and environment interactions (Table 5). Statistical analysis was made using appropriate models. The selection procedures followed in the last few years is shown in Figure 1.

Table 2: Mean performance of potato population B in the pre-national variety trial over three locations in the year 2000*

Variety	Yield (T ha^{-1})	ATW (g)	ANT (M^{-2})	AUDPC*
CIP-392640.501	34.3 gh	85.5 cde	40.1 de	1467.1 cd
CIP-391058.505	34.7 tgh	46.7h	77.5 a	635.8 fgh
CIP-392640.513	41.6 cde	58.0 gh	73.4 a	1878 bc
CIP-391058.545	50.9 a	89.8 bcd	57.3 b	729.2 efg
CIP-392640.505	40.3 def	97.7 bc	41.6 de	247.9 gh
CIP-392622.511	46.3 abc	94.1 bcd	50.3 bc	291.7 gh
CIP-392640.534	31.0 h	75.7 ef	40.7 de	2258 b
CIP-392640.529	49.0 ab	129.1 a	40.3 de	1178 de
CIP-392618.511	37.4 efg	80.6 de	45.7 cde	782.efg
CIP-392627.511	44.8 bcd	99.5b	46.4 cd	1232. de
CIP-392640.511	42.3 cde	99.2 b	43.9 cde	187 h
CIP-391058.526	33.3 gh	87.6 bcde	38.2 de	895 ef
AL-624	12.6j	44.9 h	29.0 f	3115 a
Tolcha	23.2i	65.9 fg	38.1 e	694 efgh
LSD $_{0.05}$	5.82	13.64	8.28	481.6

**ATW = average tuber weight in grams, ATN = average tuber number, AUDPC = area under the disease progress curve (recorded at Holetta)*

Table 3: Mean performance of potato population A genotypes tested at different AEZ in Ethiopia*

Genotypes	Tuber yield (t/ha)	ATW (g)	ATN (m^2)	AUDPC	DM (%)
KP-90134.2	28.62	66.14	41.85	43.7	21.13
CIP-389701.3	26.12	44.71	61.81	367.5	16.13
CIP-387676.24	25.49	54.61	48.75	32.8	20.60
KP-90143.5	29.81	66.01	46.00	111.6	19.53
KP-90138.12	29.94	75.67	40.63	41.6	22.69
KP-90108.5	27.04	68.48	39.83	109.4	23.51
CIP-386423.13	29.17	55.73	55.69	61.3	20.93
KP-90134.5	28.85	84.32	35.19	197.2	19.13
Sta.check-Tolcha	18.96	59.15	32.12	507.5	20.92
Susceptible check	6.37	21.10	20.08	2050	18.94
LSD0.05	2.705	6.051	4.235	79.85	
CV%	24.55	27.43	22.8	53.58	

**ATW = average tuber weight in grams, ATN = average tuber number, AUDPC = area under the disease progress curve, DM = dry mater in percent, and AEZ = agro-ecologies*

Table 4: Tuber yield, average tuber weight, tuber number of potato clones at Holetta, Adet, and Kulumsa

Clone	ATN/m^2	ATW (g)	Tuber yield (t/ha)	AUDPC	Dry matter (%)
CIP392640.513	80.28	38.73	28.26	684	25
CIP391058.545	58.23	58.11	32.46	648	21
CIP392622.511	53.25	54.36	27.52	368	30
CIP392640.534	39.83	66.50	25.66	292	24
CIP392618.511	54.13	75.46	35.82	219	31
CIP392640.511	40.72	74.34	29.61	460	32
St.Check	37.82	68.68	25.01	838	28
Local	58.41	16.96	9.178	1921	24
C.V (%)	35.94	28.22	17.10		
LSD (0.05)	10.66	9.269	2.625		

**ATW = average tuber weight in grams, ATN = average tuber number, AUDPC = area under the disease progress curve, and DM = dry mater in percent*

Table 5: Tuber yield and stability parameters of potato genotypes tested at 10 environments

Genotype	Tuber tield (t/ha)	b	S^2d
KP-90134.2	28.62	1.315	3.14
CIP-389701.3	26.12	1.101	195.65
CIP-387676.24	25.49	1.238	194.47
KP-90143.5	29.81	1.075	250.34
KP-90138.12	29.94	0.944	248.16
KP—90108.5	27.04	1.414	205.71
CIP-386423.13	29.17	0.601	0.84
KP-90134.5	28.85	1.063	86.03
St. check	18.69	0.678	88.02
Susce. check	6.37	0.027	90.51
LSD 0.05	2.706		

Source: *Gebremedhin et al., 2008*

Year 1	Introduction of germplasm →	TPS, Tuber Families. Advanced Clones (Under Quarantine)
Year 2	Selected Clones Nursery →	At Holetta Research Center Single row
Year 3	Advanced Clones Nursery →	At Holetta Research Center and Multiplication of the Good performing clones Single row
Year 4	Pre-National Variety Trials (PNVT) →	At three locations in three replications (plot size of 3*3 meters
Year 5 and 6	National Variety Trials (NVT) →	In a minimum of six locations in 4 replications of 3*3 meters
Year 7 and 8	Multiplication of Clones with wide adaptation →	At Holetta and Adet Research Centers
Year 9-10	Submission of Outstanding Clones for Release and Release of new Variety →	Holetta and National variety release committee
Year 11----	Multiplication , demonstration and adaptation trial →	EIAR. RARIs, MoA and NGOS,

Figure 1: Potato Variety Development/Selection Scheme, Ethiopia

Resistance with major gene

As with the majority of crops, the early breeding work of potato was concentrated mainly on resistance mediated by major genes (R genes). The introduction of a population with these genes laid the basis as a source of a gene pool for resistance—that is, population A germplasm. This is a breeding population whereby horizontal resistance to LB is improved in the presence of major genes. The main sources contain both types of genes: minor genes (or polygenes) that express horizontal or quantitatively inherited resistance, effective against all races of the pathogen, and major genes (or R) genes that exhibit vertical or qualitatively inherited resistance that is race specific. It became clear, however, that such resistance was short-lived because of the ability for the causal organism to overcome it (Landeo et al., 1997, 2000a, 2000b).

Population A is the first improved breeding population developed at CIP for horizontal resistance to LB. The clones were developed between 1980 and 1990.

From this population, several resistance clones were introduced and tested in Ethiopia, and those varieties released up to 2008 were from this population.

Resistance in the absence of major gene

Because of short durability of resistance in the early breeding population, emphasis was shifted to the creation of durable or horizontal resistance. A major feature of this population is that testing and selection for horizontal resistance to LB are simplified significantly in the absence of major R genes. Because of the elimination of the effect of R genes, breeding materials can be exposed readily to local isolates present in favorable environments, allowing effective screening and selection for horizontal resistance. This new population is referred to as population B. The Ethiopian potato improvement program received 18 tuber families containing about 1,200 clones in 1997 out of which more than 900 were selected and advanced. These clones were subjected to rigorous selection across different agro-ecologies in the country.

Six clones from population B that gave higher yield and showed tolerance to LB with good horticultural characteristics from PNVT Set II in 2000 (Table 2) were promoted to be tested in the NVT Set II in 2002 and 2003 cropping seasons. These clones, together with the local and standard check, were evaluated at different environments—two years and four locations (Table 4).

The experiment was laid out in a randomized complete block design with four replications. Each clone was planted in four rows of 3m length spaced 75 x 30cm apart between rows and plants, respectively. Fertilizer was side-dressed at time of planting at a rate of 195 and 165 kg/ha for DAP and Urea, respectively.

Data Collection and Analysis

During the vegetative growth of the plants, germination percentage, plant height, stem number, and days to flowering were recorded. LB severity assessments were done at weekly intervals from the onset of the disease symptoms and calculated to AUDPC. At crop maturity, prior to harvesting, stand count was done. At harvest, potato tuber yields, numbers of tubers per plant, and mean tuber weights in grams were recorded. Fresh tuber weight per plot was subsequently used to compute mean tuber yield in tons per hectare. In addition, tuber shape, color, and eye depth was taken and clones were assessed for the quality in regard to chips, crisp, and quality. Several clones of the new population showed better resistance in Ethiopia. To the date of the current report, one variety, Belete, is released and others are in the pipeline for official release.

The main advantages of population B, with high level of horizontal resistance to LB and free of R genes, can be summarized as follows:

- The nature of resistance to LB would be entirely horizontal, and therefore effective against all races of the pathogen;
- The absence of R genes would simplify seedling screening and field-testing. Complex races and their maintenance and management would no longer be required. Screening can be done under local isolates;
- On-site testing for LB resistance and selection under local conditions would improve dramatically the adaptation and adoption of selected resistance materials;
- Horizontal resistance to LB can be combined with other disease resistances more effectively because of the simplicity of screening for LB resistance locally; and
- Selected resistant clones with general combining abilities for resistance and tuber yield can be used as parental breeding lines in other programs and for TPS for commercial production.

To date, chemical control of LB, though still effective, is gradually facing several disadvantages due to the following circumstances

- High cost, making its use for controlling the disease more expensive and almost prohibitive in many developing countries;
- Systematic fungicide (Metalaxyl containing) is increasingly becoming less effective because of the quick development of resistant strains in the pathogen as a consequence of their excessive use; and
- Increasing concern of environmental protection agencies results in government policies restricting the use of pesticides in general and banning some due to their harmful effect on humans and the environment. Some LB control fungicides are already under scrutiny. The lack of adequate chemical control of LB would prevent cultivation of most susceptible cultivars grown worldwide and risk their extinction;

Changes in the epidemiological pattern of the disease are increasingly reported worldwide because of the spread of the new migrating population carrying A1 and A2 mating types of the fungus (Fry et al., 1992). Early outbreaks of blight epidemics are becoming common phenomena everywhere. Recombination of both mating types A1 and A2 would increase generation of new genotypes in many folds, allowing selection for more adapted strains with increased aggression. Host genetic resistance is presently becoming the most significant alternative to help diminish the effect of LB disease, and is the subject of increasing attention in most breeding programs. However, the type of resistance in view— horizontal resistance— is to be perceived as the major component that can be used best within the concept of an integrated approach.

Multilocation trials

Multi-environment trials play an important role in selecting the best cultivars (or agronomic practices) to be used in future years at different locations and in assessing a cultivar's stability across environments before its official release. The agro-ecological classification essentially stratifies the environment, but usually is based on macro-environmental differences such as temperature gradients, rainfall distribution, and soil types. Interaction of genotypes with location in a given agro-ecology and with its environment, however, remains large due to micro-environmental variations. Thus, the Ethiopian Potato Improvement Program has been promoting varieties that have been suitable for growing in relatively diverse environments with wider adaptability. When the performance of a cultivar is compared across locations, several cultivar attributes are considered. Cultivars grown in multi-environment trials react differently to environmental changes. When the Standard International field trials (SIFT) grown in Uganda and Kenya were compared, their performance varied significantly among seasons and locations (El-Bedewi et al., 2001). The variation in genotype performance was suspected to be due to genotype x environment (GxE) interactions, which is the change on cultivars' relative performance over environments, resulting from differential response of the genotypes to various edaphic, climatic, and biotic factors (Dixon et al., 1991).

Stability in performance across environments is one of the most desirable properties of a genotype to be recommended for wide cultivation. Assessing any genotype without including its interaction with environments is incomplete and thus limits the accuracy of yield estimates (Tolessa et al., 1996). Previous work indicates the existence of considerable variation in the performance of potato genotypes based on phenotypic stability in different environments. However, this depends on the level of accuracy of yield estimates and magnitude of GXE interactions.

GXE interactions are considered by plant breeders to be among the main factors limiting responses to selection and, in general, the efficiency of breeding programs. The significant differences in the performance on the genotypes across seasons and locations could be attributed to differences in GxE interactions (Nakitandwe et al., 2005).

Wide adaptability

In Ethiopia, where potato is widely grown under different environmental conditions, varietal improvement work involving multi-environment trials is important in varietal selection for different locations and in stability assessment across environments. This necessity is due to possible high GxE interactions experienced in previous studies (Gebremedhin et al., 2003; E1-Bedewy et al., 2001; Bekele et al., 1996; Berga et al., 1994).

The differential response of cultivars from one environment to another (i.e., GxE interaction) makes it difficult for breeders to develop widely adapted, stable, and high-yielding genotypes in Ethiopia. Therefore, the Ethiopian Potato Improvement Program has been promoting varieties that have been suitable for growing in relatively diverse environments with wider adaptability. When the performance of a cultivar is compared across locations by the breeding program, several attributes of cultivars are considered within the domain of adaptability: yield potential, disease resistance, crop maturity, horticultural characteristics, and consumer preference.

The Ethiopian Potato Improvement Program aims at developing varieties that are widely adapted, high yielding, and resistant to biotic and abiotic stresses. This, combined with varying agro-climatic conditions and microclimate variations, considerably affects yield stability and their estimates. With this understanding, the national research program evaluates varieties using multilocation trials over many selected sites from different agro-ecologies that represent the major potato growing regions in the country. Selection of outstanding clones for commercial release is done using the results of the multilocation variety trials for tuber yield stability and genotype response across environments.

Specific adaptation

The national program was founded in 1975 to consolidate the efforts in potato improvement. Since then, evaluation of the clones for wider adaptation was the major objective, as was a focus on obtaining improved varieties that are higher yielding, LB tolerant, and adaptable to wider agro-ecologies. However, several years of multilocation variety testing across ecologies consistently indicated the presence of genotype differential response in yield and LB tolerance. Thus, starting in the mid-1990s, evaluating potato genotypes for a specific agro-ecology has been accepted as a fine-tuning step towards specific ecology-based releases. In this approach, clones that are at the stage of PNVT and NVT and/or those nationally released were included for evaluation. Using this approach, a number of varieties have been released for specific agro-ecologies of the country by regional research institutions (Gebremedhin et al., 2008).

On-farm participatory variety selection

Varietal selection involves on-farm participatory evaluation whereby farmers and other stakeholders identify the right variety for their locality. On-farm testing of potato varieties encourages farmers to participate in the evaluation and selection of varieties that would satisfy their needs and expectations. Included here is the assessment of the performance of advanced and released varieties under farmers' cropping system and an understanding of attributes desired by farmers so as to establish feedback among researchers, extension workers, and farmers (Gebremedhin et al., 2006).

In the central highlands of Ethiopia, participatory potato technology development and dissemination were undertaken. The methodologies used to address the constraints of potato production and to disseminate the available technologies were Farmers Field School (FFS), on-farm variety adaptation trials, trainings, and informal seed production through farmers' participatory approach. The FFS helped farmers to understand and participate in the integrated management of potato LB. In all the trials carried out, yield was not the determining factor for crop variety selection. Besides yield, farmers considered other parameters such as frost tolerance, earliness, color, disease tolerance, taste, and appearance. FFS increases efficiency of extension systems especially during the transfer of knowledge-intensive technologies like LB management, where oral communication and package approaches fail to provide detail and specific information. FFS hands-on exercises are sustainable and effective. FFS addresses farmers' in-groups and contributes quickly to greater outreach of successful results.

Strategies to select new varieties and their diffusion

Varietal selection and release have no value if diffusion to farmers is too slow. A good strategy takes into account fast seed-bulking processes and well-organized seed systems to rapidly diffuse to farmers to enjoy the benefits of the new variety. The success of variety diffusion depends on seed systems and their efficient spread. Some strategic approaches, taken into account in informal and formal seed systems, and the participation of individuals and group seed producers have encouraging results. The cooperatives organized in Jeldu and Welmera and, recently, in Gumer, Geta, Wonchi, Chelea, and Atsibi woredas have been instrumental in the diffusion of new potato varieties by making seed of these improved varieties available.

The existing potato variety selection scheme requires 10–12 years or longer from the time varieties are introduced to the time they are released. This period can be shortened by developing efficient seed programs. Similarly, well-developed variety adoption programs may not be a problem as released varieties do satisfy growers' and market demands. Further diffusion may take place smoothly through well-established seed programs.

The Ethiopian Potato Improvement Program, with almost 35 years of CIP's technological support through its regional office in Kenya and its headquarters in Peru, has been able to release more than 30 varieties; however, the rate of adoption and diffusion has been quite limited. Of the released varieties, Jalene, Gudene, Guassa, and Gera are the most widely grown potatoes at present. In most cases, the main limiting factor for variety diffusion was insufficient amount of clean seed. It is characterized by the limited formal seed system that was overwhelmingly dominated by the informal system.

Although the program has shown progress over the years, further improvement is still needed, particularly in accelerating varietal selection and release schemes and increasing adoption and diffusion rates.

Suggested Promotion scheme for new varieties

Farmer participatory varietal selection approaches have been practiced in their different forms, such as on-farm participatory research, FFS, Farmers' Research group (FRG), and others, with the idea of improving the possibilities of technology development and adoption. The process of varietal selection and release may improve the rate of adoption and diffusion through the participation of a wider range of stakeholders, shortening the time for release and making seed available at release time. Still other stakeholders may need to be part of the selection process. We suggest that the program adopt the following components.

The first component is related to the participatory process of multistakeholders such as farmers, traders, processors, and consumers, during multilocation trials in farmers' fields to help identify promising clones. The second component is the short timeframe needed to evaluate, identify, and release new varieties. The third component is the seed increase (bulking scheme) parallel to trials for use in the multilocation trials and as starter seed for diffusion when a variety is released. In the past, there was not enough seed when a variety was released and bulking (seed increase) usually takes too long, making diffusion limited and lengthy. Such a scheme is considered as a tool to speed-up the release of new varieties and to subsequently increase the rate of adoption.

Diffusion of new varieties has been lengthy and limited; thus old potato varieties are still present in farmer's fields covering significant areas. In other words, new varieties are struggling to reach larger areas or replace the old ones. Farmers would like to replace their old varieties with new ones because of diminishing productivity, but they usually have not heard of the release of new ones. Even if they are aware, there is no seed supply priced affordably. Therefore, the lack of quality seed in sufficient amount is the major limiting factor for varietal diffusion.

Improving the efficiency of minituber production

Traditionally, production of minitubers is done on soil-base substrates that were steam sterilized to avoid soil-borne diseases and pests in Ethiopia. However, owing to low multiplication rate of this traditional method of minituber multiplication and the uncertainty of the produced tubers to seed health test, new and alternative methods are needed. Apparently, the best alternative is to use nutrient solutions instead of soil substrates, which is a common practice already established for minituber production in other countries as a technology called aeroponics. CIP has already developed an economic module that is being promoted for developing countries. Since 2010, with the help of CIP, the Common Fund for Commodities, and the U.S. Agency for International Development, the Ethiopian Institute of Agricultural Research has installed this technology (two aeroponics units) at the Holetta Agricultural Research Center (HARC).

This technology consists of growing plantlets in specially designed boxes where shoots grow on top and the roots grow downward while suspended in the air within the box and in darkness (Fig. 2). Roots are fed with pressurized nutrient solution as mist at short intervals. This set provides good conditions for easily developing tubers on stolon near the roots.

Figure 2: Minituber production through aeroponics facility at HARC.

There are several advantages of this technology as compared to the traditional soil-based substrates. The most important ones are healthy tubers are obtained because no soil-borne diseases could develop under this condition, and more tubers per plant are produced with repeated harvesting, thus reducing production cost. On average 30.5 minitubers per plant were produced with aeroponics as compared to 5 tubers on soil substrates. Therefore, the efficiency of minituber production is 6–10 times more than that of soil substrate. This type of technology can improve the efficiency of minituber production at the national level and partially solve the limited capacity. It can be expanded further through private laboratories, which will finally solve the chronic shortage of clean stocks at the pre- and basic seed production level. As a result, the diffusion of existing and newly released varieties are facilitated. The production of the mintubers using aeroponics can be supported by planting the small-sized minitubers under screenhouse conditions or use of plantlets under the screenhouse.

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Sustainable Seed Potato Production in Ethiopia: from Farm-Saved to Quality Declared Seed

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Introduction

In potato production, seed quality is an important determinant for the quantity and quality of the tuber yield (Struik and Wiersema, 1999). Current yields in Ethiopia are low (8 t ha^{-1}) but could easily be doubled or tripled. Perhaps the most significant constraint to increasing productivity and overall production is the chronic shortage of good quality seed tubers. Seed systems can be defined in the way farmers produce, select, save and acquire seeds (Sthapit *et al.*, 2008). In the absence of a commonly agreed definition for different seed systems, this paper will differentiate between three different types of seed production systems, i.e. formal, alternative and informal seed production systems.

The formal system involves seed certification by Ministry of Agriculture according the Ethiopian Standard for Seed Potato (ES 494:2005). The legal framework for a formal root and tuber seed certification scheme is in place but not implemented. Given the Ethiopia's large area size, the still limited road infrastructure and the fact that seed potatoes are being produced by hundred-thousands of small-scale farmers (instead to few large-scale commercial producers), the costs for implementing a formal seed certification scheme would be prohibitively high; so the logistic requirement is extremely challenging. It is therefore unrealistic to assume that such a system could be under operation at a national level in medium term. However, it might be feasible to certify seed produced by these few large-scale producers; particularly for those aiming at exporting potato seed to neighboring countries.

In the alternative system, farmer cooperatives and farmer groups (farmer cooperatives in the following) with technical support and supervision from the national research and extension system produce seed of relatively high quality, in the same way by special projects and universities. In contrast, the informal system is characterized by the absence of quality control mechanisms. Relatively poor quality seed, derived from farmers' own fields (farm-saved), and local markets or neighbors is planted for an unspecified number of generations.

According to (Gildemacher *et al.*, 2009), the informal system is the predominant seed production system accounting for 98.7% of the total potato seed produced in the country while the alternative system meets 1.3% of the national seed requirements and no certified seed is being produced at present. To put these percentages into perspective, the quantities of seed involved should be considered. The total area cropped to potato in Ethiopia is around 160,000 ha (Gebremedhin *et al.*, 2006). The annual seed requirement is therefore around 320,000 tons; out of which 315,840 tons (98.7%) are supplied by the informal seed system and the remaining 4,160 tons by the alternative system.

The informal and alternative seed systems will therefore remain to be the dominant seed production and dissemination mechanism in the country for the time being. Interventions designed to improve farmers' access to quality seed at affordable prices should therefore aim building upon the existing two systems, trying to improve seed quality and overall system efficiency. It is the purpose of this paper to provide an outline on how the alternative seed system could be strengthened by building upon the informal system and by introducing the concept of quality declared planting material (QDPM).

Improving farmer access to affordable quality seed

Seed quality is an important determinant for tuber yield and quality. The national research system and Solagrow PLC, a private company, are now producing potato minitubers (Generation 1 – G1 seed). While in 2011 less than 60,000 minitubers were produced, and it is likely that the total production in 2012 may exceed 300,000. The question remains, though, how could more than 2 million potato growing households benefit from this high quality seed, the minitubers.

A centralized approach whereby G2 (generation 2) and G3 (generation 3) seed is produced at only a few locations would involve huge logistic and cost to make this seed available to potato farmers in major rural seed production areas. This calls for a more decentralized seed production and multiplication system that is presented in the following. It links producers of pre-basic minitubers with farmer-based seed multiplication and dissemination systems, thereby creating a new hybrid system that incorporates components of the alternative as well as informal seed systems. Such a system would have the potential to give large numbers of potato farmers' access to quality seed.

Figure 1 illustrates the envisaged scheme for potato seed multiplication. The initial source materials are disease-free in-vitro plantlets produced by the national research system and private tissue culture laboratories. These plantlets are grown in screenhouse or the newly built aeroponics units to produce pre-basic minitubers (G1). Given the small size of the pre-basic minitubers, experienced seed potato producers with under semi-controlled condition to give G2 seed should then multiply these; access to irrigation is an important requirement at this stage. These experienced multipliers include research centers, private enterprises, and leader farmers, ideally located at head points of traditional seed systems. These G2 seed is then sold to seed producer cooperative/ private sector multipliers who in turn may sell the subsequent generation to surrounding farmers: seed produced groups and private sector multipliers through farmer-to-farmer exchange. It is assumed that for the first two generations the entire produce would be kept as seed, however, as of generation three it is likely that an increasing proportion of the produce will be sold or consumed as ware immediately after harvest to satisfy farmers need for cash and food. It is difficult to assess for how many generations the seed will be recycled before used as seed for ware thereby reaching the consumer as ware potatoes. However, given experiences from other high-altitude areas, it is assumed that the seed could be multiplied for five to eight generations, especially if positive/negative selection techniques would be employed.

Farmer Cooperative and Model Farmers located in these seed producing areas play a key role in producing quality seed, catering for their own seed needs and providing seed to other growers operating in that area. Such a system requires more input/ resources initially, however, once established, it may drastically reduce transaction costs and dependence on outside intervention and functions in a sustainable manner. The small volume pre-basic minitubers (5 to 20 g) ideally complement such a system, since they can easily be transported to remote multiplication sites located at head points of these seed flows. This again greatly reduces potential transport bottlenecks of more centralized systems. For such a system to make best use of these expensive minitubers, it is important that the head points of these seed flows are located at high altitudes where disease pressure is greatly reduced. Subsequent seed generations should then gradually move to lower altitudes and ware crops can be grown in the lowlands. Minitubers are currently multiplied at research centers (Holetta, Adet, and Mekelle) to produce G2 seed tubers. However, initial tests to multiply minitubers by farmer cooperatives are encouraging; for example, during the Meher season of 2011 farmers in the Gurage zone managed to successfully multiply these minitubers. Out of 1000 G1 minitubers, they produced 10,650 G2 tubers. This is an excellent multiplication ratio of above 10 - a multiplication ratio of 6 to 8 was considered standard. This result show that farmers cooperatives are capable of successfully multiplying minitubers and the production of G2 seed that could be further decentralized into major seed producing areas.

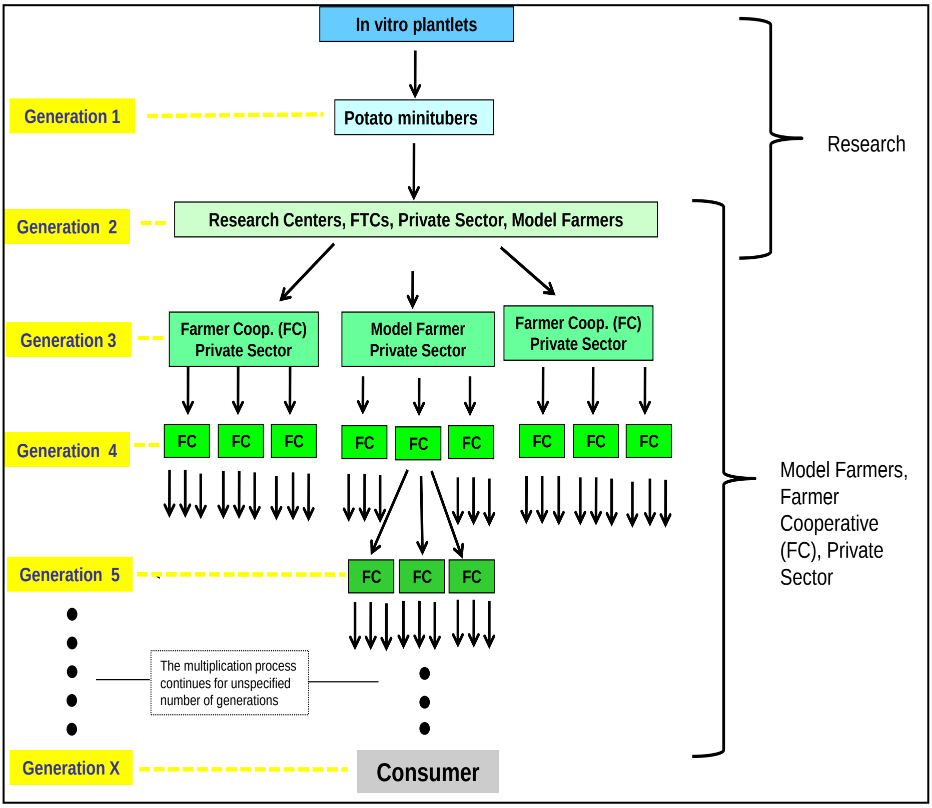

Figure 1: Decentralized seed multiplication scheme

Seed potato value chain

Seed and ware potatoes are distinct commodities that need to be treated differently from planting to harvesting and then storage. However, in Ethiopia value chains for these two commodities are largely identical. In the absence of a labeling system, it is difficult to distinguish seed tubers from ware potatoes in the market. A value chain analysis found that most seed potatoes sold in markets are simply graded and re-classified as ware potatoes. "Clever" traders, therefore, buy ware potatoes, declare them as planting material, and eventually sell them to farmers and other buyers / NGOs. Given this uncertainty, buyers of seed potatoes are reluctant to pay premium prices needed to justify the extra costs associated with the production of quality materials. It will therefore only be possible to establish separate value chain for seed potato if the following two pre-conditions are fulfilled:

- Seed potatoes are clearly recognizable as such in the market; and
- Buyers of seed potato are assured that they purchase unadulterated, high quality planting material.

Labeling

The first pre-condition is relatively easy to implement by introducing a labeling scheme for seed potato. Such a scheme is currently being piloted by EIAR, TARI, SARI and the BoAs in SNNPR, Oromia and Tigray with support by the "Wealth Creation" project, funded by the Common Fund for Commodities and the "Better Potato for a Better Life" project with USAID funding. Quality seed potatoes are produced and stored by seed producer cooperatives under supervision of research and extension staff. At the time of sell, paper labels are provided to the cooperatives and attached to the seed bags. The labels state the name and address (including telephone number) of the cooperative, the variety, weight and date of harvesting. An example of such a label in Amharic and English is shown in Figure 2. The initial experiences are encouraging as the scheme helps to link seed producers and buyers and contributes to the branding of the producers. Cooperatives consistently producing good quality seed will become known in their region and customers are more likely to return in future.

Figure 2: Labels of potato seed in Amharic and English

Seed Quality Assurance

In the absence of an operational seed certification scheme, seed tuber quality described as in the alternative system is maintained by staff of research organizations and seed potato projects whose jointly ensure the minimum quality standards. However, as the demand for quality seed is growing, this system is gradually reaching its production limits. Moreover, in case where it relies on projects' interventions it is not sustainable. Alternative mechanisms at regional and/or local level need to be developed, tested, and promoted to ensure that the producers of planting materials adhere to minimum quality standards.

Quality declared planting material

Ensuring that farmers have timely access to seed and planting material of good quality is one of the most important elements of successful agricultural production and development. Despite this reality, seed and planting material available to small-scale farmers in many parts of the world is often of insufficient quality, negatively affecting yields and undermining crop performance. This bottleneck is particularly acute in countries where small-scale producers dominate the production system and where fully-fledged seed certification schemes are not a viable option because of their high costs and logistical requirements.

To address this bottleneck, FAO, in consultation with partners, produced a technical guideline on Quality Declared Seed (QDS) in 2006 for crop species propagated by true botanical seed. These guidelines are now used and consulted worldwide (FAO, 2010). However, vegetatively propagated crop species have not been included in the QDS guidelines, despite their importance for agricultural production and food security. Therefore, FAO, in consultation with CIP and international experts, has developed protocols and standards for the production of Quality Declared Planting Material (QDPM) of the most important vegetatively propagated crops such as potato, sweetpotato, cassava and yam more recently (FAO, 2010). It is the aim of the QDPM guidelines to raise the physiological and phytosanitary quality, and hence, yield potential of planting material available to small-scale farmers, thereby increasing agricultural productivity. The QDPM protocols allow for easy and low cost inspection of planting material and facilitate the production of planting material that fulfills agreed on quality standards. The assessments are based on visual observations made by trained farmers, research, or extension personnel.

The QDPM guidelines need to be adapted to the prevailing conditions and available resources. The underlying principle is shown in Figure 3 as a function of "inspection costs" and "seed quality", assuming a decreasing marginal benefit with increasing intensity of seed inspections. The best quality seed will be attained with a formal seed certification scheme, however, as discussed earlier, such a system is currently not a viable option for potato seed production in Ethiopia due to its costs and logistical requirements. Therefore, an acceptable compromise between cost and seed quality needs to be found. "QDPM light" refers to a minimum inspection intensity already resulting in tangible seed quality improvements while "QDPM intense" refers to a more sophisticated but also more expensive inspection regime.

The QDPM concept does not intend to replace seed certification schemes. Rather it should be considered as an intermediate step towards the establishment of a certification scheme. As soon as conditions and resources allow it, the inspection intensity should be increased to further improve seed quality. The Government of Ethiopia is very much cognizant of the need to improve the quality of seed and planting material for achieving the ambitious targets set for agricultural growth in the current five-year plan. Recognizing that formal seed certification schemes may currently not be attainable, the QDPM concept forms part of the policy recommendation produced by the Agricultural Transformation Agency and is included in the new national Seed Proclamation.

QDPM guidelines for potato: An example

Based on the FAO guidelines for QDPM, the following production guidelines for quality declared potato seed tubers are suggested

- Isolation: the seed potato crop should at least be 50 m apart from the next ware potato crop; and
- Crop rotation: At least a 3-year crop rotation should be maintained ensuring that the previous 2 years no solanaceous crops were produced on the seed potato plot

At least one field inspection should be carried. In fields of less than 2 ha, 10 counts of 100 plants each are taken. The plants should be assessed based on the tolerances listed in Table 1. Aphid counts should be taken on all assessed plants. In case of a slight infestation (1 to 2 aphids on few plants), no measures need to be taken. In case of moderate infestation (2 to 5 aphids on most plants), the crop should be treated with an insecticide. In case of a severe infestation (>than 5 aphids on most plants), the crop should be treated with an insecticide and early haulm destruction is recommended. In addition, a post-harvest inspection should be carried out to ensure that the stored seed is graded to agree on seed sizes (e.g. 35 to 70 mm), the seed is stored in diffused light stores, is reasonably free of soil and that different varieties are kept apart.

Examples for tolerances for pests, diseases and other criteria for the field and post-harvest inspection are given in Tables 1 and 2. These tolerances would still need to be reviewed and adapted to the conditions/ constraints on the ground. Important is, however, to ensure that the selected indicators can be assessed through visible observations by trained persons (farmers, research and extension staff) without the need for expensive laboratory testing. The threshold levels need to be realistic and attainable by reasonably trained and experienced seed producers. If the tolerances are too strict, farmers will be discouraged to continue with the system, falling back to the informal system without any quality control. These guidelines would need to be adapted to the envisaged seed quality requirements, the inspection intensity and resources available for the inspections.

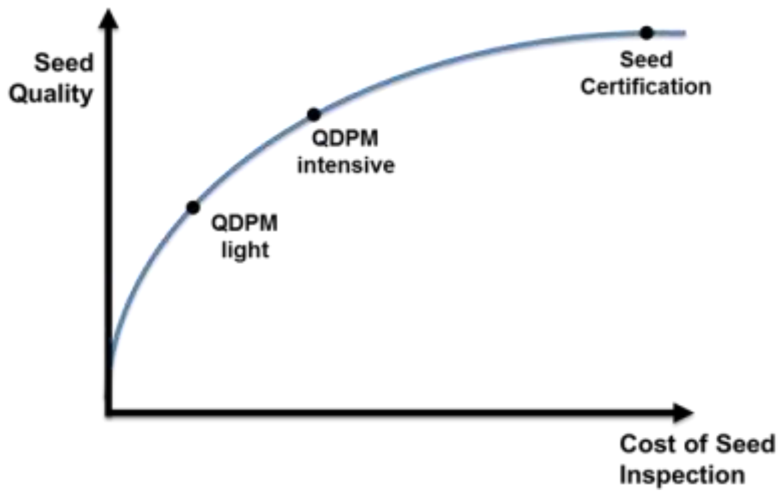

Figure 3: Schematic illustration of the effect of different seed quality control mechanisms on inspection costs and seed quality

Table 1: Example tolerances for the field inspection of QDPM seed plots

Disease or defect	Tolerance
Off-type potato plants	1%
Leaf roll (virus)	5%
Severe mosaic (virus)	5%
Total severe virus (leaf roll + severe mosaic)	10%
Mild mosaic (virus)	10%
Total virus	10%
Blackleg	2%
Bacterial wilt	nil

Table 2: Example tolerances for the post-harvest inspection

Disease, pest or defect	Tolerance
Wart disease (Synchytrium endobioticum)	Nil
Late blight (Phytophthora infestans)	5%
Powdery scab (Spongospora subterranea)	8%
Tuber necrosis caused by strains of PVY	0.5%
Soil (by weight)	2%
Off-type seed tubers	1%

Inspection mechanism

Depending on the inspection intensity and, of course, availability of resources, two separate inspection mechanisms could be envisaged, roughly corresponding to QDPM light and intensive, as shown in Figure 3. The QDPM light would correspond to a self-inspection scheme implemented by seed producer cooperative themselves without direct outside support and follow up. Examples of such self-inspection teams already exist in the country. Seed producer cooperatives around Holetta who have been supported by EIAR for several years have established internal inspection committees consisting of 3 to 6 members of the cooperative (Gebremedhin, pers. comm.). They visit the seed plots of all members and decide based on visual observations whether a certain plot fulfills the cooperatives requirements/ tolerances for seed production. In some cases, the cooperative even compensates members if their seed plot is rejected to encourage the farmer to comply with their recommendation to sell the produce for consumption purposes. These examples clearly show that cooperative-level inspection systems are a farmer-acceptable and a viable option for low-level, informal seed inspection schemes (QDPM light). Building on these existing experiences, the system could be strengthened by agreeing on and applying uniform tolerances for pest and diseases and by training the self-inspection teams. Subsequently the system could be promoted and applied in other seed producing areas of the country.

The QDPM light system could be further strengthened and formalized by establishing a second inspection committee, operating at woreda level (QDPM intensive). This committee should involve staff of research and development institutions present in the woreda and 1 or 2 representatives of the seed producer cooperatives. It may not be possible for this committee to inspect all seed plots in the woreda. Instead a sample of all seed plots of a cooperative would be inspected. Depending on the available resources, the seed plots may be inspected once or twice during the growing season, in addition, a post-harvest inspection should be carried out to ensure that the seed is graded, stored in adequate conditions (diffused light stores), and that different varieties are clearly separated.

The woreda-level committee should then estimate the total quantity of seed the cooperative has produced for sale. Based on this estimate, the committee provides the corresponding number of seed labels to the cooperative for the seed produced during this particular season. In addition, the cooperative should be awarded the title of "Recognized Seed Producer" for a given period and should be authorized to market its seed as QDPM seed.

Footing the bill: who is going to pay for the inspections?

Production costs of quality seed potatoes are substantially higher than ware potatoes. This is explained by the fact that yields of seed crops are generally lower than ware crops and by extra costs associated with rouging, dehaulming, and grading. In addition, seed tubers lose between 3 to 4% of weight during storage in diffused light stores (Endale *et al.*, 2008) and farmer runs the risk of not being able to find a buyer for his seed. The inspection itself (transport, per diems, and accommodation) and the labels for seed potato bags increase the costs of QDPM seed even further.

These costs may initially be borne by special projects supporting seed potato value chain; however, ultimately they need to be incorporated into the seed price paid by the buyer. To convince seed buyers that quality seed justifies the extra cost, substantial efforts in advertising and awareness creation, ideally in combination with field demonstrations by showing that quality seed does translate into visibly better yields and hence justifies the initial investment should be major activities at present.

In this context a word of caution: The formal Ethiopian seed potato market is unique in the sense that it is dominated by institutional buyers (NGOs, MoA, EIAR, FAO and aid agencies). Farmer to farmer seed exchanges (gifts, bartering) does take place, however, only limited quantities of seed are being sold directly between farmers and neighbors. In the absence of well-established value chain for seed tubers, it is very difficult to assess the actual demand for quality seed. Therefore, efforts to produce quality seed would need to be matched by efforts to link producers to either institutional or private buyers of quality seed.

Seed potato vision for 2020

The Ethiopian potato subsector is vibrant, the potential of this crop to contribute to improved food security and nutrition are increasingly being recognized and future prospects for the seed potato subsector are bright. This is exemplified by increasing donor interest in the crop (viz Irish Aid) and the fact that the Disaster Risk Management and Food Security Sector (DRMFSS) of the Ministry to Agriculture has just created a task force for root and tuber crops to exploit the potential in emergency situations.

For the year 2020, the author's vision for the Ethiopian potato sub-sector would be that average potato yields have doubled and overall production has tripled. Self-financed, sustainable seed inspection system applying QDPM standards function without outside support in all major seed producing areas. QDPM seed meets at least 50% of the national seed demand. In addition, a formal seed certification scheme is in place for large-scale commercial seed producers. The involvement of NGO and government agencies into purchasing and distribution of seed tubers is greatly reduced as seed is traded directly from farmer to farmer and seed exports into neighboring countries generate appreciable amounts or foreign currency. An internet or mobile phone based information exchange platform is established, effectively linking seed producers and buyers and providing up-to-date market price information.

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Tackling Low Potato Yields in Eastern Africa: an Overview of Constraints and Potential Strategies

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Introduction

Improvement of the potato production system in sub-Saharan Africa (SSA), where potato is an important cash and food crop, can be a pathway out of poverty. Potato has a short cropping cycle and a large production per unit area in a given time. It provides more nutritious food per land unit in less time and often under more adverse condition than other food crops due to its efficient water use. It is one of the most efficient crops in converting natural resources, labour, and capital into a high quality food. Potato is a cash crop of the future for the densely populated East and Central African highlands, with a high potential to raising the livelihoods of smallholders. Furthermore, potato provides a cheap but nutritionally rich staple food required in the fast growing cities of SSA, contributing protein, vitamins, zinc and iron to the diet.

For SSA, (Scott *et al.* 2000) projected a 250% increase in demand for potato between 1993 and 2020, with an annual growth of 3.1%. The growth in area under production is estimated at 1.25% a year, the rest of the increase being achieved through predicted growth in productivity. For both increased productivity and area under production, a well-timed availability of good quality seed of improved potato varieties will be vital, which is also a very efficient way of promoting adoption of high yielding, disease resistant potato varieties that have acceptable qualities for both table and processing. Increased potato productivity will play a buffer role to the increasing food prices and thus enhance household income in the project countries with a spill over to other countries in SSA.

Major Constraints and Strategies for Increasing Potato Productivity in Eastern Africa

Current average potato yields in Sub Saharan Africa stand at 7.8 tons per hectare (FAO, 2012). Yields of 25 tons are, however, being attained by progressive farmers using best production practices, under the same rain-fed conditions as their neighbours who attain yields of 5-6 tons per hectare. This yield gap can be attributed to the use of low quality seed potatoes (Kinyua *et al.*, 2001), low yielding varieties, poor disease management (Olanya *et al.*, 2001), and inadequate soil fertility management (Lemaga *et al.*, 2001).

Low quality seed

Availability of good quality seed in the region is very limited and hence most farmers use seed, either from their previous harvests or from local markets, whose source is not well known. Such seed is usually diseased and or physiological in poor state, resulting in very low yields. The few farmers that access good seed of improved varieties harvest may double their yield compared with their neighbours (although good data remains lacking in many cases). Many farmers, being aware of such advantages are willing to pay premier prices for better quality seed of improved varieties produced by public institutes or recognized seed growers, but are constrained by the acute shortage of such seed. Moreover, traditionally with the National program whole cycle of producing certified potato seed, typically takes 5-7 seasons and the potato seed stocks inevitably accumulate seed borne diseases such as viruses or bacterial wilt through each cycle.

Therefore, the International Potato Center (CIP) has developed, and with its national partners, tested the components of an innovative seed strategy, which both dramatically lowers the cost of production of pre-basic or "starter" seed coupled with extension based interventions to train smallholders in the better on-farm management of their own seed. A more efficient and responsive seed system will improve production, distribution, use, and profitability for farmers. Promising rapid multiplication technologies, the "3G revolution," and an engaged private sector can provide needed capacity to broaden adoption of quality seed and accelerate availability of new varieties with more prospect of benefit. Better integration of national agricultural research and extension systems into the value chain; as well as farmer training schemes in seed management and storage, can accelerate innovation. A regional perspective can help exploit economies of scale for sharing knowledge and technology, implement creative applications of information communication technologies, advocate for farmer-friendly seed-related regulations and policies, improve the business enabling environment, and expand intra-regional trade for seed of the highest categories. The International Potato Center (CIP) has produced a Roadmap document having a five-year strategy described for Ethiopia, Kenya, Rwanda, Tanzania, and Uganda targets business investments in key areas along the seed potato value chain to increase the availability of high-quality seed potatoes from less than 1% to at least 5% of demand (except Kenya, where the target is 10%) and promote improved seed management. This will raise incomes of smallholder farmers, improve food security, and add to the rural and growing urban economies in these five countries.

Five mutually reinforcing core investment areas (IAs) are proposed to put the interventions of seed potato value chain into practice. Three IAs make up country-level business plans:

- Improving quality seed production and distribution;
- Enhancing profitability of quality seed use; and
- Upgrading value chain coordination

Two IAs are regional and potentially cross-cut all five countries

- Promoting regional networks for sharing knowledge and best practices
- Growing intra-regional trade in seed

The IAs build on a mix of value chain fundamentals and the accomplishments and lessons learned from recent projects, such as the two-year, USAID-funded 3G project. Led by CIP and implemented in Kenya, Rwanda, and Uganda, the 3G project increased access to and production of basic seed potato in both public and private sectors; successfully introduced aeroponics technology and supported its adaption and adoption; and significantly increased production of minitubers at the national and regional scales. The project fostered private adoption of the three-generation (hence the "3G") seed multiplication strategy and improved knowledge and skills leading to average yield increases of 20% for over 15,000 smallholder growers on potato production technologies and best practices. Other seed-related projects have generated complementary experience with improving farmer seed management that can be scaled up, such as the Common Fund for Commodities (CFC) project in Uganda, Kenya, and Ethiopia, USAID funded "Better Potato for a Better Life" project in Ethiopia and the Irish Aid-funded project in Malawi. The investment proposed in the Roadmap is expected to direct the increase in yield of 20% in the five target countries to achieve three overarching objectives: a 15% increase in farm incomes, improved food security through a 10% increase in potato production, and more business opportunities for at least 240,000 households of smallholder potato growers.

Low yielding varieties

Most of the varieties (Many of CIP origin) being used by farmers in the region were released in the 1990s, which in the process have either degenerated or lost their resistance to important diseases such as the potato late blight.

Another important quality of many new varieties is virus resistance. This will greatly facilitate the value-enhancement of new seed discussed above and make seed production easier and therefore more profitable. There are many other characteristics that new potato varieties can bring to small-scale farmers including variation in maturation periods and dormancy period—allowing more flexible planning—resistance to drought, and greater yield stability. Some qualities come unknown to farmers as breeders are now selecting varieties with higher nutrient value. Most potatoes produced in eastern Africa are consumed fresh. Nevertheless, with population doubling every 25 years and urbanization predicted to grow by 13% in the next 10 years, consumption patterns are rapidly changing in favour of easy-to-prepare foods such as chips (French fries). There is high potential for the growth of the potato processing industry, and market access in the region is improving with increased demand for both fresh-cut and frozen potato chips. CIP and partners are involved in the development of new varieties that combine processing quality with one or more of the robustness characters mentioned above. Although several new varieties have been released since then by the joint effort of CIP and National Agricultural Research Institutes (NARIs) in the region, these have not been adequately adopted by farmers due to shortage of seed and poor promotion strategies and approaches followed in the region. This can be attributed to several reasons

- Lack of demand for seed may be an issue in the case of new varieties because of an inadequate supply of information on their advantages. Thus, farmer awareness is an important element in adoption of new varieties;
- Potato inherently has a low multiplication rate (about 10 seed tubers per plant) and potato seed is bulky and perishable;
- Lack of investment in National programs, "land-grabs" and consequent loss of key land for seed multiplication like for instance in Kenya and rising fuel prices have all contributed to this situation;
- The current practice of potato variety release mechanisms in Eastern Africa are focused primarily on high-input agriculture. While this fits some of the farmers in the region, most farmers work under low input conditions and the relative responses of varieties is not consistent across input regimes. Some varieties are known to be good scavengers for nutrients and may provide much better yield stability to low-input farmers. Policy

makers should take this into consideration and a two-tiered evaluation system may be needed; and

- Harmonization and shortening of evaluation and selection processes would be key for accelerated release of improved germplasm. Much of the region have similar environmental conditions, and a similar spectrum of biotic constraints, which means that with certain exceptions, the performance of a particular potato variety can be expected to be similar in all parts of the region. For this reason, potato workers in the region have long discussed the need for harmonized policy across the region that would facilitate rapid release of new varieties. The primary mechanism for this would be the use of trial data from one location in other parts of the region. To date, this has happened to a limited extent, but a formal structure for sharing of data across the region has not been fully implemented yet.

High incidences of diseases

High incidences of late blight, bacterial wilt (BW) and viruses affect potato production in Eastern Africa. The high incidence of these diseases in the region ensued from the lack of good seed system, inappropriate use of chemicals to control fungal diseases and lack of proper sanitation, crop rotation, and varietal resistance among other factors. The incidence of viruses and bacterial wilt is very much linked with the general lack of clean seed.

Potato late blight (LB) is the most important plant disease because it causes severe, direct crop losses virtually the world over. Typically, small-scale farmers continuously use fungicides to combat LB, but this practice creates a dependency on pesticides and compromises human health and the environment.

The control of LB implies actions on different fronts, so any project that targets the disease should consider using an interdisciplinary approach to tackle this problem. Decades of research into LB at the International Potato Center (CIP) suggest at least five key areas of effective intervention

- Design and conduct baseline, risk, and impact assessments to better quantify the problem, provide a strong foundation for improved decision making by stakeholders, and demonstrate outcomes and impacts;
- Enable appropriate disease management for small farmers: combining state-of-the-art scientific information with farmer knowledge will improve LB management practices;
- Improve development of durably resistant cultivars with market appeal. Resistant potato varieties constitute the cornerstone of the LB control

strategy, particularly for resource-poor potato growers who cannot afford intensive fungicide use;

- Maximize impact by rolling out these intervention tools through farmer capacity building; and
- Opportunities to involve the private sector as well as create public-private partnerships (PPP) as variety users need to buy into sustainable low-pesticide potato. PPP opportunities also exist in quality seed production and novel control options such as phosphonate-based fungicide control.

Farmers identified BW as a major threat to intensive potato production in the East African highlands (Gildemacher et.al., 2009; Turkensteen, 1987). The BW problem is expected to increase because of shorter rotations and low seed quality. The disease survives in the soil for several seasons. Hence, one essential component of BW management is denying the bacteria a host by not growing potatoes or any other host crop for several seasons, combined with a strict removal of volunteer potato plants (Lemaga et al. 2005). In this respect, the effect of organic and inorganic soil amendments and the evaluation of antagonistic agents in BW control should be investigated more closely. Likewise, the efficiency of local crop rotation system should be tested in respect to their contribution to BW control and farm income.

The management of BW is further complicated by the lack of reliable seed sources and the heavy reliance on farm saved seed potatoes as planting material, which results in frequent reinfection of fields. The bacteria survive in non-symptomatic tubers that are stored for future planting; making them to vectors for the infestation of new fields, they are planted. Therefore, BW control has to include a seed potato quality management component, reducing the use of infected seed. Moreover, tools have to be developed for more accurately, easy to use and cost effective detect and quantify BW inoculum in soil, seed and water, to help National Programs and extension services in reducing losses caused by the disease.

Inadequate soil fertility management

An adequate soil fertility and crop management are not only key components for sustainable crop production in potato based cropping systems but also decisive factors to increase productivity and crop quality. Especially in SSA the gap between actual and potential yields is caused to a great extent by insufficient nutrient supply to the crop and nutrient mining of the soil. This situation aggravated by a crop like potato which has a high nutrient demand but a low nutrient recovery rate. The negative effects are felt more strongly in practices that use little crop rotation. For farmers to invest in potato production there should be a convincing benefit that the potato brings against other competing crops. This call for a reliable market for potatoes, which potentially exists but needs to be systematically enhanced in a value chain approach. Furthermore, soil fertility management also stimulates microbial soil life and decomposition processes, which in turn decrease the incidence of soil or seed borne diseases such as BW. Ethiopia as an example, faces a wide set of soil fertility issues that require approaches that go beyond the application of chemical fertilizers– the only practice applied at scale to date. Core constraints include topsoil erosion, some sources list Ethiopia among the most severely erosion-affected countries in the world, along with Lesotho and Haiti. Acidity-affected soils covering over 40% of the country significantly depleted organic matter due to widespread use of biomass as fuel, depleted macro, and micro-nutrients, depletion of soil physical properties, and affecting soil salinity.

Four areas in which significant improvement in on-farm practice will yield substantial production gains are:

- Severe organic matter depletion, driven by competing uses for crop residues as livestock feed and manure as fuel. The use of dung as fuel instead of fertilizer is estimated to reduce Ethiopia's agricultural GDP by 7 percent;
- Severe topsoil erosion of up to 10-13 mm per annum or 137t/ha/year;
- While crop rotation and fallowing have implementation challenges related to food security and the small size of land holdings, intercropping does not face these same challenges, yet current use are nearly non-existent. This is mainly due to the limited use of basic practices and benefits; for example, minimum tillage, and soil and water conservation); and
- Limited use of integrated, locally tailored solutions. Required enablers (for example, robust, simple soil diagnostic tools) are not widely available outside of research projects. These interventions are constrained by a lack of up-to-date data; many interventions depend on major national soil surveys dating to the 1980s (FAO) and macronutrient studies from the1950s–60s. In addition to the lack of actionable, relevant data, the weak linkages between research and extension inhibit the adaption and adoption of these practices by smallholder farmers.

Specific to fertilizer, there are a set of value-chain constraints

- Chemical fertilizer faces significant constraints in terms of low availability of credit and limited reach of distribution networks in contexts where appropriate application can enhance yields;

- Bio-fertilizer is constrained by low demand, due to lack of awareness and understanding of the product, and limited production capacity. Extensive testing of benefits to identify appropriate products is needed; however, research efforts are currently limited; and
- Inadequate use of farm manure and other on-farm organic matter resources like crop residues

Inadequate seed and ware potato storage facilities

Technologies for storing seed and ware potatoes were developed by CIP long time ago, but their adoption in the three countries has been below expectations. In Uganda; however, AfriCare, an International NGO, has helped spreading the use of diffused light stores (DLS) for storing seed potatoes in the woredas of Kabale and Kisoro. All the members of the Uganda National Seed Potato Producers Association (UNSPPA) also built their own stores that have bigger capacities. The Ethiopian potato program has also had much success in promoting the adoption of DLS through its competent extension activities. In Kenya and Rwanda, a few farmers store seed potatoes in DLS.

Generally, however, the majority of the farmers store seed from their previous harvests in piles on the floor of their houses or in sacks or baskets, resulting in poor and usually long sprouts that break easily during transportation and/or planting. Such poor storage practices result in one sprout per tuber due to apical dominance, leading to one stem per plant and hence very low yields.

Experience has shown that raising awareness of farmers of the benefits of DLS will highly increase its utilization in the three countries with consequent results of increased per unit area yield. Moreover, if seed farmers use DLS, they can get much higher incomes from sale of quality seed to ware potato producers.

Besides seed potato storage, proper ware potato storage systems are of major importance to improve the value chain. One of the major constraints to increased year-round utilization has been insufficient post-harvest management systems. Post-harvest losses due to mishandling can be as high as 30% (Gebre et al., 2008).At harvest time, there is a problem of glut, which leads to very low prices (discouraging farmers) at times of abundance, and very high prices (discouraging consumers) at times of scarcity. Data from Ethiopia shows that farm gate prices fluctuate by more than 25% within 2 months before and after harvest (CSA, 2012). Unstable pricing and seasonality of supply also discourages agro-processors from investing in these value chains. Improvement in post-harvest management would expand the period of the potato availability for household consumption, providing valuable micro- and macro-nutrients for 4-6 additional months per year and increase marketing opportunities. Several technologies already exist and have been tested on a small-scale in SSA. What is lacking is widespread testing and if needed, adaption to new conditions in different countries, and then going-to-scale to ensure farmer access to these technologies. As urbanization proceeds apace in SSA, reduced postharvest losses will be key for potato to continue playing a major role in food security and being a good source of farm income across the continent. Technologies for reducing postharvest losses include reduction of physiological deterioration, increasing knowledge on appropriate transport techniques, reduction in percentage of tubers with insect and other damage, storage facilities, and market information for timely delivery and use.

Conclusions

A set of constraints along the potato value chain has to be considered simultaneously, to ensure higher yields, better income, and a significant contribution of potato farming to food security and improved livelihoods in the region. High yielding potato varieties have to be released that have good resistance to late blight and low degeneration rate as well as good table and processing qualities. These varieties should have wide adaptability, with a potential to produce well in the region. If seed of these varieties is available to growers, using rapid multiplication technologies there is a great potential to boost potato productivity and production, especially if these are coupled with best cultural practices like soil fertility management and disease control measures as well as with ware potato storage technologies.

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Effect of Field Multiplication Generation on Seed Potato Quality in Kenya

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Introduction

The current average potato yields in Eastern Africa has been reported to be about 8 $t*ha^{-1}$ (Obado *et. al.*, 2010; FAO, 2010), which is well below the yields of 25 $t*ha^{-1}$ attained by some progressive smallholder farmers, harvesting in the same soils and under the same rain fed conditions in these countries.

The adoption of clean seed and new varieties can significantly help to close this "yield gap" and boost on-farm productivity. This yield gap can be attributed to the use of low quality seed potatoes (Kinyua *et al.*, 2001), low yielding varieties, poor disease management (Olanya *et al.*, 2001), and inadequate soil fertility management (Berga *et al.*, 2001). However, potato seed quality is an important determinant of the final yield and quality (Struik and Wiersema, 1999).Low quality seed is believed to be one of the major yield reducing factors in potato production in Sub Sahara Africa (Fuglie, 2007). The accumulation of seed borne diseases in farm saved seed potatoes used for several cropping cycles causing severe degeneration (Gildemacher *et al.*, 2007). Turkensteen (1987) identified bacterial wilt, caused by *Ralstonia solanacearum* Smith and virus diseases caused by *Potato virus Y* (PVY, family Potyviridae, genus Potyvirus) and *Potato leaf roll virus* (PLRV, family Luteoviridae, genus Polerovirus) as the most important seed borne potato diseases in Africa.

Despite several efforts to enhance seed potato multiplication systems in potato sub-Sahara Africa (Monares, 1987; Potts and Nikura, 1987; Crissman *et al.*, 1993), potato farmers in Kenya still identified quality of seed potato as their major concern within potato production system and it was prioritized as an important technical intervention to improve smallholder potato profitability (Gildemacher *et al.*, 2006).

Most potato growers in Kenya have two choices when faced with the decision of where to get their seed. They can use seed from their own harvest with higher disease levels each season, purchase seed from a neighbour, the local market, or from a specialist clean seed multiplier. The clean seed multipliers in turn get their input seed traditionally from National programs who supply what is known as basic or certified seed. Basic and certified seed may have been inspected by a mandated government agency depending on National seed regulations. National programs produce basic seed by multiplying disease free "minitubers" in isolated fields, and are traditionally grown in pots in insect proof screenhouses. This whole cycle typically takes 5-7 seasons and the potato seed stocks inevitably accumulate seed borne diseases such as viruses or bacterial wilt through each cycle.

However, the choice to use high-grade seed is strongly limited by its availability. In Kenya the amount of quality, regulated (certified) seed has been less than 1% of the estimated demand of 48,000 tons per year. Another 2% of seed is produced by informal seed multipliers using basic seed (3^{rd}FG) multiplying this for 1-3 seasons before selling it to ware potato producers (Obado *et al.*, 2010). Additionally, about 2% of potato farmers practice "Positive Selection" method to improve their seed quality. The innovative extension intervention system known as "Select the Best" was developed by CIP and KARI and ran from 2004 up to 2007. Through the training potato producers learn how to maintain the quality of their potato seed for a longer period through positive selection. The process involves training farmers to recognize healthy plants, which are not showing symptoms of seed borne diseases such as virus and bacterial wilt. Healthy plants, representing about 10% of the crop, are marked and later harvested to provide next year's seed. The intervention is relatively low cost and requires less contact time than a conventional farmer's field school. Essential in the training curriculum is that the farmers plant a demonstration experiment in which they compare the yields through using their existing seed selection method, using positive selection, or buying seed from a specialist. This provides the farmers with options to improve their seed quality. However, 95% of potato farmers use seed of minor quality. Besides low availability of high-grade seed, Obado *et al.* (2010) evaluated more than 1200 potato farmers in a countrywide baseline survey and reported that the awareness of the benefits of high-grade seed was very poor and many considered the investment in high-grade seed as too high.

To increase the availability of high-grade potato seed, CIP together with its national partners, have tested and developed the components of an innovative seed strategy, which both dramatically lowers the cost of production of pre-basic or "starter" seed coupled with extension-based interventions to train smallholders in the better on-farm management of their own seed. Engagement with the private sector as a means to widen the supply base and satisfy demand for clean seed is also a key component of the strategy. Because the strategy involves the delivery of low cost quality seed to growers in 3 generations of field multiplication, rather than the conventional 5 to 7 generations, this new strategy has been named as "3G" system. CIP believes that wide-scale adoption of these technologies, as well as capacity building in conventional technology (field management and storage), would be an appropriate response to current concerns over rising food prices and to secure seed supplies for the next few seasons and to put the whole seed supply chain onto a more sustainable path for the future. The introduction of new technologies, lowering seed production costs, improving farmer knowledge, widening, and strengthening the seed supply base (including private sector suppliers) may also put the whole seed production chain onto a more sustainable basis for the future.

The purpose of this study is to determine the yield gap caused by degeneration of various seed qualities compared with Farmers saved seed (hereafter called Farmers practice). The seed qualities used were from the 2nd field generations (2ndFG) of a private seed multiplier. Basic seed from the National program (3ndFG), certified seed from a public seed multiplier (6thFG), informal seed which is seed obtained from credible farmers but which had been produced without the normal certified seed production regulations (FG 4-6) and "Positively selected seed .The yield gap caused by seed quality was determined by carrying out multi-location On-Farm trials with three main varieties over two seasons in potato growing regions of the country. Besides the evaluation of the yield gap caused by the seed quality, these trials were acting as demonstrations for farmers to create awareness of the importance in using high-grade seed. At each side field days were held were farmers, extension officers and other stakeholders were invited.

Materials and Methods

At 16 locations in the main potato growing areas of Kenya On-Farm trials with different seed qualities were set up in the "Short Rains", SR (mid October 2009 - mid January 2010)and "Long Rains", LR (mid April 2010 – early August 2010) seasons, respectively. Plots compromised 40 plants with 3 replications in a randomized complete block design (RCBD) layout at each site. In the LR an additional on station trial with 4 replications was conducted at the field research station of the University of Nairobi, Lower Kabete, Nairobi. Fertilization was based on 90 kg N supplied by a 10 N, 26 P, 10 K fertiliser applied at planting.. Late blight was controlled according to the respective disease pressure with the alternating sprays of Ridomil and Mancozeb. Following seed qualities of the varieties Asante (released in 1998 - CIP 381381.20), Dutch Robyjn and Tigoni (released in 1998 - CIP 381381.13):1-CF and 2-CF private: Project seed (USAID funded –"3G" project) multiplied by Kisima Farm, Timau, Mt. Kenya region: seed

from the first and second field multiplications, respectively. Tested and certified by the national certification body (Dutch Robyjn not available). 3-Basic: supplied by the National Potato Program of the Kenyan Agricultural Research Institute: Three field multiplications. Tested and certified by the national certification body.
6-CF: Certified Seed Agricultural Development Cooperation (ADC): Six field multiplications (Asante not included in On-Station trial) 4 inf., 5 inf., 6 inf. = obtained from credible farmers but which had been informally produced seed without the normal certified seed production regulations – four, five and six field multiplications at the same farms, respectively. PS: Positive selected seed (PS) from farmer groups involved in the project training modules. (Asante not available in SR). FP: Seed quality farmers use to plant - obtained from the same field where farmers practiced positive selection, but from a different section where PS was not practiced. The On-Station trial included PS and FP from 4 Farmer Groups of Asante and Tigoni varieties, respectively.

Assessments

Seed lots forming the different categories were tested for incidence of Potato virus Y (PVY), Potato leaf roll virus (PLRV) and Potato virus X (PVX) using enzyme-linked immunosorbent assay (DAS-ELISA:CIP, Lima, Peru) with leaf sap obtained from eyes cut after harvest and grown in aphid free greenhouse chambers for 4-6 weeks (Casper and Meyer, 1981; Torrance, 1992). At the point of testing, seed quality 6-CF was not available and thus not tested. Yield determination was made by weighing on per plot basis and transferred into $t*ha^{-1}$. Tuber number was counted for the On-Station trial and converted into tubers per m^2.

Statistical analysis

Statistical analysis was based on the SPSS GLM procedure (Version 19). Fixed effect models were analyzed per seed quality. Random effects were for the On-Station trial the replication and for On-Farm trials the interaction between replication and site. The Bonferroni-Holm Test was conducted to separate means with a confidence level of 95%. Relative values have been arcsine transformed before analyzing.

Results and Discussion

Seed quality is closely related to degeneration due to viral infections, especially PLRV and PVY which contribute to severe yield losses. The potato seed qualities tested in this study show a clear increasing virus infection level with increasing number of field generations (FG) with all three varieties (Table 1).

The results reveal that certified seed from field generation 1 and 2 (private multiplier) was free from both viruses. Considerable PVY infections could be observed in certified seed from field generation 3 (National program) with varieties Dutch Robyjn (15%) and Asante (7.5%) and lesser with Tigoni. Seed obtained from informal non-certified shown increased virus levels with both PLRV and PVY on all varieties. However, the results reveal that the variety Dutch Robyjn has the highest PVY infection resulting in a level of 40% already after 5 FG. This is mainly due to the already high PVY level from the seed from the National program, which the informal seed multipliers are using for further seed bulking. Farmers practicing the PS technology were able to half the infection levels for both viruses and varieties (Table 1).

Table 1: PLRV and PVY infections of different seed qualities available in Kenya differing in number of field multiplication generations (1-6) from certified (CF) or informal production systems as well as Positively Selected and Farmers Practice seed of varieties Asante, Dutch Robyjn and Tigoni in 2010.Variety

	Virus	No. of field generation and seed source							
	(%)	1-CF	2-CF	3- CF	4-inf.	5-inf.	6-inf.	PS	FP
Asante	PLRV	0.0	0.0	0.0	0.0	17.6	13.8	11.3	27.5
	PVY	0.0	0.0	7.5	10.0	20.6	23.8	18.8	41.3
Dutch Robyjn	PLRV	-	-	0.0	5.0	10.0	12.5	20.0	38.1
	PVY	-	-	15.0	18.8	40.0	45.0	25.0	52.4
Tigoni	PLRV	0.0	0.0	0.0	10.0	17.5	-	15.0	22.5
	PVY	0.0	0.0	2.5	2.5	15.0	-	15.0	27.5

In general, the results obtained in this study indicated that these viruses can be a limiting factor to potato (ware and seed) production in Kenya and informal seed multipliers poorly practice the importance of vector control and the practice of negative selection. Moreover, considering that all seed sources were obtained from altitudes above 2200 masl the steady increase of virus levels with number of FG's indicate that virus transmitting aphid populations may have moved towards higher altitudes most likely due to increasing temperatures and possibly caused by effects of climate change. Hence, field multiplication generations have to be reduced to maintain high yield potential, which is the rationale behind the 3G project with the main effort in reducing the number of FGs from 5-7 to 2-3 seasons. Having in mind that knowledge of insecticide applications is poor among farmers and that application of those harmful for human health should be minimized, the introduction of virus resistant varieties seems to be the most promising future option to reduce seed degeneration caused by viruses. Promising CIP germplasm with combination of late blight and virus resistance is available for variety deployment in tropical highland regions. A screening of 292 clones from B1C5 (fifth cycle of recombination of the pure native Andigena group B1) showed extreme resistance to both viruses, resulted in a high percent of clones showing resistances to PVY (70%) and PVX (73%). Likewise, 59% of clones showed resistance to PLRV (Landeo, 2003).

The yield determination undermines clearly the importance of seed quality and the prominent effect of seed borne diseases in particular bacterial wilt caused by *Ralstonia solanacearum* (Smith) and virus. However, poor seed quality also carries important seed borne diseases e.g. soft rot (caused by *Erwinia chrysanthemi*), Fusarium wilt and dry rot (caused by *Fusarium solani*) and Verticilium wilt (caused by *Verticilium albo-atrum*) and limited to two regions (Meru and Taita Hills) also *Rhizoctonia solani* (Kuehn).

The average yield of farmer's seed in the On-Farm evaluations was 11.1 $t*ha^{-1}$ and $9.3t*ha^{-1}$ in the SR and in the LR seasons, respectively, which were very low, although grown with relatively high fertiliser and strict late blight control. The low yields with farmer's seed clearly show the yield gap produced by the quality of seed. With all varieties additional FG's led to considerable yield losses (Table 2). FG 2–CF out-yielded all other seed qualities significantly with yields in-between 243 and 352% of the yield obtained with FP seed (Table 2),followed by FG-3-CF with significantly higher yields than in the plots planted with seed of lower quality. However, yield increase of FG-3-CF was lowest with variety Dutch Robyjn, which can be linked to the already high PVY infection level of this seed quality (Table1 and 2). Yields were comparable to better when seed potatoes obtained from informal seed multipliers after one informal multiplication (4 FG) were planted than the certified seed that was 6 FG old. A second informal multiplication (FG 5 inf.) although caused further significant yield losses. However, yield increases compared to farmers seed still range been between 56 and 90%. The Positive selection method also increased the yield considerably compared with FP, but the effect differed between varieties. Whereas, high yield increases of 55% and 29% and 44% (SR and LR) could be obtained with Dutch Robyjn and Asante, respectively, lower yield increases of 18 and 23 % were realized with Tigoni. The main reason might be that symptoms of viral infections are more distinct with varieties Dutch Robyjn and Asante than with Tigoni, which made the selection process more difficult and less effective with this variety. However, this cannot be confirmed by this study as the varieties were grown with different farmer groups and difference in knowledge and accuracy of selection were not determined.

Table 2: Average relative yield of different seed qualities available in Kenya differing in number of field multiplication generations (1-6) from certified (CF) or informal production systems as well as Positively Selected compared with Farmers Practice seed (=1) of varieties Asante, Dutch Robyjn and Tigoni. Data obtained from 6 On Farm sites in Short rain season 09/10 and 6 different sites in the Long rain season '10 in Kenyan potato growing woredas, respectively

Variety	Season	No. of field generation and seed source					
		2-CF private	3-CF public	6-CF public	4-inf.	5-inf.	PS
Asante	LR 2010	2.67a	2.25b	1.97c	2.18bc	1.89d	1.44e
Tigoni	LR 2010	2.80a	2.44b	1.98c	2.04c	1.90d	1.18e
Asante	SR 2009/10	2.43a	2.10b	1.92c	-	1.61d	1.29e
Dutch Robyjn	SR 2009/10	-	1.88a	1.73b	-	1.56c	1.55c
Tigoni	SR 2009/10	3.52a	2.77b	2.58c	-	1.85d	1.23e

The additional On-Station trial indicates the same effects on yield as obtained with On-Farm trials. However, the inclusion of more FG's from different seed qualities allows a better insight. The overall yield potential was limited by low precipitation and thus water deficiency at mid –end of flowering. Nevertheless, the differences in tuber number and yields are enormous between seed qualities. Whereas, no significant differences between the FG 1-CF and FG 2-CF could be observed both had significantly higher tuber numbers and yields than all other seed qualities tested. Compared to FP seed the number of tubers was doubled and the tripled with FG 1-CF and FG 2-CF (Table 3).

Table 3: Tuber number $*m^{2-1}$and yield in $t*ha^{-1}$ of different seed qualities available in Kenya differing in number of field multiplication generations (1-6) from certified (CF) or informal production systems as well as Positively Selected (PS) and Farmers Practice seed (FP) of varieties Asante and Tigoni in the Long rain season '10 at the University of Nairobi

Variety		No. of field generation and seed source							
		1-CF	2-CF	3-CF	4-inf.	5-inf.	6-inf.	PS	FP
Asante	$Tubers*m^{2-1}$	30.9a	31.5a	25.1b	22.4c	23.1bc	18.9d	16.8d	14.5e
	$t*ha^{-1}$	28.6a	28.8a	22.7b	21.6b	19.8c	16.8d	11.4e	8.7f
Tigoni	$Tubers*m^{2-1}$	38.5a	36.7a	29.5b	30.4b	24.5c	26.1c	21.8d	18.9e
	$t*ha^{-1}$	34.6a	32.1a	26.3b	25.9b	23.3c	20.7d	13.0e	11.0f

In general, yields and tuber number were reduced more or less gradually by seed age for both varieties (Table 3). However, biggest differences in yield and tuber number were determined between FG1+ FG2 from the private multiplier to FG3 from the national program (6 $t*ha^{-1}$ and 5-7 $tubers*m^{2-1}$) (Table 3), which clearly can be attributed to the virus –free status of FG1+ FG2 and the PVY infection levels in FG 3 (Table 1). Differences of PS(31and 18% yield increase with Asante and Tigoni, respectively) FP are also according to the results of the ON-Farm trials.

Conclusions

For SSA, Scott *et al.* (2000) projected a 250% increase in demand for potato between 1993 and 2020, with an annual growth in demand of 3.1%. The growth in area under production is estimated at 1.25% a year, the rest of the increase being achieved through predicted growth in productivity. For both increased productivity and area under production, a timely availability of good quality seed of improved potatoes varieties will be vital. As this study clearly reveals the number of field multiplication generations of seed potato and a good quality control system affect the productivity to a substantial magnitude. However, pressure of virus transmitting aphids is high enough in reducing the number of seed FG possible to produce high quality seed compared to European conditions and pointing out the need for varieties combining i.e. virus and late blight resistance. Other seed borne diseases could also be reduced significantly by the use of high-grade seed. In Kenya, the spread of bacterial wilt with infected seed as the predominant source of inoculum is of major concern.

The "3G" approach for making available seed to farmers in three generations instead of the usual seven or more generations provides one of the best opportunities to exploit the contribution of the potato to improve livelihoods. Objectives in this projects is the use rapid minituber multiplication technologies such as aeroponics and reducing the number of field generations and thus less land will be used per seed production unit. The overall objective is to increase the availability of high-grade seed in Kenya from 1% to 10% within the next two years. Additionally the training in the "Select the Best" method will enable farmers to keep the quality of their seed for a longer time through positive selection and suitable storage. There is a great potential to boost potato productivity and total production, especially if these are coupled with best cultural practices.

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Enhancing Potato Seed Production Using Rapid Multiplication Techniques

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Introduction

Potato is regarded as a high-potential food security crop due to its ability to provide high yield and quality product per unit input with a short crop cycle (mostly <120 days). The national average yield at present is approximately 10.5 t/ha, which is lower than the world's average yield of 17 t/ha (Muthoni et al., 2011). The potential of potato crop has not been adequately exploited. The crop is mainly grown at high altitudes of 1,500–3,000 masl by small-scale farmers, who account for over 90% of the production. Most of the production is under rainfed conditions and carried out in scattered patches of intensive small-scale agriculture (McArthur, 1989).

There are a number of production problems. The major ones are unavailability and high cost of seed tubers; lack of well-adapted cultivars to the major agro-ecological zones; suboptimal agronomic practices; the prevalence of diseases and insect pests; and inadequate storage, transportation, and marketing facilities. To address these problems, the Ethiopian Institute Agricultural Research (EIAR)—the then Institute of Agricultural Research—in collaboration with the International Potato Center (CIP), initiated potato research. The research had as its main objectives to

- develop adaptable and high-yielding potato cultivars with good resistance to biotic and abiotic stresses;
- identify the best agronomic practices and storage systems;
- adopt the use of botanical seed as an alternative propagation method;
- develop seed production system in the country; and
- train farmers and other stakeholders.

Among potato production problems, a major bottleneck that contributes to low yield in Ethiopia is the lack of healthy and quality seed tubers in the required quantity and quality (Berga and Gebremedhin, 1994). There is no formal seed system operating for clean/healthy potato seed multiplication and distribution in Ethiopia. Hirpa et al. (2010) reported that potato seed production in Ethiopia is basically informal, which in most cases operates by recycling planting materials from previous crop harvest. At present, 98.7% of the requirements for potato seed are met by informal seed supply. Sources of informal seed vary and include seed from neighboring farmers, friends, relatives, merchants, and markets where potato is sold for consumption. Moreover, it is a common practice to save the smaller size and inferior tubers that are not sold for consumption for seed purposes; consequently, this practice allows diseases to build up and yield may gradually decline, as seed gets degenerated.

Shortage of seed potato has been recognized as one of the most important factors limiting potato production in developing countries (Naik and Karihaloo, 2007). The production of clean seed is very crucial to sustain high production and productivity of potato in the country. Currently, the common method for propagation of important potato cultivars is through tubers. However, this propagation method has encouraged accumulation of tissue-borne viruses, fungi, and bacteria in subsequent seasons. This has led to significant losses in yield and tuber quality over the seasons (Tsoka et al., 2012). Therefore, the multiplication of clean tuber seed is an essential part of a strategy for organizing a potato seed program and involves different methodologies and approaches. A prerequisite to a successful and sustainable seed scheme is a continuous supply and maintenance of pathogen-free seed. Quality seed of an improved potato variety is key to increasing the productivity of a potato crop. The genetic potential and other traits of a variety are determined by the use of healthy and improved seed. This is true because the usual method of potato propagation throughout the world is using the vegetative seed tuber.

This paper seeks to review and assess the various options available for clean seed tuber production/multiplication and suggests the way forward, with particular emphasis on the applicability of rapid multiplication techniques (RMTs) such as tissue culture (TC) and aeroponics technologies for minituber production in Ethiopia.

The conventional method of propagation is one of the slowest of seed multiplication. Compared with other seed propagation techniques, like TC and aeroponics, this traditional method would create only about (1:10) daughter tubers in the course of a year (Otazu, 2008). This method has also shown to be time specific, particularly in tropical and subtropical regions where potato is a winter crop (Burton, 1989).

The main disadvantages of a conventional seed potato program are the low multiplication rate of field-grown potato plants, resulting in a slow and inflexible system, and the rising risk of catching viral, fungal, or bacterial diseases with an increasing number of field multiplication. A reduction in the number of multiplication years requires a propagule that can be produced in large numbers in protected environments in a short period (Lommen, 1995). However, pathogen-free planting material of selected potato varieties and clones are multiplied at Holetta and Jeldu research fields through a conventional method and distributed to growers to be used as a source of planting materials. To avoid diseases like bacterial wilt and viruses, a new system has been established for producing healthy seeds based on virus testing and in-vitro rapid multiplication of virus-free planting materials. Thus, different RMTs have been used for bulking up of prebasic and basic released potato varieties and promising clones for distribution to growers.

Rapid Multiplication Techniques

RMTs are extensive methods used to increase the amounts of nuclear seed stocks for further seed multiplication. RMTs provide better multiplication rates than the conventional method in vegetative increase of potato (Endale et al., 2008). The conventional method gives a lower multiplication ratio—ranging from 1:3 to 1:15—and more likely rapid virus infection. RMTs provide higher multiplication ratios (1:40–1: several thousand per year) and lower rate of contamination, particularly from soil- and seed-borne pathogens. Approximately 15% of the total area under potato cultivation around the world is used for the production of seed tubers. With the conventional propagation methods, potatoes are often prone to pathogens such as fungi, bacteria, and viruses, thereby resulting in poor quality and yield (FAO, 2008), whereas using healthy, quality seed is essential for growing an optimal potato crop (Parrot, 2010).

Different RMTs—TC-produced plantlets, stem cuttings, and aeroponics—have been used to bulk up selected potato varieties for multiplication and distribution to growers. Selected improved potato varieties of Tolcha and Menagesha have been multiplied using stem cuttings before the establishment of the system, and varieties Jalene, Gudene, Belete, and Awash have been multiplied using aeroponics (Table 1). For the stem-cutting activities, healthy and clean in-vitro plantlets received from TC and minitubers imported from CIP were planted in pots in screen houses where they get intensive care and management. Although these plants reach 20–30 cm high, the growth point of each stem was removed to stimulate growth of lateral shoots from the auxiliary buds. Cuttings, developed from auxiliary buds at each leaf, were then taken to root in moist, coarse sand at a distance of 5 x 5cm between individual cuttings for minituber production. Several techniques have been evaluated and proved to be suitable for minituber production, including aeroponics culture (Kang et al., 1996; Kim et al., 1999; Nugaliyadde et al., 2005).

In Ethiopia, techniques for minituber production that have been used include stem cuttings and TC-produced in-vitro plantlets that are then planted either in pots in screen houses or under aeroponics facility.

Table 1: Number of minitubers produced under aeroponics at HARC in 2011/12

Variety	Year of production		Total
	2011	2012	
Belete	38,390	67,078	105,468
Gudene	864	1,278	2,142
Awash	4,659	-	4,659
Jalene	233	2,362	2,595
Total	44,146	70,718	114,864

Source: CFC project annual report

Tissue Culture Techniques

Plant TC is the science of growing plant cells, tissues, or organ isolated from mother plant, on artificial media. This is facilitated using liquid, semi-solid, or solid growth media in sterilized tubes or containers. TC is one of the important new methods of plant propagation available to growers, and its use in seed production has allowed mass production of potato plants in a very short time. The system is characterized by very flexible rapid multiplication giving a high rate of multiplication (Beukema and Van de Zaag, 1990).

The TC technique employed in the micropropagation of potatoes consists of the aseptic cultivation of cells or fragments of plant tissues and organs in an artificial medium under controlled temperature and light conditions. Vigorous and disease-free potato plantlets can be obtained in the laboratory using this method, and then transferred to screen house in pots and aeroponics conditions for the production of minitubers. Moreover, the seed materials should be free of disease-causing pathogens. Clean stocks are first obtained by meristem culture, then these plantlets are transferred to seed beds, screen house in pots, and aeroponics to produce minitubers. Minitubers are commonly used in seed potato production to increase seed tubers (Öztürk, 2010). One of the advantages of this method is the maintenance of genotype identity, as meristem cells preserve their genetic stability more uniformly (Grout, 1990).

Minituber Production Using Aeroponics

Aeroponics is the process of growing plants in an air or mist environment without the use of soil or an aggregate media. Aeroponics refers to the method of growing crops with their roots suspended in a misted nutrient medium. This is an alternative method of soil-less culture in growth-controlled environments. Minitubers are those progeny tubers produced on in-vitro–derived plantlets. The term refers to their size, as they are smaller than conventional seed tubers but larger than in-vitro tubers (or micro tubers) produced under aseptic conditions on artificial media. The size of minitubers may range from 5 to 25 mm, although in current systems larger minitubers have also become common (Hassanpanah et al., 2009). Minitubers can be produced throughout the year and are principally used for the production of clean seed by direct field planting (Ritter et al., 2001). The use of minitubers in a seed program reduces the number of field multiplications. This may increase the flexibility of seed production, improve the health status of the ultimate seed, and reduce the time for adequate volumes of seed from new cultivars to become available for growers (Lommen and Struik, 1992). Though the technique is in its early stage, attempts have been made to improve production of healthy/high-quality planting materials.

Importance of aeroponics

Aeroponics method of propagation is one of the most rapid methods of seed multiplication. An individual potato plant can produce over 100 minitubers in a single row (Otazu, 2008). This contrasts with conventional methods that create only about 8–10 daughter tubers in a year and only 5–6 tubers per plant are produced using soil in the greenhouse in 90days(Hussey and Stacey, 1981; CIP, 2008). Another advantage of aeroponics is that nutrients and pH are easy to monitor. The system provides precise plant nutrient requirements for the crop, thereby reducing fertilizer requirement and minimizing risk of excessive fertilizer residues moving into the subterranean water table (Nichols, 2005) (Fig.1).

Farran and Mingo-Castel (2006) reported that soil-less production techniques, such as aeroponics, have successfully been employed in tuber production, with good prospects for certification in seed production systems. However, the worst drawbacks are the low volumes available to the root system and any loss of power to pumps that can produce irreversible damages. Traditionally, minituber production in sub-Saharan Africa countries is done on soil-base substrates that are steam sterilized to avoid soil-borne diseases and pests. However, rising prices of fossil fuels and scarcity of firewood used for the steam boilers render this practice almost prohibitive. The best alternative is to use nutrient solutions instead of soil substrates, which is a common practice of aeroponics already established for minituber production in industrialized Asian countries. CIP has developed an economic module that is being promoted for developing countries.

In aeroponics, plantlets are grown in specially designed boxes where shoots grow on top and roots grow suspended in the air within the box and in darkness. Roots are fed with pressurized nutrient solution mist at short intervals; as plants develop tubers are formed from stolons near the roots (Fig. 1). There are several advantages of this technology compared to the soil-based substrates for minituber production—namely healthier tubers due to the absence of soil-borne diseases, higher number of tuber set per plant, and reduced costs per minituber. In this system, minituber production is 10 times that of soil substrate(Fig. 2).

Figure 1: Foliage and root development under aeroponics conditions (Source: HARC, 2011)

Figure 2: Tuber development under aeroponic conditions (Source: HARC, 2011)

EIAR, with support from the Common Fund for Commodities (CFC) and USAID, established two aeroponics units at Holetta Agricultural Research Center (HARC) in 2010 for the production of minitubers of both popular and newly released varieties. The technique is suitable for early stages of seed multiplication in which the production operations are handled by the best technical support system. The technique is effective in giving high number of minitubers—up to 50 per plant—but adoption rates will be determined by availability of stable and low-cost power supply and expansion in the seed market. Minitubers produced in the aeroponics unit are multiplied in the aphid-proof screen house/net house in HARC to produce seed (Fig. 3). The minitubers that are produced in the screen house and aeroponics are usually either planted in open field or in pots in the screen house based on the size of the tubers. The aim is to improve the health status of existing seed stock by reducing the number of field multiplications (Kleingeld, 1997). Harvesting in aeroponics is convenient, clean, and allows a greater size control by sequential harvesting (Ritter et al., 2001). The number and timing of nondestructive harvests are key factors in the optimization of minituber production. To optimize the system, appropriate nutrient solutions, plant densities, number of harvests and harvesting intervals, as well as possible interaction between them should be considered (Farran and Mingo-castel, 2006).

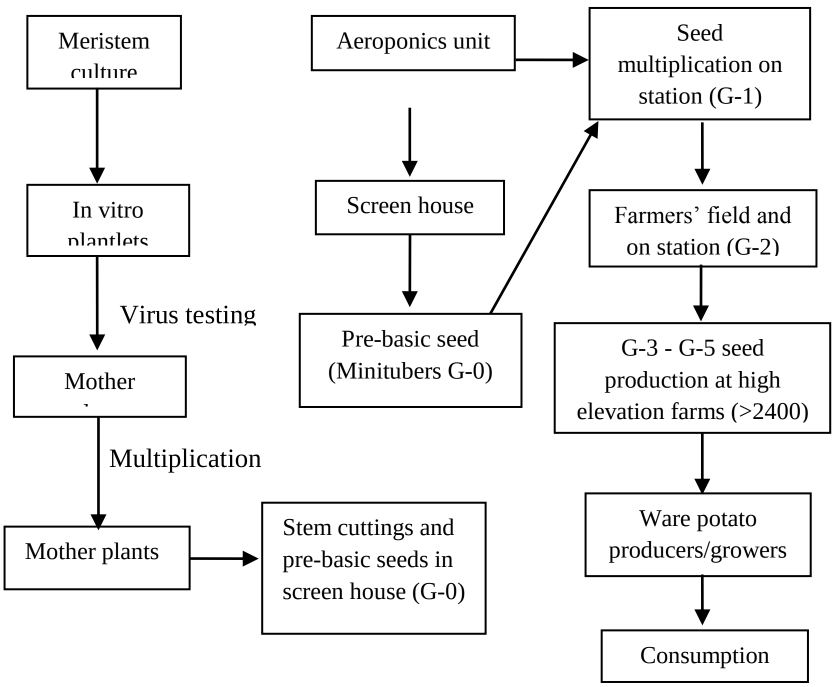

Figure3: Schematic diagram of prebasic seed potato production using RMTs at HARC

The multiplication and distribution scheme

In this program, high-quality planting materials are either imported from CIP's regional office in Nairobi or multiplied at Holetta and Jeldu research fields as well as TC laboratory. The materials are distributed to growers and different research centers for seed production or research purposes. A total of 1,669.5 tons of seed potatoes of 14 released potato varieties have been produced on station at Holetta and Jeldu from 2008 to 2011. The distribution of the materials to farmers was practiced using farmer groups organized into Farmer Field Schools or Farmer Research Groups. This had laid the foundation for reaching more farmers.

The healthy planting materials/stocks multiplied using RMTs are of the selected varieties, which are maintained under strict hygienic conditions in an insect-proof screen house. Subsequent propagation is carried out using rooted cuttings in the screen house to obtain enough planting material before they are planted in open field. A total of 227,333 MT of several clones and released varieties were multiplied in screen houses which include Awash (1710 MT), Gudene (39,518 MT), Jalene (13,179 MT) and Belete (145.870MT). Source materials for this MT production were either in-vitro plantlets or smaller MT produced from the previous season in the aeroponics units. These materials have been introduced into the center's seed production program and have played a paramount role in regenerating the stock materials (Table 2).

Table 2: Minitubers produced under screenhouses planted from in-vitro plantlets and small sized minitubers of aeroponics

Variety/Clones	**2008**	**2009**	**2010**	**2011**	**2012**	**Total**
Different clones	15,041	-	1,692	6,043	-	22,776
Jalene	3,760	-	7,440	1,979	-	13,179
Guassa	1,200	-	1,080	-		2,280
Gudene	1,800	-	1,352	9,231	27,135	39,518
Belete	-	-	-	42,871	102,999	145,870
Awash	228	228	-	1,254	-	1,710
Gorebela	1,264	-	-	-	-	1,264
Zengena	516	-	-	-	-	516
Tolcha	220	-	-	-	-	220
Total	24,029	228	11,564	61,378	130,134	227,333

Source: *CFC project annual report*

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Micropropagation Protocol for Mass Production of Released Potato Varieties

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Introduction

Potato production in Ethiopia is characterized by low national average yield of 8 tons/ha. This is ascribed to lack of healthy seed tubers, high disease pressure (late blight and viruses) and lack of improved potato seeds (Berga *et al.,* 1994). It is a crop where consistent and high yield could be obtained if disease free quality seed tubers are used. Degeneration of planting materials due to virus diseases cause a substantial yield loss especially in mixed infections (Nascimento *et al.*, 2003).The rapid expansion of main season production throughout the country was limited by unavailability of clean seed tubers. It has been impossible to meet the increasing demand of healthy improved potato seed tubers with the conventional field propagation practices. Therefore, tissue culture techniques come into application for disease cleaning and *in vitro* mass propagation to assist production of high quality seed tuber. It could be supplement to the minituber production with aeroponic systems and/or other rapid multiplication techniques for efficient ways of clean seed tuber production under the existing situation.

Plant tissue culture, in other words, the growth of plants or plant parts on artificial media under aseptic condition has many roles in crop production. Clonal mass micropropagation, disease cleaning and storage of germplasm *in vitro* are major applications to potato production (Espinoza *et al.*, 1989). *In vitro* regeneration and further micropropagation of potato need optimum medium that support the growth of plants at economical rate of multiplication. Potato can suitably regenerate *in vitro* from shoot tip, nodes, meristem, leaves and other parts both through direct and indirect organogenesis (George, 1993).

In vitro medium is composed of micro and macronutrients, vitamins, growth hormones, carbon sources and inert supports. The composition and ratio of these components should be formulated in a way that can support the growth of a given plant and plant parts, where potato can also be propagated this way. Different varieties might respond differently to a given growth media (Elshibli, 2000; Wheeler *et al.*, 1985 and Charles *et al.*, 1992). Consequently, it was necessary to investigate on the optimum growth medium/media that can support the growth of shoots from potato nodal explants of different released varieties. This experiment was then conducted with the objective of optimizing *in vitro* multiplication medium to support the efforts of quality seed tubers in potato for selected released potato varieties.

Material and Methods

Four released potato varieties namely 'Menagesha', 'Tolcha', 'Degemegn' and 'Gorebella' - were planted in screen house. These varieties were used as source of single node explants for *in vitro* culture development. Under laminar flow hood, explants were surface sterilized with 70% alcohol for 30 seconds and with 1% sodium hypochlorite solution containing few droplets of Tween-20 for 10 minutes; and then washed three times sequentially in sterile distilled water. Explants were resized to 1 cm long section having one node and placed on culture medium prepared with macro- and micronutrient salts plus vitamins in accordance to the MS (Murashige and Skoog) medium protocol (Murashige and Skoog, 1962). Cultures were maintained in a growth room, under temperature regime of 28 ± 2^{O}C and provided a 16-hour photoperiod treatment by fluorescent bulbs. By sub-culturing to fresh medium, *in vitro* plants were propagated to produce sufficient materials for the intended experiment.

When clean cultures were established, single nodes were sub-cultured on prepared media aseptically. As shown in Table 1, the MS medium supplemented with growth regulators namely *Gibberellic acid* (GA_3), *Benzyl amino purine* (BAP) and *Naphthalene acetic acid* (NAA) at different concentrations were evaluated for the *in vitro* growth of potato varieties.

Table1: Concentration of the three growth hormone combinations used as treatments

BAP (mg/L)	**GA3 (mg/L)**								
	0	0	0	0.5	0.5	0.5	1	1	1
0	1	2	3	4	5	6	7	8	9
4	10	11	12	13	14	15	16	17	18
8	19	20	21	22	23	24	25	26	27
	0	0.1	0.4	0	0.1	0.4	0	0.1	0.4
	NAA (mg/L)								

Result and Discussions

After four weeks of incubation, plantlets grown on MS medium supplemented with 1 mg/L GA_3 plus 0.1 mg/L NAA; 0.5 mg/L GA_3 alone and 4 mg/L BAP + 1 mg/L GA_3 + 0.1 mg/L NAA attained better shoot elongation with respective mean value of 65.1mm, 60mm and 58.7 mm. On these treatments, mean internode length was 10.94 mm, 10.05 mm and 10.27 mm; and mean node number was 5.3, 5.1 and 4.9, respectively (Table 2).

Potato plantlets grown on treatment number 8 showed significantly higher shoot elongation ($p \leq 0.01$), whereas on treatment 4 and 17, shoot elongation were significantly higher at $p \leq 0.05$(Table 2).On the other hand, significantly higher node number ($p \leq 0.05$) was observed for treatment number 8. Although the difference was statistically significant plantlets grown on treatment number 4 and 17 had closer mean node numbers with those grown on treatment 8 as compared to the rest of treatment combinations. Mean internode number was significantly higher only in treatment number 16 at $p \leq 0.05$. Moreover, plantlets grown on treatment 4, 7, 8, 16, and 17 were more vigorous and had well-developed leaves and roots (Figure 1).

Figure 1:*In vitro* plantlets of ‘Menagesha’ on different treatments

In vitro regeneration and propagation of plants are governed by many factors. Some of these factors are the use of appropriate growing media that can support the growth of the plants; culturing of the crops/plants under appropriate culture room conditions where the light intensity, relative humidity, and photoperiod are well managed; and the growth stage of the mother plants from which the explants collected (George, 1993). Genotype differences in morphogenesis on *in vitro* cultures have also been reported (Elshibil, 2000; Wheeler *et al.*, 1985 and Charles *et al.*, 1992).

Table: 2. Mean shoot height (mm), internode length (mm) and node number (after four-weeks in *vitro* growth) of four potato varieties

Treatment no	NAA (mg/L)	GA3 (mg/L)	BAP (mg/L)	Mean shoot height (mm)	Mean Internode length (mm)	Mean node no
1	0	0	0	38.9	7.94	4.058
2	0.1	0	0	41.3	8.34	4.148
3	0.4	0	0	26.1	6.13	3.568
4	0	0.5	0	60*	10.05	5.096
5	0.1	0.5	0	52.2	9.82	4.342
6	0.4	0.5	0	46.6	8.66	4.073
7	0	1	0	56.6	10.92	4.338
8	0.1	1	0	65.1**	10.94	5.311*
9	0.4	1	0	52.4	9.38	4.531
10	0	0	4	31.7	7.1	3.94
11	0.1	0	4	26.7	5.38	3.711
12	0.4	0	4	13.7	2.96	2.384
13	0	0.5	4	42.2	8.73	3.71
14	0.1	0.5	4	45.1	8.56	4.461
15	0.4	0.5	4	38.9	6.87	4.468
16	0	1	4	56.1	11.78*	4.452
17	0.1	1	4	58.7*	10.27	4.952
18	0.4	1	4	35.9	7.29	2.957
19	0	0	8	29.6	7.92	3.033
20	0.1	0	8	27.1	6.13	3.41
21	0.4	0	8	16.8	3.54	2.515
22	0	0.5	8	35.8	8.3	4.153
23	0.1	0.5	8	44	7.53	4.456
24	0.4	0.5	8	38.4	6.92	3.846
25	0	1	8	43.7	10.1	3.041
26	0.1	1	8	53.2	10.19	4.365
27	0.4	1	8	34.8	6.52	2.801
Grand Mean				41.2	8.08	3.93
LSD at 1 %				21.59	3.975	1.6569
LSD at 5%				16.27	2.996	1.2489
CV (%)				21	15.9	19

*** Significant at p<0.01, * significant at p<0.05*

It was found that varieties respond differently to the treatments. For instance, longer shoot length was recorded for 'Menagesha' variety as compared to the others with all treatments (data not shown).The shoot height of 'Menagesha' was the highest compared with other varieties under most treatments in this work (Figure 2). This result supports previous reports (George, 1993) that suggested the effect of genotype on tissue culture and micropropagation of plants.

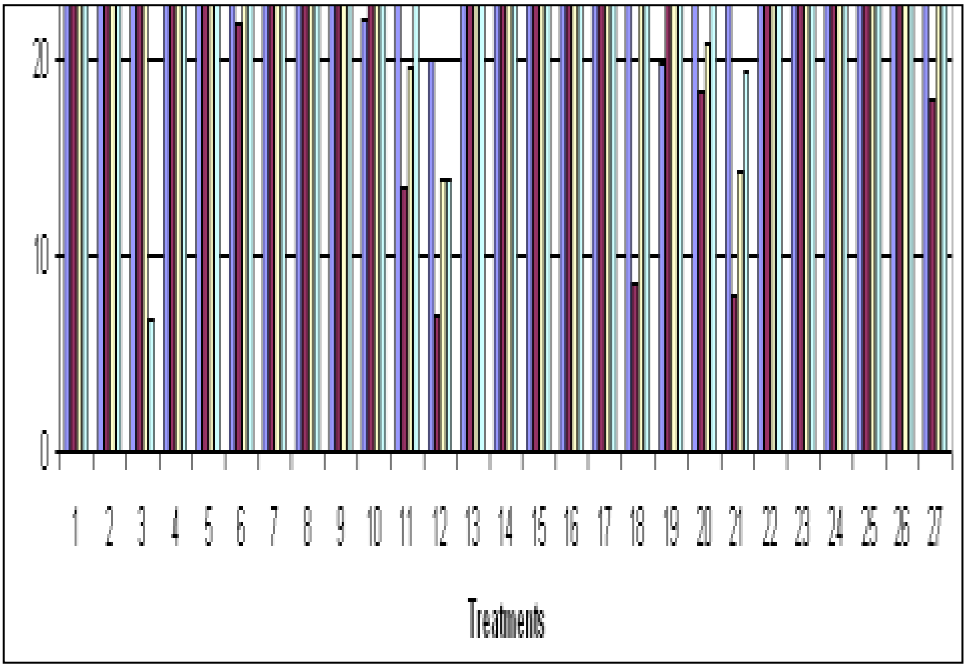

Figure 2: Mean shoot height of varieties across treatments

The effect of growth regulators is generally not absolute and specific rather it varies according to the cultural conditions, the type of explant and genotype (George, 1993). Unlike other varieties, several auxiliary shoots were observed on 'Gorebella' grown on hormone free medium. This might be related to the absence of GA_3 in the medium, which has an inhibition effect on meristemoid initiation (Jarret and Hasagawa, 1981). On the other hand, treatments containing only GA_3 at 0.5 and 1mg/l did not develop auxiliary shoot. This further justified the inhibition effect of GA_3 on auxiliary shoot development. In this experiment treatment containing BAP did not produce auxiliary shoot which was in agreement with the finding of Kane (1993).

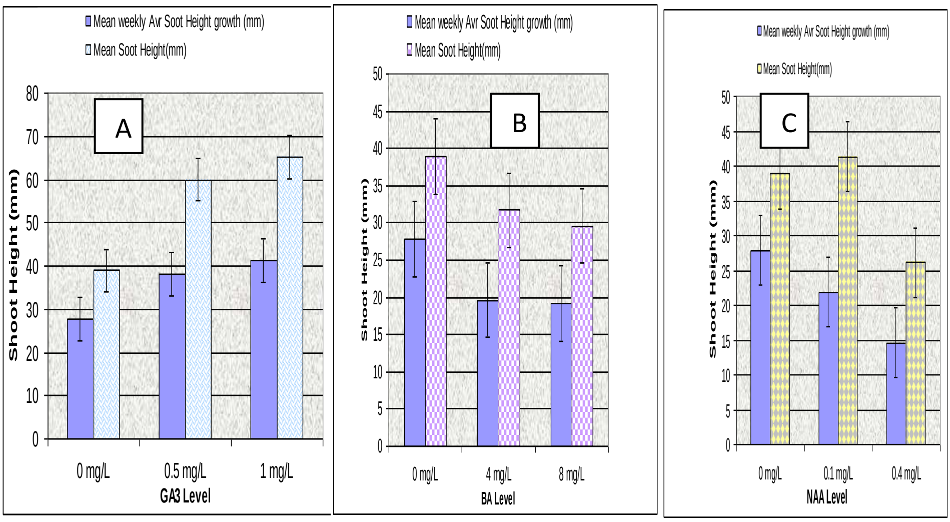

Figure 3: Effect of increasing of GA3 (A), BA (B) and NAA(C) level in MS medium on the Shoot elongation

Increasing the level of GA_3 alone in the MS medium has positive response on increasing shoot height, node number, and internode length (Figure3). As a result, higher shoot elongation of 65.1 mm was observed on MS medium supplemented with 1 mg/L GA_3. Addition of 0.5 mg/L GA_3 had also led to higher shoot elongation, i.e. 60 mm (Table 2). However, increasing of both BA and NAA levels in the medium resulted in decreasing shoot height, node number, and internode length (Figure3). Moreover, plantlets grown on MS medium supplemented with BA and NAA resulted in poor weekly increment of shoot elongation and internode length than that of MS medium devoid of plant growth regulator.

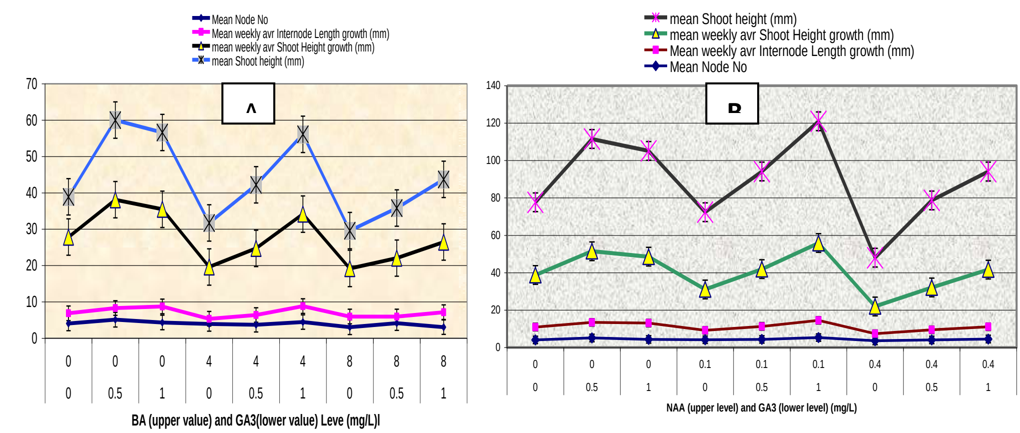

Figure 4: Effect of increasing BA (A) and NAA (B) level in MS medium on culture supporting capacity of GA3

Addition of BA in the medium mostly suppressed the efficiency of GA3 in supporting shoot elongation, internode length and node number increments (Fig. 4). In the presence of GA3, plantlets growing on MS medium supplemented with increasing BAP levels showed poor shoot elongation capacity than those growing on MS medium devoid of BAP (Figure 4). This result was in line with earlier report that suggested potato auxiliary shoot elongation is not promoted by the addition of cytokinin to the medium (Kane, 1993), However, addition of NAA to MS medium at 0.1mg/L level resulted in good shoot elongation at all GA3 levels. However, increasing NAA beyond this level showed poor shoot elongation (Figure 4).*In vitro* tuber formation was observed for 'Gorebella' culture plantlets grown on treatment number 12 (4mg/L BA and 0.4mg/L NAA) and number 21 (8mg/L BA and 0.4mg/L NAA). These treatments consisted of 4 mg/l and 8mg/l

BA respectively and 0.4 mg/l of NAA but no GA_3. These two treatments were inferior for shoot elongation. Their poor performance on shoot elongation could be related with minitubers production where they used the nutrient instead of shoot growth. Under appropriate environmental condition, plants that naturally produce tubers could be induced to produce miniature version of these storage organs, in a medium containing high cytokinin levels (George, 1993).

Treatments consisting of only NAA and NAA plus GA_3 developed good roots, which extended more than 30mm for varieties of 'Gorebella', 'Menagesha', and 'Degemegn'. This might be due to the effect of NAA (auxin). Other treatments consisting of BA did not give root growth at all on all three varieties. This might be due to the inhibition effect of BA on root growth as high concentration of cytokinin (0.5-10mg/l) inhibits or delay root formation (George, 1993). *In vitro* plantlets sub-cultured for five to seven times were successfully acclimatized with survival rate of 85% to 100% after transferred to sterilized soil in polyethylene pots in screen-house. From a single established plant, in average about three minitubers were harvested.

Conclusion and Recommendations

Plant propagation employing tissue culture technology supports the production of quality planting materials particularly in vegetatively propagated plants. Potato *in vitro* mass propagation protocol was investigated for node-explants of four potato varieties. Among plant growth regulators and their combinations tested, GA3 at 1 mg/L plus NAA at 0.1 mg/L levels supplemented to MS medium gave significantly higher node number which was implicated on *in vitro* multiplication rate. This combination was recommended where higher multiplication rate is required with easy access to both plant growth regulators. Otherwise, relatively sufficient propagation rate can be achieved by applying 0.5mg/L gibberellins (GA3) alone to the medium. This protocol was shown to work for varieties released by the national potato research program (for both national and regional varieties).The medium has been used for the mass propagation of selected released potato varieties such as 'Gudene', 'Jalene', 'Awash' and 'Belete' in order to support the production of clean seed tubers. This quality seed tuber production has been supplemented with ELISA technique to confirm disease free plant production.

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Substitution of Laboratory Grade Sucrose by Commercial Table Sugar for i*n-vitro* Propagation of Potato

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Introduction

In Ethiopia, the estimated yearly production of food products is significantly low to feed the growing population of the country. Among the root and tuber crops potato is the first and the most predominant crop in at large particularly in Amhara National Regional State. Potato can grow under wide range of agro-ecological conditions and has short crop cycle. Such quality character of potato makes it a strategic food security crop in the area. However, the productivity of potato in Ethiopia is very low. Diseases, poor crop management practices, lack of improved varieties for different purposes, use of inferior quality seed tubers of unknown sources and health status; and inappropriate storage structure are among the key factors contributing to this low yield. Research has been under way for long period to overcome these problems. As a result, reasonable number of disease tolerant varieties, improved crop management practices, and post-harvest technologies were identified and generated. Lack of clean seed or insufficient amount of pre basic and basic seed is the major limitation to distribute and adopt improve varieties on farmers' field. Establishment of a sustainable clean seed source and seed system revealed the possibility of increasing the current yield three to five folds elsewhere. Plant tissue culture at Amhara Regional Agricultural Research Institute (ARARI) has been focused on multiplication of pathogen-free potato seed tubers. Currently the laboratory successfully adopted the protocol of potato tissue culture developed by CIP. However, optimization of this protocol was very important because of unavailability and high cost of chemicals at local market. Therefore, the objective of this study was to identify the optimum level of table sugar as substitute to laboratory grade sucrose.

Materials and Methods

The experiment on determination of optimum concentration of table sugar for *in-vitro* micro propagation of potato was conducted at ARARI, Bahir Dar. Seven concentrations of table sugar including 15, 20, 25, 30, 35, 40 g/l table sugar and 30 g/l laboratory grade sucrose as a standard check were evaluated in CRD design with six replications. Two improved potato varieties (Gera and Shenkola) grown at fifth generation were cultured in MS hormone free media. Each experimental unit (jar) contained nine explants. All plant tissue culture protocol was implemented according to CIP (potato TC protocol). Data on initiation percentage at 5 days, number of nodes per plant or plantlet at 2, 3 and 4 weeks, plantlet height (cm) were collected and statistically analyzed using SPSS computer program.

Results

The result of combined analysis of variance indicated that table sugar concentration has highly significant ($p < 0.01$) effect on the initiation percentage at 5 days, number of nodes per plantlet and plantlet height of both varieties in micro propagation. Among the table sugar concentrations evaluated, 25g/l gave the heights number of nodes per plantlet and height of plantlet at 4 weeks, next to standard check (30g/l laboratory grade sucrose). As shown in Table 1, the heights response of average number of nodes per plantlet (7.58) at 4 week was in the standard check (30g/l laboratory grade sucrose) followed by a medium containing25g/l table sugar (7.02). The highest plantlet height (7.17cm) at 4 week was recorded from a treatment of 30 g/l laboratory grade sucrose while 6.28 cm was recorded from 25 g/l table sugar. However, the lowest plantlet height (4.16 cm) was recorded from the highest (40g/l) table sugar concentration.

Table 1: Performance of *in-vitro* potato plantlets on different concentrations of table sugar tested on two varieties at ARARI, Bahir Dar in 2011

Sugar level (g/liter)	**Initiation % at 5 days**	**Average No node/plantlet at (week)**			**Average plantlet height at 4 week(cm)**
		2	3	4	
15	79.0_{a}	1.83_{c}	3.19_{d}	4.16_{d}	4.22_{e}
20	83.3_{a}	2.81_{b}	4.05_{c}	5.08_{c}	5.38_{c}
25	80.9_{a}	2.86_{b}	5.03_{b}	7.02_{b}	6.28_{b}
30	72.0_{ab}	2.44_{b}	4.02_{c}	5.25_{c}	5.70_{b}
35	58.8_{bc}	1.55_{c}	3.13_{d}	4.27_{d}	4.62_{c}
40	65.3_{b}	1.75_{c}	3.08_{d}	4.05_{d}	4.16_{e}
30 (lab. grade sucrose)	88.8_{a}	3.8_{a}	6.13_{a}	7.50_{a}	7.17_{a}
CV (%)	13.0	3.2	2.5	4.1	1.25
P-level	*	*	**	**	**

Discussion

The growth and multiplication of shoots *in-vitro* are affected by many factors one of which is the concentration and type of exogenous carbon source added to the medium (Anwar *et al*, 2005). The carbon source serves as an energy and osmotic agent to support the growth of plant tissue (Lipavska, and Konradova, 2004). In the present study also *in-vitro* growth of *Solanum tuberosum* is greatly influenced by different concentrations of carbon source supplemented in the medium. Among the treatments the highest number of node per plantlet and plantlet height were achieved on a standard check (30g/l laboratory grade sucrose) which was a pre tested product for plant tissue culture. In contrast commercial table sugar was produced for table purpose and it was not pre tested for laboratory use. Moreover medium supplemented with 25g/l table sugar also showed an interesting performance of plantlets. Relatively higher concentration of sugar in the medium disturbs the osmotic balance between the medium and the plant tissue, and hence, the rate of water and nutrient uptake are consequently affected that in turn results to retarded the growth of the plant. On the other hand, lower concentrations of sugar may have adverse effect on plant growth since optimum sugar level is required to undertake the normal physiological activities for the plant (Klerk *et al*, 2002, Mohamed *et al*, 2009, Thorpe, 1982). Thus, sugar concentrations considered as treatment in this study affected the performance of potato varieties under in-vitro propagation.

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Effects of Inter- and Intra-Row Spacing on Seed Tuber Yield and Yield Components of Potato in Ofla Woreda

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Introduction

Many diverse and complex biotic, abiotic, and human factors contribute to the existing low productivity of potato in Ethiopia. Some of these include shortages of good quality seed tubers of improved cultivars; disease and pests; and lack of appropriate agronomic practices, including optimum plant density, planting date, soil moisture, row planting, depth of planting, ridging, and soil fertility status (Berga et al., 1994).

The optimizing of plant density is one of the most important subjects of potato production management, because it affects seed cost, plant development, yield, and quality of the crop (Bussan et al., 2007). The yield of seed potato can be maximized at higher plant population (closer spacing), by regulating the number of stems per unit area, or, to a certain extent, by removing the haulm earlier during the maturity (O'Brien and Allen, 2009). Rahemi et al. (2005) also reported that intra-row spacing was significant on yield of potatoes: the 20-cm intra-row spacing, in comparison with 30-cm spacing, showed 13.9, 59.8, and 30.39% increase in yield.

Intra-row distance of 20 cm increases total tuber number and weight, and tuber weight per plant and the marginal return rate increased by 13% when intra-row distance decreased from 35 to 25 cm. EARO (2004) also determined that is little difference in yield between intra-row spacing of 25 and 30 cm for all varieties released so far in Ethiopia, and the 30-cm intra-row and 75-cm inter-row spacing are accepted as standard.

Owing to the lack of region-specific recommendations for inter- and intra-row spacing, farmers in the study area (southern zone of Tigray) use different spacing (below or above) than that of the national recommendation, depending on the purpose of planting either for ware or seed tuber. Hence, it is important to maintain appropriate plant population per unit area to have high yield, marketable size, and good quality of seed tuber. Even though different research on potato plant density is done in different parts of the country, the condition in Ofla Woreda was not studied. The study presented here was conducted to determine the best inter- and intra-row spacing for optimum tuber seed yield and quality of potato seed tuber at Ofla Woreda, Northern Ethiopia.

Materials and Methods

The experiment was conducted on a farmer's field in 2010/2011 under irrigation condition in southern zone of Tigray, Ofla Woreda at Hashenge kebele. The experimental site is located at an elevation of 2,500 meters above sea level. Maximum and minimum temperatures range from 22.57°C and 6.8°C. The mean annual rainfall of the area is about 806.5 mm, with a soil pH of 6.8 (BoARD,2009).Jalene variety was used as planting material. There were 16 treatment combinations, consisting of four inter-row spacings (65, 70, 75, and 80 cm) and four intra-row spacings (20, 25, 30, and 35 cm). The experiment was laid out in 4 x 4 factorial arrangements using a randomized complete block design (RCBD) with three replications. The collected data on different growth stage was analyzed by using SAS Computer software version 9.0 (SAS Institute Inc., 2008).

Results and Discussion

Leaf area index

Intra-row spacing showed a very highly significant (p <.001) effect on leaf area index. However, the effect of inter-row spacing and interaction showed no significant difference in leaf area index (Fig. 1). The result revealed that the highest leaf area index (3.21) was recorded at 20-cm intra-row spacing, and this could be due to high number of haulms per unit area. The lowest value (2.32) of leaf area index was recorded from 35-cm intra-row spacing, which is significantly different from the other three (30, 25, and 20 cm) intra-row spacings.

This result agrees with the findings of Ronald (2005) and Tamiru (2005), who reported that the highest density they used increased leaf area index, which possibly indicates the potential partitioning of assimilates for vegetative growth

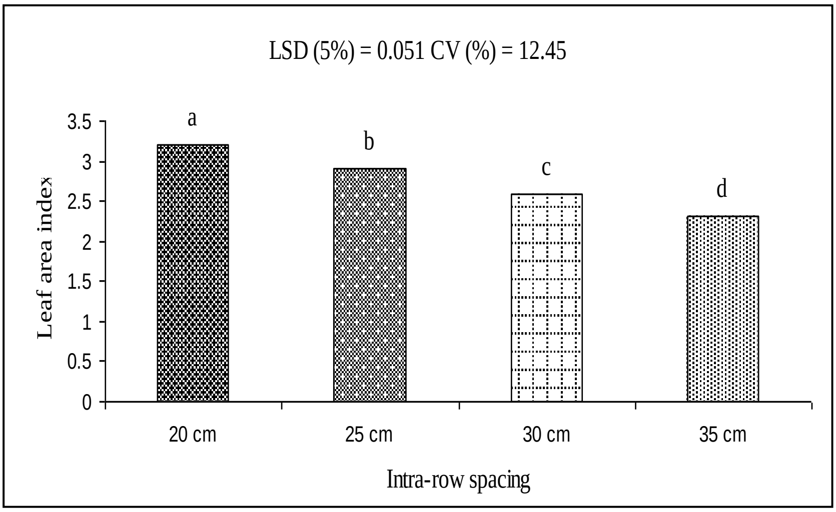

Figure 1: Mean leaf area index for the different intra-row spacing treatments of potato

Tuber seed yield

The effect of inter- and intra-row spacing showed a very highly significant (p <.001) differences on total tuber yield per hectare (Table 1). The interaction effect was non-significant (p <.05). The highest yield (36.89 t/ha) was obtained from 65-cm inter-row spacing, whereas the lowest (31.87 t/ha) yield was recorded at 80-cm inter-row spacing.

Regarding the intra-row spacing, the higher total yield per hectare (37.54 t/ha) was obtained from 20-cm intra-row spacing. As intra-row spacing increased from 20 to 35 cm, total tuber yield decreased from 37.54 to 29.38 t/ha. Intra-row spacing of 35 cm showed lower total tuber yield (29.38 t/ha) and was significantly different from the three levels. It was clearly evident from the results that the yield of seed tuber per hectare was increased with decreasing plant spacing. The increased yield was attributed to more tubers produced at the higher plant population per hectare, although average tuber size was decreased because of increased inter-plant competition at closely spaced plants leading to more unmarketable tuber yield. At closer spacing there is a high number of plants per unit area which brings about an increased ground cover that enables lighter interception and, consequently, influences photosynthesis. It is very likely that substantial increases in rate of land coverage and tuber yield could be achieved by dramatically increasing the stem density per unit area.

The present result agrees with the findings of Zabihi et al. (2011), who reported that plant density in potato affects some of the important plant traits such as total yield, tuber size distribution, and tuber quality. Increase in plant density led to decrease in mean tuber weight but not in number of tubers and yield per unit area. In contrast, Berga et al. (1994) reported that wider row width by wider intra-row distance (80 x 40 cm) gave the highest yield (34 t/ha),whereas the narrower intra-row distance (60 x 20 cm) treatment gave the lowest (22.2 t/ha) yield.

Marketable seed tuber yield

The data concerning marketable yield as influenced by planting density are presented in Table 1. Inter- and intra-row spacing showed a very highly significant (p <.001) effect on marketable yield. Significantly, maximum marketable yield (35.89 and 35.09 t/ha) was obtained at a 20- and 65-cm intra- and inter-row spacing, respectively. Although the lowest marketable yield(28.65 and 31.42 t/ha) was obtained at the wider spacing (35-cm intra-row and 80-cm inter-row, respectively), the interaction effect did not show any significant difference on marketable yield per hectare. The highest marketable yield recorded at closer spacing was attributed to more tubers produced at the higher plant population per hectare. The present result agreed with the findings of several authors (Stoffela and Bryan, 1988; Khalafalla, 2001) regarding the influence of plant density on marketability of the produce. Close spacing of 15–25 cm was reported to give better proportion of marketable yield than wider spacing of 35 cm.

Table 1: Means for the effect of inter- and intra-row spacing on total tuber yield and marketable tuber seed yield

Treatments	**Tuber seed yield (t/ha)**	**Marketable seed yield(t/ha)**
Intra-row spacings (cm)		
20	37.54 [a]	35.89[a]
25	35.75 [b]	34.49[b]
30	35.61 [b]	34.66[b]
35	29.38 [c]	28.65[c]
Inter-row spacings (cm)		
65	36.89 [a]	35.09[a]
70	35.33[b]	33.86[b]
75	34.18[b]	33.32[b]
80	31.87 [c]	31.42[c]
LSD (5%)	1.18	1.18
CV (%)	11.25	10.31

Means followed by the same letter within the same column are not significantly different at 5% level of significance.

Number of tubers per hectare

The result of total number of tuber per hectare as influenced by inter- and intra-row spacing is presented in Table 2. Inter- and intra-row spacing had shown very highly significant difference (p <.001) on total number of tuber per hectare. Significantly, maximum total number of tuber (532,865) per hectare was recorded at 65 cm inter-row spacing. The lowest number of tuber (447,586) per hectare was obtained at wider spacing (80 cm) of inter-row spacing.

Effect of intra-row spacing was significant. Maximum total number of tubers (558,174) per hectare was obtained from 20-cm spacing, whereas the lowest total number of tubers (430,311) per hectare was recorded at 35-cm spacing. Total tuber number per hectare, however, increased with closer spacing due to high number of plants per unit area. Rahemi et al. (2005) also reported that intra-row distance of 20 cm increased total tuber number and weight per unit area.

Marketable seed tuber number per hectare

Marketable tuber number (000's/ha) as influenced by inter- and intra-row spacing is presented in Table 2. Inter- and intra-row spacing had very highly significant (p <0.001) effect on marketable tuber number per hectare. The interaction effect had no significance ($p \leq .05$) on marketable tuber number per hectare.

Maximum marketable tuber number (485,144 and 501,651) was obtained at 65- and 20-cm inter- and intra-row spacing, respectively, whereas the result recorded at 20-cm intra-row spacing was significantly different from the other intra-row spacing. The lowest number of marketable tuber per hectare (411,315 and 395,106) was obtained at 80-cm inter-row and 35-cm intra-row spacing, respectively. Among the inter-row spacing, statistically the same result was obtained for 65 and 70 cm, which scored the highest marketable tuber number 485,144 and 455,026 per hectare, respectively. In a related study Burton (1989) reported that wider spacing produced few tubers as it gave rise to few stems that could lead to high number and possibly tubers, but closer spacing improved quality and saleable yield.

Table 2: Means for the effect of inter- and intra-row spacing on total and marketable seed tuber number of tuber

Treatments	Number of tuber (per ha)	No of marketable tuber (per ha)
Intra-row spacing(cm)		
20	558,174[a]	501,651[a]
25	486,858[b]	445,568[b]
30	455,014[bc]	423,513[bc]
35	430,311[c]	395,106[c]
Inter-row spacing (cm)		
65	532,865[a]	485,144[a]
70	496,599[a]	455,026[a]
75	453,307[b]	411,315[b]
80	447,586[b]	414,352[b]
LSD (5%) CV (%)	37,587.6 15.57	37,667.7 15.61

Means followed by the same letter within the same column are not significantly different at 5% level of significance.

Average fresh tuber weight (g)

Intra-row spacing showed highly significant (p <.01) difference on average fresh tuber weight per plant (Fig. 2). The main effects of inter-row spacing and its interaction with intra-row spacing had no significant (p ≤.05) difference on average fresh tuber weight. The maximum mean tuber weight (79.68 g) was recorded at 35-cm intra-row spacing, but not statistically different with 25-cm intra-row spacing. The smallest average fresh tuber weight (67.3 g) was recorded at 20-cm intra-row spacing. However, it was not significantly different from 25- and 30-cm intra-row spacing for the values of (74.24and 69.16 g, respectively).

Increase in density probably increased competition between and within plants and hence, led to decrease in availability of nutrients to each plant and, consequently, resulted in decline of mean tuber weight. This result is in line with Ali (1997), who found higher average fruit weight at wider spacing as compared to closer spacing. Berga and Caesar (1990) also reported that stem number per plant and tuber number per plant are positively related; however, average tuber weight increased with wider spacing.

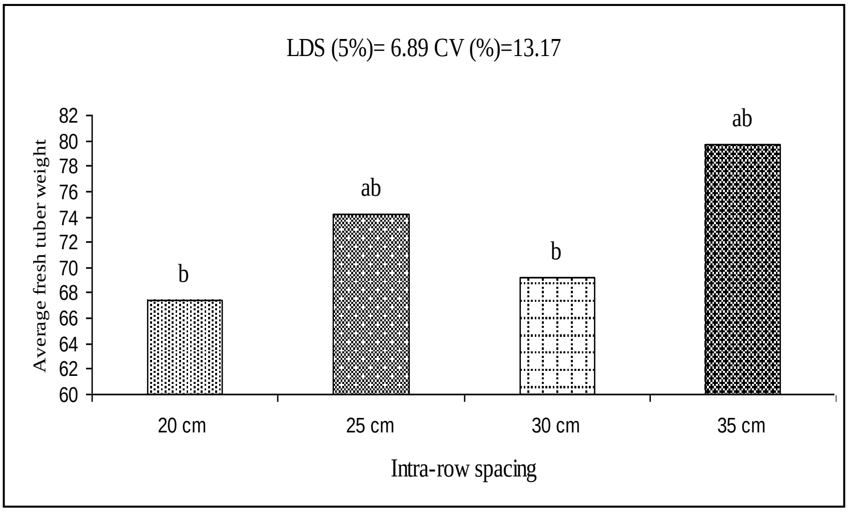

Figure 2: Mean fresh tuber weight for the intra-row spacing treatments

Tuber size category

Intra-row spacing had shown highly significant ($p<.01$) effect on number of tubers graded less than 20 mm (Table 3). A maximum (9.96%) number of small (less than 20 mm) was recorded at intra-row spacing of 20 cm. It was not significantly different from 25-cm intra-row spacing, whereas the lowest (6.629%) at 35 cm. Intra-row spacing also showed a very highly significant ($p<.001$) effect on weight of tubers graded small (less than 20 mm).However, the effect of inter-row spacing and interaction effect had no significant ($p\leq.05$) difference for number and weight of tubers graded small.

Intra-row spacing also showed very highly significant ($p<.001$) effect on tubers graded large (greater than 50 mm) in terms of number and weight. Significantly, maximum (23.74 number and 52.91 weight percent) tuber graded as large was recorded at 35-cm intra-row spacing, whereas the lowest (18.50 number and 42.30 weight percent) was recorded at 20-cm intra-row spacing. Inter-row spacing showed highly significant ($p<.01$) weight of tuber graded as medium (30–40 mm). The highest (17.14%) tubers graded as medium weight was recorded at 65-cm inter-row spacing.

The result of this investigation clearly indicated that the level of intra-row spacing largely affected potato tuber size distribution. Thus, based on market and consumers' demand, it is possible to produce or increase either seed potato or ware potato of required size through the selection of appropriate planting density (intra-row spacing).

The present result agrees with the finding of Wiersema (1987), who reported that at higher stem density, the tuber produced remained smaller than at lower stem densities. Khajehpour (2006) also reported that increase in plant density decreases mean tuber size, probably because of a reduction in plant nutrient elements, increase in interspecies competition, and large number of tubers produced by high numbers of stems. Overall, the result of this study indicates that tuber size category is influenced mainly by intra-row spacing rather than by inter-row.

Table 3: Mean tuber size for the different intra-row spacing treatments by category

Intra-row spacing (cm)	**Wt of tubers graded small (less than 20 mm)**	**No of tubers graded small (less than 20 mm)**	**Wt. of tubers graded big (greater than 50 g)**	**No of tubers graded big (greater than 50 mm)**
20	0.7335^{a}	9.961^{a}	42.30^{c}	18.50^{b}
25	0.7066^{b}	8.121^{ab}	44.21^{c}	19.02^{b}
30	0.6808^{c}	7.485^{b}	49.06^{b}	22.00^{a}
35	0.5005^{d}	6.629^{b}	52.91^{a}	23.74^{a}
LSD (5%)	0.005	1.904	3.401	2.419
CV (%)	14.10	25.2	12.12	17.55

Means followed by the same letter within the same column are not significantly different at 5% level of significance.

Conclusion

The result of this study demonstrated that yield per unit area was influenced by the different level of inter- and intra-row spacing. One can conclude that the narrow spacing (20- and 65-cm intra- and inter-row spacing) produced higher seed tuber yield and marketable yield per hectare than other spacings. Thus, farmers growing potato variety Jalene in the study area (southern zone of Tigray) can benefit if they use narrow spacing of 20-cm intra-row and 65-cm inter-row spacing as a new practice.

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Influence of Inorganic Nitrogen and Potassium Fertilizers on Seed Tuber Yield and Size Distribution of Potato

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Introduction

In Ethiopia, some farmers use inorganic fertilizers for increasing potato yields. However, they use only nitrogen (as Urea) and phosphorus (as DAP) since these are the only fertilizers commercially available in the local market. In addition, application of these fertilizers to potato crop is based on blanket recommendations that were formulated for potato grown on soils of certain sites in the country decades ago—that is, 165 kg Urea/ha (111 kg N/ha) and 195 kg DAP/ha (40 kg P/ha). These recommendations wholly disregard the specific physico-chemical characteristics of the varied soils on which the crop is grown as well as the dynamic nature of soil nutrient status.

Early reports (Murphy, 1959) of favorable potassium supply, except in a few acutely deficient soils, have led researchers and farmers to ignore the need for potassium in many parts of East Africa (Anderson, 1973). Consequently, potassium fertilizer is not entirely applied to crops by farmers in Ethiopia. Without application of phosphate and potassium, the yield response to increasing levels of nitrogen was smaller than when adequate amounts of P and K were applied (Mengel and Kirkby, 2001). Therefore, all the essential nutrients should be available to the crop to realize maximum yields.

The other major constraint to increased potato production is lack of good quality seed tuber. Access to improved seed tuber adapted to local conditions is the key to achieving sustained efforts towards food security. Agronomic practices of a seed potato crop are different from those of ware potatoes. The practices in seed production are aimed at a high rate of multiplication, high number of seed-sized tubers, and maintenance of healthy seed tubers that have optimum physiological quality (Lung'aho et al., 2007).

Potatoes to be used for seed have specific size requirements. If seed tubers are too small, they will have small number of stems that produce only a few tubers, thereby reducing yield. On the other hand, too big seed tubers may result in the production of too many stems, which eventually produce too many tubers that may compete for growth factors in soil and become too small. Thus, such tubers will be unmarketable for use as either ware or seed potato. Besides, too big tubers will be too bulky and uneconomical to use as seed or increase cost to transport. Therefore, the best seed tubers are the ones that are medium sized (39–75 g).

Fertilizer requirement for seed tuber and ware potato production may not be necessarily the same. Different levels of nutrient supply may lead to different seed tuber yields. This is because seed tuber yield is determined not only by total tuber yield but also by tuber size category and tuber numbers. Thus, nutrient levels that may lead to optimum yield of ware potato may not lead to optimum yields of seed tuber, or vice versa.

Improved potato varieties that have been recently released in Ethiopia may differ in nutrient efficiency, and could have different optima of balanced macro-nutrient requirements for maximum yield of good quality seed tubers. However, there is limited information on the optimum requirements of balanced NPK nutrition of improved potato varieties in the country.

Hence, this study was initiated to investigate the main effects of nitrogen and potassium fertilizers on seed tuber yield, size distribution, and related yield attributes of potato, and to determine the rates of nitrogen and potassium fertilizers that may result in optimum seed and ware potato tuber yields

Materials and Methods

Description of the experimental site

The experiment was conducted at Rare research field of the Haramaya University on the main campus, which is located at 9°24'N latitude and 42°03'E longitude and about 1,980 masl. The site has a bimodal rainfall distribution and is representative of a sub-humid and mid-altitude agro-climatic zone. The short rainy season extends from March to April and constitutes about 25% of the annual rainfall. The long rainy season extends from June to October and accounts for about 45% (Belay et al., 1998). The mean annual rainfall and temperature are 760 mm and 17°C. During the previous cropping season, wheat was grown at the site. The soil of the experimental site is alluvial type. The trial was conducted under rain-fed condition.

Planting materials, treatments, experimental design, and procedures

The potato variety Batas was used as planting material. The treatments consisted of combinations of five levels of nitrogen (0, 50, 100, 150, and 200 kg N/ha) and three levels of potassium (0, 100, and 200 kg K_2O/ha). The treatments were laid out as randomized complete block design and replicated three times, and randomly assigned to the plots within each rows, leaving the plants growing in the two border rows and those growing at both ends of each row. Plants were harvested to estimate tuber yield, tuber size distribution, and other yield-related parameters. Size of a plot was 4.5 x 3.9 m (17.55 m^2). The number of rows per plot was six with 13 plants per row. Forty-four plants from the four middle rows were sampled. Distances of 1 m between plots and 2 m between blocks were kept. The entire rate of K and one third the rate of the N fertilizers were applied at planting. The remaining one third of the N was applied 38 days after planting and one third at the start of flowering. P was applied basally to all plots at an equal rate (92 kg P_2O_5per hectare). Urea (46% N), Triple Super Phosphate (46% P_2O_5), and potassium sulphate (52% K_2O) were used as fertilizer sources for N, P, and K. Weeds were controlled by regular hoeing.

Data collection

Total biomass (g) refers to the fresh weight of leaves, stems, roots, stolons, and tubers. It was determined from 10 plants as a random sample from each plot just at flowering.

Shoot dry mass (g) was determined from the dry weight of the shoot biomass. This was obtained by oven-drying fresh shoot biomass at 65°C until constant weight was obtained of randomly selected 10 plants from each plot just at flowering.

Harvest index(HI) was determined as the ratio of dry weight of the tubers to the dry weight of the total biomass.

Specific gravity of tubers (gcm^{-3}) was determined by the weight in air/weight in water method (Kleinkopf et al., 1987).

Size categories of tuber for the purpose of tuber seed production, the following seed tuber categories were identified: small (< 39 g), medium (39–75 g), and large (>75 g) (Lung'aho et al., 2007). Healthy tuber with a size more than 20 g was considered marketable; tubers that were rotten, diseased, insect attacked, deformed, or undersized (less than 20 g) were categorized as unmarketable. Total tuber yields and numbers were recorded as the sum yield of marketable and unmarketable tuber yields and numbers.

To determine, **dry matter content (%)** tubers from five randomly selected plants per plot were washed, weighed, sliced, and dried in oven at 65°C until a constant weight was obtained. The dry weight was recorded and dry matter percent was calculated from it.

Data analysis

Data were subjected to ANOVA, using SAS statistical software (SAS, 2002) version 9.1. All significant pairs of treatment means were compared using the Least Significant Difference (LSD) test at 5% level of significance.

Results and Discussion

Effect of nitrogen and potassium on shoot and total biomass

The increase in both total biomass and shoot dry matter yield continued up to the highest level of the nutrient (200 kg N/ha). Thus, the highest total biomass yield was attained at the highest rate of the nutrient, and was higher than the biomass yield of plants in the control treatment by about 31%. Similarly, the highest shoot dry matter yield of the plant was attained at 100 and 200 kg N/ha, and exceeded the shoot dry matter yield of plants in the control treatment by about 20% and 36%, respectively. This result agrees with the findings of Millard and Marshall (1986), who reported a significant increment in canopy dry matter yield of potato in response to increased nitrogen application. On the other hand, neither the main effect of nitrogen nor that of potassium had significance on HI (Table 1). Consistent with this result, Zelalem (2009) also reported that nitrogen had no significant influence on HI of potato.

Effect of nitrogen and potassium on yield

Total tuber yield significantly increased when N supply was raised from 50 to 100 kg N/ha. Compared to the control treatment, the total tuber yield obtained at 100 kg N/ha increased by 33.4%. Therefore, applying 100 kg N/ha was found to be the optimum N rate for high total tuber yield of the potato crop. Beyond 100 kg N/ha, fresh total tuber yield remained statistically non significant. There was rather a tendency of decline in fresh tuber yields at the higher N levels. Corroborating the results of this study, Mulubrhan (2004) and Zelalem (2009) reported highly significant increases in total tuber yield in response to increased level of nitrogen application.

Table 1: Main effects of nitrogen and potassium on total biomass, shoot dry mass, and harvest index of potato

Treatment	Growth parameters		
	Total biomass (g/plant)	Shoot dry mass (g/plant)	Harvest index
N kg ha^{-1}			
0	658.72[c]	20.75[c]	0.78
50	683.89[bc]	21.16[c]	0.77
100	745.33[b]	24.92[ab]	0.79
150	701.44[bc]	22.37[bc]	0.78
200	864.07[a]	28.17[a]	0.78
F-test	***	**	ns
K_2O kg ha^{-1}			
0	719.71	22.49	0.78
100	724.29	23.38	0.79
200	748.07	24.56	0.77
F-test	ns	ns	ns
CV(%)	10.90	16.38	4.43

*** = highly significant (p<.01); *** = very highly significant (p≤ .001); ns = non significant (p≤ .05). Means sharing the same letter within a column are non-significantly different at 5% level of significance.*

The total tuber number increased when N supply was increased from 0 to 100 kg N/ha. However, it remained the same in magnitude across all higher levels of N supply. Similar to the total tuber fresh yield, the optimum tuber number was obtained at 100 kg N/ha. The average tuber number of plants not supplied with N was less by about 23% than the tuber number of plants supplied with 100 kg N/ha.

In agreement with the present finding, Sharifi (2005) reported that significant increases in tuber numbers in response to increased levels of N application. Similarly, Jenkins and Mahamood (2003) observed that the number of tubers varied considerably as a result of N fertilization, and doubled when N level was increased to higher levels.

Consistent with the results of this study, Zelalem (2009) also reported that total tuber yield was strongly associated with average tuber weight and total tuber number, signifying that the increase in both tuber number and size substantially contributes to increased tuber yields. Kanzikwera et al. (2001) also reported that the number of tubers per plant and mean fresh tuber weight increased as a result of nitrogen application before tuber initiation.

Marketable tuber yield increased when nitrogen supply was raised from 0 to 100 kg N/ha, but did not change in magnitude beyond this level. The marketable tuber yield of plants grown in the treatment of 100 kg N/ha was higher than the marketable tuber yield of plants grown in the control treatment by about 52%. Marketable tuber number responded to nitrogen application in a similar way to marketable tuber yield. It increased when N supply was raised from 0 to 100 kg N/ha. Thus, the optimum marketable tuber number was obtained at 100 kg N/ha. However, the change in this parameter remained statistically the same across the higher levels of N. Compared to the marketable tuber number of plants in the control treatment, the marketable tuber number of plants treated with 100 kg N/ha increased by about 92%.

The optimum marketable tuber yield was attained at 100 kg N/ha, signifying that increasing N fertilizer more than this level would be wasteful for ware potato production. On the other hand, the lowest marketable tuber yield (14.08 t/ha) and the lowest marketable tuber number (3.96 tubers per plant) were obtained at the level of no nitrogen application. This implies that producing potato without sufficient nitrogen in the soil would drastically reduce the marketable tuber yield on the experimental soil.

The increase in marketable tuber weight and number in response to N application could be attributed to the effect of the nutrient on enhancing leaf growth and leaf surface area. This would enhance the amount of photosynthetically active radiation (PAR) trapped by the leaves for production of carbohydrate, which would ultimately be partitioned to tubers. In line with this argument, Wilcox and Hoff (1970) reported that the positive effect of N fertilizer on potato growth and yield was rooted in its impact on promoting the number of tubers produced per plant, the average weight of tubers, and the establishment of optimum leaf area index and leaf area duration. Corroborating this hypothesis, Chapin et al. (1988) postulated that, in plants suffering from nitrogen deficiency, elongation rates of leaves may decline before reduction in net photosynthesis. This decline is the result of decrease in both number and duration of extension of epidermal cells (MacAdam et al., 1989). In this connection, Radin (1983) further explained that when nitrogen is deficient in the soil, a decrease in root conductivity may also be involved, leading to decreases in water availability to expanding leaves.

In the present study, increasing N level beyond 100 kg N/ha did not significantly increase total and marketable tuber yield. Reduction in yield due to supra-optimal N application could be ascribed to the phenomenon that extra N application often stimulates shoot growth at the expense of tuber initiation and bulking (Sommerfeld and Knutson, 1965). In agreement with this suggestion, Krauss and Marschner

(1971) reported that a larger and continuous supply of nitrogen to potatoes delays or even prevents tuber development.

The highest unmarketable tuber number was obtained from untreated plots, followed by plants in the treatment of 50 kg N/ha, which was a marginal N supply. However, the highest unmarketable tuber yield was obtained in the treatment of 50 kg N/ha followed by plants in the control treatment. The unmarketable tuber yield was significantly decreased at 100 kg N/ha and across all higher N rates. For example, the unmarketable tuber yield and number of plants grown at 100 kg N/ha were lower by 39% and 24%, compared to those grown at the control treatments, respectively. In this experiment, unmarketable tubers (culls) refer to rotten and undersized tubers. Most of the tubers that were discarded as unmarketable tubers included the ones that were too small. Although unmarketable tubers may be controlled more importantly through manipulating other factors such as disease incidence, pest incidence, harvesting practice, and the like rather than mineral nutrition (Berga et al., 1994), nitrogen deficiency has evidently contributed to the development of at least very small tubers due to scarcity of photoassimilate for tuber enlargement and bulking. Thus, N deficiency may have enhanced the unmarketable tuber numbers and yield at the lowest and marginal levels of N supply. Therefore, marketability of potato tubers could be improved through enhanced nitrogen nutrition as well as disease and pest control.

In the present study, applying 100 kg N/ha resulted in the optimum total tuber yield, marketable tuber yield, total tuber number, and marketable tuber number. Conversely, the markedly low unmarketable tuber yield and number obtained at 100 kg N/ha signify the superiority of this level of nitrogen for the production of optimum fresh potato tuber yield.

The vigorous response of potato yields to nitrogen application could be attributed to the low native soil N, which is associated with the very low content of organic carbon and total nitrogen (Landon, 1991). Under low organic carbon content of the soil, there is little nitrogen that may become available to plants in the form of nitrate or ammonium through mineralization during the growing season. In addition, nitrogen is lost through leaching during wet seasons and its deficiency would become severe (Mengel and Kirkby, 2001).

Potassium had no significant main effect on any of the above-mentioned tuber characteristics. Consistent with this result, Dubetz and Bole (1975) observed that increasing the level of K had no impact on total tuber yield as well as tuber number at various rates. Lack of response of potato to potassium application in terms of the aforementioned tuber characteristics is consistent also with the results of Mulubrhan (2004) in that no significant influence of the nutrient on potato tuber yields and yield components on pellic vertisols of Mekelle. The lack of response of potato to potassium application could be attributed to the already high content of exchangeable potassium in the soil.

Effect of nitrogen and potassium on tuber size distribution

The yield of medium-sized tubers remained significantly low at 0 and 50 kg N/ha, but increased significantly at the remaining higher levels of the nutrient reaching the maximum at 200 kg N/ha. This yield increased at 200 kg N/ha by about 58%, compared to the yield at the control treatment. Similarly, the number of medium-sized tubers was also significantly increased with the increase in nitrogen supply. It remained low and statistically the same at 0 and 50 kg N/ha and further increased significantly at 100 and 150 kg N/ha. (Note that the difference between 50 and 100 kg N/ha were non significant and reached a maximum at the highest level of N supply—200 kg N/ha). Thus, the medium-sized tuber numbers produced at 200 kg N/ha exceeded the tuber number produced at 0, 50, 100, and 150 kg N/ha by about 76%, 74%, 53%, and 46%, respectively. Therefore, significantly more number (about 231,111 plants per hectare) of seed tubers were obtained at the highest level of N supply than at 100 kg N/ha (151,111 plants per hectare), where the optimum total and marketable tuber yields of this tuber category were obtained (Table 2). In line with the present results, Mulubrhan (2004) reported that higher levels of nitrogen (165 kg/ha) produced significantly more number of medium-sized tubers compared to the other tuber size categories.

Thus, cultivating potato by applying 200 kg N/ha on the experimental soil would yield a quantity of seed potato tubers that could plant over half more area of land (53%) than the quantity obtained at 100 kg N/ha. However, it was not known if the number of medium-sized potato tubers would decrease, increase, or remain the same if the nitrogen rates had been increased beyond 200 kg N/ha. The yield of large-sized tubers increased highly significantly (p<.01) in response to nitrogen application. At 0 and 50 kg N/ha, the yield of large-sized tubers remained statistically the same and low. However, it increased significantly at 100 and 150 kg N/ha, but decreased at the highest level of N supply (200 kg N/ha). The increases in the yield of large-sized tubers at 100 and 150 kg N/ha were 101% and 119%, respectively, compared to the yields of large-sized tubers attained in the control treatment. The number of large-sized tubers showed a response similar to the yield of large tubers, with the highest number being recorded for 100 and 150 kg N/ha.

Emergence, seedling vigor, subsequent plant growth, and final yield are affected by seed tuber size. Although all sizes of seed potatoes can grow into a crop, seed growers should only plant tubers ranging from 39 to 75 g. Such tuber sizes produce optimum stem number (25–30 m^{-2}) since they have optimum number of eyes and lead to high yield. Since basic seed tubers are sold on a weight basis, planting large tubers (> 75 g) is usually expensive as more of them are required to plant a unit area. In addition, large tubers are also bulky to transport and handle during planting. On the other hand, small tubers have small number of buds and give rise to small number of stems and lower in vigor and yields. Therefore, potato seed producers should aim at producing medium-sized tubers (Lung'aho et al.,2007). In this experiment, the highest number of medium-sized tubers was obtained at 200 kg N/ha. Therefore, this or higher rates of nitrogen fertilization should be used by potato farmers growing the crop for seed tuber production. For ware potato production, 100 kg N/ha may be sufficient to attain optimum yield (Table 2).

Yield of small tubers decreased in response to increasing N application. However, it remained statistically high and equal at all except the highest level of N supply, where it was significantly low. The lowest small-sized tuber yield was obtained at the highest rate of nitrogen. The yield of small-sized tubers obtained at the control treatment exceeded the yield obtained at the highest level of N by about 26%. Increasing the rate of nitrogen also affected the number of small tubers. The number of small-sized tubers obtained at 50 kg N/ha was significantly higher than the number obtained at 200 kg N/ha by about 26%. The significant reduction in the number of small-sized tubers at the highest level of N supply evidently occurred at the expense of increased number and yield of large-sized tubers. These results clearly indicate that nitrogen application influenced potato tuber size distribution (Table 3). It can, be suggested that production of seed potato or ware potato could be optimized through different manipulation of rates of mineral nutrients such as nitrogen.

Table 2: Main effects of nitrogen and potassium on total tuber yield, total tuber number, marketable tuber yield, marketable tuber number, unmarketable tuber yield, and unmarketable tuber number

Treatment	Yield parameters					
	Tuber yield (t/ha)	**No of tuber./plant**	**Marketable tuber wt. (t/ha)**	**Marketable Tuber No./Plant**	**Unmarketable Tuber Wt. (t/ha)**	**Unmarketable Tuber No./Plant**
N kg ha^{-1}						
0	17.60^{c}	9.75^{b}	14.08^{b}	3.96^{b}	3.52^{a}	5.79^{a}
50	19.80^{bc}	10.96^{b}	15.84^{b}	5.86^{b}	3.96^{a}	5.10^{ab}
100	23.48^{a}	12.25^{a}	21.35^{a}	7.61^{a}	2.13^{b}	4.64^{b}
150	22.64^{ab}	11.52^{a}	20.48^{a}	7.30^{a}	2.16^{b}	4.22^{b}
200	21.98^{ab}	11.98^{a}	19.78^{a}	7.02^{ab}	2.20^{b}	4.96^{b}
F-test	**	*	**	*	*	*
K_2O kg ha^{-1}						
0	20.33	10.87	15.99	6.23	4.34	4.64
100	21.13	10.82	16.60	6.27	4.53	4.55
200	21.87	11.42	16.89	6.06	4.98	5.36
F-test	ns	ns	ns	ns	ns	ns
CV(%)	16.74	9.26	21.27	23.26	29.94	18.84

*** = highly significant (p<.01); *** = very highly significant (p≤ .001); ns = (p≤.05). Means sharing the same letter within a column are non-significantly different at 5% level of significance.*

Table 3: Main effects of nitrogen and potassium on small (<39 g), medium (39–75 g), and large (>75 g) tuber yield and number

Treatment	**Tuber size categories**					
	Small tuber yield (t/ha)	**Small tuber no/plant**	**Medium tuber yield (t/ha)**	**Medium tuber no /plant**	**Large tuber yield (t/ha)**	**Large tuber no /plant**
N kg/ha						
0	6.24[ab]	6.20[bc]	8.03[d]	2.96[d]	3.33[c]	0.59[c]
50	7.56[a]	7.39[a]	8.64[cd]	2.98[cd]	3.60[c]	0.59[bc]
100	6.07[ab]	6.56[ab]	10.72[b]	3.40[bc]	6.69[ab]	2.29[a]
150	5.76[bc]	6.54[ab]	9.60[bc]	3.55[b]	7.28[a]	1.43[a]
200	4.62[c]	5.48[c]	12.69[a]	5.20[a]	4.67[bc]	1.30[b]
F-test	*	*	***	***	**	**
K_2O kg/ha						
0	6.32	6.49	9.73	3.40	4.28	0.98
100	5.97	6.23	10.21	3.69	4.95	0.90
200	6.54	6.62	9.90	3.78	5.43	1.02
F-test	ns	ns	ns	ns	ns	ns
CV(%)	23.32	14.95	17.94	16.54	25.26	29.83

*** = highly significant ($p<.01$); *** = very highly significant ($p\leq.001$); ns = ($p\leq.05$). Means sharing the same letter within a column are non-significantly different at 5% level of significance.*

Tuber dry matter content and specific gravity

Increasing N level from 0 to 100 kg N/ha significantly decreased tuber dry matter yield. The decrease in tuber dry matter yield at this level of N supply is consistent with the high tuber fresh yield and numbers obtained (Table 2). This could be attributed to the higher tissue water content of tubers growing optimally when nitrogen is sufficiently available. In agreement with this finding, Maier et al. (1994) found reduction in dry matter content when nitrogen and potassium rates were increased.

By contrast, potassium had no significant main effect on tuber dry matter production (Table 4). Similarly, Patricia and Bansal (1999), Kanzikwera et al. (2001), and Mulubrhan (2004) demonstrated that application of potassium had no significant effect on tuber dry matter yield. The absence of change or decrease in tuber dry matter production in response to increased supply of potassium—which might result in luxury consumption of the nutrient—could be ascribed to accumulation of high water in the cells, which may dilute the dry matter yield (Maier et al., 1994).

Table 4: Main effects of nitrogen and potassium on dry matter yield and specific gravity of potato tubers

Treatments	**Tuber Quality Parameters**	
	Dry Matter Content (%)	**Specific Gravity (gcm^{-3})**
N kg/ha		
0	25.02[a]	1.088
50	25.18[a]	1.091
100	24.25[b]	1.087
150	25.62[a]	1.086
200	25.25[a]	1.088
F-test	*	ns
K_2O kg/ha		
0	25.18	1.086
100	24.72	1.090
200	25.28	1.087
F-test	ns	ns
CV(%)	3.52	0.74

*** = highly significant (p<.01); *** = very highly significant (p≤ .001); ns = (p≤.05). Means sharing the same letter within a column are non-significantly different at 5% level of significance.*

In this study, application of both nitrogen and potassium fertilizers had no effect on the specific gravity of potato tubers. There are no site- and time-specific fertilizer recommendations in most parts of the country for potato production. Therefore, many farmers continue applying blanket rates of nitrogen and phosphorus fertilizers, which are mostly too low to satisfy the demand of the crop. In addition, potassium fertilizer is not entirely used to grow crops in the country.

The findings of this study have indicated that the amount of nitrogen fertilizer to be applied for enhancing seed potato tuber yield in terms of number was found to be twice as much as the rate required for attaining high ware potato yield. Thus, seed potato growers should implement fertilizer management practices that may result in high production of seed tuber potato for each variety.

Therefore, we conclude that nitrogen was the most critically deficient nutrient in the soil to which the crop responded most vigorously, and higher rates (200 kg N/ha) should be used to optimize seed potato tuber production; for ware potato production, 100 kg N/ha is recommended.

Nitrogen per hectare is recommended. For the experimental soil, using potassium fertilizer for production of potato or other crops could be dispensed with. This could be justified by the already sufficient exchangeable potassium in the soil that may have become available to the plant during the growing season. However, further research should be done on different potato cultivars, including higher rates of nitrogen in different agro-ecologies in order to come to conclusive recommendations for both ware and seed potato tuber production.

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Yield and Yield Components of Potato Cultivars as Influenced by Period of Seed Tuber Storage at Adet

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Introduction

In Ethiopia, potatoes are stored for ware and seed. Farmers use different traditional potato storage systems (underground storage, floor storage, and raised beds and in sacks) depending on their intended use (ware or seed). Nearly all the major physical, physiological, and disease problems that cause loss were not effectively regulated in these tuber storage methods. Thus, the problem is very critical in affecting seed quality and subsequent performance of the crop in the field (Endale et al., 2008). Observations made at Holetta indicated that tubers could be stored as long as 7 months without considerable depreciation of seed quality. The storage performance, however, was noted to vary depending on the cultivar and location.

Successful potato production in the tropics depends on the storage conditions of the mother tubers and on temperatures after planting. Entire crop may fail if seed tubers are not at proper stage of physiological development when planted (Endale op. cit.).Hence, the lack of proper storage facility is one of the main factors farmers face in Ethiopia to sell their potato during harvesting at low prices. Both seed and ware potato storage is a serious challenge for most farmers, leading to storage losses of up to 50% and sometimes even higher (Bergel, 1980). In Ethiopia, farmers store tubers harvested in September for June planting, which leaves them quite susceptible to disease build up and tuber degeneration. Because of this, farmers lose benefits from the use of good quality seeds of improved varieties.

The greater availability of suitable technologies to Adet climate is in increased demand by farmers, as is their interest in producing the seed tubers to reduce production cost and increase productivity. Moreover, mainly owing to limitations of irrigation facility, potato producers use seed tubers harvested in October/November for July planting. By this stage, long-stored seed tubers get physiologically old and genotypes are being produced under suboptimal physiological conditions. Information is urgently needed about reduction of yield attributable to the use of tubers stored for long periods of time as a planting material. Information on the effect of seed tuber storage duration on subsequent crop performance of potato under Ethiopian conditions is sparse. Therefore, the study reported here was conducted to investigate the effect of seed tuber storage duration on subsequent yield performance and determine storage durations for maximizing seed performance of improved potato cultivars.

Materials and Methods

Description of the study area

The experiment was conducted at Adet Agricultural Research Center (AARC), northwestern Ethiopia, during the 2009/2010 cropping season. AARC lies between 11°16'N latitude and 37°29' E longitude at an altitude of 2,240 meters above sea level. The mean annual rainfall of the area is 1,250 mm and the maximum and minimum temperatures were 26.54°C and 11.37°C (unpublished data from Adet Meteorological Station). The soil is well-drained, red brown cambisole with an organic matter content of 6.53% and a pH value of 5.43.

Experimental materials, treatments, and design

A 2x6 factorial experiment was laid out in a randomized complete block design with three replications. Two cultivars of potato (Guassa and Zengena) and six storage durations (2, 3, 4, 5, 6, and 7 months after harvesting) were combined to produce 12 treatments. Each treatment was randomly assigned to the experimental plots of each block. A gross plot size of 3.75 x 3.3 m accommodating a net plot size of 1.5 x 2.7 m was divided into five rows and planted with 11 tubers per row, which were used for data collection.

Trial management and crop culture

To obtain seed tubers of different storage durations, tubers of Guassa and Zengena cultivars were produced from mid-January to July 2009 by planting at a monthly interval. Tubers from each cultivar were stored in a diffused light store (DLS) at temperatures of 8.04°C–29.98°Cfor two to seven months.

Uniform in size and healthy seed tubers from each variety and age group were planted in the first week of December 2009 at the spacing of 75 cm between rows and 30cm between plants. Phosphorus was applied as Diammonium Phosphate at the rate of 69 kg P_2O_5 per hectare and nitrogen as side dressing at the rate of 81 kg N/ha in the form of Urea. To maintain adequate moisture in the soil, plots were irrigated weekly. Other cultural practices like weeding, hoeing, and cultivation were carried out as required. The vines were killed two weeks before harvesting for proper skin set and wound healing.

Data collection

Days to emergence was recorded when 50% of the plants per plot emerged and the percentage per plot was also recorded after all plants had emerged. Days to flowering were recorded as the number of days from emergence to 50% of flowering. Plant height (cm) was measured as the distance from the base of the stem to the tip of five randomly selected matured plants per plot of the central rows. Leaf area (cm^2) was estimated using a portable leaf area meter (Model CI-202-Area Meter CID. Inc., USA) on five selected hills per plot after 50% flowering. Six weeks after flowering, while the vines were green but had practically ceased growth (CIP,1983), five randomly selected hills per plot were harvested and dried in an oven at 72°C to a constant mass to determine aboveground (stem, branches, and leaves) and underground (root, stolon, and tuber) dry biomass. Days to physiological maturity were recorded when the haulms of 50% of the plants in each plot turned yellowish.

The actual number of main stems per hill was recorded from five sampled hills per plot at physiological maturity. Total tuber number per hill was recorded on five selected hills of central rows at harvest. Marketable and unmarketable yields (kg) were recorded from two central rows of plants excluding two plants from each end of the two rows. Diseased and insect pest tubers were classified as unmarketable (CIP, 1983). Average tuber weight (g) was determined from 10 tubers sampled per plot at harvest. Tuber yield per hill (g) was recorded as the total tuber weight obtained from five hills per plot during harvesting and it was the average of 15 hills per treatment. Tuber-specific gravity was determined using weight-in-air and weight-in-water method (Murphy and Goven, 1959) from 5-kg tubers. For tuber dry matter content, 100 g of clean tubers were chopped and oven dried at 72°C to a constant mass. Finally, tuber dry matter content was determined as the ratio of dry-to-fresh weight expressed as a percentage.

Data analysis

The data were subjected to analysis of variance using SAS statistical software Version 9.00 (SAS Institute, 2000). Means of significant differences were compared using Least Significant Difference test at 5% probability level.

Results and Discussion

During the whole storage period, the average temperature and relative humidity of the store were recorded (Table 1).

Table 1: Mean internal and external temperature and relative humidity of DLS during storage at Adet

Place in DLS	Temperature (°C)		Relative Humidity (%)
	Maximum	Minimum	
Internal	22.2	12.2	79.4
External	26.5	13.4	61.5
Mean	24.3	12.8	70.4

Sprout number and length

Data recorded during storage indicated that sprout number was highly influenced by seed tuber storage duration and cultivar (Fig. 1). Varieties differed with respect to sprout number even at the same storage durations. Sprout number increased with seed tuber storage durations, though Guassa has given maximum sprout number at 5 months of storage (Fig. 1). Maximum number of sprouts (4.0) was recorded from Guassa stored for 5 months and the minimum (1.2) was from 3-month-old Guassa and 4-month-old Zengena tubers. Zengena did not produce sprouts until 3 months of storage, indicating its longer dormancy period as compared to Guassa.

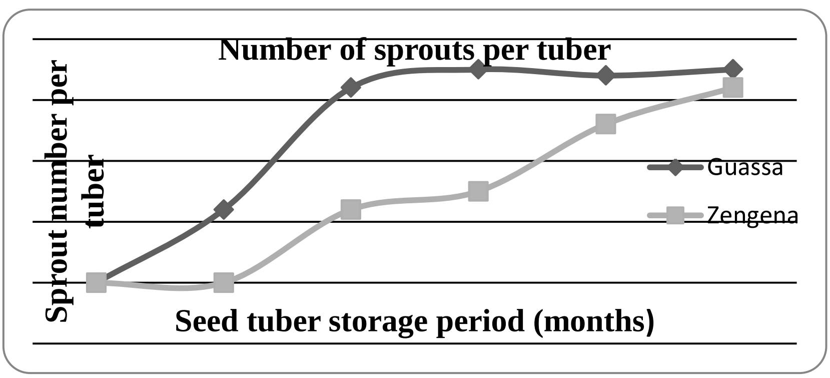

Figure 1: Effect of seed tuber storage duration on the number of sprouts per tuber for two improved potato cultivars

Caldiz (1991) reported that number of sprouts and their behavior were highly affected by seed tuber storage age at planting. Morris (1969), however, suggested that the number of sprouts per seed tuber has an implication on number of main stems produced in the field. Goodwin et al., (1969) also found that the number of main stems in the field was proportional to the number of sprouts at planting. All effects of seed tuber age can be studied in relation to the number and rate of growth and development of sprouts (Van der Zaag and Van Loon, 1987). The length of sprout increased with increasing storage durations considered (Fig. 2). The longest sprout (1.6 cm) for Guassa and (1.8 cm) for Zengena was recorded from 7 months' stored tubers. This conforms with Kawakami (1952), who found that the rapidity of sprout length growth increased with seed tuber age during storage, though sprouts that are too long and weak are not desirable as they could be damaged during handling and transport.

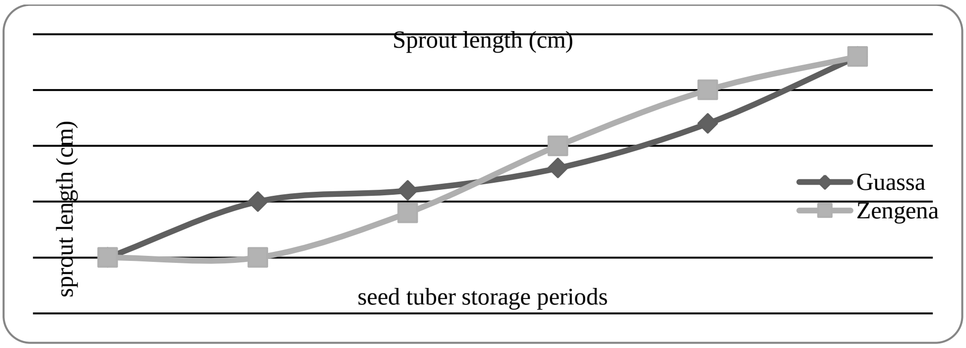

Figure 2: Effect of seed tuber storage duration on the length of sprouts per tuber for two improved potato cultivars

Storage losses

A total of 250 tubers were stored at the beginning of the study for each variety. Out of this, 26.8% of Guassa and 29.4% of Zengena were lost in 7 months' storage period (Fig. 3). Similarly, Tesfaye and Yigzaw (2007) reported that seed tuber losses may reach up to 50% during storage durations of 7–8 months at Adet depending on variety. Losses were mainly due to desiccation and insects (aphids and tuber moths). Three variables determine storage losses: potato variety, storage conditions, and duration. Storage losses are mainly caused by respiration, evaporation of water from tubers, and spread of disease (Burton and Hartmans, 1992).

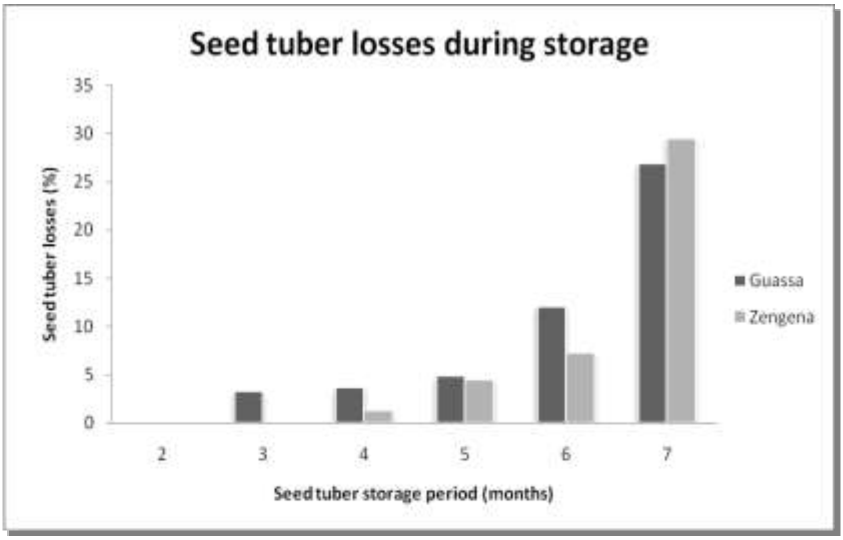

Figure 3: Seed tuber losses of two potato cultivars at different storage periods (physiological age) at AARC

Days to and percentage of emergence

The ANOVA indicated that days to emergence was influenced significantly (p<.05) by the interaction effect of cultivar and seed tuber storage durations (Table 2). Tubers of both varieties that were stored for 6 or 7 months emerged earlier (2 weeks) than tubers stored for 2 months (Table 2). According to Struik and Wiersema (1999), the length of time from planting to emergence depends on storage age of seed tubers. Madec (1978) also reported that as seed tuber age advances, time to plant emergence often decreases. Similarly, Joudu et al.(2002) noted that plants developed from physiologically old seed tubers can better assimilate nutrients from mother tubers and emerge earlier. Vander Zaag and Van Loon (1987) also reported that plants growing from seed tubers of different physiological age perform differently.

Percentage of emergence was influenced significantly (p<.05) by the interaction effect of cultivar and tuber storage period (Table 2). Regardless of the storage period, the seed tubers of Guassa exhibited high and uniform emergence percentage. In the case of Zengena, however, 7-month-old seed tubers showed significantly lower emergence percentage (72.77%) as compared to the other storage durations (Table 2). The low rate of plant establishment from old seed tubers is more explained by weak sprouts and low starch reserves for sprouts to develop in stems because of advanced seed tuber ages, though moisture and depth of planting also cause low establishment (Struik and Wiersema, 1999). Wiersema (1989) also found that rate of emergence depends on sprout viability and strength as sprout emergence decreases with increasing physiological age of seed tubers.

Madec (1978) reported that 92% emergence from 6-month-old seed tubers of potato cultivar compared to 85% from seed tubers of the same cultivar stored for 17 months.

Table 2: Days to emergence and emergency percentage of potato as affected by the interaction effect of cultivar and seed tuber storage duration at Adet

Treatments		Days to emergence	Emergence (%)
Variety	**Storage duration (months)**		
Guassa	7	14.00g	84.88a
	6	14.00g	89.09a
	5	20.00f	92.73a
	4	22.67e	90.91a
	3	30.67c	85.46a
	2	36.00b	92.73a
Zengena	7	15.00g	72.77b
	6	14.67g	93.94a
	5	25.67d	87.31a
	4	25.67d	92.12a
	3	32.00c	87.27a
	2	45.00a	91.51a
Mean		24.61	88.39
Cultivar x Storage (5 %)		2.4	10.38
CV (%)		5.85	6.94

Means followed by the same letter within a column are not significantly different at 0.05 probability level.

Days to flowering and physiological maturity

Non significant (*p*<.05) difference was observed between varieties with regard to days to flowering, but seed tuber storage durations significantly affected days to flowering (Table 3). Both varieties produced flower in almost 2 months (Table 3). Results showed that tubers stored for 6 or 7 months flowered earlier in about 53 days whereas tubers stored for 2 months required 73 days to flower (Table 3). This indicated that seed tuber age significantly shortens days to flowering. Storage of seed tubers for 2 months delayed days to physiological maturity by about 23 days as compared those stored for 6 or 7 months, which required about 98 days to attain physiological maturity.

Table 3: Plant height, leaf area per plant, days to flowering, and physiological maturity of potato as affected by the main effect of cultivar and seed tuber storage durations

Main effect	**Plant height (cm)**	**Leaf area (cm^2)**	**Days to flowering**	**Days to physiological maturity**
Variety				
Guassa	49.39b	3,411.9a	61.55	109.89a
Zengena	61.90a	2,058.8b	61.44	105.89b
LSD (5%)	3.9	492	ns	2.1
Storage Duration				
7 months old	53.25	2,921.2b	53.00d	97.50d
6 months old	58.57	3,393.6a	53.67d	98.83d
5 months old	58.43	2,218.3b	61.00c	106.83c
4 months old	52.78	2,669.5b	63.00c	109.10c
3 months old	55.52	2,587.4b	65.33b	113.33b
2 months old	55.33	2,626.2b	73.00a	121.33a
LSD (5%)	ns	852.4	2.05	3.58
CV (%)	10.13	26.03	2.79	2.77

Means of the same main effect within a column followed by the same letter are not significantly different at 0.05 probability level.

In favor of the current finding, Vander Zaag (1973) reported that physiologically old seed tubers shorten the time between emergence and senescence. Eremeev and Joudu (2007) reported that plants coming from physiologically older seed tubers with obvious signs of senescence started to appear earlier. Wurr (1982) found that storage of potato seed tubers for long periods significantly shortens days to physiological maturity of the progeny crop. Previous results of Caldiz et al. (1984) indicated that the length of incubation period (dormancy break to time of tuber initiation) was shorter for physiologically old tubers. The shortness of incubation period and consequent advance in tuber initiation was associated with higher starch synthase activity and starch accumulation in the stolon tips of old tubers (Ewing and Struik, 1992). Allen et al. (1992) showed that thermal treatment of seed tuber is one method to get earlier yield by adding physiological age to seed tubers, and this shortens the chronological time necessary for the tuber to mature early. Villafranca et al. (1998), as cited by Tekalign (2005) from a kineton-induced in-vitro tuber formation study, reported that early tuberization and maturity period increased with physiological age of the mother tuber.

Plant height

The ANOVA indicated that plant height was influenced significantly ($p<.05$) by cultivar (Table 3). Cultivar Zengena was taller (61.9 cm) than Guassa (49.39 cm). As previously reported by Kumar and Knowles (1993), a 6-month storage period was optimal in terms of growth vigor and canopy structure. The same authors stated that after 7 months of storage, the optimum physiological age of the seed tubers for plant development passed and the plants lost some of their growth vigor, which was reflected by lower canopy structure and smaller plant sizes. Reports (Ewing, 1997; Vander Zaag and Van Loon, 1987) indicted that planting physiologically older seed tubers results in smaller plants with more stems and promotes earlier tuberization and senescence. Maximum growth vigor may be earlier, may last for a short period, and may decrease when the physiological aging process is high due to long storage durations. This may be due to the narrow range (2–7 months) of storage durations used to detect the effects of seed tuber age on plant height and to classify seed tubers as physiologically young or old.

Leaf area

The results showed significant ($p<.05$) variation with respect to total leaf area per plant between cultivars and among seed tuber storage durations tested (Table 3). Guassa produced more leaf areas (3,411.90 cm^2) per plant as compared to Zengena (2,058.80 cm^2) (Table 3). This high difference in leaf area between the two cultivars could be due to genotypic variation with respect to leaf morphology and number of main stems developed per seed tuber that affected total number of leaves per hill. The highest average leaf area per hill (3,393.60 cm^2) was recorded from 6-month-old seed tubers of both cultivars (Table 3). As compared to 6-month-old seed tubers, 7-month-old tubers have produced lower leaf area (2,921.2 cm^2). In accordance to this, growth characterization study of Mikitzel and Knowles (1990) showed that the production of more leaves in older seed tubers occurred at the expense of dry matter accumulation per leaf and resulted in greatly reduced leaf area per shoot and leaf.

Main stem per hill

Statistically significant ($p<.05$) differences were found between cultivars and among different seed tuber storage durations with respect to number of main stems per hill (Table 4). Guassa produced significantly higher number of stems per hill (3.17) than Zengena (1.99). Seed tubers stored for 6 months resulted in significantly higher number of main stems per hill (4.4), followed by 7-month-old tubers (3.5) (Table 4). Seed tubers stored for 2, 3, and 4 months gave the lowest and comparable number of stems per hill (Table 4). This may be associated with more number of sprouts with advanced seed tuber storage duration for both cultivars. In connection to this, Kawakami (1952) reported that the difference in the number of main stems of different cultivars is due to the basic correlation between the age of seed tubers and the number of tubers sprouted. Iritani (1968) and Struik and Wiersema (1999) reported that storing seed tubers at high temperatures may lead to increased physiological age of the tubers with a resultant increase in stem numbers. As reported by Wurr (1974), stem density is controlled by tuber spacing and the number of stems produced per tuber. As well, the number of stems per tuber is influenced by cultivar, seed tuber size, and seed tuber age. Struik and Wiersema (ibid.) stated that after the tuber has lost its apical dominance, physiologically young seed tubers exhibited strong apical dominance and at this stage only one or two main stems developed.

Biomass yield

A significant variation ($p<.05$) in aboveground and underground dry biomass was observed between cultivars and among seed tuber ages (Table 4). Guassa produced higher aboveground and underground dry biomass of 64.95 and 12.85 g, respectively, than Zengena, which produced 58.02 and 11.82 g aboveground and underground dry biomass yield, respectively (Table 4). This could be due to the production of more stems per tuber and expanded leaves resulting in vigorous canopy. Mikitzel and Knowles (1990) indicated that plants from old seed tubers displayed reduced shoot, root, and leaf dry weights and these effects reflect altered dry matter partitioning and contributed to an overall change in plant morphology with advanced tuber age.

Table 4: Stem number per hill, aboveground dry biomass, and underground dry biomass yield of potato as affected by cultivar and seed tuber storage duration

Main effect	**Stem no. per hill**	**Above ground dry biomass (g/hill)**	**Underground dry biomass (g/hill)**
Variety			
Guassa	3.17a	64.95a	12.85a
Zengena	1.99b	58.02b	11.82b
LSD (5%)	0.40	2.44	0.97
Storage Duration			
7 months old	3.50b	65.55b	11.47b
6 months old	4.40a	77.47a	16.64a
5 months old	2.27c	66.28b	12.06b
4 months old	1.95cd	56.90c	11.39b
3 months old	1.98cd	54.38c	11.21b
2 months old	1.40d	48.35d	11.23b
LSD (5%)	0.70	4.22	1.69
CV (%)	22.64	5.74	11.44

Means of the same main effect within a column followed by the same letter are not significantly different at .05 probability level.

Tubers per hill

Variety and seed tuber storage duration affected significantly ($p<.05$) seed tuber number per hill (Table 5). Guassa produced significantly higher number of tubers per hill (12.60) than Zengena (9.80) (Table 5). The number of tubers increased with the increase in seed tuber age and the highest mean tuber number was observed for 6-month-old seed tuber, whereas the lowest was from 2-month-old seed tuber (Table 5). Results of this study showed that storage duration of seed tubers had pronounced effect on tuber number per hill, which may be through its effect on main stems per seed tuber. This is also supported by the findings of Toosy (1963), who reported that seed tuber age affected number of tubers per hill through its influence on number of sprouts and main stems per hill. Asiedu et al. (2003) also reported that physiological age of seed tuber affects number of stems per plant, number of tubers per stem, tuber size distribution, and the final yield. Chase (1995) showed that aging seed tubers in storage can affect seed handling and tuber number per hill of the next crop.

Average tuber weight

Statistically significant ($p<.05$) differences were observed between the cultivars and among seed tuber storage durations with regard to average tuber weight (Table 5). The interaction effects of cultivar and seed tuber storage durations were found to be. Guassa produced heavier (83.84 g) tubers than Zengena (74.21 g) (Table 5). The production of heavier tubers by Guassa could be due to the production of higher leaf area that favored higher dry matter production and accumulation in the tuber. This is because of large leaf area for high assimilate production resulting in large tuber sizes under more stems and number of tubers per hill in seed tubers stored for 6 months.

Seed tubers of both cultivars stored for 6 months produced large tubers (92.38 g) as compared to those stored for 7 months (76.63 g) (Table 5). Studies by Knowels et al. (2003), Moris (1969), and Joseph et al. (1992) showed a shift in tuber size distribution in relation to stem number per plant as affected by seed tuber age in storage. This is perhaps because average tuber weight is a factor of dry matter partitioning of cultivars (Morena et al., 1994). However, non-significance of 2,3,4,5, and 7 months' storage duration in the present study may be due to narrow age differences to detect age effect or harvesting time (all are harvested 4 months after planting), and more stems per hill reduce tuber size for 7-month-old seed tubers as compared to the abovementioned storage durations.

Specific gravity of tuber and dry matter content

Tuber-specific gravity and dry matter content were not significantly (p<.05) influenced by cultivar and their interaction effect with seed tuber storage durations (Table 5). However, both parameters were significantly affected by seed tuber storage durations. Guassa and Zengena produced tubers with comparable specific gravity and dry matter content. Tuber with the highest specific gravity (1.100 g cm^{-3}) and dry matter content (23%) were obtained from six months old seed tubers. It was observed that there is an increase in tuber specific gravity and dry matter content as seed tuber age advanced to multiple sprout stage and reached the maximum at six month storage duration and then declined. This indicated that to produce tubers with high specific gravity and dry matter content that are suitable for processing industry, 6-month-old seed tubers are optimal for these cultivars at Adet.

Table 5: Effect of cultivar and seed tuber storage duration on tuber number hill-1, tuber weight, tuber specific gravity, and dry matter at Adet

Main Effect	**Tuber no. per hill**	**Average tuber wt. (g)**	**Specific gravity (gcm^{-3})**	**Dry matter (%)**
Variety				
Guassa	12.6a	83.84a	1.0850	19.54
Zengena	9.8b	74.21b	1.0867	19.94
LSD (5%)	1.47	9.07	ns	ns
Storage Duration				
7 months old	14.0a	76.63b	1.0867b	21.83b
6 months old	14.7a	92.38a	1.1000a	23.00a
5 months old	11.0b	77.05ab	1.0850b	19.33bc
4 months old	10.0bc	78.50ab	1.0850b	18.50c
3 months old	9.2bc	79.67ab	1.0817bc	17.83c
2 months old	7.7c	69.93b	1.0767c	17.67c
LSD (5%)	2.5	15.71	0.008	2.65
CV (%)	19.01	16.60	0.62	11.23

Means of the same main effect within a column followed by the same letter are not significantly different at 0.05 probability level.

Tuber yield

Variety and seed tuber storage duration affected significantly (p< .05) tuber yield per hill, marketable, and total tuber yield per hectare of potato (Table 6). However, unmarketable yield per hectare was not significantly affected by variety and seed tuber storage duration. Guassa consistently produced higher tuber yield (610 g/hill), marketable (24.66 t/ha), and total tuber yield (27.29 t/ha) than Zengena (Table 6). This could be due to the production of higher leaf area that encourages higher dry matter production and assimilation in the tuber.

In the present study, the maximum tuber yield (660 g/hill), marketable (27.01 t/ha), and total tuber yield (30.30 t/ha) were obtained from tubers stored for 6 months and that were physiologically young and at multiple sprout stage when compared with 7-month-old seed tubers. Meyling and Bodlaender (1981) also reported that inter-varietal differences in tuber yield of potato cultivars were largely due to differences in dry matter production.

Generally, the productivity of the varieties increased as seed tuber age advanced and peaked at 6-month storage and then declined. This indicated that seed tubers of the varieties can be stored for the maximum of 6 months under Adet conditions for higher productivity. Results of the present study were also supported by that of Kawakami (1963), who explained that yield reduction from planting seed tubers after passing the suitable age occur consistently, but the decrease in the yield of primes is of different degrees according to the cultivar in which some of the cultivars indicate almost no decrease and some nearly 30% decrease.

Table 6: Effect of cultivar and seed tuber storage duration on marketable, unmarketable tuber yield, and total tuber yield

Main effect	**Tuber yield(g/hill)**	**Marketable Yield (t/ha)**	**Unmarketable yield (t/ha)**	**Total yield (t/ha)**
Variety				
Guassa	610a	24.66a	2.63	27.29a
Zengena	460b	18.52b	2.03	20.55b
LSD (5 %)	66	2.7	ns	2.7
Storage Duration				
7 months old	480b	17.90b	2.76	20.66b
6 months old	660a	27.01a	3.29	30.30a
5 months old	540b	20.45b	2.63	23.08b
4 months old	510b	21.16b	1.85	23.01b
3 months old	530b	21.89b	1.85	23.75b
2 months old	500b	21.11b	1.61	22.72b
LSD (5%)	115	4.68	ns	4.64
CV (%)	18.05	18.11	35.07	16.20

Means of the same main effect within a column followed by the same letter are not significantly different at 0.05 probability level.

Conclusions

Results of the study showed that varieties responded differently to seed tuber storage durations for some of the parameters considered. Generally, cultivar Guassa performed well across most parameters, including tuber yield, and Zengena was found to be more affected as seed tuber stored beyond 6 months than

Guassa. It was observed that storage of seed tubers for 7 months significantly shortened days to emergence, flowering, and maturity as well as increased stem and tuber number as compared to other storage periods.

The maximum crop performances in terms of vegetative growth, yield, and quality parameters were from those plants coming from 6-month-old seed tubers of the two varieties. Irrespective of the cultivars, the highest tuber yield (30.3 t/ha) was harvested from these 6-month-old seed tubers, whereas lowest (20.66 t/ha) was from 7-month-old tubers. This was not statistically significant. The 7-month storage period resulted in 32% yield reduction. The highest specific gravity values (1.1000 gcm^{-3}) and tuber dry matter content (23.67%) was recorded from tubers stored for 6 months.

Overall, storing seed tubers of Guassa and Zengena for 6 months was found to be good for optimum potato production for Adet climatic conditions. Seed tuber age affects variety performance. Further study was recommended by considering additional storage durations, other storage methods, different locations, and seasons to have a fuller understanding.

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Participatory Potato Seed Production: Experiences from West and Southwest Shewa, and Gurage Zones

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Introduction

Potato is an important crop for smallholder farmers in Ethiopia, serving as both a cash and food security crop. It is one of the root crops widely grown in the country with the highest rate of growth because increasing demand and emerging markets are providing great opportunity for resource-poor farmers to generate additional income.

Although potato has a relatively short history of cultivation, today it is a widely grown crop in Ethiopia. It is planted in around 164,000 ha of land producing an estimated tuber yield of over 940,000 tons every year (CSA, 2002). This is mainly because of the favorable climatic and edaphic conditions in many parts of the country that favor potato production. In Ethiopia potato production can fill the gap in food supply during the “hungry months” of September–November just before harvesting of the grain crops. Potato is a known cheap source of energy and supplies good quality food within a relatively short period. In many regions of the country, it is possible to grow potato throughout the year, which offers a way to ensure a continuous supply of potato and become a reliable source of income to small-scale farmers.

Potato in Ethiopia was grown from a garden crop in few regions to a staple crop in many regions under different agro-ecological conditions for a century and a half. However, for nearly a century, the growth in potato production and productivity was gradual and low. The national average yield did not change for long—from about 8–10 t/ha (FAO, 2001), which is much lower than the world’s average yield of 15 t/ha. The cultivation of this crop was characterized by traditional production and management practices that have resulted in low productivity. The major problems include shortage of good quality seed tubers; lack of adaptable and disease-resistant varieties; inappropriate agronomic practices; poor storage, transport, and marketing conditions; declining soil fertility; and inadequate extension services (Gebremedhin et al., 2001). To alleviate some of these constraints, the National Potato Research Project and key stakeholders implement different projects.

The “Wealth Creation Potato Project” (WCPP), funded by the Common Fund for Commodities (CFC), launched its activity inSeptember2008 at Gurage, West Shewa, Southwest Shewa, and East Tigray zones. The project was implemented by the Ethiopian Institute of Agricultural Research in partnership with the International Potato Center (CIP) and Ministries of Agriculture (MOA). The main objective of the project was wealth creation through integrated development of potato production and marketing. Its main purpose was to improve the livelihoods of smallholder potato producers in the four zones of six woredas through integrated development of the seed and ware potato production and marketing chains. This was achieved through four specific objectives

- increasing the availability of high-quality seed at an affordable price;
- increasing smallholder potato farmers’ income by boosting potato yields through improved seed potato quality management and crop husbandry;
- improving market linkages and communication between potato value chain stakeholders; and
- translating project results into national potato sector development plans and sharing project lessons with international partners.

Quality seed of an improved potato variety is a key to increase the productivity of a potato crop. The genetic potential and other traits of a potato variety are determined or manifested by the use of healthy seed (Endale et al., 2008). Unavailability of healthy seed tubers in the required quantity and quality is probably the most important in contributing to the low yield in Ethiopia (Berga and Gebremedhin, 1994a). The major focus of this activity was to increase seed and ware potato production and marketing to improve the livelihood of smallholder potato farmers who are mostly short of cash. A modest increase in cash income through improved potato farming can have a major impact on the quality of life of the whole household and the entire community in relation to health care, nutrition, and education. As potatoes are a highly commercial smallholder crop, in the highlands through which this project has benefited a large number of farmers as shown in the project achievements. Construction of DLS for the seed growers in the project woredas was also considered an important component of the seed production. The use of DLS has resulted in cooperatives having sprouted seed tubers during planting and has helped other ware producers to buy with such seeds that contribute to the increase of the potato yield.

The first beneficiaries from the project are seed growers. Through the WCPP, they develop new opportunities for their potato production enterprise and increase their profits from farming. This was realized through successive trainings on advantages of using healthy seed, appropriate seed agronomy, and appropriate use of postharvest technologies (including construction of DLS), and have also acquired knowledge of business skills management.

Ware potato growers were also the main focus group in the WCPP, which has improved their potato farming through greater productivity. It was achieved by adopting both improved seed and management through exercising positive selection or “Select the Best.” Moreover, several ware growers were invited to attend field days to boost their knowledge on the use of healthy seed tubers by observing management practices of the seed growers. A number of farmers also benefited from the project interventions through indirect contact—for example, out-of-project contact with extension workers or with fellow farmers. The project has also anticipated that the consumers will benefit from reasonably cheaper prices and sustainable market availability due to improved production and productivity of potatoes.

The project also focused on the capacity building of seed grower, ware potato growers, researchers, and extension staff of the MOA. The capacity building was implemented through conducting training of trainers, on-farm trainings, field visits, and field days. More focus was also given to strengthen the seed production capacity of the Holetta Agricultural Research Center (HARC) of the Ethiopian Institute of Agricultural Research, through rehabilitating the existing tissue culture, screen houses, and construction of aeroponic units. Two aeroponics units are constructed through projects funded by the CFC and the US Agency for International Development. With such interventions, the capacity of potato seed production of the HARC has increased to more than triple, which may boost the potato seed production in the country. The project has also focused on the linkage between commercial seed growers such as Solagrow PLC and smallholder seed growers to ware producers. The linkage between the seed cooperatives and the commercial seed growers were implemented by contract farming.

During the initial project planning phase, emphasis was given to ensuring equal opportunities for all actors in the potato value chain. The project set in each activity a benchmark for the minimum number of women and youth to be amongst the project beneficiaries, in which a 50–50% balance between men and women and a minimum of 25% youth were also set as a guideline. However, owing to several reasons (e.g., the culture and belief of the different communities in the project areas), it was not possible to balance the set targets between male and female farmers. Only 20.7% of the beneficiaries were women farmers.

Organizing farmers' groups and cooperatives

Based on results of the diagnostic survey and description of the farming systems done in the previous season, the research area was defined and farmers were selected. This was done after discussions with groups of farmers by considering the priority of community problems and objectives of the project by assessing the level commitment of the farmer to implement the proposed plan of action. Thus, only farmers who were willing to be involved in the Farmers' Research Group (FRG) were selected. Farmers were encouraged to allocate the plots necessary for the FRG trial and conduct seed production. Member farmers fully participated in the management of the trials: planting, fertilization, weeding, and cultivation, which were done according to research recommendations. Both farmers and researchers followed up the trials and researchers made periodic observations. In general, selection was made using the earlier set criteria, including willingness of the farmer to be a potato seed grower, willingness to work in a group, and capacity to build DLS. Based on these criteria, 20–25 farmers were selected per site in the first season (2008). Selection and organization of FRG continued in the following seasons using the same procedure, but more than one group of FRG per site. Many farmers were willing to participate in the project after observing the varieties and the benefits of participant farmers. A total of 139 FRGs with 3,390 members were organized: 65in Guragie zone, 53 in West Shewa zone, 20 in Southwest Shewa zone, and 1 in East Tigray zone. These FRGs were organized and facilitated by those interested members and are relatively of better caliber. In general, organized farmers got additional training on potato late blight (LB) management, seed and ware potato production, and storage technologies in workshops and discussions. These groups were getting strong technical backup of researchers and extension agents of Bureau of Agriculture at local level throughout the project period.

More quality seed made available to farmers

The most feasible way in which the growing demand for potato can be satisfied is through increased production and productivity (Gildermacher et al., 2009). There are known agronomic technologies that can improve potato productivity, among them quality seed is one of the most critical components (Endale et al., 2008, Gildemacher op. cit.). However, this basic component in modern potato production is in short supply (Wagoire et al., 2005; Endale op. cit.) and expensive, accounting for 40–50% of potato production costs (Wagoire op. cit.). Quality seed potato is the single most important component in improving potato productivity, considering that much of the current growth in potato production in East Africa is attributed to area expansion than productivity per unit area (Gebremedhin et al., 2008, Gildemacher op. cit.). In most areas of Ethiopia, it is a common practice among local farmers to save the smaller and inferior tubers for seed. These tubers cannot be normally sold for consumption; and when used as a seed are with inherent degenerative status due to seed-borne diseases such as viruses and bacteria wilt (BW). It is believed that this practice has contributed to the buildup of high level of virus diseases in the locally grown potato cultivars in Ethiopia. Informal seed production in the farmers' fields may contribute in producing healthy and sufficient seed tuber if proper inspection and cleaning are done with research support. Thus, in addition to seed tuber production conducted by research centers, informal seed production in the farmers' fields now become a major practice which has helped farmers get relatively clean and sufficient potato seed.

The system enables farmers to get improved varieties, relatively healthier and sound seed potatoes than the local varieties, and seed at an appropriate physiological age for planting. Trainings were also given to farmers at each location on selection techniques at field level for disease-free seed, optimum tuber size, and construction and use of DLS to ensure quality seed tuber production at farmers' level.

Stringent measures were taken to ensure production of disease-free seed at the main research centers such as the HARC. Field inspection and indexing of seed against BW and viruses were conducted. A total of 93.3 tons of healthy seed was provided to the trained seed farmers from the project sites and more than 49 tons of seed were used as revolving seed (RS)—that is, seed given to seed growers in the previous year is collected and given to other and new farmers in the next season. The total amount of seed produced from the project sites was more than 3,062 tons. The average seed yield obtained was 32.12 t/ha, which is more than fourfold the national average yield of 8 t/ha.

The demand for basic seed-by-seed multipliers and quality seed by ware potato farmers increased exponentially due to successive training and awareness creation made by the research and extension. RS technique is used in the project to increase the quantity of seed supplied to farmers. The only concern in using this method would be the quality of seed produced under farmers' conditions. However, the HARC and the extension department of the respective woredas have been following and conducting supervision to ensure the quality of seed tubers circulated by farmers. The project has also adopted a method of training seed producers in groups. This has been able to increase the flow of information among farmers in relatively shorter period. These, together with demonstrations that were covered with the local media, have enhanced transfer of knowledge and information on potato.

Production of pre-basic and basic seed

In Ethiopia, no formal seed system exists to produce prebasic and basic seed under certification scheme. Research institutes produce similar quality materials to fill the gaps in seed demand, and produce and distribute basic seed of potato. Informally, the basic seed is distributed through the farmer-based seed system where the recipient farmers multiply it at least once before it is distributed to ware potato growers. According to Berga et al. (2009), the system has many different advantages

- it increases the quality of seed that is available to ware potato farmers with little waste of high-quality basic seed;
- it brings other players into the seed potato production process and reduces public monopoly;
- it eases the burden on public institutes in seed potato production and distribution;
- it is a precursor to the private sector-led seed potato production scheme;
- it encourages public private partnerships in seed production; and
- it creates new enterprises among farmers who adopt and invest in seed potato production.

The informal seed system is the major option to the formal seed systems in Ethiopia. The system largely involves on-farm seed selection and multiplication by the farmer himself and seed exchanges among farmers. In addition, the use of planting material as seed saved from previous harvests is not regulated and controlled. In Ethiopia, farmer-based seed production (FBSP) has been practiced for potato seed. In this approach, farmers are provided with relatively clean starter planting material of the improved varieties to multiply and sell at an affordable price (Table 1). The farmers are also trained by research institutes to help them build skills on basic potato seed production, including negative selection (rouging out infected plants) and positive selection (marking clean plants with a stake). In the central highlands, farmers organized in FBSP serve as sources of potato seed tuber for most of the potato growing areas in the country. According to Berga et al.(op. cit.), seed potato production by FBSP has been growing since 2004 and peaked in 2008.

Since the start of the project in 2008 and up to 2012, a total of 93.3 tons of clean seed were distributed from HARC to the seed-producing groups established in six woredas of project implementation. In addition, 49.8 tons of seed were used as RS collected from the farmers to be used to scale up technology for newly formed farmer groups (FGs) within the woreda. From these starter seeds, 2,313 tons of relatively healthy seed—mainly from the varieties Gudene and Jalene—were produced to be used as seed for the producing farmers themselves (Table 2). The seed was distributed for sale in different parts of the country for ware potato production and allows farmers to get a good amount of income to improve their livelihoods while contributing to the availability good quality seed. Consequently, the project has contributed to solving the problem of seed in the country in general and in project areas in particular.

Table 1: Different varieties and seed supplied to the project woreda from 2008 to 2012 in (tons)

Woreda	Variety	2008	2009		2010		2011		2012		Total Seed	
		HARC	HARC	Revolving	HARC	Revolving	HARC	Revolving	HARC	Revolving	HARC	Revolving
Cheliyia	Jalene	2	1	1.6	0.75	1.49	2	-	0.4	0.6	6.145	3.69
	Gudene	2	-	1	1.85	-	4	2	2	6.5	9.854	9.5
	Guassa	3	1	1	-	0.58	2	1	-	0.87	6	3.446
T/inchini	Jalene	2.6	-	2	-	-	-	-	-	0	2.6	2
	Gudene	1	-	1	-	-	8	-	4	5	13	6
	Guassa	1.6	0.5	1	-	-	-	-	-	-	2.1	1
Wonci	Jalene	3	1	2	-	-	2	-	1	-	7	2
	Gudene	3	1	2	-	-	6	-	1	1.56	11	3.56
Gumer	Jalene	0.5	1	0.5	2.5	1	2	2	-	-	6	3.5
	Gudene	0.5	1	-	5	1	6	4.5	2	-	14.5	5.5
Geta	Jalene	-	0.6	-	2	0.6	2	2	1	1.91	5.6	4.51
	Gudene	-	-	-	2	-	6	2	1	2.29	9	4.29
	Guassa	0.5	-	0.4	-	0.4	-	-	-	-	0.5	0.8
Total		**19.7**	**7.1**	**12.5**	**14.1**	**5.07**	**40**	**13.5**	**12.4**	**18.73**	**93.3**	**49.796**

Table 2: Area planted and seed yield produced at by seed farmers, 2008–2012

Woreda	Variety	2008		2009		2010		2011		2012		Total	
		Area (ha)	Yield (ton)	Area (ha)	Yield (ton)	Area (ha)	Yield (ton)	Area (ha)	Yield (ton)	Area (ha)	Yield (ton)	Area (ha)	Yield (ton)
Cheliyia	Jalene	1	28.61	2.15	40.88	0.75	12.8	1	35.52	0.5	20.2	5.4	138.01
	Gudene	1	42	1	44.17	0.93	26.9	3	152.17	4.25	189.5	10.18	454.69
	Guassa	1.5	63.75	0.9	13.09	0.29	5.5	1.5	42.19	0.43	11.87	4.62	136.4
T/inchini	Jalene	1.3	18.01	1.25	10.58	-	-	-	-	-	-	2.55	28.59
	Gudene	0.5	12.55	0.75	14.31	-	-	4	168.74	4.5	136.9	9.75	332.51
	Guassa	0.8	9.51	0.75	11.92	-	-	-	-	-	-	1.55	21.43
Wonci	Jalene	1.5	44.81	-	-	-	-	1	41.31	0.5	17.04	3	103.16
	Gudene	4	137.3	-	-	-	-	3	153.65	1.28	33.54	8.28	324.47
Gumer	Jalene	0.25	12.02	1.16	52.42	0.25	11.2	2	35.86	-	-	3.66	111.5
	Gudene	0.25	13.86	1	39.57	3	114.4	5.25	126.13	1	10.21	10.5	304.17
Geta	Jalene	-	-	0.3	12.73	1.75	65.35	2	37.88	1.46	45.93	5.51	161.88
	Gudene	-	-	-	-	0.8	26.6	4	82.9	1.65	59.86	6.45	169.37
	Guassa	0.25	8.5	0.21	8.88	0.25	9.6	-	-	-	-	0.71	26.98
Total		**12.4**	**390.9**	**9.47**	**248.55**	**8.01**	**272.35**	**26.8**	**876.35**	**15.6**	**525**	**72.15**	**2313.15**

The five-year average seed tuber yields in the six project locations was 27.17 and 35.53 t/ha of Jalene and Gudene varieties, respectively (Fig. 1). Whereas the national average yield of potato is 8 t/ha. Overall mean of the two varieties was also 36.66, 35.12, 30.0, 29.72, 27.82, and 22.66 t/ha in Wonchi, Cheliya, Atsibi, Gumer, Geta, and T/Inchini woredas, respectively. Gudene variety gave high mean seed tubers in Cheliya, Wonchi, and T/ Inchini (Fig. 1).

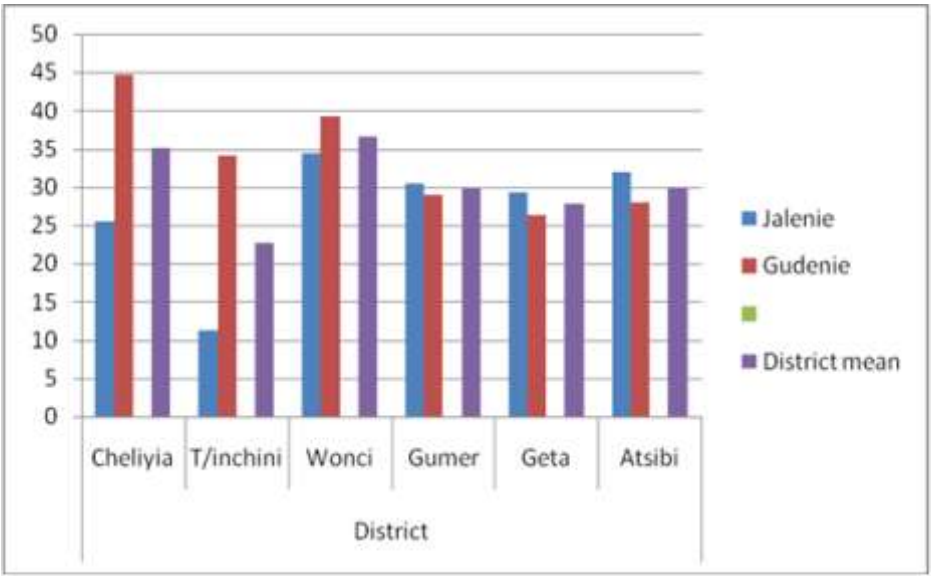

Figure 1: Mean tuber yield in t/ha of the varieties included in the seed production across different woredas, 2008–2012

Diffused light store for seed quality enhancement

Potato is a source for higher income and a better diet for small-scale rural farmers. Increasing consumption of potato demonstrates its importance for food security; however, seed storage is not easy, especially because temperature fluctuations and excessive light exposure cause its deterioration, jeopardizing availability of quality seed materials. It is crucial to guarantee a good seed storage method for communities that depend heavily on potato production. An efficient practice to overcome the storage problems of potato seed material is the use of DLS, which can be adapted to any existing on-farm storage. If a farmer is able to store his own seed potatoes in good condition, it enhances the probabilities of a good harvest the following season. DLS uses indirect natural light and good ventilation or airflow instead of low temperature to control excessive sprout growth and associated storage loss of seed potatoes. DLS is a low-cost method of storing seed potatoes and has been found to extend their storage life and improve their productivity.

The principle that light reduces potato sprout growth has been long established in scientific literature, and CIP has adapted the technology for use by potato farmers in developing countries.

EIAR tested demonstration models of DLS structures in the community of Wolmera, Jeldu, and Degem woredas in the highlands of Ethiopia. Since its introduction in 1988, DLS has been rapidly adopted, as it is very useful and simple to construct with locally available materials.

Since the start of the WCPP, 110 DLS were constructed in West Shewa, Southwest Shewa, East Tigray, and Guragie zones by seed multipliers with technical support from MOA and EIAR(Table3). Before construction of DLS, a one- to two-day training session was given to the farmers and development agents regarding the use, construction, and maintenance of the store.

Table 3: Number of DLS constructed by seed potato growers in woredas of the project sites during 2008–2012

Woreda	**Number of DLS Constructed**					
	2008	**2009**	**2010**	**2011**	**2012**	**Total**
Cheliya	3	5	2	9	8	27
T/inchini	2	3	0	7	5	17
Wonchi	1	4	0	1	1	7
Gumer	1	2	6	4	1	14
Geta	1	2	2	3	2	10
Atsbi		33		1	1	35
Total	**8**	**49**	**10**	**25**	**18**	**110**

Six large DLS with a capacity of 25–30 tons (one in each project implementation woreda) were constructed for communal use with the help of project funding (Fig. 2). During the construction, the project provided the corrugated iron sheets for roofing and the nails, EIAR allocated skilled personnel for construction, and the farmers provided the timber and labor so that they might feel it is their own property to use and maintain for a longer period.

Farmers found DLS to be a low-cost method of storing seed potatoes, extend potato storage life, improve farmers' productivity, and provide a new opportunity for poor farmers to conserve quality seeds. Farmers who get the improved potato variety and healthy seed from the seed growers tended to construct their own DLS.

The quality and shelf life of seed tubers have been improved, which then increased the yield of ware potatoes. Ware growers, when buying sprouted seed tubers, ask seed growers to sell based on weight—practices that seed producers are not willing to do. The argument is that, when the seed is kept for long periods under the DLS, weight will be lost due to respiration. This has created a problem for the amicable interaction between seed producers and ware growers, and needs research to solve the problem.

a b

Figure 2: DLS constructed at Wonchi (a) and Gumer (b) with CFC-provided construction materials and EIAR technical support.

Seed quality assurance

Good quality planting material is one of the foremost prerequisites of healthy and successful crop production. Planting materials are an important vehicle for innovative technologies and may eventually disseminate serious pests, including disease-causing pathogens. There are many seed-borne diseases of potato recorded in Ethiopia, of which the most important are viruses, BW, and LB. For instance, BW has spread to many new woredas of the Amhara and Tigray regions in just a few years through infected seed tubers from Shashemene, a known hotspot area for BW (Dereje and Gebremedhin, 2012). This kind of disease dissemination can occur for many important and serious seed-borne diseases and pests if phytosanitary measures are not incorporated into the seed production and distribution system. A known solution for this kind of problem is the production and distribution of high-quality, disease-free planting materials. Thus, production and distribution of quality seed need serious attention and a well-designed system that ensures a separate value chain separate from ware potato production. As a result, production of good quality planting materials should be properly designed to suit the circumstances of potato producers that exist in the country (Adane et al., 2010).One of the methods we should follow to alleviate the problem of disseminating seed-borne potato disease is the use of seed inspection and indexing.

Partnership and its significance to quality seed potato production

The WCPP has been working in close collaboration with other potato projects that are being implemented in similar project intervention areas. The CFC project works closely with a USAID-funded project in Ethiopia. Among the inter-project partnerships, the WCPP has made various contributions to the sister project and in return, has received various in-kind support, including in the area of DLS, minitubers, logistics during planting and harvesting, and training. The two sister projects constructed one aeroponics unit each at HARC. They share costs of common equipment such as generator for backup power, pumps and containers for spaying nutrient solutions, and training. The USAID-funded Ethiopia project has been a market for the WCPP seed producers. Such partnership helped the improvement and availability of healthy seed tubers at research and on-farmers level in the country. The other partners in the project were all government institutions, including the woreda administration of the MOA, women and youth affairs, information affairs, and private seed grower Solagrow PLC. All these institutions supported the production of healthy potato seed at their respective woredas.

Disseminating technologies for increased productivity

Seed potato dissemination and promotion approaches in this project include field days, open days, trade fairs, and demonstrations. Since the start of the project, 17field days were held in project intervention areas to develop linkages between seed producers and ware potato growers. The field days were organized by the farmers themselves in West Shewa, (Cheleya, Tikur-inchini), Guragie Zones (Gumer and Geta), Southwest Shewa (Wonchi), and East Tigray (Atsbi) woredas. The field days were done during the vegetative growth and at harvesting stage of the crop to create awareness of the different stages, including LB tolerance of the released varieties and potential to yield using the improved agronomic packages. Different stakeholders, including the politicians, MOA staff, researchers, woreda administrative staff, and neighboring farmers, participated. In addition, the project facilitated the exchange visit involving representatives of FGs and extension staffs from the different project woredas. The field days organized by EIAR attracted over 2,000 people and were publicized through the national TV and radio programs using different local languages. More than 90 farmers attended the Solagrow PLC's field days.

To facilitate the promotion of quality seed potato, the project supplied seed potato tubers and provided training for FGs. Some farmers were able to compare demonstration plots with seed from positive selection and farmer selection, which helped the extension experts and the project convince and demonstrate the advantage of healthy seed over degenerated seed. The project has also facilitated the attendance of more than eight trained extension experts of the ministry in field/open days. Representatives of trained seed potato multipliers were able to attend field days out of their woredas to share experiences.

Linking seed producers to ware potato producers

A public trade and demonstration fair was held at Hawassa, and some seed farmers from Gumer and Geta exhibited their produce. More than 20,000 individuals, including higher government officials, attended the fair at Hawassa. In all the trade and demonstration fairs, the CFC participant displayed seed tubers of the varieties Jalene and Gudene. Many were attracted to the WCPP stand by the high-quality potato tubers and products that were displayed. Moreover, the fairs were broadcast on national and regional TV and radio programs, which helped the products of the farmers—including seed potatoes of different varieties, other crop varieties, and dairy products—to be known by more people as the media reaches almost the entire country. In Ethiopia, field days in most cases are organized by government organizations or nongovernmental organizations to demonstrate the technology adopted by farmers. However, the farmers organized most of the field days on potato technologies in the project areas, and the groups covered most of the costs. This is unusual and may well indicate that FGs organized to produce seed potatoes are well informed and benefit from it.

Improved communication between potato value chain stakeholders

To improve the market linkage and value chain interaction and communication, the WCPP designed the use of local stakeholders' forums. Four forums were established—one each in Gumer, Geta, Tikur Inchini, and Chelea woredas. The local stakeholders include the following:

- MOA head and (agricultural expert assigned as CFC project focal person, agricultural extension, extension communication, input demand supply);
- Woreda administrator;
- Women and children affairs head of the woreda;
- Health affairs head of the woreda;
- Youth and sport affairs;
- Government communication affairs;
- Cooperatives;
- EIAR staff; and
- WCPP coordinator.

The responsibilities of the stakeholders are shown in Table 4. The forum meets regularly every six months in the MOA office of the respective woredas. In most cases, the meetings are conducted at the same time as farmers' training to save time and minimize cost. The MOA served as chairperson; CFC/EIAR served as the secretary. Through local stakeholders, smooth communication was created among value chain actors for potato crop in each woreda and beyond.

Table4: Activities and responsibilities shared by stakeholder forum members, Ethiopia

Institution	Activities and Responsibilities
Woreda administration	Participate in the stake holder forum meetings Facilitate all the project activities in the woreda (legal and security support during meetings, trainings and workshops) Take a lead in awareness creation to the project beneficiaries and to the community as a whole
Government communication affairs	Documentation and publicizing of the project activities and achievements using video Preparing flyers on the best experiences for further scaling out Broadcasting the project activities and achievements on local FM radio Creating awareness using mini-media in school, market days, court, etc.
Women and Children affairs	Encourage women farmers to participate in the project activities Arrange training on the recipes preparation from potato for rural and urban women Awareness creation on the nutritive value of potato with emphasis on children Facilitate market linkage to participant seed multipliers women farmers
Health Office	Awareness creation or encourage farmers to participate to use potato products during their planned activities eg. Model household trainings, community discussion and house to house visits Support during the trainings on the utilization of potato
EIAR and BoA	Play the roles as specified in the project document The BoA heads chair the respective woreda forums and EIAR will act as a secretary

Capacity building: a tool for sustainable quality seed and ware potato production

Several methods were used to upgrade the capacity of seed and ware potato farmers, extension agents of the MOA, and technicians from the research institutes. These methods include training of trainers (ToT), workshops for development agents, on-the-job trainings for researchers, demonstrations, and on-site training for participant farmers and organizing field days (Tables 5 and 6).

Table 5: Number of farmers trained on seed production, 2008–2012

Woreda	2008	2009		2010		2011			2012		Total	
	M	F	M	F	M	F	M	F	M	F	M	F
Gumer	25	-	129	15	79	66	316	69	31	20	580	170
Geta	15	5	82	7	67	11	138	41	175	44	477	108
Chelyia	41	7	188	39	50	3	151	66	180	93	610	208
T/Inchii	56	7	105	5	-	-	128	31	65	21	354	64
Wonchi	107	6	338	50	-	-	148	55	43	38	636	149
Atsibi					31	3					31	3
Total	244	25	842	116	227	83	881	262	494	216	2,688	702
Grand Total											**3,390**	

Table 6: Number of experts who received ToT in a follow-up workshop and refresher course,2008–2012

Woreda	ToT in		Follow-up training in				ToT		Refresh course		Total	
	2008		2009		2010		2011		2012			
	M	F	M	F	M	F	M	F	M	F	M	F
Cheliyia	10	1	18	2	7	-	7	1	9	3	51	7
T/inchini	10	1	17	1	-	-	6	2	15	1	48	5
Wonchi	3	1	-	-	-	-	7	-	7	-	17	1
Gumer	2	1	13	1	13	4	8	2	11	2	47	10
Geta	1	1	12	1	14	1	5	3	12	3	44	9
Azia/	-	-	-	-	-	-	2	1	-	-	2	1
Cheha	-	-	-	-	-				5	-	5	-
MuhirnaAklil	1	1	-	-	-	-	3	-	-	-	4	1
Weliso	-	-	-	-	-	-	3	3	-	-	3	3
Kokir	1	1	-	-	-	-	-	-	-	-	1	1
Degem	4	-	-	-	-	-	1	1	1	2	6	3
Holetta City	-	-	-	-	-	-	1	1	3	-	4	1
Adeaberga	-	-	-	-	-	-	-	-	3	1	3	1
HARCStaff	-	-	-	-	-	-	6	4	4	4	10	8
Total	**32**	**7**	**60**	**5**	**34**	**5**	**49**	**18**	**70**	**16**	**245**	**51**

Capacity building for seed potato producers

A ToT workshop was held for extension officers, from West Shewa and Guragie zones. Seed farmers were trained in seed potato production, including postharvest handling and grading. A total of 3,390 farmers were trained on the improved potato seed production technologies, for example, seed agronomy, integrated pest management, and postharvest.

Manuals on how to conduct training for FGs on positive selection in Amharic were published and distributed for both trainers and farmers. Moreover, a potato production manual on principles and best practices for seed production was published and hundreds of copies distributed, mainly to potential potato farmers and development agents of the MOA. Farmers in the project location who were trained are now able to grow healthy potato seeds. The six large DLS constructed by seed growers with the help of the WCPP have encouraged farmers to save their seed for more than eight months. The seed kept in the DLS is for their own use and for sale. Seed kept in the store are with good sprouts and contribute to the high yield of potatoes. In addition, the price of the seeds kept in DLS is higher than the seed kept by traditional methods.

Business management skill

A one-day training course on business management skills was conducted in Holetta, Wolkite, Hawassa, and Wukro. Attendees included individual seed potato producers, members of seed cooperatives and seed groups, and MOA staff from the respective woreda (Table 7). The general objective of the training was to improve income and food security status of potato seed producers in the targeted areas by enhancing their awareness of group and business management skills. Specific objectives were to:

- Introduce participants to the benefits of collective action and group formation;
- Introduce participants to the most commonly used techniques in potato seed grading for seed and ware and labeling of bags;
- Empower participants on group management and business creation skills;
- Create awareness for business skill development among participants;
- Introduce participants to sustainable group business management, specifically with quality potato seed production and selling; and
- Identify appropriate business skills training needs of FGs to address priority needs of the potato seed producer communities of the targeted areas.

The primary targets for the workshop are seed producer farmers organized in groups/cooperatives and sector representatives. Given the roles they will have in the future, it was particularly important to involve in the training the agriculture office, cooperatives office, and research institutes. There were also a few private potato producers in some of the centers. The composition made is recognized as very important as the technical supports are expected from the sector organizations for the sustainable operations of the groups/cooperatives. In fact, the discussion was nearly full among the FGs. Participation of the sector representatives was limited to mainly explaining legal and policy aspects, where necessary.

Table 7: Number of farmers and MOA staff trained in business management skills

Training Center	Participants
Holetta	34
Welkite	31
Hawassa	22
Wukro	25
Total	112

Output and impacts

Capacity

Trainings, field days/open days, and exhibitions have increased the knowledge of the seed and ware growers. The project has managed to organize more than 140 FRGs and cooperatives with more than 3,390 farmers trained on seed production, becoming sources of seed of the improved varieties. The project has also produced more than 3,072 tons of healthy seed, mainly from the varieties Gudene and Jalene. More than 15,000 ware potato growers have learned about the advantage of using healthy seed, and grow Jalene and Gudene in 2012 cropping season in the rainy season. The project has contributed its share in solving the problem of seed potato in the country in general and in project areas in particular. Another success of the WCPP is in all the woredas the cooperatives have been organizing field days on their own initiatives and cost. This has helped farmers link to markets as the field days/open days are visited by several farmers' representatives of governmental and nongovernmental organizations. The regional and national media in different local languages also broadcast the field days, which helps to reach a larger audience.

Food security

Thousands of farmers are growing potatoes during the main season in the highlands in the project woredas. This was not the case before the intervention of the WCPP due to LB. During September–October, farmers face food shortage and travel to far areas to work as day laborers. But the project introduced LB-resistant varieties and farmers can now produce food during the hunger period, thus making them food-secured during the period. Farmers witnessed this by saying that, "We have been able to increase our food stock in the month of October because of potato. "In the 2012 crop season in Wonchi woreda alone, more than 4,249 farmers have plated the improved varieties on more than 442 ha of land for seed purpose in six villages where the project has been giving trainings. The woreda MOA has also reported that 3,362 ha are covered with improved varieties for ware—mainly with Gudene and Jalene, which the project introduced. In all the 18 villages in the Gumer woreda, more than 3,961 households grew potato on more than 807.5 ha for ware purpose of the improved varieties in the 2011 crop season. In 2012 the woreda MOA reported that more than 40% of the households grew improved potato and reported as being food secure. The average yield of the varieties across all woredas and villages of the project was found to be more than 32 t/ha, which is fourfold of the national average yield of 8 t/ha.

Increase of household incomes

In addition to food security, several farmers have increased income from the sale of potato seed and ware potato, which has helped to improve their living standard in all the project woredas. Farmers at Wonchi earned more than 26,489,200 Birr in 2011 and expected more than 42,074,000 Birr in 2012. As the income of the farmers increase, most of them have saving accounts at different banks. The project, in collaboration with the USAID project, has provided trainings on business skill management at different woredas of the project area to help farmers in financial management. Household case studies conducted with individual members of the cooperative in the different project locations indicated that potato production has improved household food security, nutrition quality, income diversification, and overall quality of living of the farmers who participated directly and indirectly through different communication. In general it was learned that

- With proper technical advice and backstopping, farmers are able to produce high-quality seed through their own management;
- Farmers can handle Generation 1 minitubers, which were produced under aeroponics;
- Farmers are willing to invest in clean/seed, as exhibited by the high number of trained seed multipliers who are currently producing seed commercially;
- Use of quality seed leads to increased tuber yields at farm level (average of 32.12 t/ha);
- Farmers are willing to invest in the DLS as indicated by the number of DLS constructed without support;
- Use of different media helps to create awareness on use of improved varieties and healthy seed (as seen from the number of farmers demanding the technologies);

- Working in partnership is important for technology dissemination;
- Farmers are keen on improved technologies (other agricultural technologies);
- Farmers are not interested in "Select the Best," which takes more time, and prefer improved seed; and
- Organizing farmers into FRGs or cooperatives helps to reach more farmers in technology dissemination.

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Experiences, Challenges, and Opportunities in Participatory Quality Potato Seed Production: the Case of Western Amhara Region

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Introduction

Because of absence of a formal seed multiplying and disseminating body limited the area planted by improved potato seed to only 329 ha of the total figure indicated above (CACC, op. cit.). Almost all area is planted with late blight (LB)-susceptible, low-yielding, and poor quality (degenerated) seed tubers of unknown origin that eventually restricted the adoption and diffusion of improved varieties and associated technologies to end-users. Consequently, potato growers have not benefited from the massive public investments made to develop these technologies. However, there is many opportunities for seed producers considering the high seed rate requirement of potato per hectare. In Amhara Region alone, over 140,000 tons of seed tuber is needed at least every three to four years.

To ease this demand, an informal seed multiplication and dissemination was launched by agricultural research centers (ARCs), nongovernmental organizations (NGOs) and the Bureau of Agriculture (BoA) working in the region. The same system has proved to meet over 90% of the smallholder farmers' seed demand in Southern African countries (Monyo et. al., 2004). Such decentralized seed production system is very effective for crops like potato, which has high seeding rates and transport cost for remote areas. Impressive success stories were also registered by ARCs within Ethiopia—notably the Holetta Agricultural Research Center's (HARC) efforts in central Showa on potato, Melkasa ARC on onion, and DebreZeit ARC on lentil. Scaling-up of such experiences is crucial to meaningfully address the problems of improved varieties seed in the country. In doing so, efforts of all stakeholders involved in technology generation and dissemination need to be coordinated in an interdisciplinary and inter-institutional approach to effectively utilize the scarce resource and guarantee sustainability of the scheme.

The project discussed below was initiated to meet the understated general objective of targeting to alleviate food security problems and contribute to the attainment of the five-year strategic goal of the Amhara National Regional Government. Specific objectives include

- To systematically organize the existing farmer-to-farmer seed exchange scheme and ensure accesses to seed of improved varieties at community level;
- To enhance the diffusion and adoption rate of improved potato varieties and their associated technologies; and
- To create access of improved potato varieties seeds that have table and processing quality for potato growers.

Methodology

The process has passed two stages of varying levels of intervention: pilot-level informal seed multiplication and then scaling-up. Hence, the following steps were included. A pilot level of informal seed multiplication activity is carried out on relatively small plot in three woredas of organized Farmer-Research-Extension Group (FREG) farmland. At this level, discussion is made on the plan with the FREG members, and then training is given to all. Finally, members selected progressive host farmers to start with. Subsequent activities include the following

- Suitable varieties of different purposes, table and processing types—Gera and Jalene for table and Zengena, Guassa and, and Wochecha for processing—were selected;
- Initial/starter seed tuber was provided to organized farmers, individual farmers, or investors on a repayment loan basis at least to return in-kind in order to guarantee the second phase redistribution to other new participating groups;
- This initial seed tuber is agreed to pass at least two to three cycles of multiplication before it can be used. This will help increase the amount of seed tubers available to small-scale farmers for further seed or ware potato production;
- Finally, following the consecutive field days, the number of farmers requesting these varieties was increased. To meet this demand, the second step (i.e., scaling-up of these pilot level experiences to wider area and woredas) was implemented;
- Accordingly, a regional workshop with stakeholders is carried to exchange ideas and experiences, build consensus on plan, and share responsibilities. Similarly, a woredas-level workshop was carried out for the same purposes with administrators and steering and technical committees;

- Training was given on seed production techniques, disease identification and management options, and postharvest handling to improve the knowledge and skill of participants;
- Diffused light stores (DLS) were constructed by cooperatives or private seed multipliers; and
- Finally, to guarantee the sustainability of the system and create market for the produce, field days were arranged and attended by pertinent stakeholders, including zone and woreda administrators, heads of (BoAs), seed enterprises, cooperative promotion agencies, investment promotion agencies, NGOs, and farmers.

To this effect, best practices in potato seed tuber multiplication and management were followed as the guiding principles to the scaling-up of technology multiplication and dissemination.

Results of the activity

Following this scheme, very promising results that proved the validity of such community involvement was observed. Among those worth mentioning are

Before the implementation of this project, seed growers of improved potato varieties was absent in the area. But currently the number of both individual and grouped farmers as well as professional seed growers is; and

Some of the professional growers are scaling up their activity every year. This is one of the successes of the project whereby the group became seed multipliers and suppliers to meet requests from in the country. Hence, in a region where very small amount of seed is multiplied every year in the past by research centers and few others, it is now a reality to produce improved seeds of different varieties close to 9,000 quintals.

Potato seed growers who have been linked with buyers were able to earn from as little as 1,500 up to more than 176,000 Birr per season. As a result, some of the farmers cleared the loan taken from Amhara Credit and Saving Institute, some bought oxen and horse, and others built houses or DLS. On average, the professional seed grower groups who multiply potato seed on an area of close to 7 ha of land created 160–360 casual-job opportunities on monthly basis. This is a job during both rainy and off-season operations under irrigation.

Challenges

- Lack of strong coordination among the partners involved in the system as stipulated in the role and responsibility of each members;
- Failure of farmers to abide by the agreement signed between the two parties (this includes timely undertaking of recommended cultural practices as advised, construct DLS, use the necessary input such as chemicals);
- Lack of marketing opportunity threatened seed producers to keep seed tubers until planting time which resulted in the unwise use of seed as ware potato; and
- Lack of consistent follow-up and supervision of seed grower fields to monitor the health and quality of seed tubers they are producing.

Lessons Learned

- Working with partners was important in increasing the diffusion of technologies;
- The possibility of strengthening informal seed system provides better quality seed tubers if partners show enough commitment in the area; and
- Need to create strong linkages of growers with ARCs and BoA to regularly obtain fresh and healthy starter seed tubers.

Conclusion and Recommendation

Stakeholders involved in agricultural development should work more cooperatively to overcome drawbacks. Propagation of vegetatively propagating crops demands a careful approach that reduces the dissemination of seed-borne diseases. Failure to do this may result in the infection of disease-free areas with devastating diseases such as bacterial wilt and several viral diseases through seed tubers. Hence, it is recommended to consider a strong backup of the system by ARCs to replenish the stock with quality seed sources, train growers on seed production, and monitor fields for quality assurance to sustain availability of good quality seed tubers of potato in the region.

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Experiences, Challenges, and Opportunities in Participatory Quality Potato Seed Production: the Case of Southern Region

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Introduction

In Ethiopia, as in many other countries in sub-Saharan Africa, the informal seed system is still the dominant system for seed supply. It is the system in which farmers select their crops and varieties, produce their own seed, and/or locally exchange and purchase seed. Annual potential seed requirement of Ethiopia is estimated to be 150,000 tons, but the formal sector supply does not exceed 20,000, or only about 13%. The formal sector plays a role in more accessible areas and mainly for a few cereal crops (Marjia, 2008). Despite the huge demand, there is a great shortage of seed supply from this formal sector. Farmer-based seed production is the cornerstone to fill the gap between the demand and supply of seed for most of the crops (ibid.). Lung'aho (1997) indicated that the informal (farmer-based) seed system in many African countries remains the surest option of obtaining potato seed of the desired varieties to satisfy almost 99% of the seed potato required annually. Regardless of the advantage of modern plant breeding, most of the crop varieties planted in developing countries is the product of farmer selections and innovations (Robert, 2001).

Although different varieties have been developed and released at national and regional levels by research for larger production and utilization, a significant challenge remains that the improved varieties with their production technologies have not gone to a wider section of the farming communities (Robert, op. cit.). South Agricultural Research Institute, as a part of the national research system, involved in on-station seed multiplication and dissemination activities. However, the effort was inadequate because of limited production capacity and lack of sufficient effort in promoting and popularizing new technologies. The institute went through structural changes in research and dissemination activities, focusing more on impact orientation. In the 1990s, participatory research was initiated as part of this re-orientation.

Hawassa Agricultural Research Center (HARC) carried out participatory variety selection, variety adaptation, and demonstration and enhancing the availability of improved potato varieties through the development of informal farmer seed production system in different agro-ecologies of its mandate area. The center had strong support from potato national research program, regional government, and operational research funded by the Irish government. Hence; this paper aims to indicate the overall progress, success, challenges, and future direction in improving potato seed supply system in SNNPR.

Progresses and Success

Enhancing informal seed potato production and prescaling-up of technologies

HARC, in collaboration with the U.S. Agency for International Development and the International Potato Center, is currently carrying out informal seed multiplication on 16 farmers' fields at Bulle woreda, Herede kebele. In this area farmers previously used seed of their own farm-saved seed, from relatives and neighbors, or local market which was produced and handled as a ware potato. Owing to repeated use of seed potato, adverse results were obtained on potato production akin to other potato-producing areas of Ethiopia. Among these the accumulation of diseases, yield reduction, and quality deterioration are some of the problems and were thought to have been solved by the introduction of improved technologies in the area. Before the inception of the project, training and awareness creation workshops were conducted. Overall progress and achievements are indicated in Table 1. Likewise, the regional research institute (SARI) funded prescaling-up activities in Bulle woreda on two additional kebele. A total of 235 farmers participated in this seed production activity.

Participatory variety selection to strengthen the informal potato seed system

In 2005, Adet Agricultural Research Center (AARC) released three potato varieties: Bulle(CIP-387224.25), Marachere(CIP-389701.3), and Shenkola. All were adapted to a wide range of climatic conditions and mid- to high-altitudes in southern Ethiopia. In 2009, another variety, Dancha, was released. This variety produce 32–39 t/ha at research stations and up to 29 t/ha on farmers' fields, which is far higher than local varieties (5–8 t/ha). However, the new variety has not been widely adopted by farmers because of lack of seed, which in of itself might be due to lack of properly organized public or private efforts dealing with potato seed production. Therefore, the research system aimed at introducing improved varieties and production technologies by strengthening the informal seed in potato producing areas of the southern region.

In October 2008, participatory problem appraisal was carried out and farmer research and extension groups were established in different woredas. Bulle, Dara, Wolayta, and Chencha woredas were chosen for potato variety selection. AARC has also multiplied newly released potato varieties Bulle, Marachare, Shenkola, and Jalene(best adapted variety from the National Potato Program) for distribution. Potato seed was produced at high altitude areas, and stored under DLS for sprouting before being introduced to farmers.

Table 1: Progress of informal potato seed production at Bulle woreda

Kebele	Variety	No. of farmers	Seed distributed(q)	Yield (q/ha)		DLS	
				Estimated	Actual*	Planned	Constructed
Herede	Jalene	16	40	500	---	4	3
Suko Cooperative	Gudene	104	40	400	300	1	1
Sika	Jalene	32	115	1150	----	-	1
Sika	Gudene	10	47.5	475	----		
Andegna Okolo	Jalene	54	125	1250	----	-	1
Andegna Okolo		19	33	330	--		-

*Note: CIP/USAID = International Potato Center/U.S. Agency for International Development. * Actual data were not collected.*

In March 2009, farmers from Bulle, Chencha, Dara, and Wolayta woredas were selected and trained in potato seed production. Two farmers from Dara, three from Bulle, four each from Chencha and Wolayta, and two from farmer training centers (FTCs) of each woreda were selected for the trials. Farmers were encouraged to construct DLS to initiate participatory variety selection and seed production. About 20 kg potato seed tubers of one improved and one local variety were planted on each selected farmers' fields and FTCs at the same time. All improved varieties were planted with their full agronomic package. All varieties were planted at spacing of 75 x 30 cm; Urea and DAP fertilizers were applied at the rate of 165 and 195 kg/ha, respectively. The researchers and farmers made frequent follow-ups at various stages after crop establishment. Four months after planting the crop was harvested and yield data were recorded. Farmers and researchers evaluated the vegetative performance and yield of varieties in all locations. Performance data and farmers' perception of the varieties were collected and analyzed. Farmers ultimately selected and retained their preferred varieties for further multiplication and use.

Performance of varieties

The performance at both farmers' fields and FTCs is presented in Tables 2 and 3.

Farmers' fields. Among three varieties evaluated, Bulle gave the highest marketable and total yield at Bulle, Chencha, and Dara woredas. At Wolayta, Marachere gave the best tuber yield. At all locations, the farmers' variety (local) gave the lowest marketable and total yield (Table 2).

Table 2: Performance of potato varieties on farmers' fields at Bulle, Chencha, Dara, and Wolayta

Location	Variety	Marketable yield (t/ha)	Unmarketable yield (t/ha)	Total yield*(t/ha)
Bulle	Bulle	31.71	1.95	33.66
	Local	13.11	5.30	18.41
Chencha	Bulle	28.03	3.83	31.86
	Marachere	23.75	6.05	29.80
	Local	12.50	3.10	15.60
Dara	Bulle	32.80	4.16	36.96
	Marachere	32.39	5.40	37.79
	Local	9.90	3.04	12.94
Wolayta	Bulle	31.42	1.57	32.99
	Marachere	35.34	1.59	36.93
	Local	6.81	1.62	8.43

** total yield= marketable yield + unmarketable yield*

Table 3: Performance of potato varieties at FTCs

Woreda	Variety	Ave. tuber no./hill	Ave. tuber wt./hill(kg)	No. of main stem/hill	Ave. tuber dia (cm)	Marketable yield (t/ha)	Unmarktable yield (t/ha)	Total yield (t/ha)	Disease observed	Disease severity
Bulle	Jalene	12	0.84	4.4	4.6	45.53	4.68	50.21		
	Marachere	9.4	0.88	4.6	4.96	31.21	2.34	33.55		
	Shenkolla	10.8	0.62	3	4.43	15.96	3.05	19.01	PLB	30
	local	16.4	0.3	3.6	3.52	3.97	1.99	5.96	PLB	80%
Chencha	Bulle	12.6	0.68	3	5.5	20.50	1.92	22.41	free	-
	Marachere	14.8	0.9	3.4	4.52	14.61	2.91	17.52	free	-
	Shenkolla	5.8	0.4	1.6	4.98	6.74	0.57	7.305	PLB	40
	Local	28.8	0.82	4.2	3.94	13.48	5.60	19.08	PLB	85
Wolayta	Bulle	18.5	1.76	2.3	6.25	30.09	2.16	32.25		
	Marachere	21.2	1.92	2.4	5.96	39.79	1.84	41.63		
	Wechecha	11.8	2.22	2.6	7.02	34.04	0.78	34.82		20
	Local	10.7	0.595	1.9	3.54	5.60	1.35	6.95		

Farmer training centers

Although different varieties were evaluated in each location, improved varieties consistently performed better than local ones. The local variety was severely infected by potato LB and gave low yield, except at Chencha, where it outperformed improved varieties Shenkola and Marachere, probably due to its tolerance to high soil acidity. Among varieties evaluated, Jalene recorded the best performance at Bulle, though it was tested in one location only (Table2). Jalene, Bulle, and Marachere gave the best total tuber yield in Bulle, Chencha, and Wolayta woredas, respectively (Table 2).

Farmers' perceptions

Farmers at different locations selected the improved varieties of their preference. Jalene and Bulle were selected for their excellent agronomic traits (ground cover, freedom from diseases) and excellent consumption values (taste, uniformity, large tuber size, palatability, etc.) at Bulle. Jalene also had the potential to give more yield if left in the ground for an additional 1–2 months. Similarly, farmers in Chencha and Wolayta selected Bulle and Marachere for their large and uniform tubers, high tuber yield, earliness, and freedom from diseases. Shenkola and local varieties were rejected because of their susceptibility to diseases, low vegetative performance, and yield. Based on these results, farmers selected and maintained new potato varieties for further multiplication and distribution to other producers.

Participatory potato variety selection for arid areas in SNNPR

This activity was carried out at Umbullowacho water shed of Hawassa and Boricha woredas. Different varieties, including the local checks, were planned to be considered for evaluation. However, the lack of a local variety meant that only the improved varieties were evaluated. The variety Marachere outweighed all variables of evaluation except for stem girth (cm), in which case the performance of both varieties was the same (Fig. 1).

Even if the performance of the tested varieties was different, the farmers selected both varieties by different merits. They preferred Marachere for its excellent ground cover, establishment, stem thickness, freedom from foliar and tuber diseases, and uniform tuber size. Marachere, according to farmers, has minor drawbacks. It feels bitter and pungent taste upon swallowing while eaten boiled. They suggested that using the variety for "wat" preparation may reduce its unpleasant taste by the reaction of spices and hot pepper. They also preferred the variety Dancha for its delicious taste, short time for cooking, and uniform tuber size. The farmers also preferred Dancha for its earliness, as they could cultivate this variety in the short rain before the onset of the recurrent drought experienced in the watershed (Table 4).

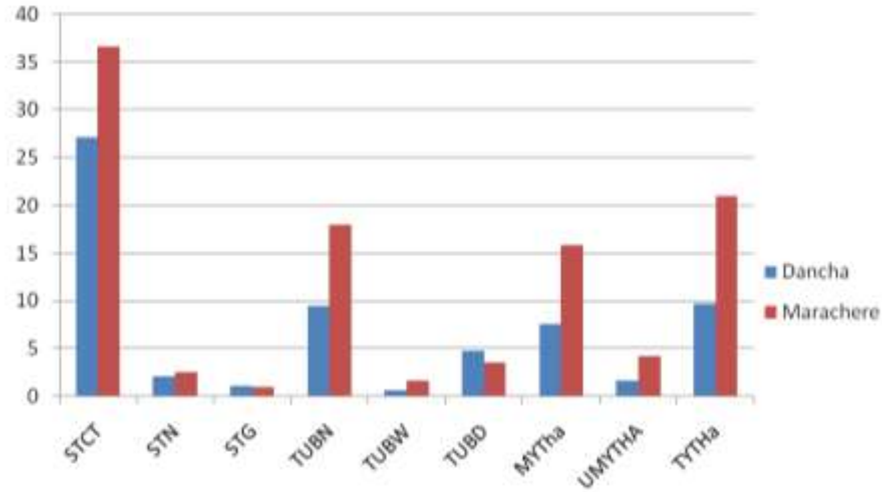

Figure 1: Performance of improved potato varieties under Umbullowacho climatic condition (STCT = stand count at harvest; STN = stem number/hill; STG= stem girth (cm); TUBN = tuber number/hill; TUBW = tuber weight/hill (g); TUBD = tuber diameter (cm); MYTha = marketable yield t/ha; UMYTHA= unmarketable yield t/ha; TYHa = total yield t/ha)

Table 4: Farmers' preferences

Farmer	**Varieties**	**Farmers Evaluation of Varieties with Respect to the Given Parameters**								
		Tuber yield	**Tuber uniformity**	**Ground cover**	**Establishment**	**Freedom from disease**	**Tuber color**	**Taste***	**Cooking time***	**Earliness**
Eyasu Ayula	Marachere	High	High	Excellent	Excellent	Free	Excellent	Very good	Short	Late
Eyasu Ayula	Dancha	low	High	Low	Low	Tuber disease	Excellent	Excellent	Long	Early
Eyasu Ayula	local	Not harvested at a time because it was not matured during harvesting the other varieties								
Yonas Adamo	Marachere	High	High	Excellent	Excellent	Rot	Excellent	Very good	Short	Relatively late
Yonas Adamo	Dancha	low	High	Low	Medium	Tuber disease, Red ant	Excellent	Excellent	longer	Early
Yonas Adamo	local	Not planted Due to the lack of seed tuber								
Musse Bedene	Marachere	High	High	Excellent	Excellent	Free	Excellent	Excellent	Short	Late
Musse Bedene	Dancha	low	High	Poor	Poor	Free	Excellent	Excellent	Short	Early
Musse Bedene	local	Not planted Due to the lack of seed tuber								
Negesso Leke	Marachere	Harvest before the arrival of the researchers								
Negesso Leke	Dancha	Harvest before the arrival of the researchers								
Negesso Leke	local	Harvest before the arrival of the researchers								
Markos Dafursa	Marachere	High	High	Excellent	Excellent	Free	Excellent	Very good	Short	Relatively late
Markos Dafursa	Dancha	Medium	Variable	Low	Low	Free	Very good	Excellent	Short	Early
Markos Dafursa	local	Not harvested at a time because it was not matured during harvesting the other varieties								
Samuel Nuna	Marachere	High	High	Excellent	Excellent	Free	Excellent	Very good	Short	Relatively late
Samuel Nuna	Dancha	Low	High	Poor	Poor	Free	Excellent	Very good	longer	Early
Samuel Nuna	local	Not planted Due to the lack of seed tuber								
	* Seen after boiling									

The correlation of variables can be considered as a good indicator for selection of varieties for their tuber yields (marketable, unmarketable, and total tuber yields) that directly related with farmers criteria of selection. As indicated in Table 5, both marketable and total tuber yields are correlated both ways with stand count, stem number, and tuber number per hill. These are the most important parameters that determine the overall yield of potato crop. The increase in yield from increased plant density might be due to the increase in the areas of photosynthesis, which increases the rate of assimilation. The result confirms the finding reported by Beukema et al. (1990), who stated that tuber size and plant population were important indicators of marketable tuber yield. Plant density affects the total yield as well as the average tuber size. By increasing plant density, yield increases.

Enhancing informal potato seed multiplication in selected areas of SNNP

The team of breeders, socioeconomists, and extension personnel had undertaken assessment of the growing localities ahead of the project excursion for market outlets, productivity, weather condition, and cooperative situations. Training on seed and ware potato production, DLS construction, and handling had been given at Holetta Agricultural Research Center (HoARC) to selected 12 farmers and six development agents from Hossana, Gummer, Chencha, Bulle, Bodit, and Hagereselam. They were selected for their actual and potential experience/capacity of potato production. After training, improved varieties Tolcha, Wechecha, and Menagesha were delivered with their full technology package. Packages include fertilizer rate (165kg/ha Urea and 195kg/DAP), spacing (60 x 30cm) between rows and plants, and proper planting. A free, initial seed and fertilizer was given to each of the participating farmers based on the availability of materials and the land that they owned. On average, from both varieties around 20kg of seed tuber was delivered to cover, an area of 100m^2.The construction of DLS was made with locally available materials delivered by farmers themselves. Both HARC and HoARC provided technical support. Researchers and extension workers from office of agriculture provided monitoring and advice to farmers in the course of seed production. After production, farmers, with the collaboration of woreda agricultural office, set the price for seed potato and the seed was sold for different bodies on request. Major achievements on potato seed multiplication and distribution have been mentioned (Table 6).

Table 5: Correlation of yield and yield components of potato crops

Variables	**STCT**	**STN**	**STG**	**TUBN**	**TUBW**	**TUBD**	**MYTha**	**UMYTHA**	**TYTHa**
STCT	1								
P value									
STN	0.391809	1							
P value	0.259								
STG	-0.04878	-0.23047	1						
P value	0.893	0.52							
TUBN	0.532969	0.728685	-0.01158	1					
P value	0.109	0.015	0.975						
TUBW	-0.09429	0.543444	0.238088	0.450667	1				
P value	0.795	0.1	0.506	0.187					
TUBD	0.119941	-0.37092	-0.0438	-0.43683	0.85011	1			
P value	0.74	0.288	0.904	0.203	0.001				
MYTha	0.676669	0.718426	-0.44725	0.618165	0.161553	-0.10852	1		
P value	0.029	0.017	0.191	0.053	0.654	0.765			
UMYTHA	0.424664	0.002617	0.342799	0.466222	0.213176	-0.35748	-0.05727	1	
P value	0.217	0.994	0.329	0.17	0.552	0.307	0.875		
TYTHa	0.814161	0.653126	-0.32494	0.73027	0.175519	-0.18723	0.936462	0.291367	1
P value	0.003	0.037	0.357	0.014	0.626	0.603	0	0.411	

Improved seed yield obtained from the initial seed production during 2002 in all farmers' fields was 75.5 quintals. In the next season (2003), each farmer planted major portion of the previous year seed and further disseminated remaining seeds for other farmers. From 2003 production, 194.8 quintal of improved potato seeds were obtained (Table 6).Again the farmers planted larger portion of seed for their own and sold to other farmers and NGOs. More than 50 farmers were able to get seed of improved potato varieties from these seed-producing farmers while the farmers were distributing/selling to other farmers, woreda experts assured quality of the seed. This indicates that informal seed dissemination is proceeding as usual but with a little intervention of formal sectors for attaining quality requirements such as seed size, freedom from disease and insect pests, damage, and sprout size. This is true in Kenya for improved potato seed supply in informal system (Chrissman et al., 1993), who also reported the significance of informal seed flow in Uganda. Table 7 indicates that the benefits attained and observed changes in farmers' lives and their dependents (e.g., a farmer named Yoseph Debo got 6640 Birr from the sale of his seed).

As indicated in Table 7, the life of seed potato-producing farmers was changed by the sale of seed potato at market, for other farmers, and their relatives. Accordingly, most of the farmers settled their credit from their income. Others were able to cover school fees and other school costs for their children. All farmers were able to obtain a good proportion of household food for their family. A large proportion of farmers bought heifers, oxen, sheep, and clothing. The incomes of all producing farmers were improved.

Table 6: Seed potato obtained and benefits attained in the year 2002–2003 by seed potato-producing farmers

Farmer	Zone/Woreda	Variety received	Seed Potato Yield Obtained (q/ha)		Seed Maintained for Further Multiplication (quintal)	DLS Constructed
			2002	2003		
Mariam Jara	Gedeo/Bulle	Tolcha	7.5	28	3	Yes (16m² spacing)
		Wechecha	-	1	-	
Kasahun Kumb		Tolcha	12	24	4	No (seed mixed)
		Wechecha	-	6	-	
Mengistu Keltu	Wolayta/Bodditi	Tolcha	3	7.5	5	Yes(seed mixed)
		Wechecha	-	2.5	2.5	
Jarsa Shirku		Tolcha	3	8.5	4.5	Yes
		Wechecha	-	2	2	
Yoseph Debo	Sidama/Hagereselam	Tolcha	23	60	7	Yes
		Wechecha	-	-	-	
Lamiso Legide		Tolcha	5	30	6	Yes
		Wechecha	1	6	1	
Markos Habte	Hadiya/lemu	Tolcha	-	-	-	No
		Wechecha	3	3	3	
Denbello Tesema		Tolcha	-	-	-	No
		Wechecha	3	3	3	
Nuriga Shikur	Gurage/Gumer	Tolcha	-	-	-	No
		Wechecha	3	2.6	2	
Ablaji Sheredi		Tolcha	-	-	-	Yes
		Wechecha	3	2.7	-	
Getachew Teka	Gamo Goffa/Chencha	Tolcha	-	1	-	No
		Wechecha	5	-	4	
Samuel Erido		Tolcha	-	7	-	yes
		Wechecha	4	-	7	

[1] ***Source:*** *Teshome Anshebo, Asefa Toffu, and Tesfaye Tadesse. Enhancing the availability of potato varieties through the development of an informal farmer-seed production." Hawassa Agricultural Research Center, unpublished document.*

Table 7: Benefits obtained from 2002–2003 seasons

Farmer	Seed potato yield(q)	Income (Birr)	Observed Change in Life/Benefits Obtained
Mariam Jara	35.5	2,840	2 oxen, 2 sheep, 1 heifer, household food/side dish, school fees for children Distributed to other 18 farmers, one of who was able to get 1,700 Birr. The others got about 3,999.5 Birr DLS constructed Credit settled
Kasahun Kumb	42	3,360	
Mengistu Keltu	13	1,040	
Jarsa Shirku	13.5	1,080	
Yoseph Debo	83	6,640	2 oxen, 2 blankets, wedding party for 2 daughters, household food, school fees for children Distributed to other 13 farmers DLS constructed Credit settled
Lamiso Legide	42	3,360	1 ox, household food, clothing, school fees for children Distributed to other 4 farmers DLS constructed Credit settled
Markos Habte	6	480	
Denbello Tesema	6	480	
Nuriga Shikur	5.6	448	
Ablaji Sheredi	5.7	456	
Getachew Teka	6	480	
Samuel Erido	11	880	

Challenges

Among the most important challenges for ware and seed potato production in the region are the following:

- Unpredictable rainfall;
- Diseases and insect pests;
- Lack of either governmental or private seed potato producers;
- Lack of postharvest handling experiences (especially at peak harvest);
- Lack of market roots for seed potato;
- Limited number of researchers engaged in potato improvement;
- Shortage of facilities like field vehicle and laboratory equipment;
- Low quality of data obtained from development agents because of farmers' traditional reluctance to reveal the amount of income from a particular enterprise; and
- Expectation of farmers for free inputs and DLS construction materials.

Opportunities

Increasing price of cereals leads people to shift gradually from consumption of cereal products to cheaper horticultural crops. This increased the demand of potato in the market, which encourages the farmers to produce potato in larger plots (hectares);
Fertile land and conducive climate;

- Availability of extension services up to grassroots level;
- Increasing demand of quality seed potato;
- Improved varieties (more than 27);
- Supportive governmental policy; and
- Increased habit of consuming horticultural crops.

Issues to be addressed

As there is no organization to multiply root-and-tuber planting materials, the intervention of research centers is essential to strengthen the existing informal seed system and thus enable small-scale farmers to easily access potato seed at local levels. The BoA, rural development, cooperatives, and NGOs are expected to exert more concerted effort in organizing farmers at local level for potato seed production and marketing.

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Experiences, Challenges, and Opportunities in Participatory Quality Potato Seed Production of North Shewa

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Introduction

Though potato is produced in most parts of the region, largest production acreage is in the Amhara National Regional State (ANRS). However, the production and productivity of potato are below expectation. Some of the factors include low-yielding character of varieties grown and susceptibility to diseases, poor fertility status of soil, and unsatisfactory water and soil management.

The general objective of this study is to improve production and productivity through assisting the dissemination of potato seed production technologies. Specifically, the study aims at the following issues

- Sensitize and provide farmers with the improved potato seed varieties and their production systems;
- Select best adaptive and more productive varieties; and
- Enhance production of potato seeds and the multiplication of seeds for further promotion.

Material and Methods

The study areas

The study area, north Shewa, is located in the southeastern part of the Amhara National Regional State. It covers about 18,000 km^2 and has three agro-ecological zones—Dega, Woyina Dega, and Kola—comprising about 37.4%, 30.1%, and 32.5%, respectively (DBARC). The study has been carried out at Basona Werana woreda for about six years and at Angolelana Tera woreda for two years.

PVS and demonstration

In the case of Basona Werana woreda, participatory demonstration and evaluation of potato seed production technologies were undertaken in 2005. Primarily, the trial was started on 10 innovative farmers after training. Successive on-farm evaluation and field days were embarked on by involving participating farmers, development agents (DA), subject matter specialists (SMS), researchers, and administrative personnel both at zonal and woreda levels.

At Angolelana Tera woreda, initial training was organized for farmers and extension workers to create awareness of seed production practices, management, harvesting, and postharvest handling techniques of potato. Farmers Research Extension Group (FREG) was established comprising 20 farmers (6 female). Participatory variety evaluation trial was conducted on three farmers' fields. On-farm trial evaluation and field days were undertaken by involving participating farmers, DA, SMS, researchers, and administrative personnel both at zonal and woreda levels. Farmers participated in the study and evaluation of trials at different stage.

Technology dissemination/promotion

In Basona Werana woreda, the demonstration activity conducted in 2005 built greater awareness and increased interest by surrounding farmers. As a result, more than 300 farmers participated. In all years, field days were conducted with participation of the main stakeholders, particularly farmers, researchers, extension agents, cooperatives, and administrators. Like that of Angolelana Tera, the technologies were promoted to all FREG members on a plot of about 400m^2 on each farmer's plot.

Seed storage and linking with market

In the meantime, while we were performing the promotion activity, demonstration was carried out how to construct a simple diffused light store (DLS) at household level. In addition, the Christian Children's Fund (CCF), a nongovernmental organization (NGO), which is engaged in development works at that location, supported farmers by constructing a modern DLS. At this time, farmers were encouraged to form a seed tuber producers association with the help of the research center and cooperative at woreda level. Farmers sold their potato seed tuber to members of their association at a 50–100% price advantage over surrounding markets.

A successful potato seed system, which can be a part of a larger value chain have the following major characteristics

- Provides a farmer access to planting material that is of better quality;
- Demonstrates continuum flow from breeding to marketing; and
- Success lies in the risk acceptance about the linkages and interactive feedback and learning process

Results and Discussion

Basona Werana woreda

Primarily in collaboration with extension agents, we evaluated, demonstrated, and promoted village-based potato seed tuber production and handling technologies with participation of 10 innovative farmers at "Mush" through FREG. The promotion activity has been conducted to enhance potato production for about six consecutive years (2005–2010). Training was organized on how to plant, cultivate, harvest, and store potato. Seeds of variety Gera and Gorebella were supplied to farmers. In the first year, evaluation was carried out on 10 x 20 m (200 m^2) plot of each participant farmer. Subsequently, seed tubers were dramatically disseminated through farmer-to-farmer seed exchange system. In the meantime, farmers were organized to form potato seed tuber producers association. In addition, the NGO CCF supported this newly organized association by constructing a modern DLS. The association was engaged in marketing of potato seed tubers (purchasing fresh seed and selling sprouted seed tubers) (Table 1). All members were engaged in potato production of improved varieties (Gera and Gorebella) in both the rainfed and irrigation. Currently, the association has 136 members and 380,000 Birr capital. The association enabled farmers to harvest profit from selling potato seed to their association and to other farmers. The price of potato seed tuber in the association was about 50–100% higher than the surrounding market.

Table 1: Progresses of the Mush potato producers' cooperative

At the start	Status
Established, March 2007	Data collected, December 2011
Initial capital, 2,920.60 Birr	Current capital, 380,000 Birr
Number of members,40 farmers	Number of members, 136 farmers

Farmers producing potato seed tuber in the study area built assets and saved money in addition to becoming food self-sufficient (Tables 2 and 3). Therefore, potato seed growers association must be established in potential growing places. These associations need to be assisted by the research system in renewing varieties and seeds from tissue culture-driven tubers that are free of diseases.

Table 2: Area allocated to improved potato varieties in ha in the 2011 season

Variety	Mean	Min.	Max.
Gera	0.25	0.125	0.75
Gorebela	0.275	0.20	0.375
Local	0	0	0

Table 3: Asset created (from 10 sample farmers)

Assets created	No. of farmers benefited	Estimated capital
Corrugated house constructed	7	147,150.00
TV set purchased	6	11,100.00
Clean water access	6	6,600.00
Electricity access	7	-
Educating child	10	-
Animal purchased	4	-
Mobile purchased	4	2,100.00
Money saved	-	68,000.00

Angolelana Tera Woreda

A FREG accommodating 20 participating farmers, 5 researchers, and 3 extension workers was organized after being trained. Variety selection and promotion were carried out at Angolelana Tera woreda in 2010. Performance of 10 potato varieties, released elsewhere in the country, was assessed with the participation of FREG members. Selection criteria were primarily selected by FREG members and included tuber yield, resistance to LB, earliness to escape frost, color of flesh tuber, dwarf and strong-stalked variety that does not lodge, and palatable foliage to animals. The farmers critically evaluated the performance of varieties tested at different stages. As a result three varieties—Shenkolla, Gera, and Gudene—were selected by FREG. A statistical analysis of the data collected was accomplished by the use of SAS statistical software version 9. Accordingly, Shenkolla gave the highest marketable yield (31.56 t/ha) followed by Gera (29.78 t/ha). This result shows that more or less both farmers and researchers had selected the same varieties. Finally, awareness and interest enhancement was launched on the FREG members in 2011. Promotion activity was undertaken and about 18 farmers were engaged in potato production (Tables 4–6).

Table 4: Area coverage and number of farmers engaged in potato production in the Angolelana Tera Woreda during 2011crop season

Variety	Participant	Area coverage (m^2)	Remark
Gera	13	2,800	All farmers constructed small DLS from locally available materials
Shenkolla	5	1,000	
Total	18	3,800	

Table 5: Productivity of major crops in the study area (q/ha), 2010/11; Meher season

Crop	National	Regional	N. Shewa	Basona werana	Angolelana Tera
Barley	16.28	13.12	14.42	23.03	24.26
Wheat	18.29	16.54	17.63	26.66	30.93
Fababeans	12.92	14.22	15.94	17.7	26.98
Potatoes	82.83	87.95	99.31	266.7	145.5

Table 6: Area coverage and yield of potato for private peasant holdings, meher season (CSA)

Area	Area Coverage (ha)		Estimated Yield in q/ha	
	2010/11	2011/12	2010/11	2011/12
Ethiopia	57,517	59,626.46	79.93	83.78
Amhara	23,156	21,990.22	93.54	87.05
North Shewa	650	138.79	72.56	94.93

Lesson Learned

The approach used

PVS and production give information about farmers' needs and help to use the indigenous knowledge of farmers and understand the criteria to pick select superior varieties and make their preferences as a cornerstone for future varietal development strategy. Since farmers participate in evaluation at different stages, it increases awareness and trust of the technologies, which facilitates transfer and reduces time and cost of undertaking selection.

Establishment of seed producers cooperative

Gathering in cooperatives allowed members to decide on market issues and sales of the potato seed tubers they produced and permitted customers to buy potato seed tuber from one location with fixed price. This enabled two profits to be made: first, selling fresh potato tubers to their members, and second is from sales of sprouted seed tubers to customers. This enabled them to build assets and save money in addition to becoming food self-sufficient.

Challenges

- Initially, some of the farmers were reluctant to adopt a full package of the technology;
- The Lack of screen house facility for safe multiplication of tissue culture-derived minitubers at research centers, which limited access to clean or diseases-free tubers for planting; and
- Lack of adequate DLS, which limited the cooperatives from buying the produced seed

The way forward

- Over time, the quality and yield of the potato seed may reduce. This is due to viral and other diseases that may colonize or invade tubers and soil and cause seed to deteriorate. Therefore, there is a need to continuously renew potato seed by disease-free planting materials from the research system. So, there is a need to strengthen the capacity of research centers to deliver clean potato seed;
- There is a need to strengthen the capacity (skill and knowledge) of both seed growers by training on quality seed production and postharvest management as well as regulatory officers to implement potato seed inspection and certification;
- There is a need to arrange a revolving fund to build more DLS; and
- Cooperatives need to enhance capacity in using better containers for seed potato during transportation and sustainable market access.

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Participatory Potato Seed Production in Tigray

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Introduction

The agriculture system in Tigray has been mainly cereal based. There have been various efforts to increase the productivity and quality of horticultural crops produced in the region. Moreover, many new horticultural crops were being introduced by different governmental and nongovernmental organizations (GOs and NGOs). However, the productivity and quality of these crops have not been optimum due to various problems, including indiscriminate introduction of planting materials, improper disease and pest management, suboptimal production practices, as well as lack of good quality planting materials (TARI, 2003).

Potato has been one of the important crops in Tigray for the last several years. The agro-climatic conditions of the region—particularly the eastern, southern, and central zones—are ideally suitable for good quality potato production. The eastern and southern zones are particularly the highest potato producer, which accounts for more than 83% of the total area covered by potato and more than 74% of the total potato production of the region (CSA, 2003). Potato is cultivated in nearly 575 ha with an average yield of 10 t/ha (ibid.). It is grown during the belg and meher seasons in Tigray (ibid.). Guasa, Jalene, and Tolcha are popular varieties in Ethiopia. These are short duration varieties, white skinned, and have high dry matter and good keeping quality. There is no formal seed system existing in the region; if any, it is limited to the few crops and crop varieties (mainly cereals). Although various research activities have been undertaken to improve the production and productivity of potato in Tigray, smallholder farmers are still using traditional production techniques and low-yielding varieties. As a result, productivity of potato is very low in the region compared to other parts of Ethiopia. The major reason for the prevailing low productivity of potato in Tigray has been the shortage of good quality seed potato. The potato tuber used as seed in the region is being transported from Awassa, Holetta, and Wondo-Genet. In addition to the high transportation costs, the sprouted potato tubers are damaged during transportation. Moreover, the sources of the planting materials are unknown, which has led to the introduction of various diseases (Berga et al., 1992).

In 2006, the Mekelle Agricultural Research Center, in collaboration with Holetta Agricultural Research Center (HARC), Bureau of Agriculture and Rural Development (BoARD), and other stakeholders, initiated a project on the production, multiplication, and diffusion of good quality seed in Atsbi woreda for increased production in Tigray. The objective of the study was to document and share experiences and lessons learned from the seed production practices in Tigray. The special emphasis is on undertaking situation analysis, participatory varietal selection (PVS), potato seed production and promotion, capacity-building activities to the seed producer groups, and other ongoing activities on seed production.

Methodology

Activities of the project were started in Atsbi woreda, which is a highland located in Eastern zone of Tigray. In this woreda potato production was not practiced, which was considered as a good opportunity to produce high-quality seed. The methodology employed in data collection was literature review, consultative meeting with stakeholders, focused group discussions with cooperative members, household case studies, and personal observation.

The steps followed in establishing potato seed producer cooperative were:

- **Stakeholder identification and consultation**. The initiative was taken by HARC and Tigray Agricultural Research Institute (TARI). Multidisciplinary researchers from both institutions consulted various stakeholders such as BoARD (at regional and woreda level), farmers, and other NGOs (REST, WVE, ADCS). During the stakeholder consultation the potentials, constraints, and possible roles and responsibilities of stakeholders were identified;

- **Participatory evaluation of potato varieties**. Following stakeholder consultation, PVS was conducted in Atsbi woreda. About 7 nationally released varieties were tested on farmers' fields to select best performing varieties for its yield, disease resistance, and market demand;

- **Establishment of farmer groups**. Farmer groups (FGs) who have participated in the PVS and have access to irrigation were grouped to work together to benefit from the seed production practices;

- **Capacity building**. Practical training (technical and managerial/business skills training) was planned to be given to the FGs and extension experts.

Moreover, it was planned to facilitate and assist farmers in the construction of diffused light stores (DLS) as part of capacity building; and

- **Field days**. Organization of field days was planned to be used as an important means of bringing stakeholders together to discuss the status of ongoing activities and linking the seed growers with ware potato producers. Moreover, participation of FGs in the regional farmers' festivals/events was also used to promote their business.

Results and Discussion

Stakeholder identification and consultation

The stakeholder consultation was facilitated by HARC and TARI. Groups of researchers with multidisciplinary teams from both organizations visited the region and consulted farmers, BoARD (regional and woreda levels), NGOs (REST, WVE, ADCS), Mekele University, and cooperatives. During the visit potential stakeholders that can work in the potato subsector were identified. The following stakeholders were identified with their respective roles and responsibilities (Table 1). In the course of implementation, the involvement of other actors such as TAMPA (Tigray Agricultural Marketing Promotion Agency), seed enterprises, microfinance institutions, and the private sector was underlined for the successful implementation of the program.

In addition to the identification of stakeholders, the team organized consultation forums focusing on the current situation of potato in the region, mainly potentials and constraints of potato production in the region. The major potato production in the region were the following expansion of irrigation; increasing consumption of potato (demand); and stable market price of potato compared to other vegetables, government commitment to increase production and productivity in the region, and availability of technologies (improved potato varieties with their packages) that can increase productivity in more than threefold.

- The stakeholder consultation has also identified shortage of quality potato seed; limited experiences in potato production—mainly seed production techniques by farmers and experts; limited capacity in terms of DLS construction; absence of price distinction between seed and ware potato in the market; and susceptibility of existing varieties to diseases and pests that result in low productivity. The stakeholder consultation has also developed criteria for site selection for potato seed production:
- Highland climate, which is suitable for the production of disease-free potato seed;

- Absence of local potato varieties to avoid disease contamination and mix of types; availability of suitable soil types; and
- Access to irrigation so that seed production will be supplemented with irrigation during main season and produce in the belg season under irrigation.

Taking these criteria in to consideration, Atsbi Wonberta woreda was selected as appropriate woreda with highland climate and no previous introduction of potato varieties. In this woreda, Felege Weini tabia (the smallest administrative unit) was selected for its easy access and availability and expansion of irrigation.

Table 1: Roles and responsibilities of stakeholders

Stakeholder	Roles and Responsibilities
EIAR/TARI	Provision of technology Leading the PVS of proven potato varieties Provision of training Technical backstopping
BoARD (at region, woredas, and tabia levels)	Follow-up of day to day activities from region to tabia level Help organize farmers into Farmers Research Groups (FRGs) and cooperatives Provide training Organize field days Market linkage Assist in site and farmers selection
NGOs (WVE, ADCS, RES)	Capacity building activities such as assisting in the construction of DLS, training Market linkage of potato seed
Farmers	As actors of the development, farmers perform all farm activities and actively participate in the training and capacity-building activities

Establish Farmers Research Groups

After site selection, the next step was to establish Farmers Research Groups (FRGs) in the tabia, based on the experiences of EIAR and TARI. One FRG with 13 members were established. Training was given by staff from HARC and TARI on potato seed production and postharvest handling/management. The training was organized with practical exercise on farmers' fields.

Participatory variety selection

PVS was conducted on farmers' fields in 2006 with the objective to select potato varieties that are adaptable and high yielding under farmers' field conditions in the area. Seven nationally released improved potato varieties (i.e., Tolcha, Digemegn, Zengena, Guassa, Gera, Jalene, and Gudene) were evaluated under farmers' conditions. The three best performing varieties were Jalene, Gera, and Gudene (Fig. 1). They were selected for their disease resistance, market quality/demand, and high yields: Gudene (382 q/ha), Gera (388 q/ha), and Jalene 390 (q/ha), respectively. This yield is very high compared to the regional average of 80 q/ha. Hence, PVS results have revealed the possibility of increasing farmers' income more than fourfold with the use of improved varieties compared to the local varieties, which are susceptible to disease and pest.

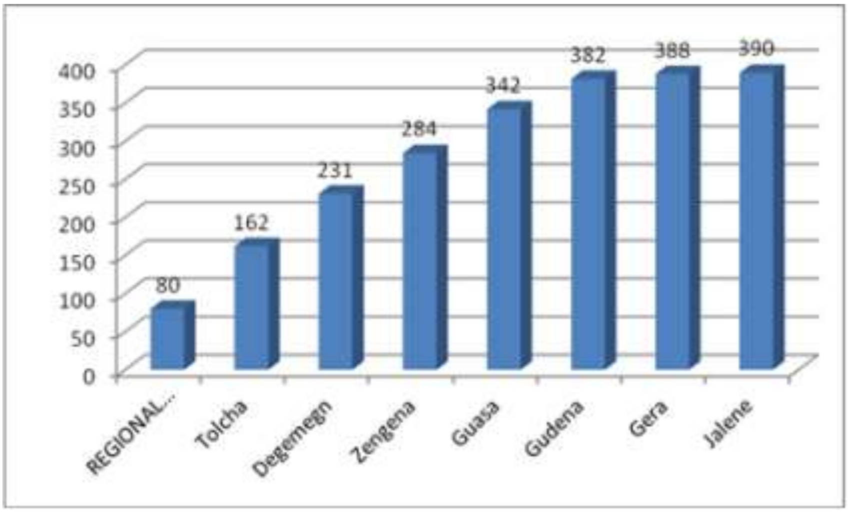

Figure 1: Average yield (q/ha) of potato PVS, 2006, under farmers' conditions in Atsbi.

Establishing cooperative

The FRGs formed to undertake PVS with 13 members was changed into a cooperative. The seed producers' cooperative, Shewit Irrigation Cooperative, was established in 2007 to facilitate the smooth functioning and marketing of improved potato seed tuber in the region. The establishment of this cooperative has helped farmers reduce transaction costs such as collection, transportation, and storage of potato seed tubers; improved the bargaining power of seed producers; and facilitated the promotion and sale of potato seed. Membership in the cooperative increased from 13 to 34. Out of these, 3 were female-headed households. The initial capital of the cooperative was only 3,750 Birr, but the capital has now grown to 1.5 million Birr, without considering individual assets (Table 2).

According to the cooperative members, organizing them into groups has enhanced their strength; eased capacity building and support from NGOs and GOs; reduced the gap in technical knowledge among members due to practical self-support in their field; improved market access for produce and inputs by reducing transaction costs; and improved the food security and livelihoods of members.

Table 2: Capital of Shewit Cooperative as of Nov. 2012

Description of capital	**Amount (Birr)**
DLS (10 by 6 mts at 70% depreciation)	105,000
DLS new (12 by 6 mts)	250,000
Office and multipurpose hall	350,000
Capital goods (2000 Eucalyptus tree @35Birr/piece)	70,000
Saving in DECSI	100,000
Saving in the form of seed	200,000
Credit to members for inputs	300,000
Collections from various sources	180,000
Total capital	**1,555,000**

Capacity building

Capacity building was one of the most important components that have helped strengthen the cooperative and included the training of cooperative members on practices of seed and ware potato production, postharvest management, and business skills. The training was given by HARC, TARI, and BoARD. Field days was another important component that has increased experience sharing on potato seed production and promotion or market linkage for farmers producing potato seed to ware potatoes. In the field days, farmers from potato-producing woredas, GOs (from BoARD and TARI), and NGOs have participated. Of the three field days organized, two were fully organized and sponsored by the cooperative.

Production and productivity

Since the establishment of the cooperative, potato production has increased overtime, from 357 qt in 2006 to 2,500 qt in 2012 (Fig. 2). Similarly, the income of the cooperative members has increased from 112,500 Birr to two million over the seven years (Fig. 3). The five-year average yield of Jalene, Gera, and Gudene was 320 q/ha, 300 q/ha, and 280 q/ha, respectively (Fig. 4), whereas the regional average yield of potato is 80 q/ha (CSA, 2010). According to the cooperative members, the productivity of Jalene has reduced overtime mainly due to the continuous use of the variety. However, efforts have been done by CIP and the Common Fund for Commodities to renew the existing varieties through the provision of clean foundation potato seeds. Currently, members of the cooperative reported that they have increased the productivity of potato varieties by doubling the recommended fertilizer rate.

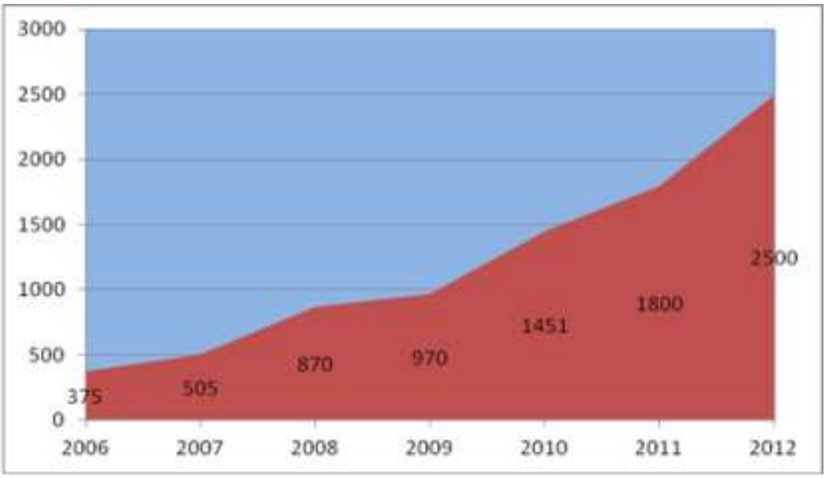

Figure 2: Improved potato seed production (in quintals) from 2006 to 2012 by Shewit Seed Producer cooperative

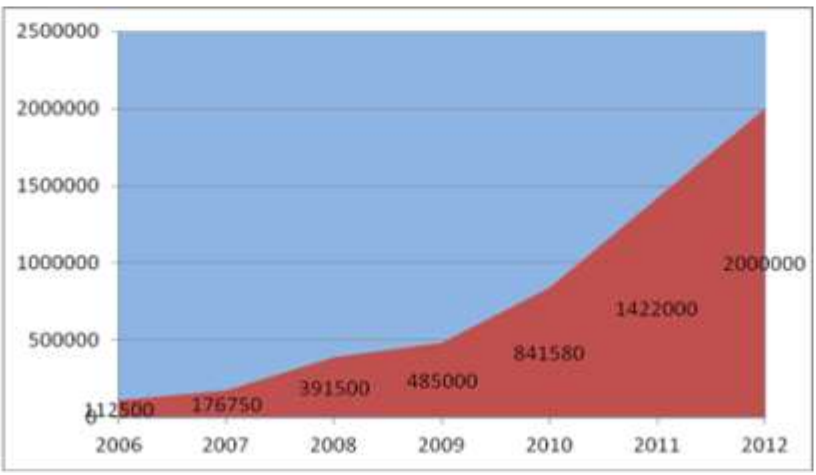

Figure 3: Annual income (in Birr) of Shewit Seed Producer cooperative

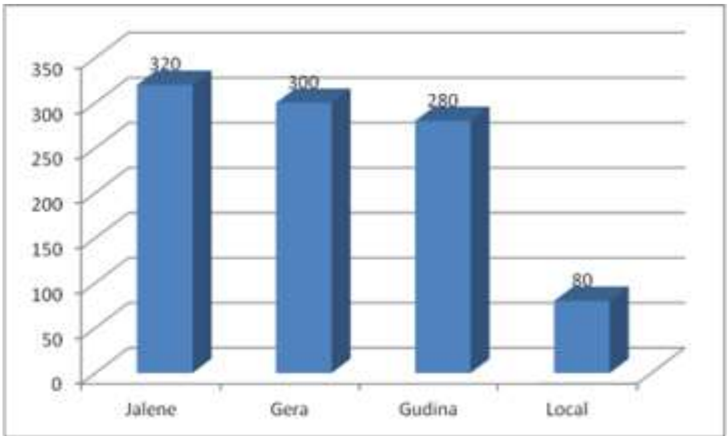

Figure 4: Five-year average yield of potato seed produced under farmers' field conditions in Atsbi woreda (2008–2011)

A partial budget analysis was conducted following CIMMYT (1998) to see the economic feasibility of using improved potato varieties with their recommended agronomic packages over the use of local varieties with farmers' practice and alternative common crop (faba bean)(Table 3). Using improved potato varieties with their recommended packages has a net benefit of 112.187 Birr/ha. Whereas the use of local potato varieties and alternative crop (faba bean) resulted in a net benefit of 34,400 Birr/ha and 22,350 Birr/ha, respectively. The marginal rate of return (MRR) to shift from the use of local varieties with farmers' practice to the use of improved potato varieties with their recommended packages is 530%. This implies that for every unit of investment in the use of improved potato varieties with their recommended packages, about 5.30 Birr extra return was produced. Similarly, the MRR for farmers shifting from faba bean production to the use of improved potato varieties with their recommended packages is 357%. Considering the rule of thumb of marginal analysis, the percentage of MRR on the use of improved potato varieties with the application of their recommended packages, compared to the use of local varieties with farmers practice and faba bean production, is by far profitable. The use of improved varieties with their packages is highly profitable and needs to be promoted.

Table 3: Partial budget analysis of improved potato varieties with their recommended practices, local potato varieties, with farmers' practice and faba bean production

	Improved potato variety	**Local potato variety**	**Faba bean**
Yield (q/ha)	280	95	25
Farm gate price/qt	500	500	1,000
Gross value (Birr/ha)	140,000	47,500	25,000
Variable costs (Birr/ha)			
Cost of seed	12,000	6,300	1,800
Cost of labor	13,000	5,000	850
Cost of fertilizer	2,813	1,800	
Total Variable Costs	27,813	13,100	2,650
Net Benefit, Birr/ha	112,187	34,400	22,350
MRR (%)		529%	357%

Potato utilization

Of the total production in the first five years, 71% of the potato produced was sold as seed to different organizations and farmers. The remaining produce—13%, 12%,and 4%—was saved for own seed, consumed at home, or marketed as ware potato, respectively (Fig. 5).

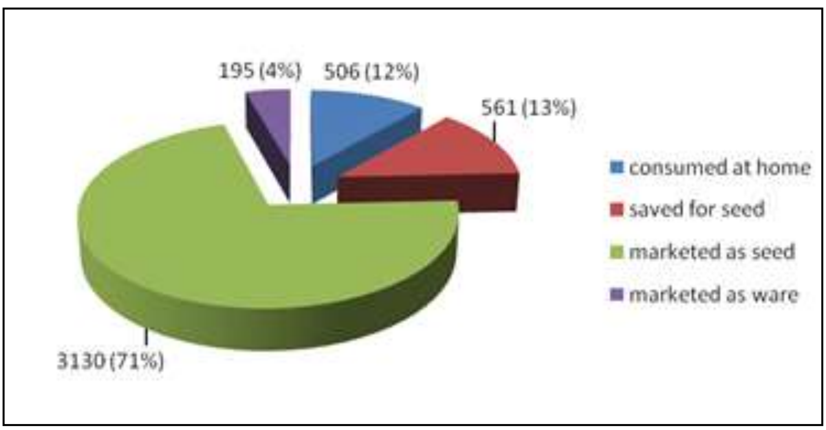

Figure 5: Potato utilization, 2006–2010, by Shewit Seed Producer cooperative

Impacts

Through increased capacity the cooperative provided input and credit service to members. As noted above, the capital of the cooperative has increased from 3,750 to 1.5 million Birr and included the construction of office and multipurpose hall, common DLS with the capacity of 700 qt, other capital goods, and savings collected from its members. In addition to the increased capital of the cooperative, the livelihoods of its members have greatly improved. Focus group discussions (FGDs) with members of the cooperative have indicated that they have created productive assets and increased and diversified their income. Members have purchased 23 motorized water pumps both as a group and individually; own over 20 cross-bred dairy cows and bulls; built family-based DLS with capacity of 10 qt; own modern bee hives, goat fattening, and fruit tree plantations such as apple. A wealth-ranking exercise conducted during the FGD resulted in classifying the cooperative members into three categories. These are the wealthiest group, with 11 members (1 female-headed household) having assets estimated to be over 160,000 Birr; the second group with 23 members and assets estimated at 40,000–60,000 Birr; and the remaining 9 members with assets of 20,000–40,000 Birr. FGD participants and woreda food security desk also added that out of the 33 members, 29 have graduated from PSNP; the remaining 4 members are candidate graduates. Household case studies conducted with individual members of the cooperative have shown that potato production has improved the household food security, nutrition quality, and income diversification of members (Case Study Box 1).

Box 1: Case study

My family size is 3 with education level of 4th grade; my major occupation is farming with land size of 0.75ha, out of which 0.25 hacan be irrigated. Before the cooperative, I focused on the cultivation of cereals and pulses, but now diversified into potato, garlic, onion, and fruit production. The number of livestock holdings has increased now with the main focus on dairy cross-bred cows, goat fattening, and modern beehives. The traditional plough was the only farm implement that I have, but now I own two motorized water pumps and DLS with the capacity of 10 qt. My house is now changed from "hidmo" (soil roof, which requires frequent maintenance) to corrugated ilron sheet roof. I was dependent on relief and PSNP support, but I havesince graduated from PSNP and earn an annual income of more than 73,000 Birr. The nutritional status of my family has greatly improved due to the consumption change from cereals to potato, milk, eggs, and honey. Before the project egg and milk have been marketed as a source of cash, but now potato is the major source of cash. There is a local saying to explain the importance of potato: "Sigem Zitehanen kesem Zihanen waga yeblun," meaning "those who depend on barley for food and tree leaves as fuelwood are valueless." My social status has also improved due to provision of seed and technical support. Relatives from long distance come to ask me and contribute free labor in my potato field.

But all these improvements are not without challenges. Limitations on market linkages, shortage of water during belg season, which reduces productivity, shortage of DLS as we plan to produce more seeds, sprayer and its spare parts not available in the local market, absence of motor maintenance service, and fuel station in the locality are among the major constraints.

Araya Emun,
Member of Shewit Cooperative

Best practices of the cooperative

- Used new variety with their packages and doubling of the recommended fertilizer rate;
- Multiplied new and improved varieties received from research and investing in potato research in collaboration with research partners;
- Introduced new barley varieties as crop rotation to the potato seed production;
- Created job opportunities to nearby farmers, mainly landless youth;
- Organized self-sponsored farmers' day as promotion activity and market linkage;
- Exemplary (teaching ground) to others; and
- Piloted QDPM on potato seed production together with CIP.

Conclusion

The adoption and supply of improved technology and good quality starter planting material increased seed potato production and potato productivity in the region. The income of poor farmers increased through enhanced productivity. The potato growers of Atsbi woreda were convinced that they could produce a high-quality seed for distribution to different parts of Tigray and thereby improve their livelihoods. The organization of potato seed tuber growers into a cooperative has helped them facilitate the collection and selling of their produce and improve their bargaining power.

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Bacterial Wilt: an Emerging Threat to Ethiopian Potato Industry

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Introduction

Bacterial wilt of potato is caused by *Ralstonia solanacearum* Smith, which is a serious disease of many economic crops that include potato, tomato, pepper, cotton, banana, tobacco, geranium, eggplant and many other plant species in the tropical and sub-tropical countries (APS, 2005; EU, 2003). In Ethiopia, some studies were made to understand this disease in the past. Accordingly, bacterial wilt of potato was first reported by Stewart in 1956 (Stewart, 1956) and later confirmed by others (Tesfahun and Anisimoff, 1986; Yaynu, 1989; Fikre and Zelle, 2006; 2007a). Although much was not done, some plant species that include potato, tomato, pepper, eggplant, and cotton (Tesfahun and Anisimoff, 1986; Yaynu, 1989; Fikre and Zelle, 2006; 2007a) were recorded as alternative host plants in the country.

In mid 1970s, the disease was not considered as a serious threat to potato production in Ethiopia except in very limited areas like Wendogenet and Shashemene. In the mid-1980s, however, the disease was recorded in many regions that include Kefa, Sidamo, Welega, Welo, Gamugofa, Shewa and Alemaya that eventually changed its status. Latter in mid 1990s, it was considered as one of the most important diseases of potato constraining production (Bekele and Berga, 1993). Currently, moreover, this disease was reported to spread to other two regions namely Gojam, and Tigray (Gebremedhin, unpublished) and likely to inflict serious damage to potato crops in many places. Presently many farmers around Shashemene reached a time when they can't produce potato in their fields due to this disease.

Ralstonia solanacearum becomes successful due to several features including (i) it has wide host range, (ii) survives as saprophytes in soil for long, (iii) spread in many ways that include planting materials, irrigation water, farm implements and vectors, and (iv) survives in vegetation as latent infection (APS, 2005; EU, 2003; Granada and Sequeira, 1983). Knowing these features of the disease is useful to analyze conditions that determine disease development and plan sound interventions. The disease is gaining importance in the Ethiopian potato industry due to several reasons that may include

- there is no well-developed seed system that certifies and regulate the distribution of good quality seed potato in the country;
- there is no health inspection in seed potato farms/fields and farmers recycle their deteriorating potato tubers;
- there is no quarantine system to safe guard new (disease-free) areas and susceptible plant commodities from bacterial wilt invasion;
- new plant species susceptible to the disease are started to be cultivated and the bacterium infects many important export commodities;
- there is less tendency of using pest management practices in our farming culture; and
- this disease is an important quarantine pest of many countries to where we export our produces. Therefore, the country has to develop sound strategy against this risky disease.

This paper, therefore, presents and briefly discusses the current status of bacterial wilt of potato and the momentum at which it gains importance in the Ethiopian potato industry with the aim to show the level of risk under which we operate. The disease and causal agent, symptoms and host range, distribution and losses, its epidemiology and management, accepted phytosanitary measures and risk management practices are implicated for future research and development considerations.

The Disease and Its Symptoms

Bacterial wilt of potato affects the underground part of the plant and usually occurs in foci associated with accumulation of water in lower areas and sometimes scattered in the field. It is common to find several adjacent plants showing wilt in a row under furrow-irrigation. Leaves of infected potato plants show wilting in daytime and sometimes recover during cool hours in night, which resembles lack of water. The entire plant wilts quickly without showing chlorosis during rapid disease development period or wilting of only a part of the stem, or one side of the leaf/stem may be observed while the rest of the plant looks healthy. It can also cause stunting or yellowing of the host. Heavily infested tubers release the bacteria when wounded or on its 'eyes'. Cutting diseased tubers will show a browning and a death of the ring and the immediate surrounding tissues. On the cut tuber to half, a creamy fluid appears on the vascular ring. The vascular tissues in the lower stem of wilted plants show a dark brown discoloration. A cross section of the stem with bacterial wilt infection produces a white, milky strand of bacterial cells in clear water when kept upright. Wilted plants do not produce marketable tubers (Anonymous, 2007; APS, 2005; Daughtrey, 2003).

The Pathogen, Host Range, Distribution and Losses

Bacterial wilt of potato is caused by *Ralstonia solanacearum* Smith, which was previously known as *Pseudomonas solanacearum* Smith for many years (EU, 2003; Henok *et al.*,2007; Yabuuchi *et al.* 1995). The genus *Ralstonia* was established to accommodate *Ralstonia solanacearum* together with two closely related species (*Ralstonia picketii* and *Ralstonia eutropha*) that have similar rRNA homology (APS, 2005).*R. solanacearum* is a gram-negative rod shaped bacteria with the size of 0.5-0.7μm width and 1.5-2.5μm length, and having a motile, aerobic, oxidase and catalase positive character, which accumulates poly-beta-hydroxybutyrate. Colonies are non-fluorescent on complex media. Most strains produce nitrite from nitrate. This bacterium is an extremely complex and diverse species that enables it to be pathogenic to several hundred-plant species in over 50 families (APS, 2005; EU, 2003).

Globally, there are five races varying in host range and to some extent in geographic distribution (Table 1). Race 1 has wide host range infecting many plant species mainly solanaceous plants while Race 2 mainly infects banana and Race 3 is known as the potato race and found worldwide except in Canada and the USA. Race 4 infects ginger and Race 5 affects mulberry (Daughtrey, 2003). In Ethiopia only Race 1, Race 2 and Race 3 were reported to occur (CABI, 1999; Fikre and Zeller, 2006; 2007a; Yaynu, 1989). Race 1 infects potato, tomato, pepper and tobacco. Race 2 infects banana and ensete while Race 3 infects potato, tomato and eggplant in Ethiopia being known to have abundant plant diversity as hosts. Stewart first recorded bacterial wilt of potato in Ethiopia in 1956 (Stewart, 1956) in Kefa province and latter substantiated by others (Stewart and Dagnachew, 1967; Tesfahun and Anisimoff, 1986). Records on its occurrence increased with increase in production of potato in the country with time (Table 2). In early days, when potato was grown in small acreage, the distribution of the disease was limited to only Wendogent and Shashemane. Presently, however, bacterial wilt in potato was reported from many parts of the country that include Kefa, Gamugofa, Sidamo, Welega, Welo, Shewa, Arsi, Alemaya, Gojam, and Tigray (Stewart, 1956;; Bekele, 1996; Gebremedhin *et al.*,2006).

Table 1: Host rang and global distribution of *Ralstonia solanacearum* races

Race	Host range	Global distribution	Climate
1	Over 100 plant species from 50 families (e.g. potato, tomato, and weeds)	Kenya, Ethiopia, Rwanda, Somalia, Congo, Burundi, Uganda, Asia, Australia, Americans, etc.	Warm climate 35 to 37°C
2	Banana and other *Musa* spp.	Brazil, Caribbean, Libya Ethiopia, Malawi, Somalia, Philippines	Warm climate 35 to 37°C
3	Potato, tomato, tobacco, geranium, marigold, eggplant, pepper, pelargonium, etc.	Worldwide (e.g. Ethiopia, Kenya, Burundi, Zambia, South Africa) except USA and Canada	Cool tropical Highlands
4	Ginger	Asia	Humid zone
5	Mulberry	China	Cool highland

Source: *Fikre and Zeller, 2006; 2007a; Daughtrey, 2003; EU, 2003, Yaynu, 1989*

Table 2: The increase in occurrence of bacterial wilt and expansion of potato production in Ethiopia in the last 50 years

Year	Production ('000 ha)*	Bacterial wilt occurrence in regions
1656	nd	Kefa, (First recorded by Stewart)
1965	nd	Kefa, Gamugofa, Sidamo, Welega
1975	30	Kefa, Gamugofa, Sidamo, Welega, Welo, Shewa
1985	50	Kefa, Gamugofa, Sidamo, Welega, Welo, Shewa, Alemaya
1995	100*	Kefa, Gamugofa, Sidamo, Welega, Welo, Shewa, Alemaya,Arsi
2005	160	Kefa, Gamugofa, Sidamo, Welega, Welo, Shewa, Alemaya, Arsi, Gojam, Tigray

Source: *Stewart, 1956; Stewart and Dagnachew; Tesfahun and Anisimoff, 1986; Bereketsehay, 1988; Bekele, 1996; Gebremedhin et al., 2006. (nd = no data and * = estimation).*

Since Shashemane area was known to be infested by this pathogen and was major sources of seed potato for many years, it is likely that bacterial wilt was spread and increased with potato expansion in the country through seed exchange and repeated potato cultivation. Still, the country has great potential for potato expansion (Gebremedhin *et al.*, 2006) and potato acreage is increasing every year at which the danger of this disease also rises with this expansion if enough precautions are not taken to limit the spread disease through quality seed production and inspection system.

Bacterial wilt is a serious disease causing severe yield losses on potato in many countries. 50-80% in Kenya, Burundi and Uganda (Ajanga, 1993), 70% in India, and varying degree losses in many potato growing countries of the world (APS, 2005). In Ethiopia although wilt incidence up to 63% was reported, yield losses were not yet quantified (Bekele, 1996). Since most wilted potato plants do not give marketable tube, yield losses of potato due to bacterial wilt could be very high under Ethiopian conditions, and hence, studies are required to understand the impact of this disease on potato crop. In a preliminary study (Bekele, 2007), relationship of potato yield (Y) and wilt incidence (X) was given by **$Y = -0.28X + 39$ ($R^2 = 0.50$)**. The regression of marketable tuber yield (t/ha) over bacterial wilt incidence (%) recorded from a two-year experiment at Mutulu clearly indicated that yield significantly (p=0.05) decreases with increase in wilt incidence (Figure 1). The mean yield loss of 16.6% ranging from 3.2 to 30.8% was observed in this study, which seems reasonable only for ware potato. In seed potato, however, all infected tubers do not give rise to a potential plant and are vehicle to spread the disease, which eventually are discarded that increases the losses in case of seed tubers.

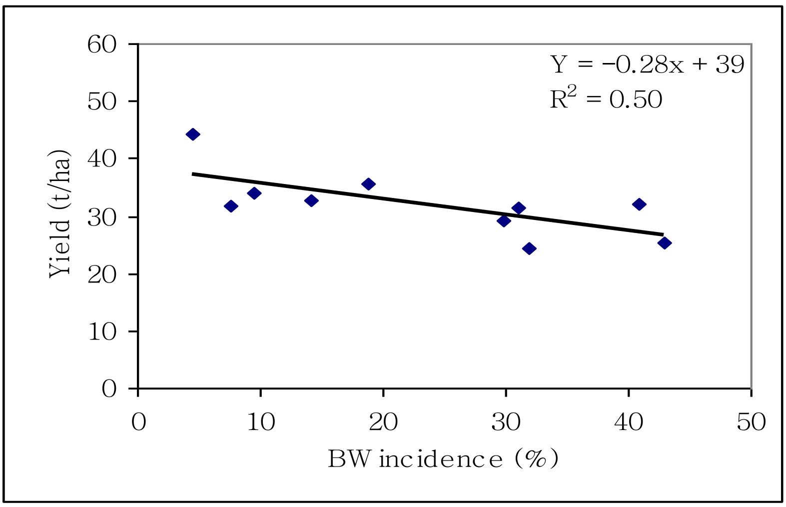

Figure 1: Relationship between potato tuber yield and incidence of bacterial wilt using susceptible variety CIP-384321.3 at Mutulu, Guder in 1996 and 1997 crop seasons (Source: Bekele, 2007).

Disease Cycle and Epidemiology

Infested soil and latently infected tubers are the main sources of bacterial inoculum to cause wilt in potato. The pathogen can survive in the rhizosphere of non-host plants including weeds. A wide host range guarantees long-term survival in soil during the absence of the main susceptible host. Soil factors influence the survival of the bacterium (EU, 2003). For example, bacterial wilt is becoming a devastating disease of potato in Shashamene where the moderate soil reaction and moderate-to-high temperatures support longer survival of bacteria in the soil. However, suppressive soils to this pathogen promote desiccation and/or microbial activity that favor antagonistic microorganisms thereby reduces wilt diseases in crops.

R. solanacearum through mainly infected planting materials (potato tubers, tomato and pepper transplants), contaminated water, or farm tools and laborers that are contaminated from infested fields (APS, 2005) can infest disease-free areas. Transmission though seed is more common (EU, 2003; Kelman, 1981). Once the disease is established in an area, the most significant method of pathogen dissemination is through contaminated irrigation water and tools used for cultivation.

R. solanacearum can infect undisturbed roots of susceptible hosts through microscopic wounds caused by the emergence of lateral roots. Transplanting, nematodes, insects, and agricultural equipment are also able to wound roots, and hence, predispose plants for infection. The bacterium then colonizes the cortex and advance towards the xylem vessel, from where it rapidly spreads in the plant. Bacterial masses prevent water flow from the roots to the leaves, resulting in plant wilting. Severity of the disease depends on soil temperature, soil moisture, soil type, host susceptibility, and virulence of strains. High temperature (30-35^{0}C) and high soil moisture are the main factors associated with high bacterial wilt incidence and severity, although strains vary in response. Under these conditions, high populations of bacteria are released into the soil from the roots as the plant wilts (APS, 2005; EU, 2003).

In general, conditions that favor bacterial wilt development in the field include

- crop residues left in the field that were infected by *R. solanacearum*;
- injured roots caused by farm tools or by soil pests;
- warm temperature and high moisture;
- high soil reaction;
- poor and unfertile soil;
- cultural practice followed; and
- seed sources (APS, 2005).

Disease management

Because bacterial wilt is caused by a genetically diverse soilborne pathogen with a wide host range, long survival potential, and little available resistance, it is a very difficult disease to control once it has established in the soil. No single control measure is effective to prevent losses caused by this disease (Fikre and Zeller, 2007b; Bekele and Berga, 2001; French, 1997). Since the pathogen spreads at a very fast speed in Ethiopia at present, enough attentions should be given in research and development strategies of potato industry. Especially quarantine action at a regional level and production of quality potato seed should be enhanced to prevent the spread of this dangerous disease into new disease-free areas of the country.

Cultural practices, if judiciously used, can reduce disease incidence and severity, allowing the disease to a manageable level. Seed tubers and soil where potatoes to be grown must be free from infestation. It is mandatory to use disease-free potato seeds if commercial seed producers come to the system (Struik and Wierseman, 1999). Fields should not be over-irrigated, because excess soil moisture favors disease build-up. Crop rotation with non-susceptible crops reduces soilborne populations of the bacterium (Bekele and Berga, 2001). Appropriate rotation period and non-host break crops should be identified and used. Shifting planting dates to cooler periods of the year can help escape the disease. Soil amendments with inorganic and organic mixtures reduced wilt incidence in some locations (Granada and Sequeira, 1983), but more research is required to provide explicit and economically feasible and reliable disease management options. Resistance should be seen as an additional factor among other management practices.

In general, preventive measures are very important. These include

- remove and destroy all infected plants;
- control soil pests;
- rotate potato with non-host crops;
- wash or expose farm tools to heat before using in another field;
- remove residues and remnants of infected plants;
- avoid planting in infested soils; and
- use disease-free seed tubers (EU, 2003; APS, 2005; French, 1997; Kelman, 1981).

Risk conditions of *Ralstonia solanacearum* for Ethiopia

Although detailed risk assessment was not the subject of this paper, scientific information available on *R. solanacearum* at present is outlined in relation to major risk elements. A brief account was made to show the risk status of *Ralstonia* *solanacearum* as a quarantine pest, if the pathogen is accidentally introduced and/or established in new and disease-free areas of the country.

Potential of the pathogen at source: Serious infection of potato and many hundred-plant species by *R. solanacearum* in many parts of the world is well known and of potato, tomato, pepper, tobacco, and eggplant in Ethiopia was repeatedly reported. Under our conditions, there was enough and virulent bacteria inoculum every season, both in main- and off-season potato production fields from our observations. On the other hand, there is no effective seed scheme to meet the demand for clean and healthy seed that increase the chance of movement of contaminated and/or infected seed within the country and thus the pathogen has high-risk possibility being sources of inoculum.

Spread potential: This pathogen can effectively move with seed potato as latent infection and other planting materials. Most potato tubers harvested from infected plants are infected and infested soil adhered to seed tubers that could carry the pathogen with it and thus the bacterium could effectively spread from place to place in these conditions and disseminate in field with irrigation water and farm tools. Therefore, the pathogen has still very high-risk score for potential to spread.

Colonization potential: Among known susceptible hosts to this pathogen, many plant species are found everywhere in Ethiopia and the country is endowed with diverse climatic factors that are conducive for disease development thus there is a high probability of the pathogen to colonize and establish in to new areas in any part of the country. Hence, these situations increase the risk score of this element to moderate level.

Economic and environmental damage: Besides potato, many economic plants like tomato, pepper, cotton, ginger, banana, geranium, tobacco etc. are susceptible and suffer serious yield and quality losses due to this disease as it can be seen from experiences of other countries. In Ethiopia, this pathogen has been demonstrated to cause severe damage on potato, tomato, eggplant and tobacco. Therefore, there is also a high survival and damaging risk to many economic crops and other vegetations in Ethiopia.

Generally, therefore, *R. solanacearum* could inflict severe losses in many plant species being it economic or components of general vegetation that are found in areas where it is absent now. This clearly suggests that *R. solanacearum* is a high risk pathogen for non-infested areas of Ethiopia. Hence, proper risk management is necessary against this pathogen.

Implications for Risk Management

Bacterial wilt is a serious disease causing severe yield losses on potato in many countries. Yield loss up to 30.8% was observed possibly for ware potato and could reach as much as wilt incidence scores in seed potato in Ethiopia. These losses could be much higher if latently infected tubers were used as planting materials and the risk to infest healthy soils is considered. Generally, this wilt disease doesn't seem to be recognized in our country and its potential danger appears to be undermined. Hence, control measure against wilt disease in potato is very timely and necessary.

Current trends of Ethiopian agriculture include small-scale irrigation and cultivating high value crops as major components. These necessitate different inputs including seed from different part of the country, where they were not produced following proper agronomic practices for seed. As a result, diseases like bacterial wilt get chance to spread to new areas through this poor quality seed (uncertified) exchange system. Therefore, Ethiopia should consider a serious seed inspection and certification system, and enforce internal quarantine procedures for different regions. Decentralized seed production program would be feasible to support effective control of wilt at local level by farm inspection system. Furthermore, since many plant species were known to be susceptible to this pathogen, particularly geranium and sweet potato, Ethiopia should regulate the movement of infected plants from place to place, especially planting materials and cutting to protect new areas and plant species by producing clean planting materials.

Quality and healthy seed potato could be produced in cool highland areas where vector activities are less and the climates are suppressive to wilt development. Thus, seed schemes to be planned should include selection of geographic locations for seed and ware potato production as wilt and virus incidences are less in higher and cooler places. Since wilt was aggravated by recycling of potato seed by farmers and they lack awareness on the use and advantage of healthy seed sources, aggressive intervention is necessary to increase the awareness of farmers on quality seed production and inspection of their farms.

Since suitable potato varieties are available to farmers at present, young educated people start to join farming, especially producing high value crops, and farmers start to specialize in seed production, proper plant protection measures should be launched among production packages when formulated for potato. Field inspection and proper phytosanitary measures should be considered as training and advisory topics for farmers.

R. solanacearum is a contentious topic in agricultural trade negotiations in the European Union and is subject to strict quarantine and eradication regulations in the United States (APHIS, 2003). This legislation has had unforeseen economic impacts on laborers in developing nations where millions of ornamental plant cuttings are produced for the North American and European markets. Ethiopia joined this venture very recently and hence shoulders some parts of this impact. Wilt disease has gained importance in protected (plastic tunnel or greenhouse) agriculture, where temperatures are usually higher, and crop rotation is not properly performed for economic reasons. This is a serious concern for flower farmers in Ethiopia, who joined the tunnel cultivation recently and lacks experience on its management.

Among currently emerging export ornamental plants in Ethiopia, geranium is one and very important, but is known to be susceptible host of *Ralstonia*, which is a strict quarantine pathogen to countries where we export geranium. At present, Ethiopia uses an expensive diagnostic kit to test millions of geranium cutting to certify export consignments every week. Therefore, its control and containment should receive serious considerations before it comes out of hand.

Future Research Areas

- Map the distribution of the pathogen, amount of losses it can cause in quality and quantity, and study the race composition and distribution of the pathogen;
- Determine the host range of the pathogen from crops and other plant species grown in the same agro ecology with potato in order to plan proper rotation and sanitation practices;
- Weigh the relative importance of possible cultural practices that are helpful when formulating an Integrated Wilt Management Strategies;
- Develop resistance/tolerance varieties by screen potato germplasm;
- Establish proper sanitation and inspection procedures for seed production in potato;
- Create awareness and train farmers how to protect their healthy field from this dangerous disease, produce seed in healthy soils, inspect seed crops and manage seed potato for quality, and properly process and handle potato seeds during storage and marketing;
- Consider regional seed production schemes so that the chance of spread of this destructive and "difficult to handle disease" could be minimized. This should be assisted by inspection and certification processes; and
- Internal quarantine procedures should be considered for potato seeds at regional level, as infested soils are not so much at present. Until then, a self-

imposed quarantine of the infested area (restricted stock, soil and farm tool movement, obligatory sanitation) would definitely help to prevent the spread of the disease.

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Control of Bacterial Wilt and Blackleg of Potato Using Effective Microorganisms

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Introduction

Bacterial wilt of potato is known to be economically important and was reported on many zones where potato is grown. The destructiveness of this pathogen and its exceptional ability to survive in soil (Hayward, 1991), plant debris and root hairs of plant hosts (Graham, *et al*,.1979; Granda and Sequeira, 1983) as well as its means dissemination contribute to massive crop losses (Kelman, 1998). Control of bacterial wilt has so far only been moderately effective, and is based on crop rotation (Bekele and Berga 2001). Even this limited control strategy is not in use by farmers for two reasons: first, most farmers do not know the presence of the technology and second farmers neglect the technology because it requires farmers' understanding about the technology, which is acting progressively unlike pesticides. EM doesn't give quick responses in controlling the disease. The other control option, breeding for host resistance, was not successful in potato due to some biotic and abiotic factors (Hayward, 1986).

In order to reduce these bacterial diseases, the use of EM which was found effective in improving soil health and plant health there by improved the quality and productivity of crops (APNAN, 1995 and Higa, 1994) as an alternative and new dimension, might be crucial for potato. EM may have an advantage of low ecological pollution rather may conserve the environment, sustainable and easy for application, and moreover, even if it needs some study under Ethiopian condition, its effectiveness in wilt control help the technology to be preferred. Research reports and reviews (MYINT and Rana, 2006) indicated that application of EM was found most effective as bio control agents of bacterial wilt disease. The purpose of this study was therefore to study the effect of EM and verify its effect on tuber borne bacterial diseases of potato.

Material and Methods

Laboratory experiment

EM suspensions were mixed in to autoclaved PDA cooled to 40 °C in the laboratory to yield final concentration of 0.4; 1.0; 2.0; 4.0 and 8.0% EM (v/v). Additional treatments were included as PDA amended with 250 µg/ml of fungicide (Mancozeb 80% WP) and only PDA. All treatments were allowed to solidify at room temperature. *Ralstonia solanacearum* and *Erwinia* sp cultured in NA for a week at 28°C in the incubator. Using a cork borer, uniform agar disks (4 mm diameter) of bacterial colony were obtained for bioassays on NA amended with EM. A colony disc was inverted and placed into the center of each amended PDA plate and incubated at 24 to 26⁰C. Growth was determined by measuring the diameter of the colony every day. The bioassays were conducted on three plates for each treatment. The data collected was subjected to analysis of variance and means were compared using the list significant difference (LSD).

Cold frame experiment

Compost were prepared in 3 x 1.5 m pit in three layers while each layer (0.5 m) was sprayed with diluted EM secondary stock solution in 1:1000 v/v dilution till it gets wet and every after 15 days an additional EM spray was done if required. The same dilution was sprayed on plants in the field at 7 days interval for one month using knapsack sprayer. The experiments were carried out at Holetta Agricultural Research Center in two cycles in the same pot filled with soil, sand and compost at the ratio of 3:1:1.Secondary EM stock solution diluted at 1:1000 v/v have been used during compost preparation and to spray plants every week for one month using knapsack sprayer.

The pots were inoculated by 10^6colonies of *R. solanacearum* suspension and replicated three times. The treatments were : Fortified compost + Fertilizer + EM Spray + Inoculated by *R. solanacearum*suspension;½ fortified compost + ½ fertilizer + ½ EM spray and soil inoculated by *R. solanacearum* suspension; farmers practices (½ fertilizer + local seed)soil inoculated by *R. solanacearum* suspension and the last treatment was improved management (full fertilizer rate, bacterial wilt free seed and uninfected soil with *R. solanacearum*). Foliage wilt was rated using 1 - 3 rating scale (where 1= no disease, 2 partial wilting and 3 full wilting) whereas latent infection was in tubers harvested from each treatment. Harvested tubers were incubated at 28 ± 2⁰C for 4 weeks and each tuber were horizontally dissected and assessed for the presence of brown ring with bacterial ooze. Treatment differences were determined by calculating in percent of the total harvested tubers.

Field trial

The field experiment was conducted from June 2009 until January 2011 in Shashemene woreda in farmer's field where bacterial wilt infestation was known very high. The locations were in three kabeles namely Faje sole, Hurso simbo and Idela burka. The treatments were:

- improved management (full fertilizer rate, recommended spacing and improved variety (Jalene);
- soil amended with full rate of EM - fortified compost, recommended spacing and improved variety (Jalene);
- soil amended with ½ EM-fortified compost and ½ fertilizer of the recommended rate for the area and recommended spacing and improved variety (Jalene);
- soil amended with ½ EM -fortified compost and ½ fertilizer of the recommended rate for the area plus ½ EM spray on the foliage weekly using the recommended spacing and improved variety (Jalene);
- farmers practice (1/2 fertilizer using local variety); and
- seed tube treated/socked in EM at a dilution of 1: 1000 v/v for 30minutes.

The experiment was a 2 x 6 factorial arrangement with RCBD where variety was being factor A and the other six treatments were being factor B. The data were subjected to analysis of variances using SAS software.

Results and Discussion

Laboratory experiment

Compared to the untreated control and EM amended NA at 8 %, 12% and 18 % v/v concentrations significantly inhibited the colony growth of *R. solanacearum* while, fungicide Mancozeb (Dithane M-45) at 250 μ g/ml amended in NA completely eradicate even the initial inoculums of the bacterium (Figure 1 and 2). The lowest (0.4 %)EM concentration had shown a suppuration effect until the end of the first week however, the radial growth of the bacterium colony become faster as time goes. The same trend of inhibition was also observed on *Erwinia* sp. (Figure 3). Results from overall study suggest that living organisms or substances released from EM might have inhibited the growth of these pathogens although the mode of action is not yet known.

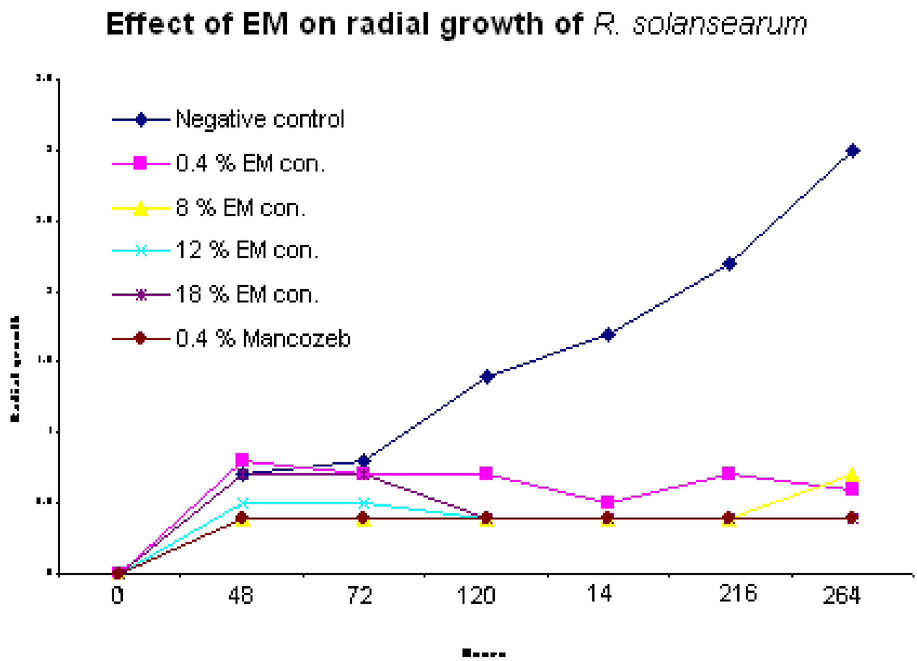

Figure 1: Progress of radial growth of *Erwinia sp.*. colony through time at different EM and fungicide amended treatments in Nutrient Agar substrate

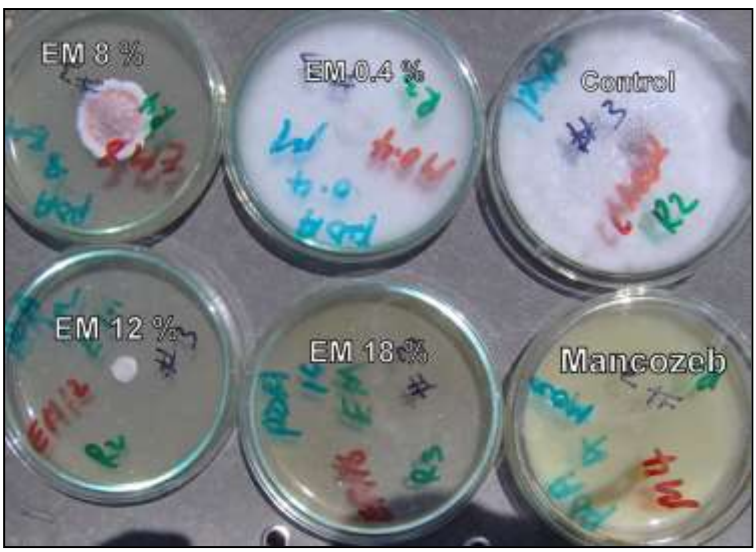

Figure 2: Radial growth of *R. solanacearum* colony in different EM concentrations and fungicide amended with Nutrient Agar substrate

Cold frame

In the first phase of the experiment, the intensity of the disease on the foliage and tubers as latent infection was minimal. The treatment that represent farmers practice (local variety, half rate of fertilizer, inoculated with BW pathogen but compost without EM-fortified compost) had the highest 3.0 disease severity (in a 1-5 rating scale) and 30 % latent infection followed by where, EM fortified compost and EM was applied as a spray after every 7 days with full rate had 2.5 % severity and 19.3 % latent infection. Nevertheless, as half reduced the rate, the severity of the disease and correspondingly percentage of latent infection was reduced. The improved management i.e. disease free seed of improved variety planted in sterilized soil found free of infection (Table 1). In order to observe the effect of each treatment, the second phase of the trial was set in the pots where the first phase of the trial was undertaken. The result validated that, symptom on the foliage was not observed on any of the treatments except on the treatment representing farmers' practices. In the same manner percent, latent infection in harvested tubers was higher (60%) with lower number of tubers harvested. Whereas, in treatments received half of the inputs and the treatment received full input had 10.5 % and 18.4 % percent latent infection, respectively. Number of tubers harvested from these treatments was more compared to the former treatment (Table 2). Since the substrate in the fourth treatment is healthy soil, there was no disease symptom as well as latent infection in tubers examined after incubation. In general except in the control treatment where percent latent infection was increased by 50 %, on the rest of the treatments which had EM-fortified compost the incidence was slightly (6%) reduced. This result may substantiate the research results reported elsewhere (MYINT and Rana, 2006)

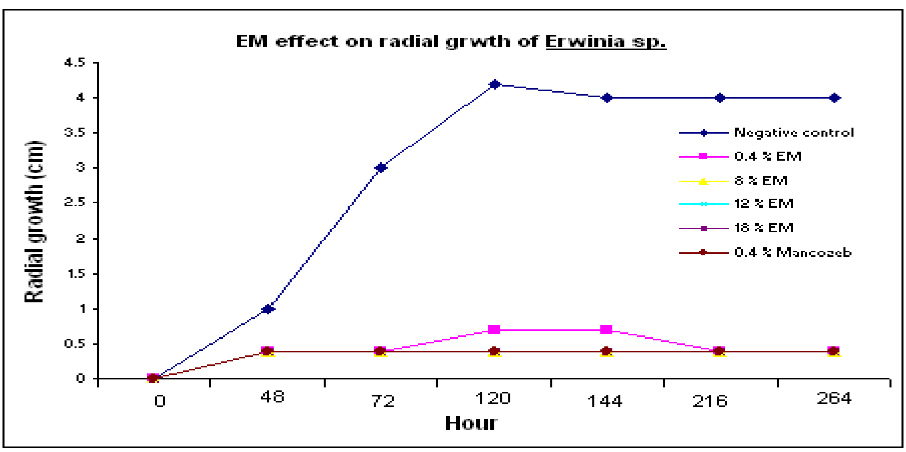

Figure 3: The progress of radial growth of *Erwinia sp.* colony through time at different EM and fungicide Dithane M-45 amended treatments in NA

Table 1: Effect of different rate of EM fortified compost and EM spray amended with fertilizer on BW severity and latent infection in partially controlled condition (cold frame) in the year 2009

Treatment	Rep.	BW severity (1-3 scale)	Total tuber harvested	Latently infected tubers	% infection
I *	I	2	17	1	
	II	1	16	3	13.0
	III	1	13	2	
	Mean	1.3	15.3	2.0	
II	I	2	8	0	
	II	2	6	2	19.3
	III	1	12	3	
	Mean	1.7	8.6	1.7	
III	I	3	9	3	
	II	1	5	1	30.0
	III	2	6	2	
	Mean	2.0	6.7	2.0	
IV	ST**	1	9	0	0
	Mean	*1.5*		*1.42*	*15. 57*

** I – ½ EM fortified compost + ½ Fertilizer + ½ EM Spray + Inoculated by R. solanacearum suspension; II - EM fortified compost + EM Spray + Inoculated by R. solanacearum suspension using improved variety; III – Farmers practices (½ fertilizer + local seed)inoculated by R. solanacearum suspension; IV- Improved management (fertilized, bacterial wilt free improved variety and un inoculated soil with R. solanacearum) as **ST- Satellite treatment*

Field Experiment

Mean disease infection on the improved and local variety was 1.9 and 3.4 (in a 1-5 rating scale), respectively. Considering both varieties, the lowest incidence was recorded on the 3rd treatment (soil amended with ½ EM - fortified compost and ½ fertilizer of the recommended rate for the area plus ½ EM spray on the foliage weekly) using the recommended spacing; although the difference to the treatments was not statistically significant (Table 3). While the interaction effect of variety by treatment was significant. Though the area where the trial was conducted is known to be with high wilt infestation, the incidence of bacterial wilt in the field was not significantly differed among varieties, treatments, and variety by treatment interaction. However, overall mean disease incidence was slightly higher on the local variety (25 %) compared to the improved variety (21 %). Though there was no significant difference among treatments in disease incidence, the highest percent disease incidence 33.0 % was recorded on local variety and 25.5 % on improved variety where full rate of EM-fortified compost was applied. The lowest (18.8 %) and (19.3 %) incidence of the disease was recorded on the improved and local variety respectively amended with ½ EM - fortified compost and ½ fertilizer of the recommended rate and ½ EM spray. Latent infection in tubers was not significantly different among varieties and treatments. However, a slightly higher (6 %) incidence was recorded the local variety over the improved variety and percent latent infection was also lowest. The highest incidence was recorded on the treatment amended with full rate EM - fortified compost and fertilizer of the recommended rate for the area plus EM spray on the foliage weekly using the recommended spacing, seed tuber treated/socked in EM at a dilution of 1: 1000 for 30 minutes, and planted with fertilizer. Probably, when the fertilizer rate increased to full rate the nitrate might increase in the soil and might affect the development the microorganisms as opposed to ½ fertilizer rates. Mean percent latent infections on the remaining treatments were in the range of 33.45 to 63.35 on the improved and 46.7 to 73.3 on local varieties.

Table 2: Effect of different concentration of EM fortified compost and EM spray amended with fertilizer on the infection rate of BW under partially controlled conditions (in the cold frame) in the year 2009

Treatment	Replication	Total tuber harvested	Latently infected tubers after 4 week incubation	% infection
I *	I	11	1	
	II	9	1	10.52
	III	18	2	
	Mean	12.7	1.3	
II	I	18	3	
	II	14	2	18.4
	III	17	4	
	Mean	16.3	3.0	
III	I	13	9	
	II	10	4	60.00
	III	7	5	
	Mean	10.0	6.0	
IV	*Satellite Plot	13	.0	0
Mean				22.30

** I- ½ Fortified compost + ½ Fertilizer + ½ EM Spray + Inoculated by R. solanacearum suspension and variety; II– EM fortified compost + EM Spray + Inoculated by R. solanacearum suspension using improved variety;III – Farmers practices (½ fertilizer + local seed)inoculated by R. solanacearum suspension; IV- Improved management (fertilized, bacterial wilt free improved variety and un inoculated soil with R. solanacearum) as **ST- Satellite treatment*

Table 3: Effect of EM on pathogens associated with potato tubers, 2009 (combined over four sites)

Variety	Treatment *	CSs (1-5 scale)	BWI (%)	Lin.(%) DAs 45
Jalene	1	1.33	22.75	53.33
	2	1.50	25.47	56.66
	3	1.30	18.84	26.73
	4	1.97	19.64	63.33
	5	1.93	25.00	33.40
	6	3.33	19.55	50.00
Mean		1.89	20.84	47.24
Local	1	3.63	27.00	53.33
	2	3.33	33.00	50.00
	3	2.50	19.20	30.00
	4	3.93	21.00	73.33
	5	3.67	31.22	46.67
	6	3.53	19.48	76.77
Mean		3.43	24.98	53.33
CV %		14.92	17.23	22.37
F- test	Variety	S	NS	NS
	Treatment	NS	NS	NS
	V X T	S	NS	NS

**1= improved management package (full fertilizer rate and recommended spacing); 2= soil amended with full rate of EM - fortified compost, recommended spacing; 3= Soil amended with ½ EM-fortified compost and ½ fertilizer of the recommended rate for the area, ½ EM spray and recommended spacing; 4= Soil amended with full rate EM - fortified compost and fertilizer of the recommended rate for the area plus EM spray on the foliage weekly using the recommended spacing; 5= Farmers practice (1/2 fertilizer); and 6= seed tuber treated/socked in EM at a dilution of 1: 1000 for 30 minutes and with fertilizer rates.*

Though difference between varieties, treatments and variety by treatment interaction, in latent infection was statistically non-significant, and the incidence of the disease on variety Jalene had slightly lower, (47.24 %) compared to the local variety that had 53.33 %. Among treatments, the 4th treatment using improved variety had the lowest latent infection (26.73 %) and the highest being (76.7 %) on local variety treated with EM before planting. The rest of the treatments had in the range of 30.0 % to 63.3 %.

The result revealed that variety did not significantly influence the marketable tuber number, total tuber number, marketable tuber weight, and total tuber weight, but treatments exhibited significant influence on total tuber weight (Table 4). Though the varietal difference was non-significant in all yield parameters considered, the local variety gave slightly greater amount and weight of tubers compared to the improved variety. On the other hand, treatments were significantly ($P<0.05$) differ in total tuber weight. In both varieties, the highest total tuber weight was recorded on the treatment where half EM-fortified compost, half fertilizer and half EM sprayed treatment. The lowest being obtained from the treatment where there is full rate of EM fortified compost but without fertilizers application.

Table 4: Effect of effective microorganism on potato tuber yield components, 2009 (Combined results over three sites)

Variety	Treatment	MTNo	TTNo	MTwt (kg)	TTwt(Kg)/5 pants
Improved	1	146	181	16.4	21.1
	2	143	182	12.6	14.6
	3	193	216	18. 7	24.4
	4	150	195	17.4	18.3
	5	151	184	15.67	17.1
	6	127	222	18.13	18.5
	Mean	152.1	186.1	16.2	17.75
Local	1	137	182	20.7	17. 6
	2	161	248	16.1	13.4
	3	213	221	20.5	19.5
	4	188	218	12.7	16.4
	5	177	216	16.6	15.9
	6	181	233	15.9	13.4
	Mean	176.7	216.5	17.1	17. 30
CV %		16.32	21.86	15.44	22.13
LSD 0.05		NS	NS	NS	S
V		NS	NS	NS	NS
T XV		NS	NS	NS	NS

**1= improved management package (full fertilizer rate and recommended spacing); 2= soil amended with full rate of EM -fortified compost, recommended spacing; 3= Soil amended with ½ EM-fortified compost and ½ fertilizer of the recommended rate for the area, ½ EM spray andrecommended spacing; 4= Soil amended with full rate EM -fortified compost and fertilizer of the recommended rate for the area plus EM spray on the foliage weekly using the recommended spacing; 5= Farmers practice (1/2 fertilizer); and 6= seed tuber treated/socked in EM at a dilution of 1: 1000for 30 minutes and with fertilizer rates. MT No.= marketable tuber No., TTNo. = Total tuber number, MTwt (Kg)= Marketable tuber weight,TTwt = Total tuber weight*

Conclusion

In order to see the influence of EM on the pathogen, such type of studies should be carried out in permanent plots because the disease-causing organism (*R. solanacearum*) are suppressed or controlled through natural process by increasing the competitive and antagonistic activities of microorganisms in EM inoculation in which the process required time. EM also improved senescence whereas the treatment without EM but with full rate of synthetic fertilizers delayed senescence. Results from these studies suggest that living organisms and substances produced or released from EM may inhibit growth of the pathogens but the mode of action is not known. So possible beneficial effect of EM, as demonstrated in the present report, it have been evaluated to a limited extent. Farther intensive investigations into potential beneficial uses may lead to the adaptation of EM technology as a component in an Integrated Bacterial Wilt management.

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Potato Tuber Seed Cycle: Contribution of Latent Infection in Progeny Seed Tubers for the Spread of Potato Bacteria Wilt (Ralstonia *Solanacearum*) and Tuber Yield Losses

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Introduction

Since BW cannot be controlled by chemicals and persists in the soil for a long time, it is increasingly becoming a major threat to potato production in the country. Apart from cultivars bread for resistance, some varieties that were not bread for resistance behave as resistant and or/tolerant in specific situations. Achat was reported to be highly resistant variety in Brazil, in Mexico, and Molinera, which was bread for resistance, and Lopez, which was not, behaved as equally resistant variety. In Rwanda, several varieties behaved as resistant or tolerant (French, 1994; Vander Zaag, 1986). Hence, host resistance has proven to be useful to control the disease, and is potentially the most effective way to control the disease, especially as components in Integrated Diseases Management (Bekele and Berga, 2001). The destructiveness of this pathogen and its exceptional ability to survive in soil (Hayward, 1991), plant debris and hair roots of plant hosts (Graham, et al,. 1979 and, Granda and Sequeira, 1983) as well as its means of dissemination contribute to massive crop losses (Kelman , 1998). The presence of a variety of weed species that are symptomless carriers of the pathogen (Tusiime et al., 1996b), infested seed tubers (Kelman, 1998) and extensive soil infestation are the main contributing factors for higher tuber yield losses. Seed tubers are the major path of dissemination for BW. Tubers harvested from polluted soils are potentially infected and convey the pathogen latently and hence tubers with latent infection are taking the largest share in dissemination of the disease as well as for huge tuber yield loss. The objectives of this experiment were to look into effect of the recycled seed on total production and disease incidence; and to quantify the losses attributed to latently infected potato tuber.

Materials and Methods

On-farm research on the tuber yield loss of potato due to BW was conducted in Shashemene Woreda, for four successive seasons (2009B, 2010A, 2010B and 2011A) using a participatory research approach with farmers. Experimental fields were located at 08°12' N (latitudes) and 08°35' N (longitude) with altitudes ranging from 2017 to 2211 masl. The selection of participating farmers and communities was based on the presence of BW in their field plot. Recommended cultural practices for potato production were applied in raising the experimental plots. Improved variety, Jalene, Gudene and Awash, which were less susceptible to BW and local varieties (Nech Abeba and Agazer) which were relatively susceptible to the disease were planted at a spacing of 75 x 30 cm; hilling at planting; rouging of volunteer potatoes; and post emergence cultivation were exercised by farmers. The experiment was laid out in a randomized complete block design. Within a season, each farmer's field (farm) was considered as a replication; the number of fields per season was 5 but, one of the experimental field was not handled properly by the group hence it was excluded.

Plots were assessed at weekly intervals to determine days to onset of first wilt symptoms. Subsequent counts of wilted plants were made at two-week intervals. At each assessment, all plants that showed either complete or partial wilting were recorded. These were marked with steak to avoid double counting in subsequent assessments and also to recognize those plants completely died during the growth period. The counts of symptomatic plants were expressed as a percent of the total number of plants emerged. Late blight was controlled with one spray of Ridomil MZ for the improved varieties and local varieties however received additional two sprays of a fungicide Dithane M-45 starting from the first visible symptoms. At harvest, data were recorded on yield, including total and marketable yields, as well as rotten tubers due to BW. Farmers participated in collecting disease data and in harvesting, followed by discussions to evaluate the treatments. Data on BW incidence were subjected to square root transformation before analysis. The relationship of mean tuber yield and disease incidence in the field was used to estimate tuber loss for ware potato production scenario. In seed potato production scenario however, the loss was determined based on the relationship of mean tuber yield and mean latent infection. Percent latent infection was calculated based on 20 randomly sampled tubers which were looking healthy from each treatment. Tubers were diagnosed for the presence of latent infection in the laboratory after the tubers were incubated at 32 ±2 °C.

Results and Discussions

The progress of the disease was significantly ($P<0.05$) increased as seed cycle repeated. In all cycles mean incidence of the disease was significantly high in both local and improved varieties. However, the incidence was higher by about 10 % on the local variety compared to the improved ones (Figure 1A and 1B). Significantly highest mean disease incidence was recorded in the fourth tuber seed cycle compared to the third and the second seed cycle. In the first cycle, mean incidence was 9 % in the improved while 13 % in the local varieties. It increased to 22 %and 30 % in the second cycle, and further increased to 31 % and 43 % third cycle for improved and local variety respectively. In the first season, the improved varieties gave the highest mean tuber yield compared to the mean yield of local varieties (Table 1). Use of tuber seeds from previous harvest for subsequent planting reflected in drastic declination of marketable tuber yield in the following harvest. Mean marketable tuber reduced by 17.1 %, 28.6 % and 40 % on the improved varieties in the 2nd 3rd and 4th seed cycle, while the corresponding percentage of mean yield on the local varieties were 12 %, 29 % and 45%. However, overall mean yield have been reduced by 20 %, 37 % and 49 % in the increased cycle respectively. The results obtained from this experiment indicated that the fair uniformity of the pathogen distribution in the field, as it is believed to be the hotspot for BW (Bekele, 1996), which enables to investigate the role of varietal differences in response to the disease to the high land race 3 biovar 2-A strain of bacterial wilt. As to the previous reports (Rueda, 1990and French, 1994) the two groups of potato varieties showed their difference in reaction to the disease, which also reflected in latent infection in the progeny tubers and total and marketable tuber yield.

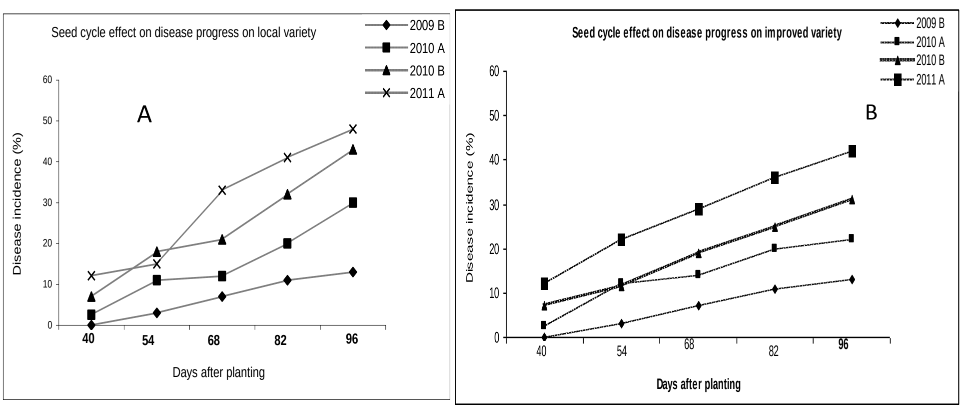

Figure 1: Disease progress with time (A) on local varieties and (B) improved varieties from 2009B to 2011A seasons in Shashemene

The improved and local varieties gave a mean tuber yield of 33 t/ha and 24 t/ha, respectively which are significantly (P<0.05) different (Table 1). Though there was significant (P<0.05) differences in the yield of progeny tubers among varieties, tuber yield in both category (improved and local)of varieties decreased as the progeny tubers was used as a seed for the subsequent seasons. However, the tuber yield of local varieties were more affected compared to the improved varieties by the tuber seed cycle.

Percent latent infection in progeny tubers of local varieties was also significantly (P<0.05) higher compared to improved varieties. In some parts of highland Ethiopia, crop senescence is not necessarily the criteria for harvest rather fields serve as a store for their produce and harvesting could often extend from June to December. Some tubers remain in the field and are used as seed for following season. The largest proportion of tubers used for seed in this system are small, inferior quality and were sources of diseases (Amsal and Bekele, 1997). However, farmers don.t realize that such tubers are low in productivity due to the accumulation of pathogens in the tubers. As a result of this type of seed system, potato yield declines year after year due to seed degeneration. In the same way farmers in the mid highland areas often keep tubers for the next planting in different ways, in some are they store in peats and some spread in floor and some acquire from the market. In all cases, farmers recycle their tubers from season to season. Results of this experiment in which the tubers are cycled for four seasons showed that, the yield significantly reduced as the progeny tuber recycled repeatedly. In the first progeny the marketable mean yield reduced by 10 % on improved and 12 % on local variety. Whereas in the 2nd and 3rd cycle percent reduction increased to 19% and 38% in improved variety, correspondingly 23 % and 41 % on the local variety. Mean tuber yield of the two group of varieties reduced by 11 %, 23 % and 41 % in the 1st , 2nd and 3rdseed cycle, respectively.

Table 1: Mean marketable tuber yield of three improved varieties and two local varieties in 2009B to 2011A,in the vicinity of Shashamene (yield data pooled from four farms)

Season	Variety and Yield (t/ha)					
	Improved	**Yield reduction (%)**	**Local**	**Yield reduction (%)**	**Mean**	**Yield reduction (%)**
2009 B	39.1	-	31.2	-	35.15	-
2010 A	35.3	10.2	27.0	12 .0	31.20	11.2
2010 B	31.6	19.2	22.4	29.1	27.0	23.2
2011 A	24.0	38.4	17.3	45.1	20.6	41.4
Mean	32.5		24.5			
CV %			13.5			

The relationship between mean tuber yield and incidence of bacterial wilt in the four season had negative and strong relationship being y = -0.3826x + 35.609 (R^2 = 0.9923) and y = -0.4423x + 38.287 (R^2 = 0.9982) over local and improved varieties (Figure 2 and 3). The mean yield loss was in the range of 7 % to 32 % on the local varieties and 4% to 21 % on improved varieties under ware potato production scenario. Tuber yield loss of local variety in the first progeny was estimated to 7 % and increased by 50 % loss in each cycle. The same trend was also recorded in an improved variety.

The relationship mean seed tuber over percent latent infection in tuber is presented in Figure 4 and 5. The relationship of mean tuber yield of varieties and latent infection demonstrated strong and significant ($P<0.001$) relationship, y = -0.4228x + 53.636 (R^2 = 0.9831) and y = -0.6971x + 56.257 (R^2 = 0.9936) with local and improved varieties, respectively. Mean tuber yield loss, on the local varieties, in the 1st seed cycle was 20.4 % whereas in the 4th cycle it increased to 67.34 %. The same increment trend was also observed on the improved variety and the tuber loss of 5.34 % was recorded in the 1st cycle whereas in the 4th cycle it was as high as 5 fold.

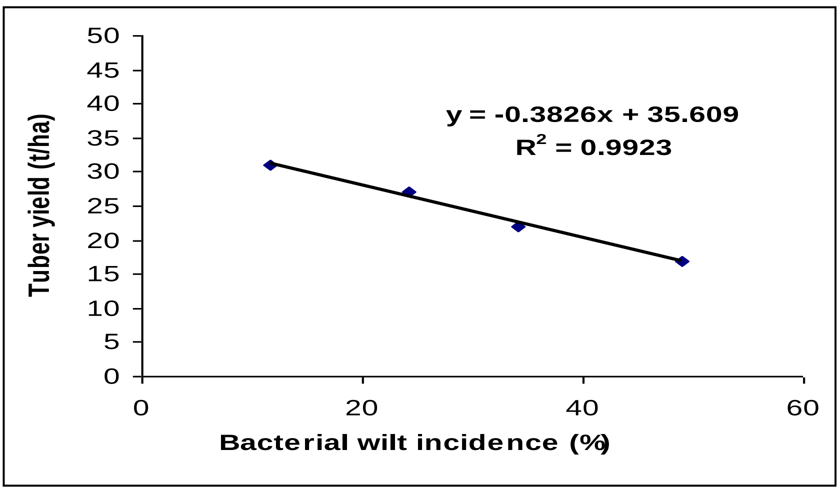

Figure 2: Relationship between potato mean tuber yield and incidence of bacterial wilt in four cycles of progeny seed tubers using local varieties in Shashamene

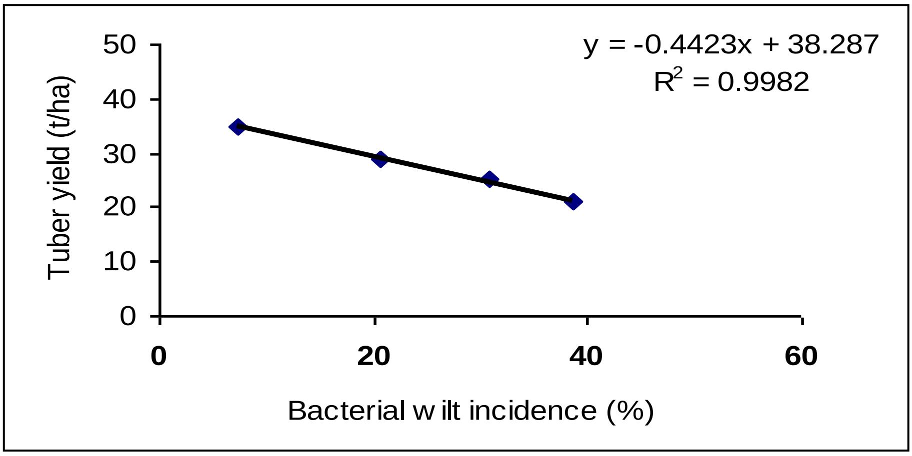

Figure 3: Relationship between potato mean tuber yield over incidence of bacterial wilt in four cycles of progeny tubers using improved varieties at Shashamene.

Seed-borne wilt or latent infection has long been recognized as the principal method of dissemination (Hayward, 1991) and the movement of tuber seed from infected fields at worm location like Shashamene to cooler areas has apparently been reported to have high incidence of the disease in healthy appearing fields. Such infected seed has often resulted in serious outbreaks of the disease appearing fields of north western and central Ethiopian highlands (Bekele, 2996, Bekele and Eshetu, 2008). This study revealed that use of previous harvest as a seed for subsequent potato planting contributed to a serious tuber yield loss in terms of seed health and over all potato production as well as help for the dissemination of the pathogen. Our results agreed with the findings of French, 1994, in which latent infection in progeny tubers are the main vehicle for the spread of the disease. Hence, seed tubers should be checked for their health from the source so that latent infection could be monitored. That would result in good wilt control, higher yields, and reduced wilt spread.

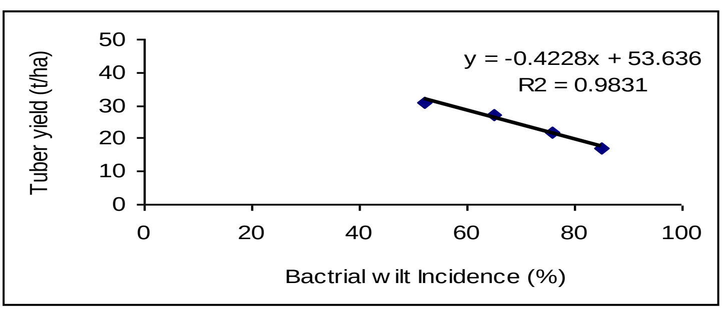

Figure 4: Relationship between potato mean tuber yield over percent latent infection of bacterial wilt in four cycles of progeny seed tubers using local varieties in Shashamene

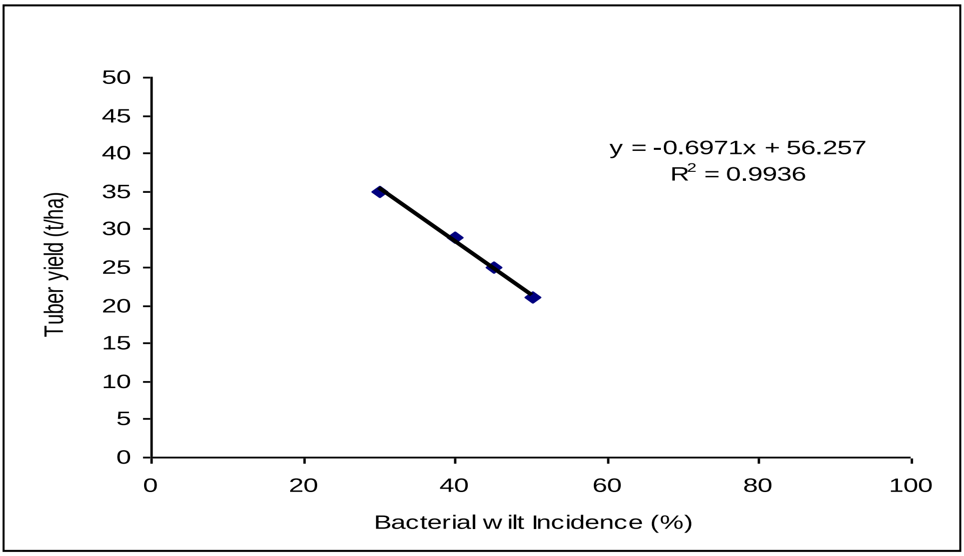

Figure 5: Relationship between potato mean tuber yield over percent latent infection of bacterial wilt in four cycles of progeny seed tubers (2009A to 2011A) of four locations using improved varieties in Shashamene,

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Viruses And Bacterial Wilt Disease Of Potato In Western Amhara

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Introduction

Diseases caused by viruses, bacteria and fungi are considered among major biotic constraints of potato production, accounting for low productivity. Symptoms suggestive of viral diseases are widely observed and distributed in the major production areas in the west Amhara region. Occurrence of potato viruses in Ethiopia was reported in studies conducted in central, south and southeast Ethiopia during the 1984 and 1985 crop seasons (Agranovsky and Bedasso, 1985; 1986). The results of these consecutive studies indicated the presence of *Potato virus X* (PVX), *Potato virus S* (PVS), *Potato leaf roll virus* (PLRV), *Potato virus Y* (PVY), *Potato virus A* (PVA) and *Potato virus M* (PVM) . These studies, however, did not include the main production areas in the country such as the west Amhara region, and the identity, distribution and status of viruses attacking potato have not been systematically studied using specific diagnostic methods. Studies made elsewhere indicate that yield losses as high as viral diseases in potato that can cause varietal degeneration (Cyperus and Bokx, 2005) can incur 90%. In addition, symptoms of some viruses of potato were often not apparent when found in association with the mosaics caused by PVX, PVY and PVS, so identification by visual observation of symptoms alone is not reliable (Fletcher *et al.*, 1996; Burrows and Zitter, 2005).

Bacterial wilt of potato (*Ralstonia solanacearum*)can also cause significant yield loss to potato (Ajanga, 1993). Because this pathogen stays in the soil for several years it prohibits subsequent production of potato in the same field. Moreover, this pathogen may stay latent without showing any symptom in the field with the consequence of high impact on tuber yield in the upcoming season. Detection of latent infections requires sensitive diagnostic methods, but as yet such methods have not been adopted in Ethiopia to inspect potato seed tubers and monitor the status of latent infection and its consequences. As the crop is propagated vegetative means, the diseases can easily be transmitted through tubers and cause very high economic losses across wide geographic areas.

This study was carried out to generate information on the identity, incidence and distribution of viral diseases and bacterial wilt of potato in the major production areas of west Amhara with particular emphasis on emerging seed production schemes and germplasm evaluation work.

Materials and Methods

Field visits and sample collection

An intensive survey and sample collection was conducted during the main rainy season of 2008 (from July– August) in selected representative potato growing areas in four administrative zones of the west Amhara region (Figure 1). Samples for virus and bacterial wilt assay were collected from three systems: potatoes grown for seed, ware potato, and research plots in the west and north Gonder zones (Table 1). Sampling was done to meet three main objectives: typing of potato viruses occurring in the region, confirmatory test for bacterial wilt, and assessment of virus and bacterial wilt disease incidence.

***Virus diseases*:** For virus typing, leaf samples with symptoms suggestive to virus infection were collected from about 1460 plants in the surveyed areas. In each field, one to three composite samples were taken depending on the type and diversity of symptoms encountered, with each composite sample being a mixture of 10 individual plants. A total of 146 composite samples were collected from 38 fields at 16 locations, including the experimental plots at the Adet Agricultural Research Centre (AARC) and the Gonder Agricultural Research Centre (GARC). Leaflets were collected from the upper, middle and lower parts of at least 10 individual plants per field. Sampling was done at a constant interval depending on the distribution of crop in the respective locations surveyed following simple random sampling techniques and by moving diagonally across each field. At the time of sampling crops were at the flowering-tuber setting stage. Disease incidence in the field was recorded visually as percent infection. Both symptomatic and non-symptomatic samples were collected, but as the main aim of this survey was to type viruses occurring, emphasis was given to symptomatic plants, with plants showing different symptoms collected separately. Testing for six viruses was conducted in the tissue culture and serology laboratory of the Amhara Region Agricultural Research Institute (ARARI) at Bahir Dar.

Sampling for bacterial wilt in the field was performed following the simple random sampling strategy outlined for the viral diseases. Instead of leaves, in this case, tuber and stem samples were collected. In addition to random samples for testing latent infection, symptomatic plants with bacterial wilt-like symptoms were collected for confirmatory tests for *R. solanacearum* infection. Stem and tuber samples were mainly collected from released varieties in seed and ware potato fields and in variety evaluation experimental plots at research stations. A total of 62 tuber and 29 stem samples were collected for laboratory testing in 23 and 12 fields from 15 and 12 locations, respectively. Emphasis was given to tuber sampling in all production systems to determine the level of infection, as tubers are the major source of inoculum.

Collected leaf, tuber and stem samples were labeled, put in plastic bags, taken to the laboratory and processed immediately or kept at 4-6^{o}C in the refrigerator until processed for testing by DAS-ELISA and NCM-ELISA, respectively, for detection of viruses and bacterial wilt pathogen. During potato field inspection, data related to crop variables such as growth stage and variety, disease symptoms, disease incidences (%), purpose of production (ware, seed or research), altitude of each location and their corresponding geographical position using the geographical positioning system (GPS) were collected.

All composite leaf samples were tested by DAS-ELISA (Clark and Adams, 1977) following standard protocols described in the International Potato Centre (CIP) DAS-ELISA kit instruction manual. DAS-ELISA kits were provided by the CIP serology laboratory at Lima, Peru. Each sample was tested for 6 viruses, namely PLRV, PVA, PVM, PVS, PVX and PVY.

Stem and tuber samples were tested for *R. solanacearum* by NCM-ELISA. Sample preparation and serological tests were performed according to procedures outlined in the CIP NCM-ELISA kit instruction manual for detection of *R. solanacearum* in potato (Priou, 2001). The kit was supplied by the CIP serology laboratory at Lima, Peru. Tuber and stem samples with bacterial wilt symptoms were directly processed and tested by NCM-ELISA without enrichment. In addition, to increase the sensitivity of the test and detect latently infected plants, an enrichment procedure was carried out for non-symptomatic plants in semi selective broth (modified SMSA) before performing NCM-ELISA. The enrichment was done by incubating the tuber and stem extracts prepared from non-symptomatic samples in M-SMSA for 48 hours at 30^{o}C(Priou, 2001).In each of the tests conducted, CIP positive (at concentrations of 10^6, 10^7, 10^8 bacteria/ml) and negative controls were used.

Results

Viral and bacterial wilt diseases incidence in the field based on symptoms

The altitudes and geographical positions of surveyed areas were between 1800 and 3260 meters above sea level, and N10° 46.743 – N12° 34.249 and E037° 027.690 – E038° 30.823. The most commonly observed virus-like symptoms in potato were leaf curling, inter-venal mosaic, mottling, reduced leaf size, deepening of leaf veins, narrow leaves and stunting. At the time of sampling, most plants were at the flowering-tuber setting stage, which is a good stage for symptom expression. Virus disease incidence assessed visually varied from zero to 100% in different farms and variety evaluation experimental plots (Table 1). The highest incidences for virus-like symptoms were commonly recorded on experimental plots. For instance, in variety trial-1 (VT-1) assessed at AARC, virus incidence as high as 100% was recorded on variety *Guassa* planted as a standard check, whilst an incidence of 50% was recorded in two other varieties, *Gudene* and *Key Abeba* (used as a local check). An incidence of 85% was also recorded in one of the test clones included in this variety trial. In variety verification trial (VT-2), disease incidence ranged from 25-70%, whereas in other variety development experiments (VT-3) evaluated, highest incidences of 100%, 80% and 80% were respectively recorded on three test clones. Low incidence (2.5%) was recorded on the standard check (Jalene), while a test clone 'CIP 392640.539' was apparently free of any virus-like symptoms at the time of survey. When on-station seed increase (OSSI) plots of released potato varieties were visually evaluated, highest (>90%) incidence for virus-like symptoms was recorded in variety 'Degemegn', and lowest incidence (2%) in variety 'Tolcha'. The other varieties had incidence of virus-like symptoms ranging from 15 – 30%. On farmers' fields, disease incidence was less when compared to experimental plots. The highest incidence recorded was in the range of 50-60% in three out of five fields assessed around the Injibara area in the Tilili woreda of the Agew Awi zone on variety 'Jalene'. Farmers' fields inspected around Adet in the Yilmana Densa woreda had highest virus disease incidences in the range of 20-30% (Table 1).

In north Gonder, disease incidence was between 10-15% on variety *Jalene* planted at an on-farm fertilizer trial field at Chilga. In the same location, 100% incidence was recorded on one of the clones included in the variety trial. Other test clones had incidences ranging between 2 – 30%. In another variety trial, the highest and lowest incidences were 75% and 5%, respectively. On the other hand, low disease incidences of 5 -10% were recorded on farmers' fields planted with improved varieties in the north Gonder administrative zone. Low levels of virus-like symptoms were recorded in farmers' fields inspected in the south Gonder zone with common symptoms being deepening of veins and inter-venal mosaic. The latter was particularly widely distributed in farmers' fields planted with local potato varieties.

With respect to bacterial wilt, plant wilting, browning of vascular tissue when cut and oozing of milky fluid from the vascular ring of cross-section cut tubers were the most commonly encountered disease symptoms. Incidences as high as 25% were observed in localities around Adet Zuria in the Yilmana Densa woreda (west Gojam zone) and some farms in the Chilga woredas of the north Gonder administrative zone (Table 3).

Viral disease identity and incidence as determined by DAS-ELISA

DAS-ELISA testing of symptomatic plants indicated that out of the six viruses for which antibodies were provided, the occurrence of five viruses was confirmed in west Amhara. PVA was not detected in any of the samples tested. Among the five viruses, PVS was found to be the most widely distributed in the sub-region followed by PVX, PVM, PLRV, and PVY (Table 2). In addition, the first two viruses (PVS and PVX) had high incidences compared to the other viruses identified. In most cases, simultaneous detection of two or more viruses was common, particularly in samples collected from experimental plots (Table 2). In addition, some uncommon symptoms such as narrow leaves were observed in some fields, which were assumed viral, but the antibodies used in this study could detect no virus.

All the five viruses were detected in samples collected from experimental and on-station seed increase plots at AARC, and farmers' seed production fields near Adet in the west Gojam zone. The highest incidence was among samples collected from experimental plots (Table 2). In all the variety trials inspected at AARC, mixed infections of all the five viruses (PLRV, PVM, PVS, PVX and PVY) were recorded. In the north Gonder zone, four of the five viruses were recovered in samples collected from experimental plots at Chilga. In this area, PVS and PVM were equally identified in 59% of the samples. PLRV and PVX were identified from respectively, 48% and 22% of the samples collected in Chilga at on-farm experimental plots. Mixed infection of one to four viruses were recorded in samples collected from experimental plots and farmers field in north Gonder. The most common virus combination was PLRV, PVM and PVS in four samples, while mixed infections of PVM, PVS and PVX; PLRV and PVS; PVM and PVS were each recorded in two samples. Combinations of PLRV, PVM, PVS and PVX;

PLRV and PVM; PVS and PVX; PLRV and PVX were each detected in one sample. Two viruses (PVS and PVX) were detected in five samples collected from farmers' seed potato production cooperative fields at Enjibara and Tilili areas (Awi zone). PVS was identified from all of the samples, while PVX was recovered in mixed infection with PVS from only 2 (40%) of the samples (Table 2).

In the south Gonder zone, leaf samples with symptoms suggestive of virus infection were collected from 10 fields (seven in Tach Gaint and three in Lai Gaint locations). The result showed that two (PVS and PVX) of the six viruses tested were detected, and all the tested samples were positive for PVX, with or without PVS. Of the total samples, 6 (60%) of 10 were PVS-infected. Mixed infections of PVS and PVX were detected in six out of 10 samples. Most of the samples tested from south Gonder were collected from farmers' fields planted with local varieties indicating wider distribution of PVS and PVX in local potato production systems as well (Table 2).

Bacterial wilt incidence and distribution as determined by NCM-ELISA

A total of 31 symptomatic plant samples (19 stem and 12 tuber samples) were collected for confirmatory testing of *R. solanacearum* infection (Table 3). All tuber samples collected from farmers' seed potato production cooperative farms planted with the variety Jalene at Adet gave positive reactions to the pathogen. Similarly, at the same location, 86.7% of the stem samples and 66.7% of the tuber samples collected from farmers' seed increase plots planted with the variety Gera tested positive. All the stem samples collected from symptomatic plants at the Chilga on-farm experimental plots were found positive when tested by NCM-ELISA.

In addition to symptomatic samples, a post enrichment NCM-ELISA test was carried out for non-symptomatic (apparently healthy looking) potato plants to detect latent infection by *R. solanacearum* (Table 4). Of the total 50 tuber and 10 stem samples tested, *R. solanacearum* was detected in 11 (18.3%) out of 60 samples. As shown in Table 4, of the five administrative zones sampled, the bacterium was detected in all except south Gonder. Latent infection by *R. solanacearum* was recovered from both the local and improved varieties that were tested.

Discussion

From this survey in the west Amhara sub-region of Ethiopia, PVS was the most frequently identified and distributed among six potato viruses tested in respective zones and across zones studied, followed by PVX, PVM, PLRV and PVY. Mixed infections with two or more viruses were also commonly detected, among which PVS and PVX combination was recorded in 12 samples. This finding correspond with the survey results conducted in central, south and southeast Ethiopia during the 1984 and 1985 seasons (Agranovsky and Bedasso, 1985; 1986) that reported PVS and PVX as the most common viruses identified with PLRV, PVY, PVM and PVA being less widely distributed in the regions surveyed. However, PVA was not identified in any of our samples collected in west Amhara region. Causing a mild mosaic, PVS is the most frequently found virus in potato worldwide and is very contagious (Cyperus and Bokx, 2005). Infection rates of 100% have been reported in many countries (Cyperus and Bokx, 2005), which agrees with the present results. It is also known that infection by PVS may result in yield losses of up to 20%, but more losses can be incurred if infection is combined with PVX. Being the second and third most widely distributed viruses next to PVS, PVX and PVM cause mild symptoms and bring about low yield loss, however, they are reported to cause significant impact on potato yield when in combination with PVS and other viruses. PLRV was the fourth most widely distributed virus, and Cyperus and Bokx (2005) indicated that more than half; while in highly sensitive varieties yield loss can be as much as 90% often reduce yields of plants with secondary infection of PLRV. As mixed infections of two or more of these viruses were recorded in many of the locations surveyed, one can assume that potato farmers are facing heavy yield losses every year, and evidence for this comes from the high disease severity and incidence observed in some farmer fields and experimental plots at research stations.

Some solanaceous plant hosts, weeds (*Chenopodium amaranticolor, Datura metel,* and *Datura stramonium)* and plants belonging to other families such as *Nicotina* spp. and *Phaseolus vulgaris* were commonly grown in the study area, and are alternate hosts for some of the viruses detected (Kook-Hyung, 2001). This contributes for wide spread occurrence of these viruses along with the presence of aphid and biting insect vectors. Another possible factors to account for the widespread and high virus disease incidences may be the overlapping potato growing seasons and lack of seed potato health testing program.

The presence of different viruses at a higher incidence rate on variety trials under research managed experimental plots than farmer's fields and on-farm seed increase plots seems paradoxical as far as the high level of management in research stations and poor management farmers' fields. However, this result seems to have been associated with the presence of susceptible clones in the test materials and/or because of high inoculum build up in the experimental stations over years without break. Rarely encountered symptoms in some potato experimental fields sampled such as narrow leaves, which were suspected to be caused by viral infection, did not give positive reaction when tested against antibodies for the six viruses. This may indicate the presence of other viruses or virus-like organisms that could not be detected by the antibodies used in this test and proposed for further investigation.

One of the objectives of using NCM-ELISA was a confirmatory test whether symptomatic potato plants are caused by bacterial wilt or not. In the direct NCM-ELISA test (Table 3), of the total of 12 tuber and 19 stem composite samples collected from symptomatic plants, *R. solanacearum* was recovered from 8 (66.7%) tuber and 17 (89.5%) stem samples, respectively. Overall, *R. solanacearum* was detected in 25 (80.7%) of the 31 tuber and stem symptomatic samples. From this result it is evident that there is high chance that most of the potato plants with wilting symptoms are infected by *R. solanacearum*. Only six (19.4%) out of the 31 samples tested were negative. Priou (2001) reported that post enrichment NCM-ELISA can detect as few as 10 bacteria per ml of extract instead of 10^6 - 10^7 bacteria/ml without enrichment. In this study, the negative reaction of some symptomatic samples when tested by NCM-ELISA without the enrichment procedure may be attributed to low bacterium concentrations in the extracts, or due to infection of plants by other soil borne pathogens and/or insects that could cause wilting symptoms similar to *R. solanacearum,* and this probably resulted in false negatives. However, had it not been for shortage of reagents during this study, it would have been imperative re-testing and confirming all symptomatic samples that were negative by using post enrichment ELISA. This therefore suggests the need for paying particular attention while collecting and rating bacterial wilt disease incidence in the field and emphasizes the importance of using efficient detection methods such as post enrichment NCM-ELISA.

When 60 random samples (50 tuber and 10 stem samples) collected from apparently healthy looking plants were tested by post enrichment NCM-ELISA for latent infection, *R. solanacearum* was recovered from 11 (18.3%) of the samples, both from improved and local varieties in different farms as well as in tuber and stem samples at higher altitudes over 2500m above sea level. This result supports findings by Ciampi *et al.* (1980) and Hayward (1991) who have confirmed latent infection of *R. solanacearum* in tropical cool conditions at altitudes above 2500m, and that of Janse (1996) who has indicated that bacterial wilt has become a serious threat to potato seed production in cool, temperate countries of Northern Europe. This level of latent infection is high, particularly considering that bacterial wilt is a quarantine disease of zero tolerance level in seed tuber production (Priou *et al*., 1999b). Interestingly, assuming that bacterial wilt is a quarantine disease of zero tolerance level in seed tuber production, higher levels of latent infection (20%) were recorded in tuber samples collected from potato seed tuber production fields at altitudes of 2626m above sea level (Table 3). These potato seed tubers were meant to be distributed to growers for use as a planting material in the subsequent growing season, indicating the potential danger of using potato seed tubers from such infected fields as planting materials in the upcoming season. As suggested by Nortje (1997) and Kakuhenze *et al.* (2000), this is a consequence of a lack of rigorous seed health testing and a certification programme, which is also one of the major drawbacks within the potato seed production system in the area. This drawback may in part be associated with the lack of technical capacity, facilities and availability of affordable and efficient detection methods.

Results of this study have shown comparably high levels of latent infection of *R. solanacearum* in both stem and tuber samples tested, indicating the potential for using stem sampling as an alternative to tubers, since tuber sampling has economic implications. Mwangi *et al.* (2008) observed similar results and found a positive correlation between stem and tuber testing. We recommend use of stems as an alternative sampling to tubers in seed health testing programmes.

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Table 1: Virus disease incidence in potato as determined from symptomatic samples in growers fields and experimental plots during a survey in the west Amhara region, Ethiopia, in 2008

Zone	**Farm type***	**No. of fields**	**No of samples**	**[a]No. of fields / exp. Plots with incidences (%) of:**							
				<5	**5-15**	**16-25**	**26-35**	**36-45**	**46-55**	**56-65**	**>65**
West Gojam	EP (VT-1)	1	18	4	7	0	0	0	5	0	2
	EP (VT-2)	1	8	0	0	1	4	0	1	0	2
	EP(VT-3)	1	11	2	3	1	1	0	0	0	4
	EP(VT-4)	1	14	1	5	4	3	1	0	0	0
	EP (VT-5)	1	20	15	2	2	1	0	0	0	0
	OSSI	1	15	4	3	6	1	0	0	0	1
	GH	1	5	1	0	0	0	0	0	0	0
	FF	3	3	0	1	2	0	0	0	0	0
	OFSI	6	6	3	0	1	2	0	0	0	0
	Sub total	16	100								
Agew Awi	OFSI	5	5	0	2	0	0	0	3	0	0
	Sub total	5	5								
North Gonder	EP (OFT)	1	3	0	3	0	0	0	0	0	0
	EP (VT-1)	1	10	4	3	1	1	0	0	0	1
	EP(VT-2)	1	14	5	4	4	0	0	0	0	1
	FF	4	4	1	3	0	0	0	0	0	0
	Sub total	7	31								
South Gonder	FF	8	8	5	3	0	0	0	0	0	0
	OFSI	2	2	1	1	0	0	0	0	0	0
	Sub total	**10**	**10**								
	Total	**38**	**146**								

**EP (VT 1-5) = Experimental plots sampled in different on-station variety trials at AARC and GARC; EP (OFT) = on-farm trial; OSSI = On-station seed increase; OFSI = Farmers potato seed production cooperative farm; OFT = On-farm trial; FF = Farmers ware potato producers field; GH = Greenhouse samples.*

[a]For experimental plots and OSSI, each sample represents a single plot of an experiment or seed increase plot and incidence was recorded per plot, whilst for other samples incidence was calculated per field

Table 2: Detection of potato viruses by DAS-ELISA in samples collected from the west Amhara region during the main rainy season, 2008.

Zone	**Woreda**	**Field types**	**No. of fields**	**No of samples**	**Viruses Detected out of the samples collected and (percent)***					
					PLRV	**PVA**	**PVM**	**PVS**	**PVX**	**PVY**
West Gojam	Adet	EP	5	71	43 (60.0)	0	38 (53.5)	60 (84.5)	40 (56.0)	20 (28.0)
		OSSI	1	15	2 (13.3)	0	5 (20.0)	6 (40.0)	2 (13.3)	2 (13.3)
		FF	3	3	1 (33.3)	0	0	2 (66.6)	0	0
		OFSI	6	6	2 (33.3)	0	1 (16.6)	4 (66.6)	4 (66.6)	1 (16.6)
	Bahir Dar	GH	1	5	0	0	3 (60.0)	4 (80.0)	1 (20.0)	1 (20.0)
Agew Awi	Tilili/Kosober	OFSI	5	5	0	0	0	5(100)	2(40.0)	0
North Gonder	Chilga	EP	3	27	12 (48.0)	0	16 (59.0)	16 (59.0)	6 (22.0)	0
		FF	4	4	0	0	1 (25.0)	4 (100)	0	0
South Gonder	Tach Gaint	OFSI	2	2	0	0	0	1 (50.0)	2 (100)	0
		FF	5	5	0	0	0	3 (60.0)	5 (100)	0
	Lai Gaint	FF	3	3	0	0	0	2 (66.6)	3 (66.6)	0
Total			38	146	60 (41.0)	0	64 (43.8)	117 (80.1)	65 (46.4)	24 (16.4)

EP- Experimental plots; OFSI-farmers seed potato production field; OSSI- On station seed increase; FF- Farmers ware potato field planted with local cultivars, GH = green house samples.

**Figures in parenthesis indicate percent infection*

Table 3: Detection of bacterial wilt in symptomatic tuber and stem potato samples from the westAmhara region in Ethiopia by direct NCM-ELISA without enrichment

Zone	**Symptomatic samples**							
	Woreda/Locality	**Altitude (m)**	**Variety**	**Field type sampled**	**Plant part Sampled**	**Field incidence (%)**	**No of samples**	**NCM-ELISA Positive samples**
West Gojam	Y/Densa - Goshiye	2626	Gera	OFSI	tuber	25	9	6 (66.7%)
	Y/Densa - Goshiye	2626	Gera	OFSI	Stem	25	15	13 (86.7%)
	Y/Densa -Adet	2205	Jalene	OFSI	Tuber	15	2	2 (100%)
	Y/Densa -Adet	2205	Local	FF	Tuber	5	1	0
North Gonder	Chilga	2254	Guassa	OFT	Stem	20	4	4 (100%)
	Sub total				Tuber		12	8 (66.7%)
					Stem		19	17 (89.5%)
	Total symptomatic samples						31	25 (80.7%)

OFSI -farmers' seed potato production field; FF- Farmers ware potato field planted with local cultivars; GH-Samples from green house potato; OFT – on-farm trial

Table 4: Detection of bacterial wilt in random asymptomatic tuber and stem potato samples from the west Amhara egion in Ethiopia by enrichment NCM-ELISA

Random samples							
Zone	**Woreda/Locality**	**Altitude (m)**	**Variety**	**Field type sampled**	**Plant Part Sampled**	**No of samples**	**Positive samples**
West Gojam	Adet	2400	Siquare(Local)	FF	tuber	2	0
		2626	Jalene	OFSI	tuber	2	0
		2400	Sisay (Local)	FF	tuber	1	0
		2205	Zengena	OSSI	tuber	1	0
		2626	Gera	OFSI	stem	5	2
		2626	Gera	OFSI	tuber	30	6
	Bahir Dar-ARARI	1800	Zengena	GH	tuber	1	0
		1800	Guassa	GH	tuber	1	0
Agew Awi	Enjibara	2503	Jalene	OFSI	tuber	2	0
		2503	Deme (Local)	FF	tuber	1	0
		2503	Samuni (Local)	FF	tuber	1	1
North Gonder	Chilga	2254	Chilga local	FF	tuber	1	0
		2254	Guassa	EF	stem	2	1
		2254	Guassa	EF	tuber	2	1
South Gonder	Tach Gaint	2892	Kara (Local)	FF	tuber	1	0
		3260	Jalene	OFSI	tuber	3	0
		3260	Jalene	OFSI	stem	3	0
	Lai Gaint- Gob gob	3054	Local	FF	tuber	1	0
	Sub total				Tuber	50	8 (16%)
					Stem	10	3 (30%)
	Total random samples					60	11 (18.3%)

OFSI -farmers' seed potato production field; OSSI- On station seed increase; FF- Farmers ware potato field planted with local cultivars; GH-Samples from green house potato.

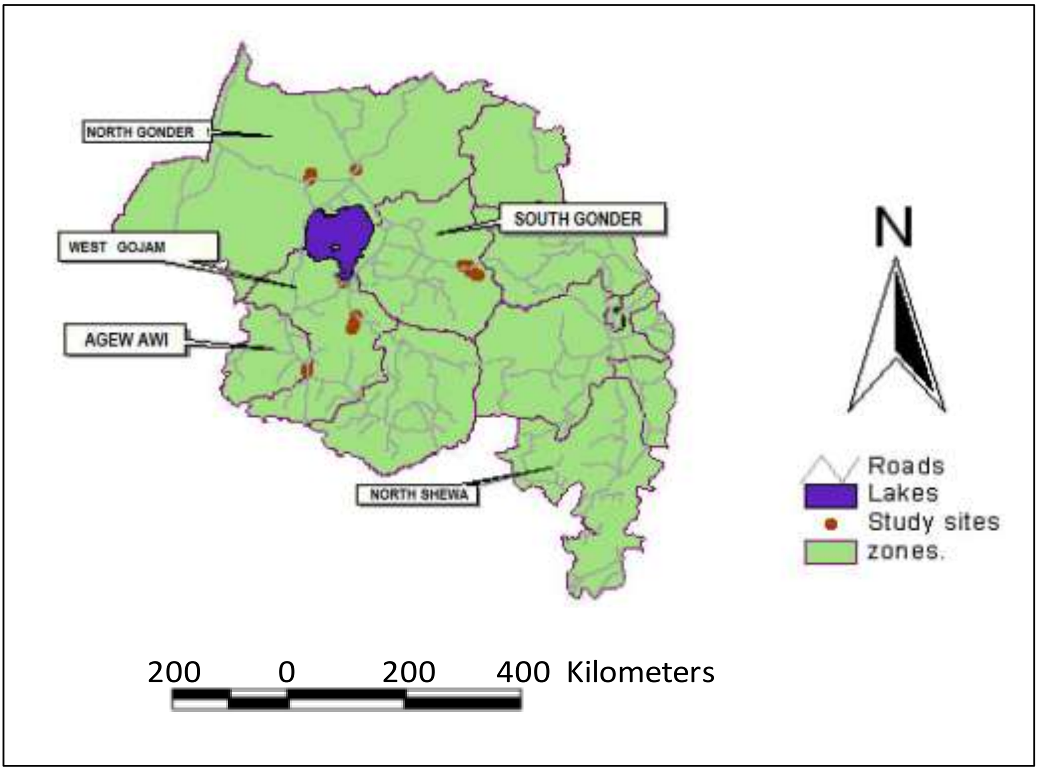

Figure 1: Map of the Amhara region of Ethiopia from which samples were collected during the main season 2008. The four sampling zones of west Gojam, Awi, north Gonder and south Gonder is shown, with the sampling sites marked.

Adoption and Impact of Potato Production Technologies in Oromiya and Amhara Regions

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Introduction

Several potato production technologies, including improved potato varieties with their associated agronomic practices, crop protection measures, and postharvest handling techniques, have been generated and promoted for beneficiaries, especially since the early 1990s. At least nine improved potato varieties, of which most originated at the International Potato Center (CIP), have been released for production since 1991 (Table 1). In addition to high-yielding and disease-resistant potato varieties, associated packages, such as recommended spacing; recommended fertilizer rate; fungicide type, rate, time of application, calibration techniques, and safe use of chemicals; and postharvest handling techniques, have been released for beneficiaries. Released improved varieties provided average yields of 218–467 q/ha under research stations and as high as 250 q/ha at farm levels. The improved varieties provided a two- to sevenfold yield advantage over the local varieties. Special emphasis was also given for the generation of appropriate seed and ware potato storage techniques. Accordingly, diffused light store (DLS) has been generated to store seed potato for longer time than local storage practices. Estimates from on-farm trials have shown that improved potato varieties with improved management practices could yield about 150–250 q/ha (Progress Reports of Horticulture Division, 2000). However, the potential yielding ability of these varieties under good management practices is more than 40 t/ha.

These innovations have been made available to farmers through the outreach activities of Holetta Research Center (HRC) in collaboration with Office of Agriculture and Rural Development and various other governmental and nongovernmental organizations (GOs and NGOs). These include verification and demonstration trials, scaling-up of technologies, farmer and subject matter specialist trainings, farmer field days, and other appropriate measures (Progress Report of Horticulture Division, 2001–2006; Progress Report of Research and Extension, 2004–2006). Informal seed multiplication schemes were also developed to create minimum access to seeds for the beneficiaries. CIP played key role in the introduction of potato germplasms as well as provision of financial and technical assistance. The Regional Potato and Sweetpotato Improvement Program (PRAPACE) has also contributed financial and technical assistance during technology generation, dissemination, and capacity building.

Table 1: Released potato varieties in Ethiopia

Varieties	Year of release	Average yield (q/ha)	Suitable altitude (m)	Agro-ecology
Awash	1991	254	1,500–2,000	Wide adaptable
Wechecha	1997	218	1,700–2,800	Wide adaptable
Menagesha	1993	270	Above 2,400	Wide adaptable
Zengena	2001	300	2,000–2,800	Northwest Ethiopia
Digemegn	2002	467	1,600–2,800	Wide adaptable
Jalene	2002	448	1,600–2,800	Wide adaptable
Guassa	2002	224	2,240–2,630	Northwest Ethiopia
Gera	2003	259	2,700–3,200	Specific adaptation
Gudene	2006	291	1,600–2,800	

Source: *Potato profile, unpublished report*

In Ethiopia, adoption of improved agricultural technologies has been a long-term concern of agricultural experts, policy makers, agricultural researchers, and many others linked to the sector. However, evidence indicates that adoption rate of modern agricultural technologies in the country is very low (Asfaw et al., 1997; Teressa and Heidhues, 1996). Empirical studies on adoption of agricultural technologies are very few and limited in geographical coverage. It is pertinent to undertake area-specific studies to assess the status of adoption and identify constraints that hamper further adoption of technologies. Therefore, this report presents information on the status of adoption of potato production technologies and some impacts observed by adopters in the major potato production areas where the technology has been introduced and promoted.

Materials and Methods

The study sites

The study was conducted in the major potato-growing areas of Oromiya and Amhara regions. Two zones, where potato production technologies have been widely disseminated, were selected from Oromiya region and one zone from Amhara region. In each of the zones, one representative woreda was selected based on the extent of dissemination of potato production technologies. Accordingly, Jeldu woreda was selected from West Shewa zone and Degem woreda was selected from North Shewa zone, both from Oromiya region.

Data collection techniques and sample size

The overall data were collected in three stages: secondary data collection, rapid appraisal, and quantitative survey. Each of them is briefly described below.

Secondary data collection. In the first stage, secondary information relevant to the study was collected from various published and unpublished sources. Secondary information available from zonal, woreda, and development station of Office of Agriculture and other partners was reviewed in detail. This stage helped to get the general understanding of the subject matter related to the objectives of the study before the study team goes to the grassroots level. It helped to develop a checklist that was used in the second stage. Review of secondary sources also helped to identify the issues and gaps that need to be addressed adequately with appropriate methodologies and tools.

Rapid appraisal survey. In the second stage, the study team collected a rapid appraisal survey to collect qualitative information and gain an understanding of how potato production technologies are used by the beneficiaries. The approach also allowed a free discussion of farmers and the study team on various issues related to the objectives of the study. This stage was a prerequisite to develop a questionnaire that was used to collect quantitative data in the third stage. A checklist that was developed with some of the predetermined questions based on the objectives of the study and general information obtained from secondary sources was used as a tool in the second stage. Additional relevant questions were also raised during the discussion based upon the observations and responses. The questions were open-ended and the interview system was informal. A rapid appraisal report was generated to help design structured questionnaire.

Quantitative survey. In the third stage, a focused formal survey was conducted following the rapid appraisal survey to quantify some of the most important parameters. Quantification of some parameters helped to verify the qualitative information collected in the second stage and presents the findings with empirical evidence. A structured questionnaire was designed based on the reports of the rapid appraisal survey. The questionnaire was pretested for consistency and time it would take to fill it. Enumerators were recruited and trained both theoretically and practically on how to fill in the questionnaire and interview the selected farmers. During data collection, researchers, experts of the woreda office of Agriculture, supervised enumerators closely and Development Agents located at village levels. A total sample size of 336 respondents was selected randomly and interviewed from each of the study woredas (Table 2).

Table 2: Sample sizes in the study areas

Woreda	Sex	Participant		Non participant		Total	
		n	%	n	%	n	%
Jeldu	Male	60	98	71	93	131	96
	Female	1	2	5	7	6	4
	Subtotal	61	100	76	100	137	100
Degem	Male	42	84	51	94	93	89
	Female	8	16	3	6	11	11
	Subtotal	50	100	54	100	104	100
Banja	Male	16	100	74	94	90	95
	Female	0	0	5	6	5	5
	Subtotal	16	100	79	100	95	100
Grand Total		127	100	209	100	336	100

Analytical tools

Appropriate analytical tools were used to analyze the data and summarize the information. Information obtained from first and second stages was summarized using maps, tables, descriptions, diagrams, and graphs. To analyze the quantitative data collected from third stage, the questionnaire was coded and the data were cleaned and prepared for analysis. Some of the most important statistical tools were employed to analyze the data and summarize the information.

Results and Discussion

Adoption status of released varieties

Adoption rates of released potato varieties in Jeldu woreda. Farmers of Jeldu woreda have good experience of diversifying potato varieties and grow 23 types of both local and improved varieties. In Jeldu woreda, participant farmers started adopting improved varieties of potato, mainly since 2001; nonparticipant farmers started since 2003. The farmers of Jeldu woreda have adopted six types of officially released varieties. The adoption rates vary from one variety to another and from one year to another. In the 2005 cropping season, the adoption rates of released varieties by participant farmers varied 3–39%,whereas adoption has increased in 2006 and varied 11–66% (Table 3). At an adoption rate of 66%, the most adopted variety in Jeldu was Jalene.

Table 3: Adoption rates of released potato varieties in Jeldu woreda

Variety grown	Year	Participants		Non participants		Overall sample	
		n	Adoption rate (%)	n	Adoption rate (%)	n	Adoption rate (%)
Menagesha	2006	17	28	3	4	20	15
	2005	24	39	2	3	26	19
Wochecha	2006	12	20	--	--	12	9
	2005	18	30	--	--	18	13
Jalene	2006	40	66	2	3	42	31
	2005	11	18	--	--	11	8
Gudene	2006	20	33	--	--	20	15
	2005	5	8	--	--	5	4
Gera	2006	20	33	1	1	21	15
	2005	4	7	--	--	4	3
Digemegn	2006	7	11	--	--	7	5
	2005	2	3	--	--	2	1

The adoption rate increases from one year to another for some varieties, but declines for others. For instance, the adoption rate of old improved varieties, such as Menagesha and Wochecha, shows a declining trend from 2005 to 2006

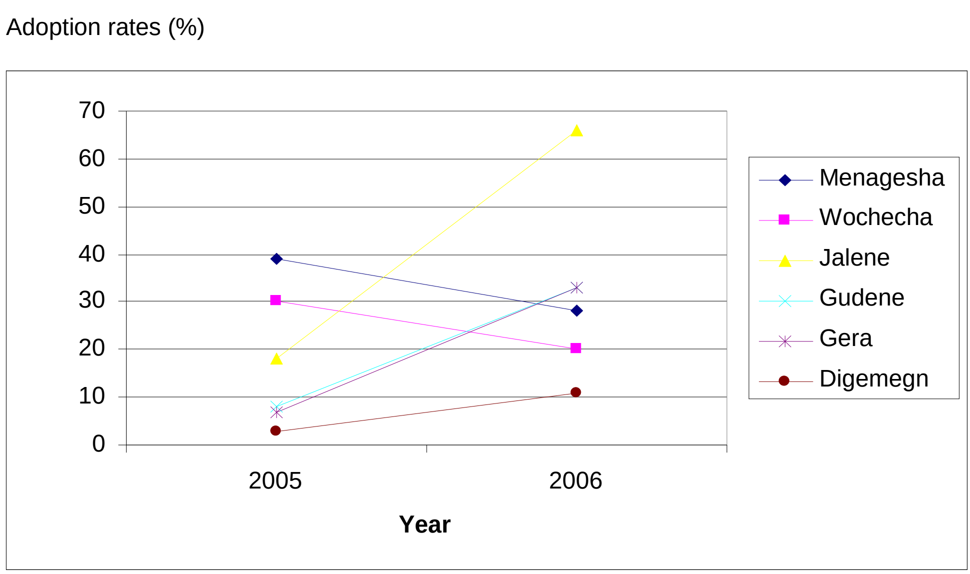


Figure 1: Adoption trend of released potato varieties by participant farmers in Jeldu woreda

cropping season. The adoption rate of the new varieties, such as Jalene and Gudene, shows an increasing trend (Fig. 1). Farmers replace one variety with another depending on the merits of the new variety.

It was also realized that diffusion of improved potato varieties mainly follows road sides, and diffusion off the road was very limited (Fig. 2). This suggests that appropriate mechanisms have to be in place to diffuse the technologies to the beneficiaries located off the road.

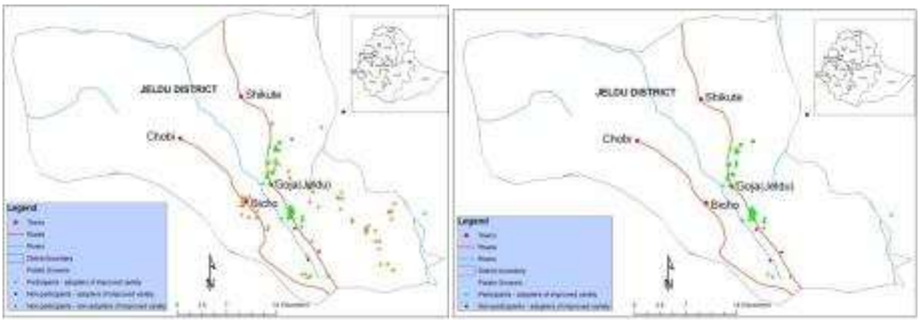


Figure 2: Diffusion status of improved potato varieties in Jeldu woreda

Adoption rates of released potato varieties in Degem woreda. Potato is mainly produced in the meher season than in other seasons in Degem woreda. In the years 2005 and 2006, 38% and 62% of the farmers, respectively, produced potato in the meher season. Farmers of Degem woreda grow 11 types of potato varieties, of which 5 are officially released by the Ethiopian Institute of Agricultural Research (EIAR). Other varieties are clones but not officially released for production. Since potato is a new introduction to the farming systems of Degem woreda, adoption rates of improved varieties is increasing from time to time (Fig. 3).

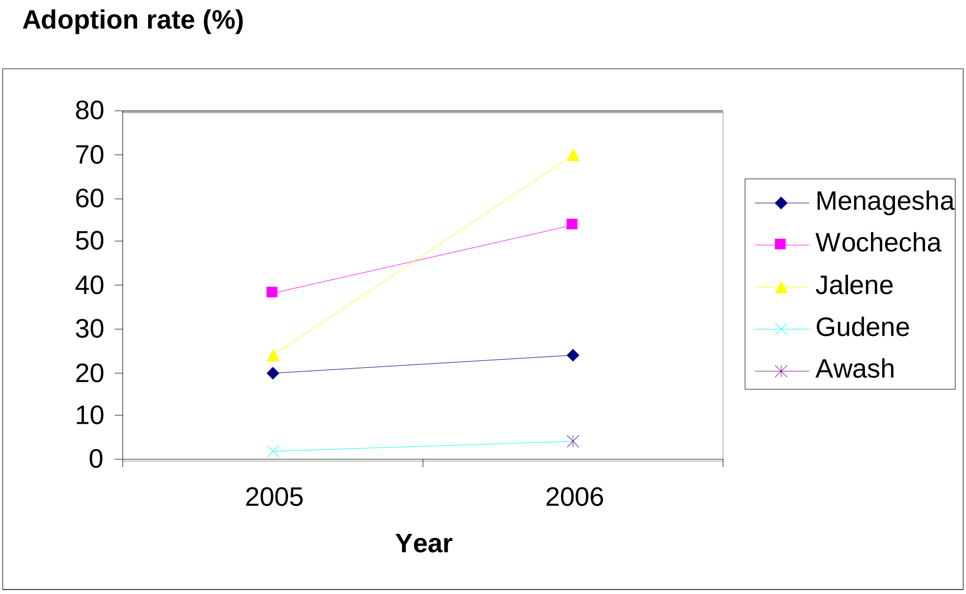


Figure 3: Adoption trend of CIP varieties by participant farmers in Degem woreda

In Degem woreda, participant farmers started adopting improved potato varieties since 1998; nonparticipant farmers started since 2001. In all the cases of released varieties, the adoption rate is higher in the 2006 cropping season than the 2005 cropping season (Table 4). Among the participants, Jalene is relatively the most adopted variety, with adoption rate of 70% by sample farmers in the 2006 cropping season. The nonparticipant farmers have also adopted some released varieties, such as Wochecha (adoption rate of 15%) and Jalene (adoption rate of 6%), especially in the 2006 cropping season.

Diffusion status of released varieties in Degem woreda is relatively better than other woredas and includes not only along the roads but also off the roads (Fig. 4).

Table 4: Adoption rates of released potato varieties in Degem woreda

Variety grown	Year	Participants		Nonparticipants		Overall sample	
		n	Adoption rate (%)	n	Adoption rate (%)	n	Adoption rate (%)
Menagesha	2006	12	24	1	2	13	13
	2005	10	20	1	2	11	11
Wochecha	2006	27	54	8	15	35	34
	2005	19	38	5	9	24	23
Jalene	2006	35	70	3	6	38	37
	2005	12	24	1	2	13	13
Gudene	2006	2	4	0	0	2	2
	2005	1	2	0	0	1	1
Awash	2006	2	4	0	0	2	2
	2005	-	-	-	-	-	-

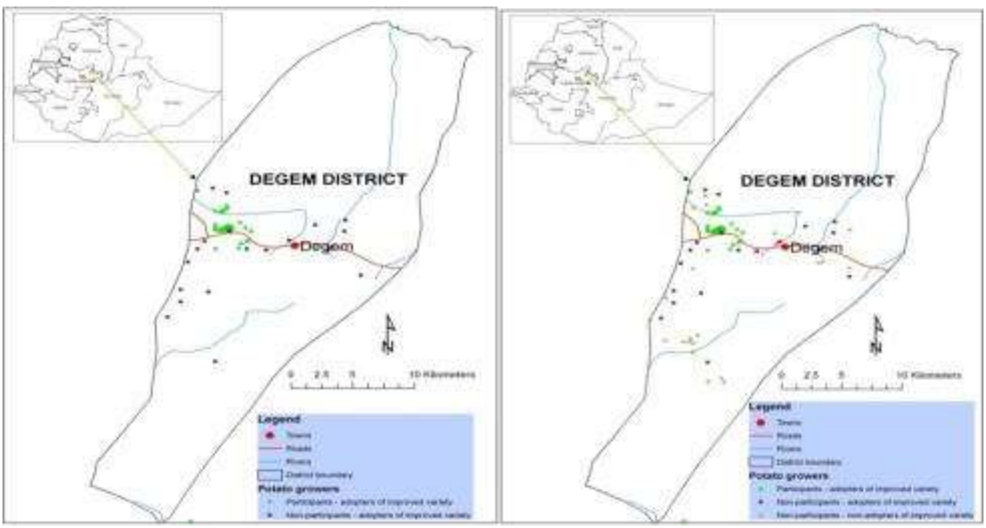


Figure 4: Diffusion status of improved potato varieties in Degem woreda

Adoption rates of released potato varieties in Banja woreda. In Banja woreda, potato production is a common practice three times a year: the Meher season, the belg season, and residual moisture. Farmers grow 18 types of potato varieties, most of which are local ones. They started adopting improved varieties since 2003; nonparticipant farmers started in 2004.

Even though four types of released varieties were identified in the woreda, their adoption rate was still lower than other study sites. In the case of varieties, Guasa is relatively better adopted, with adoption rate of 31%, followed by Jalene with adoption rate of 25% in the 2006 cropping season (Table 5). A few nonparticipant farmers (4%) have adopted Zengena variety. In Banja woreda, adopting improved varieties is a recent practice and shows an increasing trend (Fig. 5). However, diffusion status indicates along the road (Fig. 6), which suggests that further promotion work on potato production needs to be done in Banja to include areas located off the main roads. In general, the findings indicate that adoption of technologies vary over space and time. This is in line with findings of past research studies (Degnet et al., 2003).

Table 5: Adoption rates of released potato varieties in Banja Shikudad woreda

Variety grown	**Year**	**Participants**		**Nonparticipants**		**Overall sample**	
		n	**Adoption rate (%)**	**n**	**Adoption rate (%)**	**n**	**Adoption rate (%)**
Jalene	2006	4	25	-	-	4	4
	2005	-	-	-	-	-	-
Zengena	2006	2	13	3	4	5	5
	2005	2	13	7	9	9	9
Degemegn	2006	1	6	-	-	1	1
	2005	-	-	-	-	-	-
Guasa	2006	5	31	-	-	5	5
	2005	-	-	-	-	-	-

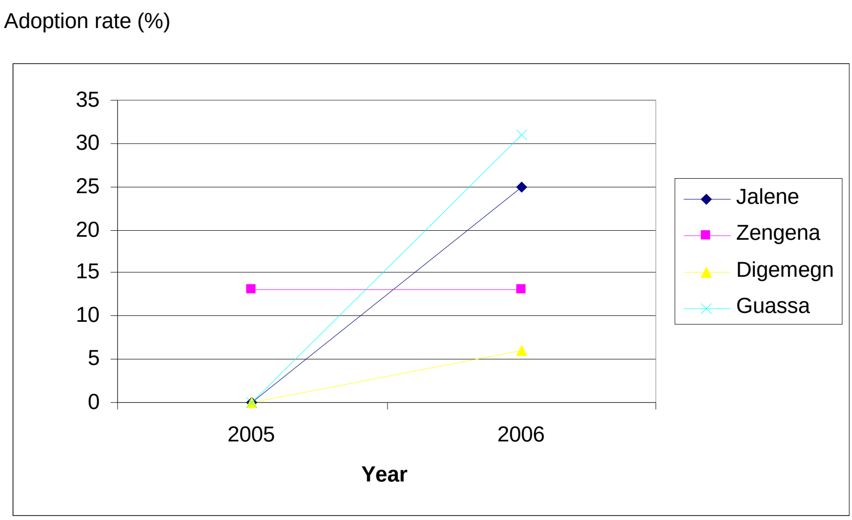


Figure 5: Adoption trend of released potato varieties by participant farmers in Banja woreda

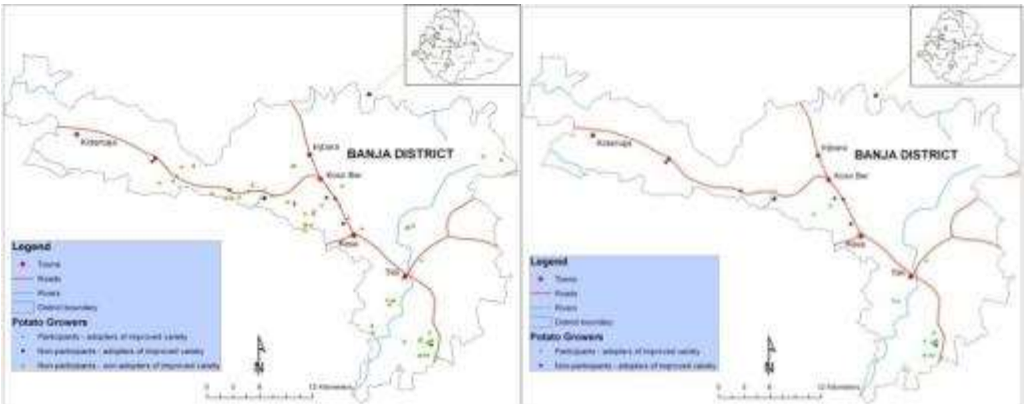


Figure 6: Diffusion status of improved potato varieties in Banja woreda

Intensity of adoption for released potato varieties

Farmers allocated different sizes of land for the different potato varieties. Old improved potato varieties occupy relatively larger area of land than recently released ones.

Size of land occupied by released varieties in Jeldu woreda. In Jeldu woreda, participant farmers allocated 0.1–0.25 ha of land for released potato varieties (Table 6). In the case of participants, improved varieties released earlier, such as Menagesha and Wochecha, occupied higher area of land than recently released varieties, such as Jalene. Menagesha occupied 0.25 ha of land on average ranging 0.0025–0.3 ha, followed by Wochecha, which occupied 0.13 ha of land on average. Recently released and most widely adopted variety, Jalene, occupied 0.1 ha of land on average, ranging 0.0025–0.5 ha. Some farmers have even started allocating as much as 5 ha of land for new varieties, such as Jalene and Gudene. This is because these varieties are in high demand and are sold at premium prices, which are 17–33% higher than other improved varieties.

Table 6: Average size of land (ha) allocated for released potato varieties in Jeldu Woreda

Participation	Varieties	Mean	Minimum	Maximum	SE
Participants	Menagesha	0.25	0.0025	3.0	0.0725
	Wochecha	0.13	0.01	1.0	0.0327
	Jalene	0.10	0.0025	0.5	0.0172
	Gudene	0.11	0.0025	0.5	0.0249
	Gera	0.12	0.0025	1.0	0.0416
	Digemegn	0.10	0.005	0.25	0.0321
Nonparticipants	Menagesha	0.07	0.03	0.13	0.0272
	Jalene	0.15	0.06	0.25	0.0937
Overall sample	Menagesha	0.24	0.0025	3.0	0.0679
	Wochecha	0.14	0.01	1.0	0.03271
	Jalene	0.10	0.0025	0.5	0.0168
	Gudene	0.11	0.0025	0.5	0.0249
	Gera	0.12	0.0025	1.0	0.0403
	Digemegn	0.10	0.005	0.25	0.0321

Size of land occupied by released potato varieties in Degem Woreda. Even if rate of adoption was high in Degem woreda, intensity of adoption (average size of land occupied by improved varieties) was still low. Participant farmers allocated 0.004–0.13 ha of land for released varieties. Wochecha occupied 0.13 ha ranging 0.0075–0.5 ha of land (Table 7). The most widely adopted variety, Jalene, also occupied 0.03 ha of land on average ranging 0.0025–0.14 ha. Nonparticipant farmers allocated 0.16 ha of land for Jalene ranging 0.025–0.5 ha. The average size of land occupied by Awash variety is too small (0.004 ha). This is because farmers replace Awash with other new varieties, due to its susceptibility to LB, and it was on the way to be phased out of production.

Size of land occupied by released potato varieties in Banja Woreda. Even though adoption rate of Guassa is higher than other varieties in Banja woreda, its intensity of adoption is lower. Participant farmers allocated relatively more land for Zengena (0.48 ha ranging 0.06–1.38 ha) than other released varieties (Table 8).Guassa occupied only 0.1 ha of land on average ranging 0.06–0.125 ha. Nonparticipant farmers planted only Zengena variety and allocated 0.045 ha of land on average ranging 0.005–0.125 ha.

Table 7: Average size of land (ha) allocated for released potato varieties in Degem Woreda

Participation	Varieties	Mean	Minimum	Maximum	SE
Participants	Menagesha	0.06	0.005	0.19	0.01059
	Wochecha	0.13	0.0075	0.5	0.01870
	Jalene	0.03	0.0025	0.14	0.00488
	Gudene	0.05	0.03	0.0625	0.01083
	Awash	0.004	0.0025	0.005	0.00125
Nonparticipants	Menagesha	0.0125	0.0125	0.0125	--------
	Wochecha	0.09	0.03	0.25	0.01741
	Jalene	0.16	0.025	0.5	0.11528
Overall sample	Menagesha	0.06	0.005	0.19	0.010146
	Wochecha	0.12	0.0075	0.5	0.01516
	Jalene	0.04	0.0025	0.5	0.01071
	Gudene	0.05	0.03	0.06	0.01083
	Awash	0.004	0.0025	0.005	0.001250

Table 8: Average size of land (ha) allocated for released potato varieties in Banja Woreda

Participation	Varieties	Mean	Minimum	Maximum	SE
Participants	Jalene	0.06	0.03	0.125	0.02180
	Zengena	0.48	0.06	1.38	0.30014
	Digemegn	0.125	0.0125	0.125	……
	Guassa	0.10	0.06	0.125	0.015
Non participants	Zengena	0.045	0.005	0.125	0.01098
Overall sample	Jalene	0.06	0.03	0.125	0.021803
	Zengena	0.17	0.005	1.36	0.09502
	Digemegn	0.125	0.125	0.125	……
	Guassa	0.1	0.06	0.125	0.015309

Adoption rates of potato storage technologies

DLS technology has been widely adopted in Jeldu and Degem woredas. In the case of participants, 90% in Jeldu, 80% in Degem, and 25% in Banja woredas have adopted the use of DLS technology to store potato seeds. Even nonparticipant farmers have become beneficiaries of DLS through spillover effects. For instance, 21% of nonparticipants in Jeldu, 24% in Degem, and 6% in Banja woredas have adopted DLS technologies. Farmers stored potato seed tubers for as long as 6–7 months in DLS. However, some potato growers (among both participants and nonparticipants) in all the study areas did not use DLS mainly because they are not well aware of it. Moreover, small quantities of produce did not encourage them to use DLS.

Adoption rate of recommended seed rates

The recommended seed rate for improved potato varieties is 18–20 q/ha. It was realized that almost all the participant farmers have adopted recommended seed rates ranging from 16.5 to 28.7 q/ha for released varieties (Table 9). Nonparticipant farmers are using seed rates ranging 8.6–23.1 q/ha. In general, seed rate used for released varieties is mostly either recommended or above the recommended rate. According to the farmers, higher seed rate is mostly considered as a compensation for low level of management. However, seed rates considerably higher than the recommended might result in higher cost of production.

Table 9: Average seed rates (q/ha) used for potato in all the study areas

Varieties	**Participants**		**Nonparticipants**		**Overall sample**	
	n	**Mean**	**n**	**Mean**	**n**	**Mean**
Released varieties:						
Menagesha	63	22.1	5	23.1	68	22.2
Wochecha	76	20.9	13	8.6	89	19.1
Jalene	82	24.31	6	10.3	88	23.3
Gudene	26	22.1	-	-	26	22.1
Gera	22	27.3	1	16.0	23	26.8
Zengena	4	16.5	10	18.2	14	17.7
Digemegn	7	28.7	-	-	7	28.6
Guassa	4	28.0	-	-	4	28.0
Tolcha	110	20.9	42	13.6	152	19.0
Awash	1	26.0	-	-	1	26.0
Other varieties:						
Genet	4	18.0	-	-	4	18.0
Diredawa	75	18.4	144	11.4	219	13.8
0.2	6	22.2	2	6.0	8	18.2
0.13	3	18.7	8	16.3	11	17.0
Red flower	5	27.5	2	15.4	7	24.0
Abesha	20	10.3	51	10.5	71	10.4
0.5	36	13.0	8	8.8	44	12.2
Chobe	30	16.3	37	13.0	67	14.5
Shashemene	2	14.6	28	15.0	30	15.0
Mirtzer	18	25.8	190	18.3	208	18.9
Samun	4	15.0	98	19.0	102	18.9
Deme	20	34.7	19	19.2	39	27.1
Aterabeba	11	32.5	28	27.8	39	29.1
0.14	2	9.2			2	9.2
Jiga	-	-	10	23.3	10	23.3
Key dinich	-	-	13	25.3	13	25.2

Adoption rates of spacing mechanisms

The recommended spacing between plants is 20–30cm and between rows is 60–75cm. Participant farmers ranging 52–65% in all the study areas have adopted the recommended spacing between plants (Table 10). The proportion of nonparticipants who adopted the recommended plant-to-plant spacing is also considerable (39–47%). Moreover, participant farmers ranging 48–57% and nonparticipant farmers ranging 27–36% have adopted the recommended spacing between rows (Table 11).

Table 10: Adoption rates of 20– 30cm between plants spacing

Woreda	Participants		Nonparticipants		Overall sample	
	n	Adoption rates (%)	n	Adoption rates (%)	n	Adoption rates (%)
Jeldu	41	64	25	47	66	56
Degem	36	65	22	42	58	54
Banja Shikudad	11	52	31	39	42	42

Table 11: Adoption rates of 60–75cm between rows spacing

Woreda	Participants		Non participants		Overall sample	
	n	Adoption rates (%)	n	Adoption rates (%)	n	Adoption rates (%)
Jeldu	31	51	19	25	50	36
Degem	27	54	14	26	41	39
Banja	12	75	29	37	41	43

Adoption rates and intensity of adoption of soil fertility management practices

In Jeldu woreda, 46% and 39% of the participant farmers have adopted application of DAP and Urea, respectively, on potato crops. Application of DAP is also a common practice among 51% of nonparticipants. Farmers of Degem (42%) and Banja (37%) woredas have also adopted application of DAP on potato. In general, inorganic fertilizer has been more adopted in Jeldu and Degem woredas than in Banja, whereas organic fertilizer has been more adopted in Banja woreda than in other study areas. Moreover, one of the recommended agronomic practices in potato production is application of fertilizers on potato fields, and most of the farmers have adopted this approach. The recommended practice suggests that inorganic fertilizer should be applied at the time of planting. Accordingly, 85% of the participants and 91% of nonparticipants have adopted application of inorganic fertilizers at planting in all the study areas. The practice is the same for all other types of fertilizers.

The recommended fertilizer rate on potato is 195 kg/ha DAP and 165 kg/ha Urea. However, participant farmers in Jeldu on average applied less rate (119 kg/ha DAP and 97 kg/ha Urea) than the recommended rate (Table 12). Even though the rate of inorganic fertilizer applied is less than the recommended, the farmers maintain the fertility of potato fields with additional application of organic fertilizers (compost and farm yard manure). The use of organic fertilizer has also contributed to reducing costs of inorganic fertilizers. For instance, in the case of participants of Jeldu woreda, 39% of the cost is reduced from DAP and 41% from Urea in reducing the amount of inorganic fertilizers and compensating with organic fertilizers (Table 13).

The rate of DAP applied by participant farmers of Degem woreda is 80.4 kg/ha and for Banja woreda is 175.6 kg/ha. Participant farmers of Jeldu woreda applied 1.8–2.2 t/ha of organic fertilizers. The rate of organic fertilizers applied is even higher in Degem and Banja woredas. In general, farmers in all the study areas have the practice of maintaining the fertility of potato fields through application of both inorganic and organic fertilizers.

Table12: Average rates of fertilizer (kg/ha) adopted

Woreda	Fertilizer type	Participants	Non participants	Overall sample
Jeldu	DAP (kg/ha)	119	47.8	95.1
	Urea (kg/ha)	97	53.0	96.0
	Compost (t/ha)	1.8	--	1.8
	FYM* (t/ha)	2.2	2.7	2.6
Degem	DAP (kg/ha)	80.4	78.9	80.2
	Urea (kg/ha)	66.7	95.6	69.6
	Compost (t/ha)	2.9	8.4	4.3
	FYM (t/ha)	5.6	8.7	7.9
Banja	DAP (kg/ha)	175.6	110.5	143.0
	Urea (kg/ha)	145.0	73.3	105.1
	Compost (t/ha)	4.1	3.2	3.2
	FYM (t/ha)	6.0	2.5	2.8
	Oil extract (t/ha)	2.8	0.8	1.5

** FYM = Farm yard manure*

Table 13: Cost reduction as a result of compensating inorganic with organic fertilizers

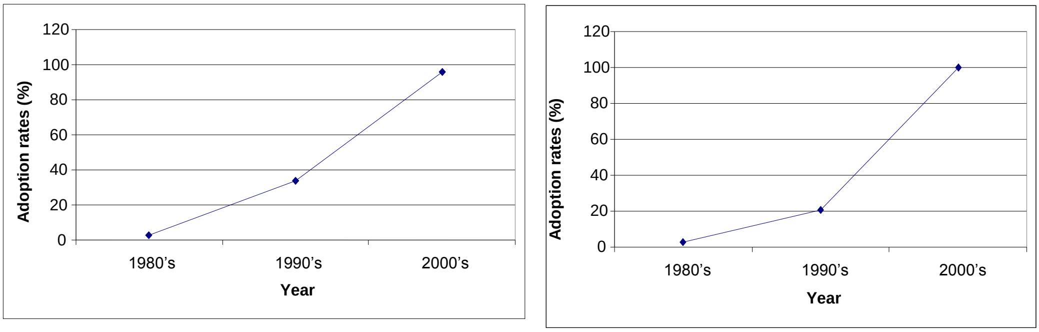
Woreda	Fertilizer type	Reduced rate applied (kg/ha)	Cost reduction (% of total cost of recommended inorganic fertilizer)
Jeldu	DAP (kg/ha)	119.0	39
	Urea (kg/ha)	97.0	41
Degem	DAP (kg/ha)	80.4	59
	Urea (kg/ha)	66.7	60
Banja	DAP (kg/ha)	175.6	10
	Urea (kg/ha)	145.0	12

Adoption of chemical control technologies for late blight

Adoption rates of fungicides increased over time in Jeldu woreda. The use of fungicides has been almost fully adopted by all the potato growers, irrespective of participation in Jeldu woreda. The cumulative adoption rate is 98%for participants and 100% for nonparticipants (Table 14). The nonparticipants learned the technology from their neighbors and through advice of the Office of Agriculture in their woreda. This is because they realized that chemical control of LB is becoming compulsory to produce potato. In the 1980s and 1990s, 34% of the participant farmers adopted chemical control of LB, whereas the proportion was only 21% for nonparticipants. This indicates that participants are adopt earlier than nonparticipants (Fig. 7).

Table 14: Adoption rates of fungicides over years in the study areas

Woreda	Time started using fungicides	Participants		Nonparticipants		Overall sample	
		n	Adoption rates (%)	n	Adoption rates (%)	n	Adoption rates (%)
Jeldu	1980s	2	3	2	3	4	3
	1990s	19	31	14	18	33	24
	2000s	38	62	60	79	98	72
Degem	1980s	--	--	--	--	--	--
	1990s	--	--	--	--	--	--
	2000s	49	98	13	24	62	60
Banja Shikudad	1980s	--	--	--	--	--	--
	1990s	--	--	--	--	--	--
	2000s	1	6	--	--	1	1



(a) **(b)**

Figure 7: Adoption trends of participants (a) and nonparticipants (b) for fungicides in Jeldu woreda

However, the proportion of adopters increased in the 2000s in both cases of sample farmers. Introduction of improved technologies by EIAR in collaboration with CIP and PRAPACE has contributed to creating awareness for the farmers to use fungicides to control LB. Enhanced demand from farmers has encouraged urban businesses to make the chemicals readily available on the local market. Availability of chemicals on local market has contributed the nonparticipant farmers to adopt chemical control even for their local potato variety.

In Degem woreda, almost all of the participants (98%) and 24% of nonparticipants have adopted chemical control technology of LB. They started using fungicides recently in the 2000s.

However, the practice is different in Banja woreda, where there is almost no adoption of chemical control technology for LB. It was realized that the farmers were not aware of fungicides, nor are they available on the local market. Therefore, this calls for promotion of fungicide technology in Banja woreda.

Productivity of potato (q/ha)

The yield obtained from released varieties at farm level ranged 99.3–232.5 quintals per hectare on participant farms (Table 15). The lowest yield is obtained from the variety Zengena (99.3 q/ha), while the highest yield is obtained from the varieties Gera (232.5 q/ha) and Guassa (213.6 q/ha). However, most of the participant farmers obtained yields ranging 150–195 q/ha. The yield obtained by nonparticipant farmers from released varieties ranged 65.6–212.9 q/ha. Even though the potential of improved varieties is more than 400 q/ha, the performance of most released varieties at farmers' level is almost by half less than the potential.

Table 15: Average yields (q/ha) of potato varieties in the study areas

Varieties	Participants		Non participants		Overall sample	
	n	Mean	n	Mean	n	Mean
Released varieties:						
Menagesha	63	162.4	5	212.9	68	166.1
Wochecha	76	151.9	13	126.7	89	148.2
Jalene	94	194.9	5	65.6	99	188.4
Gudene	27	174.8	--	--	27	174.8
Gera	23	232.5	1	80.0	24	226.1
Zengena	4	99.3	9	96.3	13	97.2
Digemegn	8	134.6	--	--	8	134.6
Guassa	5	213.6	--	--	5	213.6
Awash	1	150.0	--	--	1	150.0
Tolcha	109	146.7	42	117.4	151	138.5
Other varieties:						
Genet	4	58.0	--	--	4	58.0
Diredawa	73	130.1	132	81.3	205	98.6
0.2	6	196.2	2	72.0	8	165.1
0.13	3	253.3	8	165.7	11	189.6
Red flower	5	185.3	2	30.7	7	141.1
Abesha	16	81.2	46	73.5	62	75.5
0.5	35	133.2	8	99.2	43	126.9
Chobe	27	139.0	36	165.8	63	154.3
Shashemene	2	129.0	26	116.3	28	117.2
Mirtzer	18	70.8	179	53.0	197	54.6
Samun	4	41.0	92	62.6	96	61.7
Deme	20	89.9	19	49.8	39	70.3
Aterabeba	11	128.5	26	83.0	37	96.5
0.14	2	48.0	--	--	2	48.0
Jiga	--	--	10	66.3	10	66.3
Key dinich	--	--	13	83.5	13	83.5

Impacts observed from the use of improved potato production technologies

In general, the extent of diffusion of improved potato production technologies is limited follows mainly accessible areas and roadsides. There are impacts observed for some of the adopters, and among them, considerable impacts are observed for some elite groups. The impact areas mainly focus on asset creation, better housing, and improvements in other livelihood components. The proportions of adopters that brought impacts on different impact areas are indicated in Tables 16–18.

Table 16: Impact of potato production technology on asset creation

Impact areas	Jeldu		Degem		Overall sample	
	n	%	n	%	n	%
Purchased oxen	22	65	22	49	44	56
Purchased cows	16	49	20	44	36	46
Purchased bulls	13	38	10	22	23	29
Purchased heifers	9	27	5	11	14	18
Purchased sheep and goat	21	62	22	49	43	54
Purchased donkey	7	21	14	31	21	27
Purchased horse	16	47	3	7	19	24
Purchased mule	2	6	0	0	2	3

Table 17: Impact of potato production technologies on housing

Impact areas	**Jeldu**		**Degem**		**Overall sample**	
	n	%	**n**	%	**n**	%
Built new grass-roofed house	6	18	13	29	19	24
Rehabilitated existing grass-roofed house	3	9	6	13	9	12
Built new corrugated-roofed house	25	74	18	40	43	54
Rehabilitated corrugated-roofed house	7	21	6	13	13	17

Table 18: Impact of potato production technologies on other livelihood components

Impact Areas	**Jeldu**		**Degem**		**Overall**	
	n	%	**n**	%	**n**	%
Expanding farm land	21	64	20	44	41	53
Schooling for children	13	39	10	22	23	30
Purchase TV	5	15	0	0	5	6
Purchased mobile phone	7	21	0	0	7	9
Improved household incomes	33	97	44	98	77	98
Ensured food availability	34	100	45	100	79	100
Meet household expenses	34	100	43	96	77	98
Settling debts	34	100	43	96	77	98
Better health care	34	100	40	89	74	94
Use hired labor	24	71	20	44	44	56
Fulfill clothing needs	31	91	39	87	70	89

Major problems that hindered further diffusion of potato production technologies

The most important factors that hindered further diffusion of potato production technologies to more production areas and more beneficiaries include lack of clean seed tubers of improved varieties, problem of sustainable demand for seed and ware potato, unaffordable price of clean potato seed tubers, and deterioration of earlier released varieties due to disease leading to low yields. The findings indicate that participant farmers in all the study areas ranging 41–69% and nonparticipants ranging 78–83% faced problems of getting high-quality seeds (Table 19). The complaint from participants is that the existing improved varieties are becoming susceptible to LB which has resulted to yield declines. Nonparticipants complained that they could not get quality improved seeds.

Table 19: Proportion of sample respondents that faced problems in getting high quality seed

Woreda	**Participants**		**Non participants**		**Overall sample**	
	n	%	**n**	%	**n**	%
Jeldu	25	41	63	83	88	64
Degem	25	50	42	78	67	64
Banja Shikudad	11	69	62	79	73	77

The earlier released varieties, such as Digemegn (33%), Wochecha (25%), and Menagesha (16%), are facing problems of low yield and susceptibility to LB (Table 20).This highlights the continuous need either for generating new improved varieties or cleaning the disease from existing ones using appropriate mechanisms.

Potato is becoming a cash crop, especially since introduction of improved technologies. However, some problems related to marketing are still hampering further diffusion of the released varieties to more potato production areas. The two major problems associated with potato marketing in Jeldu and Degem woredas are lack of buyers and low prices. Participants in Jeldu woreda (47%) complained of lack of buyers for their potato seed, while nonparticipants (47%) complained of low prices (Table 21). In Banjana Shikudad woreda, the major problem related to potato marketing is low prices. In general, ware potato is suffering from low prices and improved potato seed is suffering from luck sustainable demand. There used to be good demand for improved seed potato, and the buyers were mostly GOs and NGOs. However, at the time of this study, the demand from these organizations has declined and thus farmers started complaining. Seed producers have minimized this problem by selling the seeds for neighboring farmers at lower prices.

Table 20: Problems encountered on released potato varieties (% of respondents)

	Low yielding	Susceptible to LB	Susceptible to bacterial wilt	Late maturing	Small tubers	Low marketability	Not tasty	No response
Menagesha	18	16	3	0	5	5	26	27
Wochecha	21	25	4	2	2	4	10	32
Jalene	2	15	0	5	6	0	5	67
Gudene	0	0	5	5	5	0	0	85
Gera	0	16	5	0	0	5	5	69
Zengena	0	20	0	10	0	10	0	60
Digemegn	0	33	17	17	0	0	0	33
Guassa	0	0	0	0	0	0	0	100

Table 21: Problems related to potato marketing in the study areas

Woreda	**Problems selling potato**	**Participant**		**Non participant**		**Total**	
		n	%	n	%	n	%
Jeldu	No problem	6	10	6	8	12	9
	Lack of sustainable demand for seed	24	39	11	15	35	26
	Low prices for ware potato	15	25	21	28	36	26
	Transportation problem	3	5	7	9	10	7
	Theft	1	2	--	--	1	1
	Lack of market information	1	2	--	--	1	1
	Monopolization by organized groups	1	2	--	--	1	1
Degem	No problem	7	14	6	11	13	13
	Lack of sustainable demand for seed	20	40	10	19	30	29
	Low prices for ware potato	20	40	20	37	40	38
	Transportation problem	3	6	14	26	17	16
	Price fluctuation	1	2	--	--	1	1
Banja	No problem	10	63	10	13	20	21
	Lack of sustainable demand for seed	--	--	4	5	4	4
	Low prices for ware potato	2	13	14	18	16	17
	Tubers lost their quality in storage (desiccation, rotting, etc.)	--	--	4	5	4	4
	Transportation problem	--	--	2	3	2	2
	Researchers' delay to pay	1	50	--	--	1	1

Conclusion and Recommendations

In the study areas, adoption rates of potato production technologies varied in time and space. However, adoption of the improved varieties and associated packages, especially in Jeldu and Banja woredas, occurred along the main roads, which the technology did not diffuse further to potato production areas and beneficiaries located off the roads. This was mainly because verification, demonstration, scaling-up, and promotion activities were concentrated along the road sides due to accessibility. Partner institutions, such as Office of Agriculture, did not make adequate efforts to disseminate and promote these technologies in the areas.

The major problems that hindered further diffusion of improved potato production technologies were identified to be lack of clean seed tubers, unaffordable prices of clean seed tubers, lack of sustainable demand for clean seed tubers, and low prices of ware potato. Inadequate awareness about technological packages, such as storage, chemical application, and others, also contributes to less diffusion. Earlier released varieties were also becoming susceptible to LB.

The following recommendations are suggested to enhance diffusion levels of package technologies

- Adoption rates of improved varieties released earlier were showing a declining trend in some areas. This is because of their susceptibility to LB and yield decline. This suggests that replacement of these varieties by new improved varieties should be a regular and continuous process;
- Adoption of technological packages could be sustainable if key stakeholders in the area are accountable and committed to discharge their responsibilities. Office of Agriculture should play key roles in dissemination and promotion of technology packages to wider areas located off road;
- Lack of sustainable markets was reported to be a major problem for participant farmers. This was because potato varieties generated by research so far were not designed for diversified uses. Sustainable markets could be created by generating varieties with processing qualities. Thus potato products, such as chips, are in high demand by the market;
- For nonparticipant farmers, lack of clean seeds of improved varieties was reported to be a major problem. This calls for organizing and strengthening of informal seed producers in the locality to ensure sustainable supply of seeds for the neighboring farmers and other areas;
- The use of a combination of inorganic and organic fertilizers has become a common practice among farmers. This has helped reduce the cost of potato production. However, the optimum recommended rate of inorganic and

organic fertilizer combination was not known, and this calls for the need to determine the rates; and

- In areas such as Banja woreda, adoption of improved potato production technologies is much less, largely because promotion and dissemination of technologies were not conducted intensively. There is lack of improved seeds in the area. This calls for strengthening promotion and dissemination activities. Informal seed production system should also be established to create easy access to improved seeds.

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Determinants of Adoption of Improved Potato Varieties in Welmera Woreda

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Introduction

Empirical evidence shows that the area under potato production in Ethiopia is about 73,095 ha, with an average national yield of 10 t/ha for the main cropping season (CSA, 2007). Because of this, the Ethiopian Institute of Agricultural Research (EIAR) under its different research centers has been introducing different kinds of improved potato varieties to the nearby community. The released potato varieties, along with improved package of technologies, have been disseminated through the Ministry of Agriculture (MOA) and its regional and grassroots structures. For this reason, most farmers in West Shewa were able to produce thousands of tons of potato tuber.

However, some farmers did not adopt some of these new technologies. Identifying why some farmers adopt or reject the improved potato production packages is critical for professionals engaged in agricultural development. Therefore, this study aimed to identify determinant factors for the adoption of improved potato technologies.

Methodology

The study area

Welmera woreda is about 40 km west of Addis Ababa. The woreda is divided into 24 rural kebeles. The woreda had a total population of 83,784persons of which 49.8% are female. The altitude of the woreda ranges 2,060–3,380 meters above sea level. Temperature ranges from 0.1°C up to 26.9°C. The mean annual rainfall ranges 1,000–1,100 mm. The rainfall pattern is usually bimodal: January–May for belg season and June–October for meher season. The potato-based system is found in all parts of Welmera woreda (MOA, 2009).

Sampling techniques

In this study two types of sampling techniques were applied. The first stage was purposive sampling technique to select Welmera woreda and four kebeles: Bekeka and Korehodo, Burkusame-gebeyarobi, Wajituharbu, and Welmerachoqa.

Following this, a simple random sampling technique was employed to select 112 households. The kebeles were selected by reviewing secondary data. After preparing up-to-date list of the sampling frame, households were selected based on probability proportional to size of total potato-growing farmers in each kebele. Following that, potato varieties adopter (60) and non-adopters (52) were selected by simple random sampling techniques.

Data type, sources, collection, and analysis

To answer the research questions and assess the research objective, primary and secondary data were collected. Interview schedule and four group discussions were conducted to gather the information of demographic characteristics, socio-economics, institutional, and psychological dimensions and to find out determinant factors of adoption of improved potato varieties. Relevant secondary data were collected from published and unpublished sources. Descriptive statistics were applied for quantitative data. In addition, t-tests, chi-square tests, one-way analysis of variance (ANOVA), and a Tobit regression model were carried out. Adoption index (AI) is the dependent variable for this study. It indicates the extent of adoption of improved potato recommended packages; it is a type of continuous dependent variable. The farmers who meet the recommended rates in the packages were given 1 and for those who did not 0 was given.
The formula was calculated as follow.

$$AI_i = \frac{LP_i + VA_i + SR_i + FR_i + CA_i + SP_i + SS_i + PM_i + WF_i + ST_i}{10} \times 100$$

Where: LP_i Land preparation of *i* farmer
VA_i Varieties land coverage by *i* farmer farm
SR_i Seed rate usage by *i* farmer
FR_i Fertilizer rate usage by *i* farmer
CA_i Chemical application by *i* farmer
SP_i Spacing usage by *i* farmer
SS_i Seed size usage by *i* farmer
PM_i Planting method by *i* farmer
WF_i Weeding /hoeing and hilling frequency applied by *i* farmer
ST_i Seed storage method by *i* farmer

This happened because not all sampled households use the entire recommended potato package. On the basis of AI, respondent farmers were classified in two categories—low and high adopter. Independent variables are household personal and demographic characteristics variables, institutional variables, economic variables, farm characteristics, and psychological variables. These variables are explained in Table 1.

Table 1: Summary of descriptive variables

Variable	Variable code	Operational Definition of the Variable
Sex of household	SEX	It is a dummy variable 1 for male and 0 for female
Farm experience	FAREX	Continues variable measured by number
Household head education	EDU	It is a dummy variable 1 for read and write and attending regular class and 0 for otherwise
Leadership statues of the house head	LEADSTA	It is a dummy variable,1 for farmers has leadership position and 0 for others
Membership in cooperative societies	MEMCOOP	It is a dummy variable,1 for members in cooperative and 0 for others
Land holding	LAHOLD	Continues variable, shows the land size the farmer has
Access to credit	ACCREDT	It a dummy variable 1 for accessed to credit and 0 for not
Extension contact	EXTCONT	It is a dummy variable, 1 for farmers who have extension contact and 0 for not
Participation in demonstration	DEMO	It is a dummy variable 1 for participant in demonstration related to improved potato technologies and 0 for not.
Participation in field day	FIELDY	It is a dummy variable,1 for farmers who have participated in field day the last three years and 0 for others

The farmer may adopt only some part of the recommended practices from the package and may also do this on 1% or 100% of his/her farm. So, Tobit model is more appropriate to give reliable output of both discrete and continuous variable combination. In consequence, this model output gave information for both probability and intensity of adoption of improved potato production package.

The model parameters are estimated by maximizing the Tobit likelihood function of the following form (Maddala, 1997; Amemiya, 1985).

$$L = \prod \frac{1}{\sigma} f\left(\frac{AIi - \beta_i X_i}{\sigma}\right) \prod F\left(\frac{-\beta_i X_i}{\sigma}\right)$$

AIi*.>0AIi*≤.0

Where f and F are, respectively, the density function and cumulative distribution function of AI_i*.∏ means the product over those i for which $AI_i \leq 0$, and ∏ which $A_i^* \leq 0$
AI_i*.>0means the product over those i for which AIi*>0.

The change in the probability of adopting a technology as independent variable X_i changes is

$$\frac{\sigma F(z)}{\sigma Xi} = f(z)\frac{\beta i}{\sigma}$$

The change in the intensity of adoption with respect to a change in an explanatory variable among adopters is

$$\frac{\sigma E(AIi *> 0)}{\sigma Xi} = \beta i\left[1 - z\frac{f(z)}{F(z)} - \left(\frac{f(z)}{F(z)}\right)^2\right]$$

Where,

F (z) is the cumulative normal distribution of Z,

f(z) is the value of the derivative of the normal curve at a given point (i.e., unit normal density),

Z is the z-score for the area under normal curve,

Β is a vector of Tobit maximum likelihood estimates and σis the standard error of the error term.

Results and Discussion

In this study, based on the level of adoption of improved potato production packages (AI), farmers were categorized into three categories: non-, low-, and high-adopters. Those who never have grown improved potato varieties were considered as non-adopters. The AI score of low adopters ranges 0.01–0.60 and for high-adopters the AI score was 0.61–1 (Table 2).

Table 2: Distribution of respondents by adoption category of improved potato technologies

Adoption category	**n**	**%**	**AI Score**	**Mean**	**SD**	**F value**	**P value**
Non-adopter	52	46.4	0.00	0.000	0.00000		
Low	30	26.8	0.01-0.60	0.5233	0.09353		
High	30	26.8	0.61-1	0.7467	0.05713		
Total	112	100	0.00-1	0.3482	0.32604	50.79***	0.000

**** = significant at 1% level.*

Demographic characteristic

Sex of household head

Males have more freedom of mobility and so can participate in different kinds of meetings, field days, symposiums, and demonstrations. These kinds of frequent contacts consequently could help them to access pertinent information about new technologies. So, sex was considered as one of the influencing factors for the adoption of new technologies in favor of male-headed households (Table 3).

Table 3: Sex of household head among adoption categories

Sex	Adoption Categories						Total	
	Non adopter		Low		High			
	n	%	n	%	n	%	n	%
Male	48	92.3	22	73.3	19	63.3	89	79.5
Female	4	7.7	8	26.7	11	36.7	23	20.5
Total	52	100	30	100	30	100	112	100

(χ^2=10.72,df=2,p =.005) significant at 1% level

As Table 3 shows, out of the total sampled households 79.5% were male-headed and 20.5% were female-headed. The majority of female-headed households were found in high-adopter category, which shows that if they have access to new agricultural technologies, women can apply all technology packages as recommended. In this study, statistical analysis of chi-square also revealed (χ^2=10.72, p=.005) a significant difference between the adoption categories.

Age of the household head

Age is controversial in terms of technology adoption. Older farmers could be fast adopters because they have enough farming experience in the field of agriculture (Tadesse, 2008). On the other hand, because of their risk-averse nature, older farmers were more conservative than younger farmers to adopt new technologies (ibid.). In general, vegetable producers face a risk associated with relatively high cost of production, market price fluctuation, and very short storage life of products. As shown in Table 4, the average age of the respondents was 45.98 years, with standard deviations of 14.05. The maximum and minimum ages of the respondent farmers was 82 and 20 years, respectively. The result of ANOVA test show that there is no significant difference among adopter categories(F = 0.75, p= .830).

Family size

Most agricultural operations are labor intensive and thus require the participation of family members. As shown in Table 4, the average family size by respondent farmers was 5.74 members. The minimum and maximum household numbers are 1 and 14 persons, respectively. One-way ANOVA shows no significant difference among the adopter categories (F=0.549, p=.865). From group discussions, farmers reported labor shortages during planting, weeding and hilling, and harvesting times on production process.

Table 4: Age, total family size, and potato-farming experience of respondent with level of adoption of improved potato technology

Variable	Adoption category	N	Mean	SD	F* value	P value
Age of respondent	Nonadopter	52	46.44	15.45	0.758 NS	0.830
	low	30	45.17	11.68		
	high	30	45.90	13.88		
	Total	112	45.96	14.05		
Family size	Nonadopter	52	5.12	2.23	0.549 NS	0.865
	low	30	7.27	2.88		
	high	30	5.27	2.149		
	Total	112	5.74	2.56		
Potato farming experience	Nonadopter	52	0.00	0.00	1.500 NS	0.205
	low	30	3.56	1.33		
	high	30	4.4	1.37		
	Total	112	3.98	1.40		

**NS= nonsignificant*

Potato farming experience

Farming experience is highly linked to the adoption of new technologies. A more experienced farmer may have a lower level of uncertainty about the innovations' performance (Tadesse, 2008) and could evaluate the benefit of new technologies in a better way. The average potato farming experience of the respondents was 3.98 years. High adopters have more average farming experience on potato production than the low-adopter category. However, statistical ANOVA showed insignificant mean difference (F=1.500, p=.205).

Educational status of respondent household heads

A better-educated farmer can understand the information very easily and internalize the information transferred from development agents, researchers, NGOs, and other development stakeholders (Table 5).

Table 5: Educational level of respondent farmers across adoption categories

Adoption categories	Educational Level of the household				Total	χ^2
	Illiterate	1-4 grade	5-8 grade	>8 grade		
Nonadopter	38	8	3	3	52	
Low	17	4	7	2	30	
High	3	9	16	2	30	
Total	58	21	26	7	112	36.19***

*Source: Own survey 2011,*** (χ^2=36.190,p = .000)=significant at 1% probability level*

From the sample household heads, 51.8% of respondent farmers were illiterate and the rest were educated. Most of the high adopters were educated up to junior secondary school. It helped them to internalize and apply the technology packages properly. Chi-square test also showed the significant difference among adopter categories of improved potato technologies (χ^2=36.190, p=.000).

Resource ownership of the sample households

Adoption of agricultural technologies is related to resource endowment of households such as total land holding, capital for purchase of inputs (improved seed, fertilizer, chemicals), livestock ownership, and labor availability.

Total land holding

Land size could show the capability of an individual farmer to adopt new agricultural technologies. The average land holding of sampled farmers was 1.79 ha, ranging 0.25–7.0 ha. In this study, large size landholders were mostly adopters. As shown in Table 6, the mean land holding of nonadopters was 1.29 ha, of low adopters was 1.84 ha, and that of high adopters was 2.61 ha. ANOVA also showed significant mean difference among adoption categories (F=2.528, p=.002).

Table 6: Total land holding and area covered by improved potato varieties

Land (ha)	Adoption category	n	Mean	SD	F value	*P* value
Total land holding	Nonadopter	52	1.29	1.02	2.528***	.0020
	low	30	1.84	1.06		
	high	30	2.61	1.51		
	Total	112	1.79	1.29		
Land coverage under improved potato technologies	Nonadopter	52	0.00	0.00	30.857***	.0000
	low	30	0.30	0.24		
	high	30	0.68	0.41		
	Total	112	0.49	0.38		
Livestock ownership	Nonadopter	52	6.94	4.64	1.406	.263
	low	30	9.84	5.17		
	high	30	9.00	5.67		
	Total	112	8.27	5.19		
Labor availability	Nonadopter	52	2.62	1.62		
	low	30	3.17	2.64		
	high	30	3.57	2.21		
	Total	112	3.02	2.11	1.038	.439

*Source: Own survey, 2011, ***, significant at 1% probability level*

Livestock ownership

In the study area, farmers used mixed-farming systems. Livestock means many things to farmers: traction power, manure, and source of income by selling the animals and byproducts. On the other hand, number of livestock shows the wealth status of an individual farmer. In this study, ownership of livestock was expected to have a positive relationship with adoption of improved potato production. However, ANOVA test showed insignificant difference between livestock ownership and the adoption of improved potato production packages (Table 6).

Labor availability

Potato production activities required more labor. It is common to use family labor for each activity, and if the activities are beyond their capacities, to use hired labor and mobilize labor from their neighbor. The average labor availability of the sampled household in terms of man-equivalent was 3.02 ±-2.11forces (Table 7). The mean man-equivalent labor showed non-significant difference between adoption categories (F=1.038, $p = .439$).

Table 7: Distribution of respondents by labor shortage and solution practiced in potato production

Solution to labor shortage	**n**	**%**
Labor mobilization from neighbor	45	40.2
Hiring daily laborer	22	19.6
Both cooperation and hiring	10	8.9
No problem	35	31.3
Total	112	100.00
Labor shortage problem	n	%
Yes	77	68.8
No	35	31.3
Total	112	100.0

As shown in Table 7, 68.8% of the respondent farmers had labor shortages in 2010. Common labor shortages occurred at the time of planting, weeding/hoeing, hilling, and harvesting. To overcome this problem, 40% of the farmers used cooperation labor force and then hired day laborer or both cooperation and hiring. That seems why labor availabilities show insignificant difference among adoption categories.

Economic variable

Off-farm farm income. This income from the sale of agricultural products after meeting family consumption. Farmers used farm income as the main source of income to purchase inputs and other household goods. Farm income was calculated based on the sale of crop produce, livestock, and livestock products. In addition, vegetable crops, including potato, were sources of cash. As shown in Table 8, the average income of potato sale was 8,114.16 Birr per year. As compared to the average total farm incomes, farmers have got 37% of their income from potato sale in 2010 production year.

Table 8: Mean annual income of respondents from sale of potato in Birr (n=60 respondents)

Distribution statistics	Income size (Birr)
Mean	8,114.16
SD	1,440.70
Minimum	100.00
Maximum	88,000.00

Source: *Own survey, 2011*

The mean annual income of the sampled households was about 8,331.25 Birr (Table 9). The average annual income of nonadopters, low, and high adopters was 5,280.57, 9,899.36, and 12,050 Birr, respectively. One-way ANOVA also revealed the income mean difference among the adopter categories at 5% probability level (F=2.47, p=.012).

Table 9: Average annual farm income of respondents across adoption categories (Birr)

Adoption category	n	Mean	SD	F	*P value*
Nonadopter	52	5,280.57	1,091.71	2.47**	.012
Low	30	9,899.36	1,005.86		
High	30	12,050.97	2,025.75		
Total	112	8,331.25	1,404.07		

***represents significance at 5% and 5% probability level*

Off-farm income. In the study area, grain trading, vegetable trading, animal products trading, and daily labor are some of the common off-farm jobs (Table 10). Only 34 respondents participated in off-farm activities. Participation in off-farm activities showed insignificant difference (χ^2=2.094, p = .351) with the adoption of improved potato production package.

Table 10: Off-farm activities and adoption of improved potato production package

Do you participate in off-farm activities?	Adoption categories			
	Non adopter	Low	High	Total
Yes	18	10	6	34
No	34	20	24	78
Total	52	30	30	112

Source: *Own survey, 2011,* χ^2 *value 2.094, df=2,p =.351, NS = Non-significant*

Institutional factors

Institutional factors are believed to influence adoption of potato production packages. In this section, access to market, access to credit, contact to extension agent, mass media exposure, participation in a cooperative, and attending extension visits are discussed.

Access to credit

The number of high adopters' access to credit is not high as compared to non- and low adopters. It is because high adopters have enough cash to purchase fertilizer and fungicide. Therefore, they were reluctant to take credit, which shows that high adopters are found in better financial position than non- or low adopters. Chi-square test revealed significant difference among adoption categories (χ^2=12.52, *p* =.002) (Table 11).

Table 11: Relationship between access to credit and adoption of improved potato production package

Access to credit	Adoption Categories			
	Nonadopter	**Low**	**High**	**Total**
Yes	11	18	11	40
No	41	12	19	72
Total	52	30	30	112

**** χ^2= 12.52, df=2, p =.002 significant at 1% level contact to extension agent*

Farmers get extension services from development agents, researchers, and different NGOs in the study area. Major sources of information were development agents. The frequency of visits or availability of extension services is perhaps the single variable that emerged significantly in most of the research work on technology transfer and adoption (Asfaw et al., 1997; Tadesse et al., 2008). It is hypothesized that frequent contact with extension agents may increase farmers' probability of adopting improved agricultural technologies. As shown in Table 12, 34 nonadopters have no contact with development agents, whereas 20 of high adopters have received extension advice for more than 7 days per year. On the other hand, larger share of no contact with extension agents comes from nonadopters. Statistical analysis of chi-square shows positive difference among adoption categories (χ^2 = 70.512, df=8, *p* =.000).

Table 12: Distribution of sample households by frequency of contact with extension agent

Frequency of contact	Adoption Categories			
	Nonadopter	Low	High	Total
0	34	0	0	34
1-2	6	5	1	12
3-4	5	9	5	19
5-6	3	1	4	8
>7	4	15	20	39
Total	52	30	30	112

*** χ^2= 70.512, df=8, p =.000, significant at 1% level

Mass media exposure

The more people are aware, the more likely they are to be flexible and accept new things easily. Mass media exposure was related to respondents' ownership of TV/radio and thus had significant difference (χ^2 =5.64, df=2, *p* =.059) among the adoption categories (Table 13).

Table 13: Relationship of mass media access and adoption of potato production package

Farmers' Response	Adoption Categories			
	Nonadopter	low	high	Total
Yes	37	23	28	88
No	15	7	2	24
Total	52	30	30	112

** χ^2= 5.64, df=2,p =0.059,significant at 5% level

Regarding distance to market place, respondents travelled on average 9.14 km (Table 14). The ANOVA also showed significant difference between adoption of potato technologies and distance of market place (F = 2.69, *p* = .002).

Table 14: Distribution of respondents by average distance travelled to reach the nearest market centre (km)

Adoption category	N	Mean	SD	F value	*P* value
Nonadopter	52	11.90	7.70	2.69***	0.002
Low	30	7.76	4.17		
High	30	6.73	2.99		
Total	112	9.41	6.306		

*** F= 2.69, p =0.000, significant at 1% level

Participation in cooperatives

According to the Welmera woreda Rural Capacity Building Office, there were 33 cooperatives of which 8 involve improved seed production. These cooperatives are delivering different kinds of improved seed, including potato to the local farmers and to cooperatives in other area. Cooperatives serve as important sources of input and credit for rural communities, and their members have more chances to get credit (Tadesse, 2008). As shown in Table 15, chi-square analysis reveals that (χ^2 =30.29, df=2, p =.000) participation in cooperative had positive difference on the adoption of potato technologies. Among the high adopters 25 participated in cooperative societies, whereas only 14 of nonadopters participated in the cooperative. Thus, membership in cooperatives plays a significant role in the adoption of new technologies

Table 15: Relationship between participation in cooperative society and adoption of improved potato production package

Farmers Response	Adoption Categories			
	Nonadopter	Low	High	Total
Yes	14	22	25	61
No	38	8	5	51
Total	52	30	30	112

χ^2 value 30.29, df = 2, p =.000, significant at 1% level

Attending extension events

Participation in field days, attending agricultural trainings, and participating in demonstrations by the sampled households are discussed below.

Field days. Field days are one of group extension teaching methods and field day participation by adoption categories in the study area showed significant difference among adoption categories at 1% level significance (Table 15).

Training. There is practical and theoretical training that helps farmers to practice new technologies properly. If a farmer has low skills and knowledge about the application and use of a given technology, the probabilities of adopting the technology would be less. Out of 112 households sampled, most have training (Table 16).

Table 16: Attendance at field days, training, and hosting demonstration among adoption categories

Characteristics	**Farmers' Response**	**Adoption categories**				**X^2**
		Non adopter	**Low**	**High**	**Total**	
Attended on field days	Yes	1	16	22	39	48.931***
	No	51	14	8	73	
	Total	52	30	30	112	
Ever attended agricultural training	Yes	23	22	22	67	7.869**
	No	29	8	8	45	
	Total	52	30	30	112	
Hosted extension demonstration	Yes	5	13	17	35	22.388***
	No	47	17	13	77	
	Total	52	30	30	112	

X^2 = 48.931, 7.869, 22.388 =significant at 1%and 5% probability level

The result showed (F=7.869, *p* =.02) that attending training and the adoption of improved potato technologies was significant at 5% level.

Demonstration. This is used to show the advantage of a given technology on site, based on comparison of different alternatives. Conducting demonstrations on farmers' field facilitates the adoption process. In this study, 47 of nonadopters did not get the opportunity to host demonstration on their farm, whereas 17 of high adopters have farm trial opportunities. Statically, chi-square test showed (F=22.388, *p* = .000) significant difference between adoption categories.

Psychological factors

Farmers' perception. How farmers perceived improved potato technologies is one of the determinant factors that facilitated adoption. All the adoption categories preferred the technology from different perspectives. They preferred the technology for its high yield, early maturity, high better price, and a combination of these characteristics. In the nonadoption categories, some farmers need to adopt the technology if some socioeconomic and institutional factors are facilitated. From the total sampled households, 23.2% of respondents preferred it by high yield and better price; 21% preferred by high-yielding qualities of the technology (Table 17).

Table 17: Farmers' perception of preference of improved potato technologies

Farmers' Response	Adoption Categories						Total	
	Non adopter		Low		High			
	n	%	n	%	n	%	n	%
No opinion	32	61.5	0	0	0	0	32	28.6
High yield and better price	5	9.6	11	36.7	10	33.3	26	23.2
High yield and early maturity	2	3.8	5	16.7	8	26.7	15	13.4
Early maturity and high price	6	11.5	8	26.7	1	3.3	15	13.4
High yield	7	13.5	6	20.0	11	36.7	24	21.4
Total	52	100	30	100	30	100	112	100

The common weaknesses of technologies mentioned were price of the seed, low resistance to disease, and demand-intensive farm management. About 45% of respondents complained about low resistance of the varieties to disease. The weak side of the technology that had the highest share by nonadopter, low, and high adopters was low resistance to disease and high price of the technology.

Social mobility. This dimension is the degree of orientation of the respondents towards outside social network (Tadesse, 2008), which exposes them to new technologies and other farmers. In the study area, farmers go out to nearby cities, to purchase inputs and goods, to sell farm outputs, to visit relatives, to have medical treatments, and for recreation. As shown in Table 18, there was a significant difference among adoption categories at 1% level (*p* =.000). Most nonadopters(35) go out to the nearby city sometimes and this might limit them from getting current agricultural information.

Table 18: Distribution of respondents based on their visit to nearby town

Frequency of visit to the nearby town	Adoption Categories				χ^2
	Nonadopter	Low	High	Total	
Daily	3	2	9	14	31.61***
Most often	4	8	9	21	
Once per week	8	10	2	20	
Some times	35	10	10	55	
Never	2	0	0	2	
Total	52	30	30	112	

**** 2011, χ^2=31.61, p =.000, significant at 1% level*

Leadership status.gtfrdsx23+3+-+3- Usually participation in the community development activities and leadership are perceived as a willingness of a person to work together. The relationship between leadership interpersonal networking, exchanges, and adoption is examined by looking into the differences in these attributes between adopters and nonadopters of technology. In this study, it was considered that farmers who have some position in any local organizations are more likely to be aware of new information and practices. Therefore, it was expected that there would be positive and significant difference among adoption categories (Table 19).

Table 19: Leadership status of respondent farmer and adoption of improved potato production package

Farmers' responses	Adoption Categories				χ^2
	Nonadopter	Low	High	Total	
Yes	18	18	20	56	9.456***
No	34	12	10	56	
Total	52	30	30	112	

****, χ^2=9.456, p =.009, significant at 1% level*

From 112 households, 56 participated in different leadership activities. From the adopter group, 18 non-, 18 low, and 20 high adopters participated in leadership. Chi-square (χ^2=9.456, p=0.009) analysis revealed that there is significant difference between adoption categories, implying that leadership influences adoption of potato production packages. This study is in line with the findings of Tesfaye (2006),who reported a significant difference between leadership status and adoption of rainwater harvesting technology.

Determinants of probability and intensity of adoption of improved potato production package

For Tobit model, 11 explanatory variables were used (Table 20). Out of these, 6 variables were found to have significant effects on the probability and extent of adoption: sex of household head, educational level of households, total land holding, extension contact, participation in demonstration activities, and access to credit.

Table 20: Maximum likelihood estimates using Tobit model

Variable	**Estimated coefficient**	**SE**	**T**	***P* Value**
LEADSTA	0.0713258	0.0760826	0.94	0.351
SEX	-0.1980176	0.0863414	-2.29**	0.024
EDU	0.166146	0.0838809	1.98**	0.050
FAREX	0.0003133	0.0029569	0.11	0.916
MEMCOOP	-0.0014103	0.0860703	-0.02	0.987
LAHOLD	0.1013813	0.0281221	3.61***	0.000
ACCREDT	0.1256948	0.0750411	1.68*	0.097
EXTCONT	0.3867447	0.0883794	4.38***	0.000
DEMO	0.2733453	0.0971822	2.81***	0.006
FIELDY	-0.0083988	0.0810803	-0.10	0.918
FAMISIZ	0.0002208	0.0169296	0.01	0.990
Constant	-0.247295	0.1423049	-1.74*	0.085
/sigma	0.3148992	0.0316416		
Log likelihood function =41.056827 ANOVA based fit measure=0.5674 *P*=.000				

****, **,* represents 1%, 5%, and 10% level of significant*

Effects of changes in the significant explanatory variables on probability and extent of adoption of improved potato production package significantly affected variable that does not have equal contribution in the influence of decision in each household. So, it was regressed to assess the effect of this explanatory variable on the probability of adoption and extent of adoption of improved potato production package (Table 21).

Table 21: Effects of changes in significant explanatory variables on adoption and extent of adoption of improved potato production package

Variable	**Probability of adoption**	**Intensity of adoption**
SEX	-0.268175	-0.8126314
EDU	0.2427219	0.2681375
LAHOLD	0.0969177	0.938922
ACCREDT	0.2558149	0.2260381
EXTCONT	0.3978866	0.9629811
DEMO	0.510367	0.4915593

The marginal effect of sex on probability and intensity of adoption of improved potato production package was -26.8% and-81.2%, respectively. That means female-headed farmers were better adopters of improved potato production packages than male counterparts were. As shown in Table 21, the probability and intensity of adoption were raised because of the status of the educational level better than nonadopter farmers were. The other justification is literate farmers have better exposure to market-oriented production and allocate more land for improved potato production packages.

Large landholder farmers are more likely to adopt improved potato production package than smallholders are. The probability and intensity of adoption of the package were 9.6% and 93.8%, respectively. Adopter farmers have frequent contact with development agents than do nonadopters. Similarly, farmers who have participated in demonstration trials on their farms increased the probability and intensity of adoption—51.3% and 49.15%, respectively. So, by raising the extension services to smallholders, less active farmers, and those with less access to extension service, farmers can raise the adoption rate of the improved potato production packages in the study area. This frequent contact increases the probability and intensity of adoption by 39.7% and 96.2%, respectively (Table 21). Similarly, the probability and intensity of adoption of credit accessed farmers were25.5% and 22.6%, respectively. In this study, a percent increase in explanatory variables will be certain to increase the probability and intensities of adoption of improved potato production packages.

Conclusions

Decision and behavior of technology adoption of each household are affected by different kinds of factors. These determinant factors are categorized as social and economical, institutional, personal, demographic, and psychological. Each factor was assumed to positively influence the adoption of improved potato production package.

On personal and demographic characteristics, sex showed significant differences on the adoption of improved potato production package. This study confirms that female-headed farmers are better adopters of potato production technology than male-headed farmers are. Similarly, educational status of the household head significantly and positively influences the adoption of improved potato production package.

Total land holding of the respondent farmers has shown positive relationships between the adoptions of improved potato production package. Similarly, annual farm income showed significant difference on adoption.

Access to credit, participation in cooperative societies, distance to market place, mass media exposure, and attending extension events showed significant relationships between the adoptions of improved potato production packages, indicating that potato production demands more institutional support than other crops. A majority (77.3%) of the respondents have had positive response on the adoption of improved potato production technologies.

The econometric model used in this study revealed the influence of the sex of household head, extension contact, educational level of household head, total land holding, access to demonstration, and access to credit to be significant in terms of probability and intensity of adoption of improved potato production packages.

In general, this study found that vegetable production has contributed to significant amount of income to sample households and changed their lives. Farmers participated in group discussions articulated that they benefited from adoption of improved potato production packages and improved their livelihoods. The single most important improvement mentioned was the ability to send children to school, followed by improvements in housing condition. The major problems are marketing, lack of cooperative association, and needed improvements in extension services in order to facilitate greater adoption of technology.

Recommendations and Policy Implications

- Farmers are always faced with marketing problems, and stakeholders must work hand in hand to solve these problems of potato production;
- Education significantly affects the probability and extent of adopting improved potato production packages because horticultural crops like potatoes demand skills of the production process. Thus, extension services such as demonstrations, trainings, and field day activities should be strengthened;
- Female-headed households were more likely to adopt technology packages than male-headed households were. This is obtained due to intensive follow-up by the HARC. The Woreda Agriculture Bureau should also give due attention to women farmers (female-headed households);
- The Woreda Agricultural Bureau should increase the awareness of small-sized landowners to participate in potato production. Above all, the credit system should at least be attractive to smallholders by introducing low interest rates and train both farmers and credit providers;
- The explanatory variable, membership in cooperative societies, shows significant relationship with the adoption of improved potato production packages. Expanding and strengthening cooperative institution in the woreda will increase the number of farmers adopting improved potato production. The woreda administrative and related offices should increase number of

cooperatives and improve the services provided by the existing cooperatives; and

- Potato seed quality has gradually decreased in terms of yield performance and disease resistance. To keep the seed quality to the regained standard, there should be inspection mechanisms and intensive training to seed producers.

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Multiplication and Marketing of Potato Seed Tubers to Address Productive Safetynet Agenda of Tachgaint Woreda

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Introduction

TachGaynt woreda is located in south Gondar zone of the Amhara National Regional State (ANRS). The total population of the woreda is estimated to be 109,449, with an average family size of five people per household. There are 15 rural kebeles and one woreda town (ArbGebeya). The average landholding size is 0.94 ha per person. The woreda is divided into three major agro-ecological zones: *kola*, *woinadega*, and *dega*. Its altitude ranges from 1,500 to 2,900 meters above sea level; the temperature ranges from13°C to 27°C and annual rainfall measures 900–1,000 mm. TachGaynt woreda is one of the 64 chronically food insecure woredas of ANRS. Potato is one of the widely cultivated food crops in the region and has high potential for distinct value chain.

The FH/Ethiopia project has targeted 4 of the 15 rural kebeles of the woreda to implement the introduction of improved potato tuber seed production technology. It is widely produced and consumed in 5 kebeles of TachGaynt woreda. It is a hunger reliever and emergency food crop with immense potential to contribute to food security. Over 400 ha of farm land in TachGaynt is covered annually by potato (CACC, 2003). Potato can circumvent land problems producing high yields in short periods and allows double cropping and early in season. Yet potato productivity is only 5 t/ha, which is far below the world average yield of 16.45 t/ha (FAO, 2004). This is mainly caused to the wide use of landrace potato varieties susceptible to late blight (LB) and poor quality seed tubers. LB causes very high damage of up to 95%. This could be alleviated to over fivefold if improved varieties and their associated production packages developed by the research systems are used. Pilot collaborative technology transfer efforts made earlier have proven this notion. Potato value chain assessment started in 2007 through the Support for Productive Safety Net Program (SPSNP), funded by the U.S. Agency for International Development, that ran from 2005 to 2008. It continued to be implemented in the ongoing Multiyear Assistance Program (2009–2011). The potato value chain is launched to increase the income of beneficiaries of the

Productive Safety Net Program (PSNP) and attain food security by promoting high-potential value chain of potato. It also contributes to graduation and ensure sustainable availability of quality potato seed tuber in the area. These all improve and protect assets and livelihoods of food-insecure households and community resiliency to withstand shocks.

Survey Methodology

Participatory rural appraisal was a tool selected for the study. It was helpful in getting qualitative and quantitative data from primary and secondary sources. Focus group discussion (FGD) was used to gather information and determine the efforts done so far. In addition, it was used to identify the strength and limitations encountered. Primary data were obtained through interviews of producers, cooperative leaders, and project staff engaged in implementation. Key informant interviews were made with project staff. Secondary data were acquired through literature review and collection of available statistics from the project office in both published and unpublished sources.

Chronology and Rationale of Potato Value Chain

There are two previous project documents that provide source information about the chronology and rationale of the potato value chain. The potato value chain started in 2007 through the USAID-funded SPSNP (2005–2008). It continued to be implemented in the ongoing Multiyear Assistance Program (MAP), 2009–2011. The potato value chain was launched to ensure sustainable potato seed availability in the area, examining the following issues

- Potato is one of the major staple crops, especially during food shortages;
- It gives higher yield per unit area than cereals and pulses traditionally cultivated in the area;
- It gives good opportunity to increase the income of PSNP beneficiaries and support their graduation from the program;
- Since the improved varieties are early maturing, they escape from early cessation of rainfall, so it is a feasible candidate to adapt to the erratic nature of rainfall in the woreda;
- The demand for quality potato tuber seed is unmet in ANRS in general and in south Gondar Zone; and
- In the 2007 cropping season, the area covered with potato was 71,000 ha. Demand for tuber seed was 142,000 tons, but only 458 tons were available to cover 229 ha in the whole ANRS.

Implementation Strategy

The following strategy was pursued to fulfill the project's ultimate objective:

- Organize farmers as seed producer groups (FREG), which ultimately grow to legal cooperatives;
- Organize training of trainers(ToTs) to government and FHE project staffs;
- Organize training for development agents (DAs) and farmers;
- Organize regional- and woredas-level workshops to bring the value chain actors together and to promote marketing;
- Conduct value chain analysis;
- Strengthen linkages with agricultural research centers, regional seed certification, and technical groups with other actors in the value chain;
- Introduce diffused light store (DLS) technology in the area; and
- Perform the input transfer system through rotating credit basis (RCB).

Activities and Outputs

The following 10activities were carried out to meet the project's objective:

- ToT was carried out on technology promotion and development for Woreda Office of Agriculture staff in collaboration with Adet Agricultural Research Center (AARC) and Bureau of Agriculture (BoA);
- Training is given for front-line community workers, DAs, and targeted farmers selected to implement the improved seed multiplication and marketing scheme of Irish potato;
- Two varieties of improved potato cultivar (Jalene and Gudene) were purchased from farmers organized by Holetta Agricultural Research Center;
- Farmers' field days were organized in collaboration with AARC and woreda BoA to create awareness on the availability, transfer, dissemination, and marketing interventions of new potato technologies;
- The project has carried out the promotion of high-potential value chain crops with the objective of increasing income of target beneficiaries;
- The inputs were delivered to the first five members of each group on a RCB. The beneficiaries who received inputs in the first round have in turn paid back the inputs to rotate it to the remaining beneficiaries in the next round. The project has delivered 82 tons of improved potato tuber seed;
- Technical assistance was given for target beneficiaries during each production stage and value chain analysis was done for each crop, from land preparation to produce marketing;

- Support was given to establish farmer cooperatives and hence, most of them secured legal certificate to operate business ventures in input and output marketing;
- The project has supported the construction of seven DLS by providing corrugated iron sheet, nails, and mesh wire. Local materials and labor were contributed by the beneficiaries; and
- Ninety-two tons of two improved potato varieties (Jalene and Gudene) were purchased and distributed. This seed tuber was planted on 85.46 ha of land at four kebeles using the recommended technology package.

Impact of the Project

- About 480 farmers produced 2,108.7 tons of improved Irish potato tubers, of which 841.7 tons were sold, 762 tons were consumed, and 345 tons were saved as seed for next planting;
- Average yield of potato increased from 7 tons (local variety) to 26 tons (improved variety), hence household income highly increased;
- The low-yielding variety has been getting replaced by high-yielding improved varieties that resulted in the significant trickledown of non-beneficiary farmers in the woreda;
- These farmers (482) who sold potato generated 2,097,625Birr in the last five production and marketing years;
- Household food availability increased; food scarcity decreased to only four months (previously it was about six months in a year);
- Among 482 seed producers organized in four cooperatives, 450 were beneficiaries of the PSNP and 218 households (48.6%) have been able to create assets and graduate from the program;
- As a result of the program, TachGaynt woreda has been serving as one of the seed bank and marketing center of Irish potato in ANRS; and
- Most of the farmers created the following assets (constructed tin-roofed houses; bought oxen, cows, mule, and sheep; leased urban land to construct houses; and sent their children to schools).

Tables 1–4 display various data to support and illustrate these project impacts.

Table 1: Improved potato seed multiplication intervention and achievements

Description of activity	Quantity by Implementation Year			Total
	2007	2008-2010	2011	
Diffused seed to farmers (q)	100	820	516	1,436
Potato produced (q)	678	8,409	12,000	2,1087
Potato consumed (q)	30	1,590	6,000	7,620
Potato saved for seed (q)	80	970	2,400	3,450
Potato sold (q)	568	5,849	2,000	1,0417
Potato sold (Birr)	170,000	1,327,625	800,000	2,297,625
Total hectares planted	5	33	48	85

Table 2: Average income of household by year

Year	Produced (t)	Sold (t)	Unit price (Birr/t)	Total sale (Birr)	Total HH (no.)	Income per HH (Birr)
2007	105	56.9	3,000	170,649	74	2,306
2008	183.05	90	3,500	315,000	302	1,043
2009	129.62	53.6	5,500	294,800	170	1,734
2010	455.25	197.2	5,500	757,075	222	3,410
Total	872.92	397.7	4,375	1,537,524	768	2,123

NB: *The sale potato tubers harvested in 2011 was not yet completed and thus could not be included in the average income in the result.*

Table 3: Organizations purchased potato seeds form TachGaynt (2007–2011)

Organization	Woreda	Total sold	
		MT	Birr
Simada/TG FH	Simada/TG	174.35	473,200
SimadaWoARD	Simada	2.50	13,750
CARE	Farta	92.10	506,550
Addis ZemenWoARD	Addis Zemen	0.50	2,750
Woreta WoARD	Woreta	0.50	2,750
IFAD	Estay	0.60	3,300
SLUM		1.80	9,900
ORDA-Wadla	Wadla	3.00	16,500
TG WoARD	TG	17.15	94,325
Dera WoARD	Dera	0.40	2,200
Gonder Research Center	Gonder	0.70	3,850
Lay Gaint FHE	Lay Gaynt	10.00	50,000
Kelela WARDo	Kelela	7.50	37,500
Debre Elias WARDO	Debre Elias	1.40	7,000
Total		312.50	1,223,575

Table 4: Members of the cooperatives participated in the study

Name of cooperative	Locations (kebele)	Members by sex			PSNP
		Male	Female	Total	
Meseret	3	93	9	102	102
Serto Melewet	4	115	15	130	128
Yabebal	6	203	13	216	186
Serto Metades	13	38	4	42	34
Total		**449**	**41**	**490**	**450**

Strengths and limitations of the project

FGD and key informant interviews were made to gather data; the results are summarized in the following sections. The limitations of the project are seen from different angles—for example, sustainability, market constraints and access, and available technologies.

Limitations

- The cooperatives were not actively assessing market opportunities by themselves. They are fully depend on WOARD and FH/Ethiopia TachGaynt Project;.
- No efforts were made to diffuse improved technologies on potato tuber processing. They have been using the traditional way of preserving in the farm plot until belg rain every year;
- The cooperatives did not exploit market opportunity for potato. It could have been a good income source for farmers in the highlands of TachGaynt Woreda;
- The improved varieties have been deteriorating from time to time in terms of genetic potential. This requires maintenance of these varieties under technical improvement procedures; and
- There is high dependency syndrome by the project beneficiaries (e.g., DLS constructed by the project do not have masonry work, people waiting for others to construct ditches rather than doing the work themselves).

Strengths

- The woreda cooperative office has been providing technical assistance to the cooperatives;
- The woreda agriculture and rural development office and FH/Ethiopia TachGaynt Project have been working together to meet their objective;
- Inputs were delivered to the targeted farmers on a RCB. Currently the cooperatives have 516.24 qt of Irish potato in their seed bank to give access to

PSNP beneficiaries of four kebeles on a yearly basis. An average of 208 farmers are served annually;

- Farmers' willingness to be organized in farmers' research and extension group has been increasing from time to time. It has been one of the cornerstones for the success of the project;
- The improved Irish potato crops planted in the value chain were certified on yearly basis by fulfilling the scientific seed certification standards;
- Support was given to establish four farmer cooperatives and secured legal certificate to operate as a business entity in marketing the input and output supply of their members;
- The project has supported the construction of seven DLS at the cooperative level by providing industrial materials. The co-op members contributed local material and labor for the construction;
- There has been a strong linkage with AARC. This year an effort has been underway to introduce three new varieties for the woredas (Belete, Zengena, and Guasa) plant tissue culture materials;
- The improved varieties provided for farmers have been deteriorating from time to time in terms of its genetic potential. ARARI has started providing planting materials produced by plant tissue culture to one of the project cooperatives; and
- TachGaynt woreda has been one of the few woredas serving as a market center for improved varieties of Irish potato tuber seed (see Table 3).

Recommendations

- The improved varieties provided for farmers have been deteriorating from time to time in terms of its genetic potential. ARARI has to use other improved varieties like Jalene and Gudene;
- Further exploit the newly introduced varieties of Belete, Zengena, and Guasa.
- Cooperatives should be able to stand on their own feet and actively assess market opportunities by themselves;
- FH/Ethiopia and agricultural marketing department of the BoA should give emphasis on the need for assistance in this area;
- Construction of DLS and ware potato store should be given due emphasis; and
- The labor-based road program should improve the road network of Kebele 06 and 04 Bete Yohanis. This will enhance the marketability of potato.

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Seed System Analysis of Potato in Guraghe Highlands

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Introduction

Quality potato seed is one of the most important ingredients for successful potato production. Thus, availability of quality planting material of improved varieties in adequate quantities was a major issue that needs to be addressed. This needs detailed analysis of the seed system of potato in the area. Understanding farmers' potato seed systems, the formal seed sector, and the relationship between these systems is necessary for enhanced production and productivity of the crop. In the study area, farmer-based seed multiplication scheme has been in place for a long time, but little is known about the potato seed system and the challenges posed and opportunities available that determine the production and availability of quality potato seed tuber. This study was generally aimed at assessing the potato seed tuber system in the Guraghe highlands of Ethiopia.

Materials and Methods

A purposive multistage random sampling technique was used to select sites and draw samples of farmers for the study. Gumer woredas selected because of its high potential for potato production and for its prominence in practicing farmer-based potato seed tuber multiplication. Thirty-five Farmers' Research Groups (FRGs), which were drawn intentionally from six kebeles of Gumer woreda, were selected based on their experience in farmer-based potato seed tuber multiplication. Sampling of households was carried out considering two sampling frames of farmers: participants in potato seed tuber multiplication and non-seed tuber producers. Seventy farmers (2 from each of the 35 FRGs) were randomly taken from the group who are engaged in potato seed tuber production and were considered adopters. In the same way, 70 ware potato producers (hereafter called nonparticipants) were randomly taken from total residents in the six kebeles by excluding seed tuber producers. Thus, 140 farmers were selected randomly for the survey.

Primary data necessary for quantitative analysis were collected from 140 households by conducting a formal survey using structured interview schedules from September to October 2011. A questionnaire was developed and pre-tested on 12 randomly selected farm households from six selected PAs before conducting the formal survey. The interviews and discussions were conducted in the local language (Guragigna) to ease communication. The data were analyzed using a Statistical Package for Social Sciences (SPSS version 16) computer software.

Results and Discussions

Varieties grown and selection criteria

About 28 potato varieties were identified by the respondents, out of which 6 varieties were improved varieties: Jalene, Gudene, Guasa, Wechecha, Tolcha, and Genet. The remaining 22 varieties were local and their origin is unknown. From the improved varieties, 3 (Wechecha, Tolcha, Genet) are not currently under production. From the 22 local varieties, 19 were taken out of the production due to susceptibility to diseases, low productivity, and not meeting farmers' preference. Many of these locally named varieties could be duplicates. Gebremedhin et al. (2008) also reported that in most cases there may be many names for a variety in different localities. The local potato varieties currently under production were: *qeyu denech*, *aesfo*, and *yaskiwot wangeta*. Out of participant farmers, 87.1%, 84.3, 75.7%, 14.3%, 12.9%, and 12.9% have been growing Jalene, Gudene, *key dinich, askiwot wangeta*, Guasa, and *asefo*, respectively (Table 1). In addition, 57.1%, 44.3%, 90%, 12.9%, 11.4%, and 28.6% of nonparticipants were growing Jalene, Gudene, *key dinich, askiwot wangeta*, Guasa, and *asefo*, respectively.

The survey result showed that Jalene, Gudene, and *key dinich* were most dominant varieties grown currently by majority of the studied farmers. However, potato farmers in the area typically grow more than one variety and practice growing varietal mixture. Farmers were able to identify the characteristics of potato varieties they grew during current and previous seasons and to rank them according to their selection criteria and preferences. Farmers identified and characterized three varieties (Jalene, Gudene, and *key dinich*) grown by majority of them. Accordingly, farmers because of its better disease resistance (74.3%), food quality (74.3%), and marketability (70%) favored Gudene, whereas *key dinich* was preferred for its adaptability (52.9%) and Jalene for its yield (60%) and earliness (75.7%).

Seed Sources

Farmers might use various seed sources based on various technical and socioeconomic factors in the area. This study showed that there were multiple sources of potato seed in the study area. The initial source of potato seed tuber for participants was predominantly purchased from market (41.4%) and others included purchases from other farmers (12.9%), from Ministry of Agriculture

(MOA) (30%), gift from parents (11.4%), and gift from other farmers (1.4%). Nonparticipants purchased from market (51.4%) and others included purchases from other farmers (18.6%), from MOA (8.6%), gift from parents (12.9%), and gift from other farmers (1.4%) (Table 2). The quality of seed purchased on open market was often unknown, but the buyer may able to judge only on its external quality (Beukema and Vander Zaag, 1990). Seed sources of farmers in 2010 and 2011 cropping seasons were mainly own-saved seed, Board of Agriculture (BoA), and purchase. Farmers' seed source of potato was initially purchasing from market (trader), then later on the seed source is dominated by own stock. This result agrees with the finding of Mekbib (2006) on sorghum in eastern Ethiopia. Asrat et al. (2008) also noted that farmers' seed source in normal situations is mostly their own stock from the previous harvest.

Table 1: Farmers' variety selection criteria and ranking (n = 70)

Farmers' variety selection criteria	**Varieties**					
	Jalene		**Gudene**		***Key dinich***	
	n	**%**	**n**	**%**	**n**	**%**
Yield	42	60	26	37.1	2	2.9
Disease resistance	15	21.4	52	74.3	3	4.3
Food quality	10	14.3	52	74.3	8	11.4
Earliness	53	75.7	9	12.9	8	11.4
Adaptability	11	15.7	22	31.4	37	52.9
Marketability	18	25.7	49	70	3	4.3
Varieties grown	**Participants**		**Nonparticipants**			
	n	%	n	%		
Jalene	61	87.1	40	57.1		
Gudene	59	84.3	31	44.3		
Key dinich	53	75.7	63	90.0		
Askiwot wangeta	10	14.3	9	12.9		
Guasa	9	12.9	8	11.4		
Asefo	9	12.9	20	28.6		

**Percentage above hundred indicates multiple responses*

MOA study conducted in Northwest Ethiopia indicated that 50% of the farmers used seeds from their own harvests, while 44% purchased them from the market, 5% purchased from other farmers, and 1% obtained from extension demonstration (Agajie et al., 2008). The participants get initial seed of an improved potato variety from MOA (which is obtained from HARC), they retain seed tuber for planting in the next season. As a result, the number of participant farmers who used seed from own-saved source increased from 62.9% in 2010 to 92.9% in 2011.

HARC is the major institution supplying starter seed stock of improved potato tuber seed to be multiplied by farmers or serve as technology demonstration on farmers' fields. The improved potato tuber seed reaches other farmers also through other farmers. The International Potato Center (CIP), together with the U.S. Agency for International Development (USAID), also provides seed potato tubers for farmers in the study area. The seed tuber supplied to farmers from HARC and CIP/USAID (through BoA) was in the form of a seed loan arrangement, in which the receiver pays back in-kind at harvest through BoA. The seed collected in this way is distributed to other FRG members for further scaling-up.

Table 2:Sources of initial seed in 2010 and 2011 cropping seasons

Seed Sources for Participants	**Initial source**		**2010**		**2011**	
	n	**%**	**n**	**%**	**n**	**%**
Own stock	-	-	44	62.9	65	92.9
Loan from MOA	21	30	46	65.7	24	34.3
Gift from farmers	1	1.4	2	2.9	-	-
Purchase from farmer	9	12.9	10	14.3	6	8.6
Purchase from trader	29	41.4	5	7.1	5	7.1
Purchase from NGO	2	2.9	3	4.3	-	-
Gift from parent	8	11.4	-	-	-	-
Seed sources for non-participants	Initial source		2010		2011	
	n	%	n	%	n	%
Own stock	-	-	59	84.3	36	51.4
MOA	6	8.6	9	12.9	4	5.7
Gift from farmers	3	4.3	1	1.4	3	4.3
Purchase from farmer	13	18.6	17	24.3	24	34.3
Purchase from trader	36	51.4	6	8.6	14	20
Exchange with other seeds	3	4.3	-	-	-	-
Gift from parent	9	12.9	-	-	-	-

*One farmer obtained seeds from different sources. **

Seed purchases are one of the means of seed renewal or varietal change. As shown in Table 3, about 71.4% of participant and 61.4% nonparticipant farmers purchased potato seed tubers. The frequency of purchasing seed varied among farmers, and the majority bought seed whenever they discovered an improved variety. This is reported by 62.7% and 48.9% of the participant and nonparticipant farmers, respectively. This shows that farmers presume potato yield declines were mainly due to varietal degeneration not by seed degeneration. Thus, varieties were often changed when seed is renewed. In other places, however, growers should renew their seeds after using them for a maximum of three consecutive seasons (Lung'aho et al., 2007), but there is no information concerning this in Ethiopia. Regarding reasons for purchase, most (58% of participant and 76.7% of nonparticipant farmers) were considering a better seed quality to purchase.

Table 3: Seed purchases, reasons and frequency of purchase

Seed Purchase	**Participant (n=70)**		**Nonparticipant (n=70)**	
	n	**%**	**n**	**%**
Yes	50	71.4	43	61.4
No	20	28.6	27	38.6
Frequency of Purchase	n=50		n=43	
Every season	6	12	1	5
Every year	1	2	-	-
Every 2 years	4	8	2	4.7
Every 3-4 years	8	16	2	4.6
Every 6-7 years	-	-	9	20.9
Never	-	-	4	9.3
Whenever got improved variety	31	62	21	48.9
Reasons for Purchase				
To replace old variety	9	18	2	4.7
To replace old seed	6	12	4	9.3
For better seed quality	29	58	33	76.7
No own seed	6	12	4	9.3

Information Flow and Agronomic Practices

Information

Good and timely information on new technologies and techniques is essential for farmers when deciding whether or not to adopt an innovation. The survey result showed that all potato growers (100%) in the study area had some information on potato production technologies. The major source of information for the agronomic packages were MOA extension agents as cited by 98.6% of the participant and nonparticipant farmers. This indicates that farmers who have access to better extension services were more willing to participate in seed multiplication than other farmers. The other sources for potato-related information included media (40% and 37.1%), other farmers (42.9% and 55.7%), friends/relatives (32.9% and 35.7%), neighboring farmers (20% and 30%), research centers (25.7% and 2.9%), and newspapers (21.4% and 5.7%) for participant and nonparticipant farmers, respectively (Table 4).

Table 4: Sources of information for potato technologies (n=70)

Source of information	Participants		Nonparticipants	
	n	%	n	%
MOA (extension agents)	69	98.6	69	98.6
Media (radio)	26	37.1	28	40
Newspaper	4	5.7	15	21.4
Other farmers	39	55.7	30	42.9
Friends/relatives	25	35.7	23	32.9
IAR	2	2.9	18	25.7
NGO	-	-	1	1.4
Investors	-	-	1	1.4
Neighbors	21	30	14	20

Values > 100% indicates multiple sources of information.

Agronomic practices

Land preparation. Hand digging of the soil is the major practice in the area, and the majority of participant (54.3%) and nonparticipant (67.1%) farmers cultivate their land three or more times (Table 5). Generally, growing potato involves extensive land preparation. In most cases, three ploughings, along with frequent harrowing and rolling, are needed before the soil reaches a suitable condition—soft, well-drained, and aerated (FAO, 2010).

Planting. Time of potato planting may vary from place to place. In Gumer, farmers plant potato for an extended period both in belg and meher seasons. Research findings indicate that early June for meher planting is the appropriate planting time (Gebremedhin et al., 2008). Survey data showed that most of the participant (95.7%) and nonparticipant (84.3%) farmers practice planting from end of December to end of January for belg season while majority of the farmers(74.3% of participant and 35.7% of nonparticipant) practiced planting from second week of June for meher season. Some (27.1%) of nonparticipant farmers, however, plant from July to August for meher cropping (Table 5). This agrees with Agajie et al. (2008), who reported that farmers have started diversification of planting dates and, as a result, are benefiting from potato harvests for several months a year.

Table 5: Frequency of potato production, lowing and time of planting (n = 70)

Frequency of weeding and cultivation	**Participants**		**Non participants**	
	n	%	**n**	%
Two times	-	-	3	4.3
Three times	32	45.7	47	67.1
Four and more times	38	54.3	20	28.6
Time of planting (meher)				
First week of June	18	25.7	4	5.7
second week of June	52	74.3	25	35.7
Third week to end of June	-	-	22	31.4
July to August	-	-	19	27.1
Time of planting (belg)				
End of December	67	95.7	59	84.3
January	3	4.3	-	-
February	-	-	11	15.7

Soil fertility, fertilizer application, and seed rate. Farmers have detailed knowledge of their local soil types: the soil characteristics, problems, and their suitability for various crops. They may use many different criteria to distinguish one soil from another. About 90% of the participant and 78.6% of nonparticipant farmers consider the soil fertility status of the study area to be a medium class. Some 7.1% of participant and 15.7% of the nonparticipant farmers reported their soil is depleted (Table 6). Thus, almost all respondents use chemical fertilizer. About of 34.3% nonparticipant farmers used compost and cow dung in addition to the chemical fertilizer. Participant farmers used higher quantity of DAP (182 kg/ha) fertilizer in their potato farms than nonparticipant farmers (166 kg/ha). The independent t-test result showed that DAP fertilizer application rate significantly differed between participant and nonparticipant farmers. Participant farmers used on average 99 kg/ha Urea, whereas nonparticipant farmers used about 75kg/ha Urea (Table 6). The t-test result showed that as there was highly significant at difference (p = .000) between the two groups on their Urea application. Adjustment of plant density in the fields is a good practice to produce a high proportion of medium-sized seed tubers (Endale et al., 2008). This study indicated that there is a great variation in using seed rate between participant and nonparticipant farmers. The mean seed rate used by participant and nonparticipant farmers was 20.91q/ha and 26.6 q/ha, respectively (Table 7). The higher seed rate used by nonparticipant farmers may be associated with the method of planting they practiced. About 53% of nonparticipant farmers practiced broadcasting of seed tubers, which is difficult to do inter-cultivation such as weeding and maintaining appropriate plant population. On the other hand, all the participant farmers used row planting (Table 6). The t-test result also revealed that there was highly significant ($p \leq .01$) difference between means of seed rate used by participant and nonparticipant farmers.

Farmers also plant 3–4 seed tubers per hole to ensure good field establishment; the recommendation suggests a single tuber per hole. Thus, the fact that farmers place more than one tuber per hole may generally indicate farmers are using poor quality seed tubers for planting.

Lung'aho et al. (2007) reported that the quantity of seed required by a grower depends on plant spacing and the size of the seed tubers to be planted. The same authors recommend 17.5–20, 22.5–25, and 30–32.5 q/ha for small-,medium-, and large-sized tubers, respectively, at a spacing of 75 x 30 cm. The average spacing between plants and rows used by participant farmers was 30.2 cm and 69.4 cm, respectively (Table 7). It is evident from this study that some of the recommended agronomic practices were not fully adopted by sampled households as recommended, indicating the difficulty of adopting agronomic practices in low precision agriculture in which farmers make some adjustments to fit their conditions. The planting density of a row of potatoes depends on the size of the tubers chosen, while the inter-row spacing must allow for ridging of the crop (FAO, 2010).

Table 6: Soil fertility status, type of fertilizer used and methods of planting (n=70)

Soil fertility	**Participants**		**Non participants**	
	n	**%**	**n**	**%**
Fertile	2	2.9	4	5.7
Medium	63	90	55	78.6
Depleted	5	7.1	11	15.7
Type of Fertilizer Used				
DAP and Urea	70	100	44	62.9
DAP	-	-	2	2.8
DAP, Urea, compost, and manure	-	-	24	34.3
Method of Planting				
Row planting	70	100	28	40
Broad casting	-	-	37	52.9
Both methods	-	-	5	7.1

Disease management. LB is the major disease in the area as reported by 78.6% of participant and 82.8% of nonparticipant farmers. About 36% of the participant farmers stated that they practice fungicide sprays against LB. Some 22.9% of participant and 45.7% of nonparticipant farmers perceived adjusting of planting time as appropriate method for controlling LB. Practicing early planting with chemical supplement as another option for controlling the disease was mentioned by 21.4% and 11.4% of participant and nonparticipant farmers, respectively (Table 7).

Table 7: Fertilizer and seed rate and disease management practices of farmers (n= 70)

Fertilizer rate	**Participants**			**Nonparticipants**			**T-value**
	n	**Mean**	**SD**	**n**	**Mean**	**SD**	
DAP (q/ha)	70	1.82	0.41	70	1.66	0.47	2.186**
Urea (q/ha)	70	0.99	0.35	70	0.75	0.33	4.524***
Seed rate(q/ha)	70	20.91	1.89	70	26.6	6.06	-7.434***
Spacing used							
Between plants	70	30.21	1.33	52	28.4	5.83	
Between rows	70	69.43	4.13	51	57.2	12.97	
Major Diseases		**n**	%		**n**	%	
Late blight		55	78.6		58	82.8	
Bacterial wilt		5	7.1		3	4.3	
Frost		10	14.3		9	12.9	
Disease Control Measures							
Adjust planting time		16	22.9		32	45.7	
Using chemical		25	35.7		7	10	
Using resistant variety		8	11.4		7	10	
Early planting with chemical		15	21.4		8	11.4	
Crop rotation and fallowing		6	8.6		10	14.3	
No control		-	-		6	8.6	

*** and *** show significance at 5% and <1% level, respectively.*

Potato seed tuber preparation techniques for planting

To ensure good harvests, potato farmers need a reliable source of good quality seed. The survey result indicated that 52.9% of the participant and 71.4% of nonparticipant farmers experienced problems in getting high-quality seeds (Table 8). In the group discussions, it was understood that high cost of quality seed and unavailability of seed were major problems mentioned for potato production in the area.

Almost all the potato seed tuber producers practice selection of seed tubers for planting. Considering the selection criteria, the majority (25.7%) of farmers use physical purity as a selection criterion. About 14.3%, 5.7%, 8.6%, 22.9%, and 22.9% of farmers used seed tuber size, healthiness, reputation of producers, and number of sprouts as selection criteria (Table 8). Eighty-eight percent of the participants practiced selection of appropriate tuber size for planting. Of these, 77.1% preferred medium-sized seed tubers, 17.2% of the farmers used any size they got, and 5.7% preferred large-sized tubers.

Table 8: Seed tuber selection criterion, tuber size, and techniques of sprouting

Problem of getting quality seed tuber	Participants		Non participants	
	n	%	n	%
Yes	37	52.9	50	71.4
No	33	47.1	20	28.6
Seed Tuber Selection Criteria				
Tuber size	10	14.3		
Healthiness	4	5.7		
Physical purity	18	25.7		
Witness by other farmers	6	8.6		
Sprout number	16	22.9		
Using all criterion	16	22.9		
Seed Tuber Size Preference				
Small			1	1.4
Medium	54	77.1	31	44.3
Large	4	5.7	3	4.3
Any size	12	17.2	35	50
Techniques of Sprouting				
Putting in plastic bags			9	12.9
Waiting			5	7.1
Putting in warm place			34	48.6
Covering with straws			12	17.1
Using local store			6	8.6
Putting on a floor of the house			3	4.3
Spraying ash on a basket			1	1.4

Different methods were employed by the nonparticipant farmers to enhance sprouting of seed potato during planting. These include putting in plastic bags, waiting, putting in warm place, covering with straw, using local store, putting on a floor of the house, and spraying ash on a basket to stimulate the tuber to sprout (Table 8). Farmers mentioned spreading the tubers between rows of *enset* plant and covering with straws or *enset* leaves was the method practices to enforce sprouting. A study conducted by Gildemacher et al. (2009a) also reported that placing potatoes in a warm place in the house was used by more than 23% of the farmers in Ethiopia, and putting the seed potato in bags (29%), waiting (24%), and covering with crop residues/grass (17%) were mentioned to stimulate potato tubers to sprout.

About 91.4% of the respondents have a separate plot for potato seed tuber production, with a mean isolation distance of 10.67 m. Isolation distance is the minimum separation required between two or more varieties of the same species to keep the seed pure. According to Ethiopian potato seed tuber quality standards, a 20-m isolation distance should be provided for all round potato seed tuber fields to separate from the fields of other related crop species and fields of the same variety not conforming to the varietal purity requirements (ES 494, 2000). Table 9 displays data on crop rotation and seed production practices by participant farmers.

Table 9: Crop rotation and some of the practices performed in seed production

<table>
<tr><td rowspan="4">Land allocated
isolation distance</td><td colspan="7">Participant Farmers</td></tr>
<tr><td colspan="2">n</td><td>Mean</td><td>SD</td><td colspan="3">Range</td></tr>
<tr><td colspan="2">70</td><td>0.73</td><td>0.42</td><td colspan="3">0.20-2.12</td></tr>
<tr><td colspan="2">64</td><td>10.6</td><td>12.68</td><td colspan="3">0.55-50</td></tr>
<tr><td>Having separate plot (n=70)</td><td colspan="2">n</td><td>%</td><td></td><td colspan="3"></td></tr>
<tr><td>Yes</td><td colspan="2">64</td><td>91.4</td><td></td><td colspan="3"></td></tr>
<tr><td>No</td><td colspan="2">6</td><td>8.6</td><td></td><td colspan="3"></td></tr>
<tr><td>Crop rotation (n=70)</td><td>n</td><td>%</td><td colspan="5"></td></tr>
<tr><td>Yes</td><td>60</td><td>85.7</td><td colspan="3">Roguing used (n=70)</td><td>n</td><td>%</td></tr>
<tr><td>No</td><td>10</td><td>14.3</td><td colspan="3">Yes</td><td>67</td><td>95.7</td></tr>
<tr><td colspan="3">Frequency of rotation (n=60)</td><td colspan="3">No</td><td>3</td><td>4.3</td></tr>
<tr><td>Every season</td><td>33</td><td>55</td><td colspan="5">Stage of roguing (n=67)</td></tr>
<tr><td>Every year</td><td>8</td><td>13.4</td><td colspan="3">Vegetative</td><td>40</td><td>59.7</td></tr>
<tr><td>Every two year</td><td>12</td><td>20</td><td colspan="3">Flowering</td><td>12</td><td>17.9</td></tr>
<tr><td>Every three year</td><td>5</td><td>8.3</td><td colspan="3">Maturity</td><td>15</td><td>22.4</td></tr>
<tr><td>Every four year</td><td>2</td><td>3.3</td><td colspan="3"></td><td></td><td></td></tr>
</table>

Harvesting and postharvest handling practices

Farmers carry out different activities in potato production before and after harvesting. The majority (95.7% of participant and 52.9% of nonparticipant farmers) practiced dehaulming before harvest (Table 10). Regarding the time of dehaulming, 61.2% of participant farmers carried it out 15 days before harvesting, and 14.9%, 10.4%, and 4.5% of the respondents carried it out 5 days, 10 days, and 20 days before harvest, respectively. About 9% of the respondents replied that they do not remember the number of days the practice dehaulming before harvesting. About 46%, 18.9%, 16.2%, and 2.7% of nonparticipant farmers' dehaulmed 5 days, 10 days, 15 days, and 20 days before harvesting, respectively. About 16.2% of the nonparticipants replied that they did not consider the date. Curing is a process that encourages the potato to naturally heal its wounds and it significantly reduces the incidence of postharvest rot. Most (82.9%) of the participant farmers cured their potato tuber seed before storage, of these 56.9% of the respondents cured for 5 days. About 22.4%, 15.5%, and 5.2% of the respondents cured their tuber seed for 1–3, 10, and 15 days, respectively (Table 11). The methods of curing were different among the respondents. The majority (55.2%) of the farmers spread seed tubers on the ground outdoors outside the store to expose them to sunlight for drying. About 32.8% of the respondents spread the tuber seed on the ground and sun drying by frequent mix up of the tubers, and then separate soil from the tuber after drying. About 12% spread the tubers in cellars or floors inside the house before storage.

Table 10: Harvesting practices of respondent farmers in the study area

Dehaulming (n=70)	**Participants**		**Non participants**	
	n	%	**n**	%
Yes	67	95.7	37	52.9
No	3	4.3	33	47.1
Time of dehaulming (n=67)				
5 days before harvest	10	14.9	17	46
10 days before harvest	7	10.4	7	18.9
15 days before harvest	41	61.2	6	16.2
20 days before harvest	3	4.5	1	2.7
Date not considered	6	9	6	16.2
Harvesting methods (n=70)				
Piecemeal	12	17.1	51	72.9
In bulk at once	58	82.9	19	27.1

Table 11: Participant farmers' practices of curing and grading of potato seed tubers

Practice of Curing (n=70)	**n**	%	**Practices of Grading (n=70)**	**n**	%
Yes	58	82.9	Yes	68	97.1
No	12	17.1	No	2	2.9
When to cure (n=58)			Who to grade (n=68)		
For 5 days before storage	33	56.9	All family members	19	27.9
For 10 days before storage	9	15.5	All group members	47	69.1
For 15 days before storage	3	5.2	Daily laborers	2	3
For 1–3 days before storage	13	22.4	How to grade (n=68)		
Methods of curing (n=58)			By size	6	8.8
Spreading seed tubers on ground outside the store	32	55.2	Removal of rotten and diseased tubers	13	19.1
Spreading on ground and separate the soil after drying	19	32.8	Physical damage	15	22.1
Spreading on cellar and floor inside the house	7	12	Using all criterion	34	50

Storage. All farmers have to save seed from previous harvest for planting in the next season and need storage structure to maintain good quality or protect seed tubers. Table 12 shows different places in which seed potatoes are stored in the study area. The majority (60%) of participant farmers store their seed tubers in a DLS, whereas about 61.4% of nonparticipant farmers store on a bed-like structure in the house (*ko't or alga*). The DLS is a very simple and low-cost structure that allows the diffusion of daylight and free ventilation inside in the storage that helps to suppress the elongation of sprouts (Endale et al., 2008). The participant farmers also store their potato seed on a local granary called *gotera* (4.3%), on a bed-like structure in the house (27.1%), on the floor of the house (5.7%),or leave unharvested in the soil (2.9%). About 15.7% of nonparticipant farmers store leaving unharvested on the soil, on the floor of the house (11.4%), and 10% on a *gotera*. From the survey study it was found that, for both participant and nonparticipant farmers, there is no clear demarcation for seed and ware potato storage methods other than the DLS, which is clearly meant or used for seed tubers only. It was also observed that at storage, farmers pile potato tubers in large heaps, which may reach up to 10 tubers deep. To make sure all potatoes receive light they are best kept on shelves, not more than 3–5 tubers high. If piled in a large heap, tubers in the middle of the heap do not receive any light (Gildemacher et al., 2007). The light ensures that many sprouts will develop on each tuber and the sprouts may become vigorous. About 37.1% of the respondents stored seed tubers to retain seed for the purpose of next planting, 31.4% of the respondents stored seed tubers for sale, 18.6% stored for family consumption, and 12.9% for all reasons (Table 12).

Table 12: Main places where seed potato is stored and reasons to store (n = 70)

Methods of storage	**Participants**		**Non participants**	
	n	%	**n**	%
On a local granary	3	4.3	7	10
On a bed-like structure in the house	19	27.1	43	61.4
On the floor of the house	4	5.7	8	11.5
Leaving un-harvest in the soil	2	2.9	11	15.7
On improved storage (DLS)	42	60	-	-
Do not stored anymore	-	-	1	1.4
Reasons of storage				
For sale	22	31.4		
For seed	26	37.1		
For family consumption	13	18.6		
For all the reasons	9	12.9		

Marketing of potato

Potatoes are typically marketed in small amounts during most months of a year, with a distinct peak during April and May. In this study, in the 2010 cropping season alone respondents sold on average 11.962 tons out of which nonparticipant farmers sold only 1.909 tons(Table 13). An average of 7.286 tons of potato tubers was used for home consumption, while 1.952 tons was kept for seed per household. Nonparticipant farmers on average consumed 2.341tons and retained about 0.478 tons as seed. The amount of potato consumed by nonparticipant farmers normally excludes those harvested earlier prematurely when the crop was still maturing. Some farmers never estimate whatever amount was consumed at the household level, hence the figures that have been reported might be inaccurate.

Table 13: Amount and place of potato sale

Item	Participants			Nonparticipants		
	Mean	SD	Range	Mean	SD	Range
Total produced (q)	195.99	148.16	28-670	33.99	37.20	3-200
Sold	119.92	120.01	20-570	19.09	28.29	1.5-112
Consumed	72.86	78.59	2-334	23.41	20.48	3-120
Retained for seed	19.52	11.36	2-50	4.78	5.78	0.5-30
Place of Seed Sale	n	%		n	%	
At the local market	25	35.7		38	54.3	
In other towns	3	4.3		-	-	
For NGOs	13	18.6		-	-	
For GOs	6	8.6		1	1.4	
For local farmers	23	32.9		12	17.1	
Not sold	-	-		19	27.1	

The participant farmers were asked whether they faced problems of accessing markets for their produce. About 65.7% of the respondents replied that they indeed faced problems of access to market. Market-related constraints they mentioned were lack of buyers soon after harvest (45.7%) and low demand for seed tubers (32.6%). Other constraints were lack of up-to-date information about seed market (10.9%), transportation (2.2%), and poor infrastructure (4.3%) (Table 14). Transportation of seed tubers is done manually (carrying on head) (41.4%), animal pulled cart (34.3%), and animal pack (24.3%).

Table 14: Potato market constraints and transportation

Price of Potato	Participants			Non participants	
	n =70		%	n =51	%
Constraints of market	n =46	%	Market problem	n =70	%
Lack of recipient after harvest	21	45.7	Yes	46	65.7
Imbalance b/n supply and demand	15	32.6	No	24	34.3
Lack of market information	5	10.9	**Means of transport**	n =70	%
Transportation problem	1	2.2	Head carrying	29	41.4
Lack of seed market place	2	4.3	Animal pulled cart	24	34.3
Problem of road	2	4.3	Animal pack	17	24.3

Variety loss, seed diversity, and management

The introduction of improved potato varieties was started in 2007 by HARC. The varieties introduced to local farming system were Gudene, Jalene, Guasa Wechecha, Tolcha, and Gera. These varieties were high yielding, disease resistant, and received better preferences by farmers in the area.

Potato varieties currently grown in the area are Jalene, Gudene (improved), and *key dinich* (local). Other varieties like Guasa (improved) and *asefo, yaskiwot* *wangeta*,and *nazreth* from the local varieties are grown in small proportion. The development of activities for ensuring food security in the region in particular and the country in general did not pay due attention to the conservation and sustainable use of the existing potato varieties, which could be achieved by raising public awareness at all levels. Farmers were asked how they observe the change of the varietal diversity in their areas (Table 15).The majority (81.4%) of participant and nonparticipant (71.4%) farmers said that there is a change in the performance of currently and previously grown potato varieties. Most of the farmers reported that the local varieties are low yielding and disease susceptible, and some are long maturing. They have deliberately stopped growing such varieties.

Table 15: Varietal changes

Varietal change	**Participants**		**Non participants**	
	n	**%**	**n**	**%**
Yes	57	81.4	50	71.4
No	13	19.6	20	28.6

Conclusions

Farmers in the study area identified 28 varieties, but farmers replaced 19 local and 3 improved varieties through mainly purchasing. Older varieties were voluntarily dropped due to low yields and susceptibility to LB. This is a big threat to continuation of potato production in the region.

This study showed that the initial source of potato seed tuber was purchased from the local market. However, seed sources of farmers in 2010 and 2011 cropping season were mainly own-saved seed, BoA, and purchased, which is the major means for varietal renewal. About 71.4% of participant and 61.4% of nonparticipant farmers purchased potato seed tubers for the same purpose.

The informal seed system, which constitutes farmers who produce and save their own seed of local or improved varieties and may use traditional forms of exchange, was found to be major option for obtaining seed for most potato farmers. A notable aspect of the informal seed system in the study area is that changing varieties has become a substitute for seed renovation for many potato growers. For this reason, farmers tend to change varieties rather than renewing seed and continue to recycle seed that has been exhausted after generations of cultivation.

The involvement of the farmers in the multiplication of clean planting materials, produced by the formal system, is the first step in linking the formal and the informal seed systems. It was found that the seed production-distribution chain in the system is short and simple, which needs to be strengthened further.

Based on this study, the development of small-scale seed enterprises like FRGs should serve as an important stimulus to provide improved seed to rural farmers at affordable prices and in accessible places, which in turn tends to promote productivity. For farmers to access new and improved varieties, the development of both the formal and informal seed sectors is essential. To ensure a ready and receptive market for seed potatoes, linkages need to be established between commercial seed potato multipliers and smallholder ware potato farmers through development of potato value chains.

Providing intensive training and demonstration of how the quality of farm-saved seed potatoes can be improved will promote the availability of high-quality seed potatoes and encourage ware potato producers to regularly renew seed.

Developing quality control mechanisms in the absence of a nationally applied seed certification system would give a certain guarantee to ware potato farmers in that seed growers can provide them with seed of satisfactory quality.

The government agencies should assist seed tuber producers in a legal framework to permit the marketing of truthfully labeled seed and quality declared seed, which will facilitate the growth of small-scale entrepreneurs in the informal seed sector. This will also help the farmers to trade the seed on their reputation for quality with a self-policing quality control system.

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