Root and Tuber Crops

The Untapped Resources

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Foreword

Agriculture is the principal sector in the national economy and in the livelihood of rural Ethiopia. The sector accounts for 85% of the total employment, about 45% of the Gross Domestic Product (GDP), and 90% of the foreign exchange earnings of the country. However, the majority of the rural population, which constitutes about 80% of the country's population of about 79 million, is food insecure.

Root and tuber crops have high potential towards household food security, local industries and natural resources base conservation. In this line, the crops are among the untapped resources that can be improved and utilized towards the betterment of the livelihood of the people. With this realization, since the late 1980s, there has been an appreciable effort in research on the various root and tuber crops. The major objective of the root and tuber crops research program is to generate and adapt cost-effective, improved production and utilization technologies and transfer them to development actors.

The research effort on root and tuber crops, like in other research agenda, involves the different entities of the Ethiopian Agricultural Research System (EARS) including federal and regional research centers and universities. In addition, the research approach involves international collaboration and networking and thus working with strategic international partners in these crops. The current book is a review of the research efforts and experiences on the crops over the last couple of decades. The review focuses primarily on the results of research activities conducted on the major root and tuber crops: potato, enset and sweet potato. To a limited extent, there is also information on some other important roots and tubers such as taro, cassava and yam.

The book is the first of its kind to collect and analyze our research experiences thus far in a comprehensive manner. In view of this, therefore, the book is hoped to serve as a good resource for more detailed research work. It is also believed to benefit development actors engaged in the promotion of the crops.

Finally, I would like to congratulate the National Root and Tuber Crops Research Program at Holetta Agricultural Research Center for its relentless efforts and success in producing this invaluable resource book. I would also like to thank all participating federal and regional research centers and universities in root and tuber crops research, editors of the book and others who contributed to the successful completion of the book. The support of our key partners in root and tuber crops research is also appreciated. Our acknowledgements go particularly to CIP and PRAPACE-ASARECA.

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Director General

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The editors are grateful for the continued support of the Management of the Ethiopian Agricultural Research Institute (EIAR). We would also like to appreciate the support of the Information and Communication Department of EIAR. Particular thanks go to Ato Abebe Kirub for his encouragement and support and Ato Amare Molla for his assistance in editing and design of the book. Finally we are grateful to the Ethiopian government for supporting and promoting research and development of root and tuber crops in the country.

Abbreviations and Acronyms

AARC — Awassa Agricultural Research Center
ABM — Above ground Biomass
AC — Activated Charcoal
AEZs — Agro -Ecological Zones
AFLP — Amplified Fragment Length Polymorphism of DNA
ARC — Areka Research Center
AMMI — Additive Main Effects and Multiplicative Interaction
ATN — Average Tuber Number
ATW — Average Tuber Weight
AUDPC — Area Under Disease Pressure Curve
AY — Gross Average Yield
BA — Benzil Adnine
BaDNA -- Bacilliform Deoxyribonucleic Acid
BAP — Benzyl Amino Purine
BR — Bulking Rate
Bt — Bacillus thuringiensis
CIP —Centro Internacional de la Papa
CSA — Central Statistical Authority
CV (%) — Coefficient of variation
CW — Canopy Width
D — Dominant
EARO — Ethiopian Agricultural Research Organization
DAI — Days After Inoculation
DAP — Diammonium Phosphate
DLS — Diffused Light Store
DM — Dry Matter
DMRT — Dunkens Multiple Range Test
DNA — Deoxyribonucleic Acid
DR — Diameter of Roots
EARO — Ethiopian Agricultural Research Organization
E.C. — Ethiopian Colander
EBLS — En set black leaf streak
ELISA — Enzyme Linked Immunosorbent Assay
ESV — E nset Streak Virus
FAO — Food and Agricultural Organization of the United Nation
FFS — Farmer Field School
FRG — Farmer Research Group
FYM — Farm Yard Manure
GA — Gebberellic Acid
GFB — Gross field benefit
GY — grain yield
HARC — Holetta Agricultural Research Center
HI — Harvest Index
H2 — Tepid to cool Humid Mid to high altitude
IAA — Indole -3-Acetic Acid
IAR — Institute of Agricultural Research

IBA — Indole Butric Acid
IDM — Integrated Disease Management
IDM-LB — Integrated Disease Management of Late Blight
IITA — International Institute of Tropical Agricultural
IL — Inter node length
INM — Integrated Nutrient Management
IPCA — First Principal Component Axise
IPM — Integrated Pest Management
KP — Kenyan progeny
LER — Land Equivalent Ratio
LSD — Least Significant Difference
MAP — Month After Planting
Mg — milligram
MOA — Ministry of Agriculture
MRR — Marginal Rate of Return
MRY — Marketable Root Yield
MS — Murashige and Skoog
M2 — Tepid to cool moist Mid to high altitude
N — Nitrogen
NAA — Naphthalene Acetic Acid
NB — Number of Branches
NB — Net benefit
NGO — None Governmental Organization
NR — number of root
NL — Neem leaf
NS — Neem seed
NSS — Number of Sampled potato virus A Sites
NVT — National Variety Trial
P — Phosphorous
PCA — Principal Component Analysis axes
PF — Pyrethrum flower
PGRs — Plant growth regulators
PGRC/E — Plant Genetic Resource Center of Ethiopia
PH — plant height
pH — Power of hydrogen
PH — Plant Height
PH1 — Hot to warm per-humid Low land to mid altitude
PH2 — Tepid per-humid, low to high altitude
PLRV — Potato Leaf Roll Virus
PNVT — Pre-National Variety Trial
PRAPACE-ASARECA - (Regional Potato and Sweet Potato Improvement Network in Eastern and Central Africa, Association for Strengthening Agricultural Research in Eastern and Central Africa)
PTM — Potato Tuber Moth
PVA — potato virus A
PVX — Potato Virus X
PVY — Potato virus Y
ND — Non Dominant
NMS — Number of Main Stems
NN — Number of Nodes
NR — Number of Roots per plant
NS — Non-significant
P — Probability level
PVS — Potato Virus S

RDM — Root Dry Matter content
RH — Relative Humidity
RMTs — Rapid Multiplication Techniques
RL — Root Length
RW — Weight of roots per plant
SARI — Southern Agricultural Research Institute
SE — Standard Error
SG — Stem Girth
SH —Tepid to cool sub humid Low to high altitude
SH1 — Hot to warm sub-humid Lowlands to mid altitude
SLCC(r) — Simple Linear Correlation Coefficient
SM1 — Hot to warm sum-moist Lowlands and platea
SPL — Scientific Phythopathology Labratory
TCV — Total Cost that Vary
TRY — Total Root yield
TPS — True Potato Seed
UK — United Kingdum
WR — weight of root
YPSA — Yeast Peptone Sucrose Agar

Overview of Trends in Root and Tuber Crops Research in Ethiopia

Gebremedhin Woldegiorgis, Endale Gebre, and Berga Lemagga

Introduction

Ethiopia, with an area of 112.3 million hectares, is the ninth largest and, with about 79 million people, the third most populated country in Africa. The country is divided into 18 major and 58 sub agro-ecological zones. Ethiopia is endowed with suitable climatic and edaphic conditions for quality and quantity production of various kinds of agricultural crops. In 2003, the agricultural sector accounted for about 42% of the country's gross domestic product (GDP) and about 85% of the export earnings. About 81% of the economically active population works in agriculture.

Approximately 88% of the Ethiopian population lives in the highlands (>1500 m) which cover 83% of the total landmass (EARO and ICRA, 1999). The cultivated area covered about 10.7 million ha in 2002, of which 10 million ha arable land and 0.7 million ha permanent crops. In 1999, 83 percent of rural households cultivated less than 2 ha per household and 52 percent less than 1 ha. The major crops occupy over 8 million hectares, nearly all of which is rain-fed with an estimated production of 12 million tons (EARO 2000).

The majority of the Ethiopian population depends mainly on cereal crops as food source. The food potential of horticultural crops, particularly that of root and tuber crops, has not yet been fully exploited and utilized despite their significant contributions towards food security, income generation, provision of food energy and resource base conservation.

FOOD BALANCE OF DIFFERENT CATEGORIES, 2000-2002 (1000' TONES)

Food groups	Production (+)	Export (-)	Imports (+)	Seed, Feed, Other uses (-)	Consumption (=)
Cereals	8895	29	1043	565	9344
Veg. oils	60	-	64	27	97
Sugar and sw.	311	65	22	-80	286
Root and Tubers	4568	4	1	467	4098
Meat	539	1	-	0	538
Milk	1467	-	9	60	1416

Source: FAO (2004)

The low agricultural productivity, recurrent drought and socio-political factors have greatly contributed to critical food shortages in Ethiopia. These in turn have resulted in food insecurity, which is characterized by inability of the people at all times to have a physical and economic access to sufficient food to meet their dietary needs for a productive and healthy life. Consequently, there is evidence of a reduced capacity to cope with expected setbacks in their economic or natural environments due to food shortage. Therefore, Ethiopia should device means of alleviating such critical food shortages to maintain appropriate and sustainable food security systems.

Role of Root and Tuber Crops

Among the different approaches in achieving food security, integration of root and tuber crops into the food system of the people should be given a serious attention. Because, these crops are often thought as starchy staples, that, provide low-cost energy to the human diet. In addition, they are known to contain appreciable amounts of proteins, essential vitamins and minerals. On average, cooked potatoes, and yams have about 2–3% protein. Cassava, potatoes and sweet potatoes also contain the important amino acids like lysine; which are missing in most cereal crops. Moreover, the leaves of sweet potato, cassava, taro, tannia and anchote are known to provide good amount of vitamin A. On the other hand, is a very good source of quality starch and fiber for agro-industries.

The food and non-food products of enset are steadily becoming popular in non-enset producing areas of central and northern Ethiopia, and fiber products manufacturers are increasingly using *enset* fiber as a raw material. The main reasons for the growing importance of the crop are its high yielding ability and the fact that its production and processing activities are environmentally friendly.

Root and tuber crops are most important in south, southwest, eastern and northwest parts of Ethiopia in terms of production area, distribution and consumption. They are also grown almost all over the nation. Small-scale subsistence farmers grow the crops, under resource-poor conditions. In general, root and tuber crops are parts of traditional food of Ethiopia. Their contribution to family food-self-sufficiency, income generation and soil-based resource conservation is indispensable. The principal root and tuber crops grown in Ethiopia are Enset (*Ensete veantricosum*), potato (*Solanum tubersum*), taro (*Colocasia esculanta schott*), yam (*Dioscorea spp.*), anchote (*Coccinia abyssinica*), 'Ethiopia dinich' (*Coleusedulis*), cassava (*Manihot esculantum*), tannia (*Xanthsoma spp.*) and sweet potato (*Ipomoea batatus*). Among these 'Ethiopian dinich' and Enset are believed to be indigenous to Ethiopia. Currently most root and tuber crops are grown as security crops against crop failures and/or to bridge the food deficit periods, as they are ready for harvest during "hunger months." These crops are also, tolerant to termites, which might be attributed to their higher moisture content, and thrive well on very poor soils and under moisture stress conditions. The root and tuber crops are grouped together because they are bulky, perishable and vegetatively propagated. At the same time these crops are highly differentiated in terms of origin, production and nutritional traits and use.

The diverse agro-ecologies that exist in Ethiopia allow the production of different root and tuber crops. But, despite the suitable environment of the country, the cultivation and productivity of root and tuber crops are low as compared to most of the sub-Saharan counties. Ethiopia faces a huge food deficit, which may be due to drought that occurs every other two-three years. Much of the food deficit could be avoided if root and tuber crops were cultivated with adequate agronomic practices, as they have a high productivity potential. Moreover, most of the rot and tuber crops are believed to be drought tolerant. The present in-adequate use of root and tuber crops could be attributed to many factors, such as low investment in research, extension and training of farmers on the utilization of these crops.

Research on the various root and tuber crops has been going on since the establishment of the Institute of Agricultural Research (IAR) in 1966 under horticultural crops research division at different research centers and in higher learning institutions in a fragmented manner. In 1997, after realization of the contribution of the root and tuber crops towards household food security, local industries and natural resources base conservation, the research was reorganized at national program level. The primary objective of the root and tuber crops research and development in Ethiopia is evolving to be increasing focus to finding the most cost – effective, improved crop production and utilization technologies.

As in most developing countries, the growth in production of root and tuber crops was brought about by an expansion in acreage rather than productivity. Significant achievements have been attained in this direction mainly in potato, sweet potato and enset. It has been reported that the average tuber yield of potatoes was almost constant between 6-8 t per ha in the last 20-30 years, while the area planted with potato increased from 30,000 ha to about 160,000 ha in 2001 (Gebremedhin et al. 2006).

It is now becoming increasingly clear that one of the major constraints to increased production that has not been adequately addressed is "Utilization". It is now time to move away from utilization of the crops as fresh to several other options available or to be developed. The rapid raise in urban population has created a new opportunity to alternative products other than fresh products.

How can the research system in Ethiopia best ensure that the different species of the root and tubers, particularly potato, enset, sweet potato, yam and taro as well as the indigenous root crops can make the greatest contribution to the current problem food deficit and to the national food security? How will the roles of these important crops evolve without delay to feed the growing population of the country become major sources of income to the farmers? These questions deserve a particular attention because many of the root and tuber crops give high yields of nutritious food per unit area per day compared to cereal crops. The decisions we make today regarding investments in the research and development of root and tuber crops will strongly affect their contributions to the future national food systems, improving food security and alleviating poverty.

Challenges

The major gaps that require research intervention in root and tuber crops production and use can be grouped into the following areas:

1. Production technologies

- Adaptable high yielding and good quality varieties.
- Improved agronomic packages
- Good quality seed/ planting material
- Improved soil fertility and water management
- Genetic resource conservation and utilization of indigenous root and tuber crops
- Control of major diseases such as late blight and bacterial wilt of potato, bacterial wilt of enset, virus in sweet potato

2. Post harvest, processing and utilization

- Storage, packaging and processing techniques.
- Information and awareness on different recipes.
- Appropriate processing equipment

3. Marketing and transportation

- Market information and distribution system
- Market linkages between producers and consumers

The current book focuses primarily on the results of research findings conducted in Ethiopia on the major root and tuber crops, potato, enset and sweet potato with some information also on the other roots and tubers such as taro, cassava and yam. Limited time, resource and readily available data prevented a more extensive analysis of the other root and tuber crops. Still we hope that this book will serve as the basis for more detailed research work and review of past work on these crops.

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Part I

Potato

Introduction

Gebremedhin Woldegiorgis

Potato (*S. tuberosum* L.) originated in the highlands of the Andes in South America and was brought to Europe in the 16th century. The crop was introduced to Ethiopia in 1859 by a German Botanist called Schimper (Horton 1987 and Pankirust 1964). For many years since its introduction, potato production was limited to homestead as a garden crop.

A gradual rise in production occurred at the end of the 19th century, when there was a long famine in Ethiopia (Research document, 1975). Since then potato became a very important garden crop in many parts of Ethiopia. In the mid-1970s, the total potato acreage was estimated to be 30,000 ha with an average yield of about 5 t/ha.

In 1975, a national potato research was started to develop and disseminate new production technologies. In a decade, the crop was grown more widely; a swift rise in acreage to 50,00 ha was reported in the mid-1980s. Development of appropriate production technologies through research facilitated the expansion of potato production in the country. Since the inception of the national potato research, a large number of germplasm were introduced and considerable efforts were made to improve traditional production practices.

In the course of time potato became a very important non-cereal staple in Ethiopia. Compared to cereals, potato is a short duration crop that can potentially yield up to 30-35 t/ha of starch-based produce in 3-4 months. In addition, potato is one of the few major food crops that give high yields of edible energy and good quality protein per unit area and per unit time with a short vegetative cycle that can fit into intensive cropping systems. It has the correct balance of protein calories and total calories and it is considered to be a good weaning food.

The utilization of potato in Ethiopia is very conservative. However, apart from consumption of boiled potatoes, it is now extensively used in the wide arrays of traditional stew (*wot*) preparations in both rural and urban areas. In this regard, potato is substituting pulse crops that are commonly used for these purposes. Potato consumption has expanded to include chips, crisps and mixture preparations with other vegetables which is becoming popular in urban areas in recent years. The capita calorie consumption of potato, which in 2000–2002 for instance was estimated at 9.0/day also evidence of the growing consumption of potato in the country (Table 1).

Table 1. Per capita daily calorie intake of potatoes in comparison with other selected items in Ethiopia, 2000–2002

Crop	Daily calorie intake
Rice	2
Wheat	297
Maize	397
Sorghum	194
Potatoes	9
Sugar	37
Soyabean oil	6
Palm Oil	6
Milk	32
Animal fat	12
Eggs	2
Poultry meat	2
Bovine meat	28
Sheep & Goats meat	5

Source: FAO (20004)

Ethiopia is divided into 18 major agro-ecologies. Most of these agro-ecologies have suitable climatic and edaphic conditions for the production of high yield of quality potatoes. About 70% of the cultivated agricultural land is suitable for potato production (Solomon 1989). High yields are obtained in the central, southern, southeastern, southwestern and northwestern parts where the altitude ranges from 1500 to 3000 m and the rainfall between 600- 1200 mm. Despite the availability of such extensive suitable agro-ecological conditions, the level of potato production and productivity has remained low.

Farming System

There are four potato production systems which are the *belg* (short rain), *meher* (long rain), residual crop and irrigated production. In many areas, the *belg* (January to June) crop supplemented with irrigation constitutes the bulk of potato production. This is due to less late blight pressure and favorable market during this season. In the northwestern region, the major planting time is between March and May and harvesting between July and October. Some farmers use the residual moisture from the main rainy season (June-September) to produce potato. The second, *meher* crop (June to December), helps to fill a critical food gap encountered before the harvest of cereal crops in many highland areas. An important feature of the farming systems is the intercropping experience in many production areas. Intercropping of potato is practiced with maize, linseed, rapeseed, faba bean, and haricot bean depending on agro-ecology. Many farmers also practice planting cereals (maize) in the *belg* season followed by potato or other cereals (wheat or barley) in *meher*. In general, the above production systems with multiple planting times have enabled nearly a year-round supply of fresh potatoes to the market in Ethiopia.

Production Trend

In the last three decades, the land under potato had increased from 30,000 ha in the mid 1970s to 50 thousand in the mid 1980s, and since then there has been a steep rise to about 160,000 ha by 2000 (Figure 1). The increase in potato production is attributed to different factors. These include:

1. Need for more productive crop. Due to reducing land holdings farmers are forced to move to a labor-intensive, short duration and more productive crops such as potato to meet the growing need for food.
2. The need for cash crop. Cash crops are limited in the highland areas. However, farmers have found potato to be a useful cash crop among other few vegetables to increase their household incomes and improve their livelihoods.
3. Attitude change. In the early times, potato was considered as poor man's food. This had limited its use and expansion for a long period. However, the increasing awareness of the crop and its utilization through research, technology transfer, media, and urbanization has increased the importance of the crop irrespective of economic classes.
4. Substitution to pulse crops. The increase in price of pulse crops commonly used for stew/*wot'l* preparation has also increase the utilization of potatoes as a substitute in both urban and rural area.
5. Availability of improved technologies

Since 1975 considerable research achievements have been obtained that have helped small house hold farmers to improve potato production and utilization. Using the improved production packages, farmers were able to get high yields ranging from 25 to 40 tones compared with the national average yield of 8 tones per ha (G/Medhin et al. 2001).

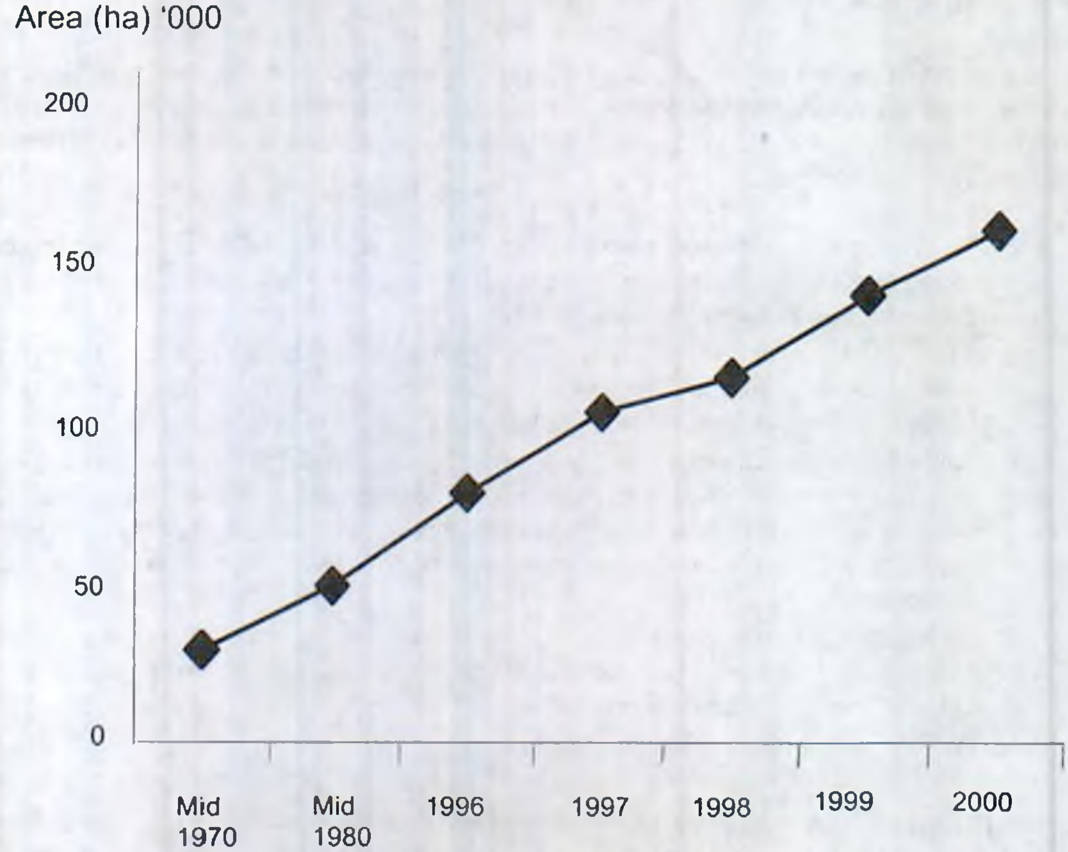

Fig. 1. Production trend (area in ha) of potato in Ethiopia, 1970- 2000

Marketing and Utilization

The utilization of potato in Ethiopia has been very conservative. In recent years, however, the consumption of potato in the form of crisps, chips and mixture of salads, stew, porage has dramatically increased. The increase in urban development and improvement in infrastructure such as road has opened a growing opportunity for potato growers to sell their potatoes to nearby towns and distant cities. Some quantity of potatoes is also exported to Djibouti from eastern and central parts and to the Sudan from the northwestern part of the country.

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Potato Variety Development

Gebremedhin Woldegiorgis, Endale Gebre and Berga Lemaga

Introduction

Over a century and two decades, potato in Ethiopia grew from a garden crop in few regions to a staple crop produced in many regions and under different agro-ecological conditions. For nearly a century, however, the growth in potato production and productivity was gradual and low. The cultivation of the crop was characterized by traditional production and management practices. Above all, the varieties in cultivation were not able to meet the requirements of growers in terms of yield, late blight resistance, and quality, among others (G/Medhin et al., 2001).

With the understanding of the production constraints challenging the production and productivity of potato, strategic potato research began in 1975. The development and dissemination of many improved varieties, coupled with other technological options, contributed greatly to the improvement and rapid expansion in potato production. The major objective of potato breeding has been to develop varieties that are high yielding, widely adaptable and resistant to late blight which has been the most devastating disease throughout the country. The breeding program also aimed at evaluating and selecting genotypes for other important traits valued by producers and consumers such as tuber shape, storability, cooking quality and taste.

The variety development work has benefited greatly from the global collaborative efforts in potato breeding, particularly through germplasm exchange with the International Potato Center (CIP) in Peru where the genetic diversity of the crop is high. Most of the germplasm materials used for selection in Ethiopia are obtained from CIP, while some are commercial cultivars (G/Medhin et al., 2003). In both cases, clones are introduced in the form of advanced clones, tuber families and true potato seed (TPS). Using the materials from the breeding population of CIP, clonal selection and stability studies are then undertaken to develop and disseminate improved varieties.

Potato Late Blight and the Environment

A potato disease is an interaction between a host (the potato plant) and a pathogen (bacterium, fungus, virus, mycoplasma, nematodes or adverse environments) that impairs the productivity or usefulness of the crop. Frequently, adverse environmental effects are sufficient to initiate disease in the absence of an infectious entity. The host-pathogen interaction is influenced by environment acting on either the potato or the pathogen or both

(Burton et al., 1992). The interaction effect is determined by the genetic capabilities of the potato in being either susceptible or resistant and the pathogen in being pathogenic (virulent) or non-pathogenic (a virulent).

Furthermore, disease or adverse environment encountered at a certain stage in the potato life cycle may later severely affect the production or quality of the crop during subsequent stages. For example, field problems also frequently become storage problems and may later limit market quality or seed performance and ultimately yielding ability. The value of potato or any other crop determines the extent to which control measure may be justified.

Late blight is probably the single most important disease of potatoes worldwide. For instance, the Irish "potato famine" of the 1840s was caused by late blight (Burton et al., 1992). The disease is destructive wherever potatoes are grown without fungicides, except in hot, dry, irrigated areas. Immense quantities of fungicides are applied to potatoes throughout the world for protection against it.

Late blight is a prevalent disease in all potato producing areas of Ethiopia. The severity of the disease depends on the susceptibility of cultivars planted and on weather conditions. The disease is devastating during the main season (June–September) if susceptible varieties are grown without protection using fungicides (Fig. 1.1). In most cases, potato growers in Ethiopia use varieties which are susceptible to *P. infestance*. The use of susceptible varieties, combined with favorable environment and unavailability of effective control measures, has favored the development of late blight or other diseases in the highlands (El-Bedewy et al., 2001:

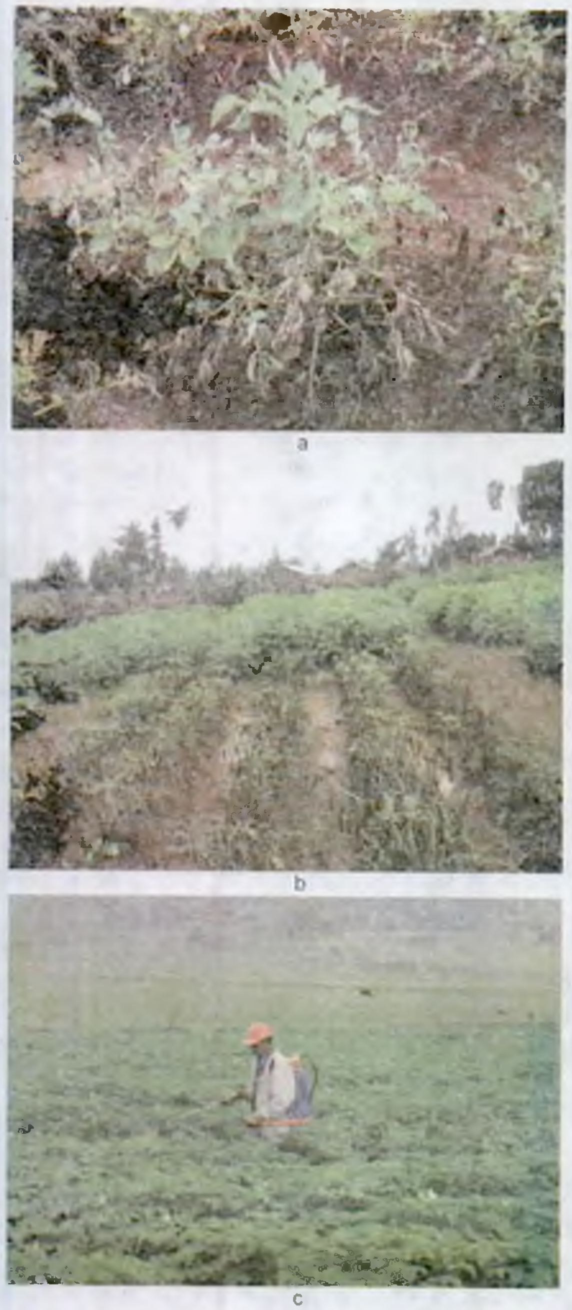

Fig. 1.1 Late blight is a major constraint in potato producti in Ethiopian highlands: (a) susceptible local variety, (b) differential performance of clones in field evaluation, (c) farmer spraying once for resistant varieties at Kurkufa Wolmera.

Berga et al., 1994; Bekele et al., 1996). Late blight pressure and unavailability of good quality seed tuber have been the major threats that forced most farmers to withdraw potato production from the main cropping season. Thus, the bulk of production comes from the *belg* season or irrigated crop.

Varieties in Cultivation

In Ethiopia there are several varieties in cultivation other than those released through research that were introduced at different times. There is no sufficient information on time of introduction, origin, quality and adaptation of the varieties. In addition, whether the different local names given to the varieties refer to the same or different genotype is not known. In most cases, however, there may be many names for a genotype/variety in different localities.

Among the varieties grown in the northwestern region, Aballo is the most popular variety grown in all seasons followed by Enat Beguaro, Janahla, Amorie and Key Abeba in order of their importance. They were selected for their yield, taste and good market price; but they are highly susceptible to late blight. In the southern region, varieties Agea and Durame have been popular; but their production declined because of late blight problem (G/Medhin et al., 2001). The varieties grown in different regions of the country and their preferred attributes are presented in Table 1.1.

Table 1.1. Varieties of potato grown in different parts of Ethiopia

Varieties	Region	Preferred attributes
Nech Abeba	South	Good tuber color and keeping quality
Key Abeba	South and northwestern	Good yield and taste
Agea	South	Good yield and taste
Durame	South	Good cooking quality
Mogur	Central	Good cooking quality
Volvo	Central	Good cooking quality
Holland	Central	Good cooking quality
Kenya	Central	Good cooking quality
Samena	Eastern	Good cooking quality
Tulem	Eastern	Good cooking quality
Kurfa	Central	Good cooking quality
Aballo	Northwestern	Good yield and taste
Aba Adamu	Northwestern	Good yield and taste
Afechat	Northwestern	Good yield and taste
Amorie	Northwestern	Good yield and taste
Enat Beguaro	Northwestern	Good yield and taste
Habesha	Northwestern	Good yield and taste
Jallahla	Northwestern	Good yield and taste
Tikurie	Northwestern	Good yield and taste
Domie	Northwestern	Good yield and taste

Breeding Strategies and Methods

The overall strategy of potato breeding focuses on developing varieties with high yield and stable levels of horizontal resistance to late blight. In addition, the varieties are also sought to exhibit good traits like ware and processing qualities, adaptability, resistance/tolerance to virus and other important biotic stresses.

The breeding strategy generally involved introducing resistance clones clonal selection and stability studies, and verification tests for official release and dissemination of varieties for production. In the past two decades, several resistance clones were introduced and tested. Out of these, many were released at different times and some were in the pipeline for release by 2006.

Breeding for horizontal resistance

Resistance clones were usually introduced from the breeding populations developed at CIP for horizontal resistance to late blight. The introductions from CIP, first from breeding population "A" and later population "B", were made based on breeding strategies for horizontal resistance with major gene or in the absence of it, respectively.

Resistance with major gene

As with the majority of the crops, the early breeding work of potato concentrated mainly on resistance mediated by major genes (R-genes). The introductions of a population with these genes laid the basis as a source of gene pool for resistance, which is named population "A" germplasm. This is a breeding population where by horizontal resistance to late blight is improved in the presence of major genes. The main sources contain both types of genes: minor genes or polygenes that express horizontal or quantitavely 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 (Londeo et al. 1997, 2000a, 2000b).

Population "A" is the first improved breeding population developed at CIP for horizontal resistance to late blight. 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 2006 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 late blight are simplified significantly in the absence of 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". Eighteen tuber families of this population containing about 1200 clones were obtained from CIP in 1997. More than 900 of the clones introduced were selected and advanced. The clones were subjected to rigorous selection across different agro-ecologies in the country. Several clones of the new population showed better resistance in Ethiopia. To the date of the current report, the resistant clones were in pipeline for release (HARC, Potato Program Progress Reports 1999 and 2000).

Clonal Selection and Stability Studies

Early stage selection

A wide genetic base germplasm were introduced from CIP and screened under Ethiopian condition. The introductions were made in the form of clones, tuber families and true potato seed (TPS), which are then planted and grown in isolated quarantine field and evaluated under the supervision of quarantine officer for one year. Evaluation at this stage focuses on quarantine diseases as well as tolerance to late blight.

In the second year clones are evaluated under induced disease pressure using local cultivars which are highly susceptible to late blight usually forming a strip border in 1:5 ratio to build late blight pressure. Evaluation at this stage focuses on plant morphology, tuber shape, color, stolon length, eye depth and tolerance to late blight (Fig. 1.2; 1.3).

Although not exhaustively followed, the generalized list covering some of the characters that are typically taken into account in potato selection program is presented in Table 1.2. However, as indicated above, early stage selection relies on an overall visual appraisal, which would take many of these characters in to account to a certain degree. At a later stage, more objective methods are used to assess the relevant characters. The produce of the plot is graded, weighed and the internal tuber examined and analyzed.

In some cases commercial cultivars are also introduced and evaluated for their yield and tolerance to late blight. The purpose of introducing commercial cultivars is to identify outstanding cultivars in a short time, usually 3–4 years. This will enable to give advice to producers that are willing to introduce commercial varieties with better performance and release outstanding ones in a manner that is effective and efficient.

Table 1.2. Typical 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 stem.
Tuber morphology	Eye depth, flesh color; growth cracks, hollow heart, secondary growth, shape
Quality	Dry matter, browning, skin color, taste, storage characters
Resistance	Late blight (foliage and tuber), viruses (PVX, PVY and PLRV)

Table 1.3. Locations where multilocational variety trial is conducted with different environmental characters

Center	Latitude	Longitude	Altitude (m)	Temp (°C)		Rainfall (mm)	Agroecology zone	Major soil type
				Min	Max			
Holetta	83o30'E	9o00'N	2400	6.2	22.1	1078	Moist highland	Nitosols, Vertisols
Kulumsa	8o01'N	39o09'E	2200	10.5	22.8	850	Mid highland	
Jima	7o46'N	36oE	1753	11.3	25.9	1554	Warm humid	Nitosol, Cambisol
Bako	09o06'N	37o09'E	1650	13.2	27.9	1210	Sub humid	Nitosol
Awasa	7o05'N	38o29'E	1700	12.1	26.9	1044	Mid alt. sub-humid	Luvisol
Adet	11o16'N	37o29'	2240	12	24	1250	Mid highland	
Sinana	7.05N	39.15E	2500	9.0	21.0	850	Highland sub-humid	
Mekele	-13.3N	39.4E-	1970-	9.7-	26.6	-550	Highland arid	

Fig. 1.4. Participatory variety selection involves different stages: identification of production problems (a), evaluation of field performance of varieties (b and c) and on farm multiplication of the best variety.

The clones with better performance in the nursery stages are replicated across three different environments in pre-national variety trial (PNVT) and evaluated for one season before they are promoted to a national variety trial (NVT). Whereas, the clones selected from the PNVT stage are promoted to a replicated study across 16 different environments (8 locations and two years) under a NVT. 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 several environments. The challenge in this approach has been the appropriateness of the weather in two to three consecutive years to represent the long term climate at each site even though the management practices in each year for all varieties across sites can be assumed uniform, which in itself can be challenging.

Since 1993, multi-location variety adaptability studies across environments have been done mostly using CIP materials. The data from several sites are combined over two to three years to analyze varietal performance across location. Wide and specific adaptations are also generated from the combined data where recommendations for national and regional release of outstanding varieties are usually proposed based on these major findings. In 1996, about 20 clones promoted from previous years nursery evaluations were tested under the PNVT. Among these, 12 outstanding clones were selected for further evaluation across different environments.

Two clones, CIP-387792.5 and CIP-381169.16, gave highest mean tuber yields of 38.6 and 36.0 t/ha, respectively, compared to the check that yielded 3.9 t/ha in the first year (Table 1.4). Highest late blight incidences were observed with the local check. The performance of clones depended on seasonal weather conditions in some instances. Most of the clones had better performance in the second season.

Clones CIP-387792.5 again out-performed others at Holetta, Bekoji and Sinana which are above 2400 m. Another clone CIP-384321.19 gave high tuber yields at Awassa and Bako which are mid-altitude areas of below 1700 m. Based on the above performances for tuber yields, tolerance to late blight and other horticultural characteristics, the clones CIP-384321.19 and CIP-387792.5 were released in 2001 with local names Jalene and Degemegn, respectively (HARC, Potato Program Progress Report 2001).

Another set of clones promoted from the 1998 evaluation consisting of 10 clones with tuber yield of above 26 t/ha and better horticultural merits were tested across 6 locations in different agro-ecologies in 2000-2001. The clones showed different yield performance and better tolerance to late blight than the standard cultivar Tolcha (Table 1.5).

Moreover, to the stability of clones across locations and years was evaluated to better understand the genotype and environment interactions. Statistical analysis was made using appropriate models.

Table 1.4. Tuber yield ton per ha and other yield components of the multi-locational variety trial, 1998–99

Cultivar	Tuber yield (t/ha)			Yield components		
	1998	1999	Mean	ATW* (gms)	ATN* m^{-2}	AUDPC*
381169.16	36.0	36.0	36.0	64.9	55.9	500.3
381381.13	28.5	40.2	34.3	49.0	68.9	456.1
382146.27	27.9	39.8	33.8	78.4	42.0	590.6
384321.19	30.4	44.9	37.6	63.2	58.9	702.4
384321.9	25.8	43.3	34.5	67.1	51.3	799.7
386029.18	13.9	21.5	17.7	57.8	29.8	277.7
386031.4	19.8	39.0	29.4	64.9	45.0	581.0
387028.1	25.9	33.9	29.9	69.7	40.8	908.2
387224.25	21.0	37.4	29.2	50.2	55.9	687.6
387792.5	38.6	46.7	42.7	84.3	50.7	416.9
Key Abeba	12.0	27.9	19.9	40.5	48.1	740.9
Tolcha	15.8	29.1	22.4	60.9	36.9	680.2
Local	4.0	19.4	11.7	46.5	19.5	1890.0
C.V (%)	15.5	20.0	17.8	19.0	21.3	48.4

* AUDPC, area under disease pressure curve; ATW, average tuber weight; ATN, average tuber number

A number of statistical methods are known for estimation of phenotypic stability. Regression of location mean of each variety on means of entries of location was first proposed by Yates and Cochran (1938). Similar models were later used by Elerhart and Russel (1966) and Finlay and Welknson (1963). According to this model, a genotype is stable and desirable if it has the ability to respond under favorable conditions. In various reports of genotype and environment interaction analyses using Eberhart and Russel techniques, the model parameter account for only a small proportion of the interactions sum of squares while the remaining variance is unexplained. This shows the interpretation and conclusion regarding performance of different phenotypes over a range of varying environments are always affected by the presence of cross effect of genotype with the environment. The Additive Main Effects and Multiplicative Interaction (AMMI) was further recommended as a useful model for producing interaction Principal Component Analysis axes (PCA) for identifying other more appropriate models for a given data sets, and the biplot from it as a tool for displaying genotype and environment means on the same graph (Gauch et al. 1996).

Using the above model the clones evaluated in 2000-2001 were analyzed to develop estimates of stability parameters of genotypes tested across the six locations and two seasons. The result indicates their interaction to the various environmental conditions as exhibited in their yield responses (Table 1.5). Such performance of genotypes arises from the inherent nature of the character and the varying biotic and abiotic factors that each location and season even for the same location. Table 1.6 presents location effects on tuber yield, indexes of the six locations and stability estimates of the nine genotypes excluding the local cultivar for its performance was confounded by severe late blight damages. The challenge remains that weather the two consecutive years can represent the long term climate performance at each site could not be sure.

Table 1.5. Tuber yield and other yield components of the multi-locational variety trial in 2000-01

Clone	Mean yield (t/ha)	ATW (gms)	ATN (per m²)	AUDPC	DM*%
KP-90134.2	28.6	83.3	51.6	43.7	21.1
CIP-389701.3	26.1	53.6	77.0	367.5	16.2
CIP-387676.24	25.5	66.1	56.0	32.8	20.6
KP-90143.5	29.8	85.0	44.5	111.6	19.5
KP-90138.12	29.9	85.4	47.8	41.6	22.7
KP—90108.5	27.0	83.5	46.8	109.4	23.5
CIP-386423.13	29.2	62.2	65.1	61.3	20.9
KP-90134.5	28.9	98.9	40.1	197.2	19.1
Standard check (Tolcha)	18.7	63.3	36.2	507.5	20.9
Susceptible check	6.4	25.3	27.3	20.5	18.9
LSD	3.176	9.90	10.63	79.85	3.261
CV%	25.4	22.7	33.7	79.8	4.3

* DM = dry matter

Table 1.6. Mean tuber yield of potato genotypes tested at five locations for two seasons

Genotype	Mean tuber yield (t/ha)							
	Env.1*	Env.2	Env.3	Env.4	Env.5	Mean yield (t/ha)	bi	S_2d_i
KP-90134.2	22.80	26.25	26.85	31.25	35.94	28.62	1.261	0.51
CIP-389701.3	21.85	24.38	24.83	28.06	31.51	26.12	0.928	9.52
CIP-387676.24	20.25	23.36	23.90	27.85	32.07	25.49	1.135	14.29
KP-90143.5	25.47	28.04	28.49	31.77	35.27	29.81	0.940	5.43
KP-90138.12	25.70	28.22	28.65	31.86	35.28	29.94	0.919	-3.06
KP-90108.5	20.50	24.38	25.05	29.99	35.27	27.04	1.417	-4.03
CIP-386423.13	26.10	27.92	28.23	30.56	33.03	29.17	0.666	-2.59
KP-90134.5	23.32	26.60	27.17	31.35	35.80	28.85	1.198	52.41
St. check	16.49	17.95	18.21	20.08	22.08	18.96	0.537	0.48
Environ. index	-4.7291	-2.1884	0.2077	1.5728	5.1370			
Mean	29.20	22.50	25.23	32.92	25.71			
CV%	11.1	18.7	26.5	28.6	24.0			
F prob.	0.001	0.001	0.001	0.002	0.031			
SE of differ.	3.615	2.105	3.348	4.70	3.08			

Env.1 = Holetta; Env.2 = Bako, Env.3 = Adet, Env.4 = Bekoji, Env.5 = Mekele)

The regression coefficient that is computed by regressing genotype mean yield at each environment on the environmental mean yield estimates the performance of a genotype to changing environments of both locations and seasons. Environmental index or mean yield shows the potential of a specific trial site based on the biological performance of all genotypes in a particular experiment. Together with the regression coefficient, the standard error of the slope (s2d) measures the closeness of the fitted line to the scattered points. Accordingly, the regression coefficients of the tested genotypes ranged from 0.54 for the standard check to 1.42 for genotype KP-90108.5. The yield results indicated that all genotypes except the standard cultivar Tolcha performed better in terms of dynamic responsiveness to better environments.

However, KP-90134.2 was more stable based on the stability indicators. Genotypes KP-90108.5, KP-90134.5 and CIP-387676.24 with regression coefficient of 1.42, 1.20 and 1.13, respectively, were more productive under favorable growing conditions, indicating their specific adaptation to better environmental conditions. The highest yielding genotype KP-90143.5 and KP-90138.12 or CIP-386423.13, however, showed stable yield over season's environments.

The biplot of the mean yields and the first principal component axis (IPCA) for 9 genotypes is presented in (Figure 1.5). The biplot showed the strength of the interactions, indicating that genotypes like KP-90138.12, which is denoted by genotype numbers 5 in Figure, that are located near the origin had little interaction along the PCA axis. Clone CIP-386423.13 was released in 2006 by the name Gudene for its high and stable yield and quality preference by farmers.

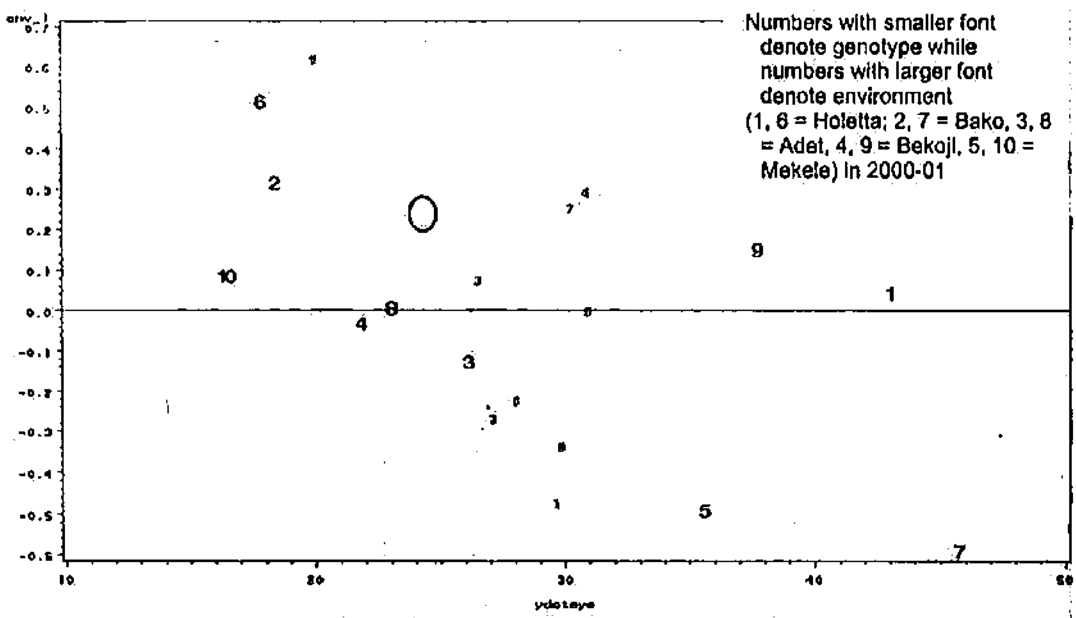

Figure 1.5. Bi-plot of the first principal component axis and genotype means

Following the change in the breeding strategy of CIP for developing varieties with horizontal resistance to late blight in the absence of R genes, the materials introduced in 1997 from the new breeding population (population "B") were screened for two seasons and then advanced to multi-location pre-national variety trial in 1999. The performance of the new genotypes was very promising; most of the clones out-yielded the standard checks in all locations. The combined means showed that ten clones yielded over 35 t/ha and the mean tuber yield of five clones was over 54 t/ha (Table 1.7).

Table 1.7. Mean tuber yield of best performing varieties in multi-location PNVT in 1999

Cultivar	Yield (t/ha)	AUDPC
CIP-392650.505	60.1	177.1
CIP-392627.512	60.0	123.7
CIP-381049.518	59.9	178.5
CIP-392650.516	57.9	114.6
CIP-392640.516	54.5	114.6
Tolcha (Standard check)	31.0	-
Mean	53.9	141.7

Nine of the clones were promoted to the national variety trial and tested across six locations at different agro-ecologies in 2000-01. The mean tuber yield and other yield components are presented in Table 1.8.

Table 1.8. Mean tuber yield and other yield components of population "B" clones tested in multi-location variety trial in 2000-01

Clones	Mean tuber yield (t/ha)	ATW (g)	ATN/m2	AUDPC	DM
392640.516	33.32	71.91	47.40	194.7	26.18
392627.512	27.26	55.02	43.01	271.2	20.83
392650.516	33.51	58.54	58.20	234.1	24.97
391058.546	24.03	55.95	44.79	1137.5	22.91
391058.500	22.35	55.84	39.08	630.0	23.58
391058.553	20.57	50.35	40.64	730.6	20.72
391058.559	23.70	57.54	40.91	879.4	22.25
Standard check	18.61	65.7	89.70	625.6	19.25
Sustainable Check	4.90	37.11	19.48	1776.2	20.21

The genotpe by environment (G x E) interaction was analyzed and varietal stability was estimated across environments. Location effects on tuber yield, environmental performance indexes and stability estimates of the nine genotypes are shown in Table 1.9. The performance of the genotypes to the changes of environments, estimated using the regression coefficient (b) ranged from 0.651 (standard check) to 1.799 (genotype 392640.516). Most varieties showed responsiveness with specific adaptation to better environments as reflected on their mean tuber yield and parameter *b* compared to the standard checks. However, clone 391058.5 was more stable based on the stability indicators. Highest yielding genotypes 392640.516 and 392627.512 were found more responsive in the low altitude environments such as Bako and Awassa.

Table 1.9. Mean tuber yield of potato genotypes from population "A" tested at five different environments for two years, 2000 and 2001

Genotype	Mean tuber yield (t/ha)								
	Env.1	Env.2	Env.3	Env.4	Env.5	Env.6	Mean yield (t/ha)	*b*	S^2d
392640.516	15.9	25.7	32.1	33.2	46.8	43.1	32.81	1.799	0.80
392627.512	19.7	26.9	31.6	32.4	42.4	39.7	32.11	1.322	130.94
392650.516	18.4	22.6	25.3	25.7	31.4	29.9	25.54	0.754	21.36
391058.546	11.4	18.4	22.9	23.6	33.3	30.6	23.37	1.269	12.80
391058.5	13.0	18.7	22.4	23.0	30.8	28.7	22.77	1.035	1.86
391058.553	11.7	17.2	20.9	21.5	29.2	27.1	21.28	1.020	8.54
391058.559	9.1	15.4	19.6	20.2	29.0	26.6	20.01	1.157	-1.14
Stand. check	11.9	15.4	17.7	18.1	23.1	21.7	17.98	0.651	6.76
Env. index	-9.4030	-3.9543	-0.3650	0.1938	7.8037	5.7248			
Mean	21.5	25.6	31.1	33.2	16.0	25.1			
CV%	11.7	32.9	21.7	15.0	21.7	21.6			

Specific adaptation

Since the foundation of the national program towards consolidating the efforts in potato improvement in 1975, evaluation of the clones for wider adaptation was the major objective with a focus on obtaining improved varieties that are high yielder, tolerant to late blight and adaptable to a wider agro-ecologies. However, several years of multi-location variety testing across ecologies consistently indicated the presence of genotype differential response in yield and late blight 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 which are at the stage of pre-national and national variety trial and/or those nationally released are included for evaluation. Using this approach a number of varieties have been released for specific agro-ecologies of the country by regional research institutions (Table 1.10).

Achievement in the Past Two Decades

As discussed earlier, the potato improvement research in the past two decades has been characterized by focusing on developing high yielding and late blight resistant varieties which are also widely adaptable to different agro-ecologies. Recently interest has grown up to select varieties for specific agro-ecology for regional release. In this process a total of 18 varieties adapted to altitudes ranging 1000-3200 m and receiving 750-1500 mm rainfall with yield range of between 21.8-46.7 and 19.0-38.3 t/ha on-station and on-farm, respectively (Table 1.10). Not all the varieties shown have been widely distributed and grown by farmers due to the very limited current capacity of the seed system in Ethiopia.

Nevertheless, through consistent on-farm technology demonstration integrated with training of farmers and seed growers, several varieties have been disseminated to different potato growing zones of the country (Table 1.10; Fig. 1.3). From the use of these improved technologies, farmers have been able to get considerable economic benefit and impacts in their lives and livelihoods. The most important benefit from these technologies, as indicated by the farmers themselves, has been the possibility of growing the potato crop during the main rainy season, which was a key challenge to production due to late blight.

Table 1.10. Average yield and some other characteristics of potato varieties released during 1987–2006

Variety	Release year	Area of adaptation		Maturity (No. days after planting)	Yield (t/ha)		Releasing research center (s) or university
		Altitude (m)	Rainfall (mm)		On-station	On-farm	
Alemaya 624	1987	1000-2000		90-100	25.9		AU*
Awash	1991	1500-2000	>750	90-100	25.4	20.0	Holetta
Tolcha	1993	1700-2800	>750	100-115	33.1	22.5	Holetta
Managesha	1993	Above 2400	>750	120-130	27.0	25.0	Holetta
Wechecha	1997	1700-2800	>750	1700-2800	21.8	19.0	Holetta
Chiro	1998	1600-2000	700-800	75-110	36.0	27.5	AU
Bedassa	2001	1700-2000	700-800	96-117	40.5		AU
Zemen	2001	1700-2000	700-800	76-101	37.2		AU
Zengena	2001	2000-2800	1000-1500	105	30.0	23.5	Adet & Holetta
Guassa	2002	2000-2800	1000-1500	110-115	22.4	23.5	Adet & Holetta
Degemegn	2002	1600-2800	750-1000	90-120	46.7	35.6	Holetta
Jalenie	2002	1600-2800	750-1000	90-120	44.8	29.1	Holetta
Gorebella	2002	2700-3200	800-925	134-159	30.1	28.0	Sheno & Holetta
Gera	2003	2700-3200	800-1000	>120	25.9	20.6	Sheno & Holetta
Bule	2005	1700-2700	980-1398	120	39.3	38.3	Awassa & Holetta
Marachere	2005	1700-2700	980-1398	120	33.3	28.4	Awassa & Holetta
Shenkolla	2005	1700-2700	980-1398	120	31.6	29.1	Awassa & Holetta
Gudenie	2006	1600-2800	750-1000	120	29.2	21.0	Holetta

* AU, the then Alamaya University which is now known by its new name Haramaya University as of 2006

Challenges and Future Directions

Potato variety improvement research in Ethiopia began in 1975. The Breeding works have thus far been geared towards developing varieties that are high yielding, widely adaptable and resistant to late blight. During 1987–2006, many improved potato varieties were developed by different federal and regional research centers and Haramaya, or the then Alemaya, University. However, there have been many challenges and problems that have been hindering the wider adoption and use of the improved varieties.

One of the major challenges that need to be addressed effectively is the seed production and supply problem. In addition, the technology transfer system is so weak to successfully promote the improved varieties to farmers in different potato growing areas. The other major challenge is associated with the current trend in variety evaluation and selection at region level. The breeding work at this level does not necessarily follow agro-ecology since regional boundaries are not based on this factor. There is therefore often duplication of efforts in the national variety improvement process. Therefore, the issue has to be addressed well by the improvement program to effectively coordinate the variety development and selection activities.

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Chapter Two

Potato Agronomy

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Introduction

As a tropical country, Ethiopia has conducive climatic and edaphic conditions for higher potato production and productivity. A large proportion of the cultivated land at present can be suitable for the production of potato with appropriate management for early canopy development and expansion and successful tuber growth in the soil (Berga *et al.*, 1994b). The higher efficiency of the potato crop in the tropical highland is attributed not to the effect of light saturation of photosynthesis, but possibly to the anatomical response of the leaf to a higher level of irradiance conferring greater photosynthetic efficiency (Burton, 1992). That also explains the good opportunity of the tropical highland situation in Ethiopia that can be exploited for increased potato productivity in the country.

So far, however, the conducive natural resources and conditions have not been properly tapped. The current national average dry matter yield estimated at 1.6 t/ha is far below optimum to reflect the existence of suitable agro-ecological conditions. The low average yield is attributed to many factors. The major problems are the susceptibility to late blight and low yielding ability of the varieties in cultivation and the poor agronomic practices prevailing in most potato production activities (G/Medhin *et al.*, 2001).

Agronomic practices like planting date, soil moisture, friability and fertility status remarkably influence crop emergence, the onset and area increase of leaves, canopy development and subsequent performance of the plant (Berga et al., 1994a; Burto *et al.*, 1989). The nature of the potato crop has to depend much on these factors that affect interception of radiation and efficiency of conversion of intercepted radiation to carbohydrate or dry matter, i.e., the tuber. Variety and its genetic potential for disease resistance may also considerably affect tuber dry matter. Nevertheless, a substantial proportion of the influence comes from a concerted role of the agronomic factors (Midmore, 1992).

Agronomic practices in most of the potato growing areas of Ethiopia leave much to desire for improvement. The agro-ecologies where farmers thrive to grow potato are characterized by diverse conditions. They vary considerably in soil type, moisture and temperature regimes, fertility conditions, and in the on-set, intensity and duration of rain. Therefore, crop management operations have to take into account of these differences to ensure high yield levels. In general, the poor crop management practices observed in most farmers' fields include the use of too low or too high plant density, absence of row planting, poor quality seed material, inappropriate land preparation, time of planting, fertilizer application, depth of planting, ridging, harvesting techniques and crop rotation. This chapter reviews the results of various agronomic studies made in the past decade.

Planting Time

Different factors affect the planting time of potato in Ethiopia. The major ones are on-set and pattern of rainfall, disease pressure, availability of irrigation water, market situation and food shortage mainly encountered before the harvest of cereal crops in many highland areas. There are four potato production systems in the country influenced by the above factors: the *belg* (short rain), *meher* (long rain), residual and irrigated crops. In *meher* production, there is more than one planting date because of the late blight problem associated with high rainfall and low temperature of the main rainy season. Farmers try to avoid the problem either by early dry or late planting that will depend on residual moisture. In both cases, a substantial amount of yield is compromised for minimizing the risk of high or nearly total loss in most highland areas.

Thus, growers do not benefit from the most reliable rain of the meher season due to the threats of late blight. However, due to increasing availability of improved resistant to late blight and high yielding varieties form the research, it has now become possible to grow potatoes at the heart of the main rainy season. This has encouragcds a remarkable expansion of the production in this season where water availability is not limiting and farmers can anticipate for higher productivity through applying appropriate crop management practices.

Along with the development of improved varieties, studies were also made to determine the optimum planting date. Studies at Holetta and Emdeber using 5 different varieties, 6 planting dates at 15 days revealed that yields were high for the first planting (10 June) at Emdeber for all the varieties and years with average 25.7 t/ha followed by 10.6 t/ha for the last planting date, 23 August (Berga et al. 1994b). The corresponding yields at Holetta were 11.3 and 3.0 t/ha (Table 2.1). At Adet, planting date was determined using two varieties with different reactions to late blight. Planting from 1 to 15 May and from 1 May to 1 June are recommended as optimum dates, respectively, for planting late blight susceptible and moderately tolerant/resistant potato cultivars for production in the Adet area (Table 2.2).

Table 2.1. Effect of date of planting on tuber yield of different cultivars at Holetta and Emdibir

	Tuber yield (t/ha)	
	Holetta	Emdibir
Planting date		
June 6	13.8	31.7
June 5	8.8	27.8
July 10	5.8	24.0
July 25	5.7	21.2
August 9	5.8	19.8
August 23	5.2	16.7
$LSD_{0.05}$	1.1	5.5
Cultivar		
AL-624	7.8	23.8
AL-252	8.4	24.4
Al-100	6.2	-
Al-610	-	22.3
$LSD_{0.05}$	0.7	NS*

Source: Extracted from Berga et al. (1994)
*NS, not significant

Table 2.2. Tuber yields (t/ha) of two potato varieties as influenced by planting dates at Adet during 1988 and 1989

Cultivar	1 - May	15 - May	1 - Jun	15 - Jun	1 - Jul	Mean
			1988			
Al- 624	17.6	15.0	15.6	7.6	4.7	12.1
Local	3.0	4.9	3.7	1.4	0.2	2.6
Mean	10.3	10.0	9.6	4.5	2.4	0.0
$LSD_{0.01}$ Planting dates = 21.1						
			1989			
Al-624	10.5	9.1	8.3	6.7	4.3	7.8
Local	8.5	7.3	2.1	1.6	1.3	4.1
Mean	9.5	8.2	5.2	4.2	2.8	0.0
$LSD_{0.01}$ Planting dates = 32.5						

Source: Extracted from Tesfaye et al. (2006) *(in press)*

At Ankober in 1997/98, a different set of planting dates (end of May, mid-June, end of June and mid-July) were evaluated using late blight tolerant variety Wechecha. First the planting was tried under dry condition before the commencement of rain. Planting at the end of May to early June gave better mean tuber yield (14.5 t/ha), while the lowest yield was obtained from the early July planting 4.0 t/ha (Table 2.3). Differential reactions to diseases were observed due to planting date and fertilizer application. The disease pressure was progressively high in the later plantings than early June. Therefore, in a similar fashion to the observations at Holetta and Emdibir, early planting reduced late blight pressure.

Table 2.3 Tuber yield of potato grown on different planting dates and fertilizer rates at Ankober, 1997-98

Planting date	Yield (t/ha)			Mean
	Control	195/16 kg	6 ton FYM + 100 kg DAP	
May 25	11.8	18.78	13.01	14.53
June 11	11.9	20.26	11.78	14.65
June 25	9.28	15.17	10.93	11.79
July 8	1.56	6.67	3.80	4.01
Mean	8.63	15.22	9.88	-

Source: Extracted from Tesfaye et al. (2006) (*In press*)

In general, the superior performance of the early June planted crop, i.e. during the commencement of the rain, could be attributed to some favorable conditions. These include the longer time available to produce abundant foliage and the prolonged period of intercepting more photosynthetic active radiation before the on-set of late blight pressure even for relatively tolerant varieties thus escaping the disease. The importance of dry planting in May as observed in the north also remains valid until farmers get tolerant varieties to late blight. Various other exercises related to early June planting have confirmed that this planting time can be applicable in most rain-fed potato production areas particularly in the high areas of the country, using improved varieties and production packages.

Plant Population (Seed Rate)

Different studies use different terms, definitions and concepts in determining the optimum number of plants per unit area for potato. For instance, the terms plant density, stem density, plant population, special arrangement and seed rate are encountered. The concepts in each terminology look at one issue from different perspectives. The interest of giving accurate decision for obtaining maximum desirable yield per unit area stems from the nature of the crop itself. A potato tuber may at the end of dormancy grow one or more sprouts, and after planting variable proportion of these sprouts develop into main stem. A plant may contain a variable number of this stem as this again is dependant up on the tuber size and treatment of the parent tuber. This in turn affects the number of tubers set, the growth and longevity of the haulm and therefore the performance of the plant and yield.

Thus, seed tuber size is an important factor to decide the seed per unit area because it affects total yield and graded or marketable tuber yields, particularly small tuber size increasing with increased size of the mother tuber (seed). The other dimension of interest for determining plant population and use of optimum spacing is the high seed rate required in potato production and the associated cost of seed which may account for up to 50% of total production cost. The establishment of practical measurement of plant population that takes into account the various factors affecting it remains to be important.

In practice, plant population in potato production is manipulated through the number and size of seed tuber planted. This may sound simple and yet the interactive nature of all its component parts needs to be understood better. The components include seed size, spacing and their combination, stem number and total and graded potato yields. In this chapter, the term plant population, occasionally interchangeably used with seed rate, is used in the scope set by the nature of the data presented in the studies reviewed.

The plant population and arrangements of the inter- and intra-row spacing that potato farmers in Ethiopia use vary considerably depending on season, soil type, cropping system, variety and purpose. In areas with shallow soils, planting at wider spacing is used to get enough soil for earthing up the potato. The studies conducted so far to determine plant population have very limited scope in coverage of many of the factors mentioned above and the extent of their effect on yield.

A study at Alemaya evaluated the effects of three row widths (60, 70 and 80 cm) in combination with four in-row distances (10, 20, 30 and 40 cm) and three seed tuber sizes (25-35, 35-45, 45-55 mm) using variety AL-624. The wider row width by wider in-row distance (80x40 cm) gave the highest yield. (34 t/ha) and the 60x20 cm treatment gave the lowest yield (22.2 t/ha). Taking into account the difficulties in field operation, a row width by in-row distance of 75x30 to 40 cm was recommended for ware and 60x10 to 20 cm for seed potato production, (Berga et al. 1994).

In view of the fact that variety has an effect on optimum plant population, in 1995 and 1996 three morphologically contrasting varieties were studied at Holetta on red soil. The varieties and their features were Awash, short and early maturing; Tolcha, intermediate; and Menagesha, vigoros and late maturing. Four row widths (45, 60, 75 and 90 cm) and four in-row distances (20, 25, 30 and 35 cm) were studied along with medium sized (35-45 mm) pre-sprouted tubers. In all varieties, the highest total yields were obtained from the in-row distance of 20 cm and row width of 75 cm. Yield was consistently and significantly improved for in row-spacing of 10, 20 and 30 cm as row width increased from 45 to 75 cm. Further increase in both ways resulted in yield decline and the rate was higher with increasing row width and in-row distance at the same time (Table 2.4 and Figure 2.1).

In a related study at Adet, more number of tubers with size grades of 30-40 mm and > 5 50 mm diameter were obtained from 60 cm and 75cm inter-row spacings, respectively. In addition, wider spacing, > 60cm inter-row distance, was found to increase tuber size and dry matter yield per tuber. Therefore, use of 75 cm inter-row spacing is found suitable for ware potato production with tuber size of > 50 mm diameter. However, use of 60 cm inter-row spacing is found ideal for seed tuber potato production. The above observation is in agreement with studies by Burton (1989), Beukema and Van der Zaag (1990) and Mwansa and Mwala (2000).

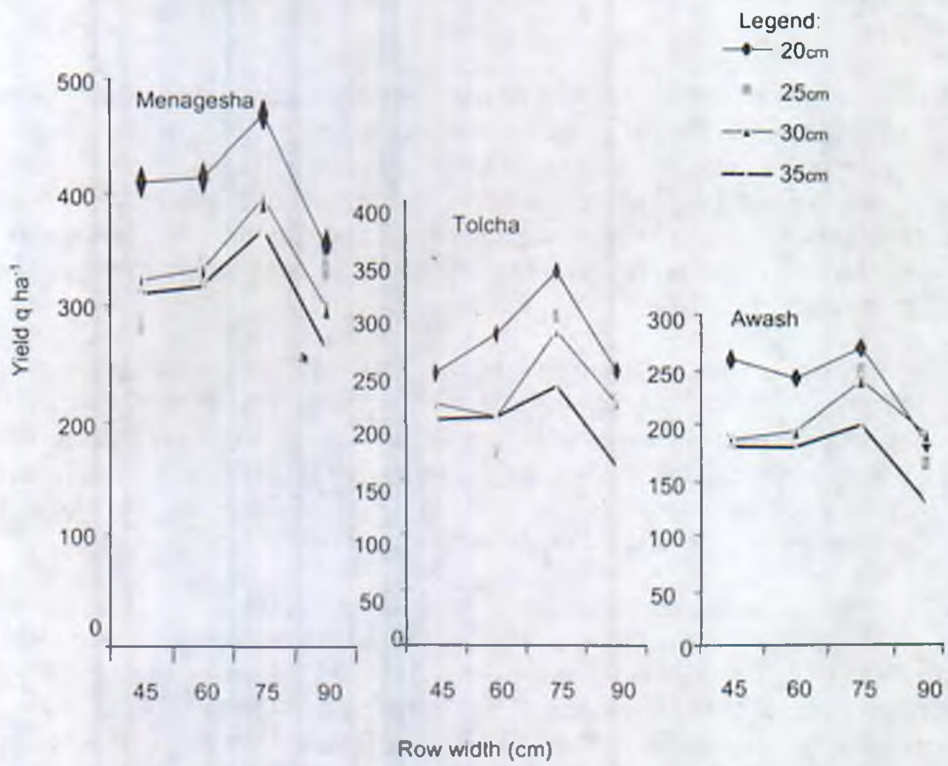

Figure 2.1. Yield responses of ther varieties for varying row width by in-row distance spacing combinations at Holetta in 1995 and 1996

Table 2.4. Combined effect of row width and in-row distance on tuber yield of three potato cultivars*

In-row distance (cm)	Yield (t/ha) Row - width (cm) 45	60	75	90	Mean
20	30.5	22.3	24.3	23.3	25.3
25	31.3	23.3	24.5	23.5	25.7
30	35.9	30.6	30.7	26.6	25.8
35	26.2	23.9	23.8	18.5	22.9
Mean	30.9	25.2	25.8	22.9	
$LSD_{0.05}$	In-row distance = 2.682			Row-width = 2.682	

* Awash (short and early), Tolcha (intermediate) and Menagesha (vigoros and late Maturing)

The study at Holetta also showed the effects of row spacing on growth attributes such as tuber sizes yield, tuber weight and tuber number per unit area. In all varieties the highest total yield was obtained from the in-row distance of 20 cm and row-width of 75 cm. In most cases, increasing row width reduced number of tubers, except 75 cm row-width that consistently gave, for all spacing and varieties, the highest mean tuber number per unit area (Table 2.5). In a situation where the number of tubers is of greater importance, as in seed production, the narrow row width (20 cm) is to be preferred. In addition, in view of the varietal differences observed in the study, optimum spacing for any purpose may be used taking into account the maturity type and vegetative vigor of the crop in addition to other factors like soil fertility and water availability.

Table 2.5. Effect of row width and in-row distance on average tuber weight and average tuber number of three varieties evaluated at Holetta in 1995 and 1996

Row-width (cm)	In–row distance (cm)			
	20	25	30	35
	AVERAGE TUBER WEIGHT (g/m^2)			
45	44.0	42.9	41.9	47.6
60	44.3	46.4	50.0	49.0
75	48.5	56.5	55.0	54.8
90	56.8	58.6	63.3	62.1
	AVERAGE TUBER NUMBER (no/m^2)			
45	52.4	52.7	53.0	44.7
60	45.8	45.6	59.0	44.5
75	72.6	58.9	59.5	57.0
90	32.7)	36.9	36.1	33.2
$LSD_{0.05}$ = 4.41 (11.36)				

Soil Fertility Management

Potato, as a high yielding crop, consumes more nutrients from the soil at a given time. Tuber yield is a product of three major processes: radiation interception, conversion of the intercepted radiation to dry matter and partitioning of the dry matter between tubers and the rest of the plant. The effect of nutrient supply on radiation use and dry matter partitioning where the nutrient in question is in short supply is a well proven phenomenon.

Many factors may affect the total nutrient consumption of the potato crop. Reports indicate that the effects of season, variety and rate and time of N and K fertilizer applications resulted in the removal of mineral nutrients in fresh tubers in the following ranges: N, 2.28–3.57; P, 0.40–0.62 and, K, 3.70–5.41 kg/t (Gunasena 1969). However, the diversity of soil types, moisture and nutrient regimes, cropping sequences, fertilizer uses and climatic conditions as well as biotic factors such as weeds, pests and diseases all many affect the sate of soil nutrient flux and use by the growing crop. The extent of use of fertilizer may also be dictated by economic factors like market prices and the economic status of a farmer.

According to Sikka (1982), application of 80–120 kg/ha nitrogen and 100–200 kg/ha phosphorus was found to be economically feasible in the tropics. Similarly, Hailemichael (1977) recommended 54/138 kg/ha N/P rates for all potato cultivars and soil types in Ethiopia. However, economical fertilizer rate may vary according to soil type, fertility status of the soil, amount of soil moisture, other climatic variables, variety, crop rotation and other crop management practices (Smith 1977). Carpenter (1963) also reported that total nutrient needs for late varieties generally are greater than for early maturing ones. In this regard, information on soil fertility has to be specific for a particular site, season, cropping pattern or genotype, and this problem perhaps remains one of the most desiring for improvement in potato production in the country for these reasons.

Much of the experimental work on the nutrition of the potato crop in Ethiopia is limited to N and P. The use of K is almost neglected in most studies due to a long standing understanding that Ethiopian soils are not deficient of it. This, however, may not hold true always as soil fertility status is a dynamic process and varies from soil to soil and from one agro-ecology to the other.

In the mid-1970s a blanket recommendation of 300 kg/ha DAP (138 P_2O_5 and 54 kg N) was given as a general formulation irrespective of soil type, variety and location (Hailemichael 1977). This had been used for over 15 years before a detail study was done at Holetta on Nitosol in 1988 and 1989 for N, P and K using a medium maturing variety Sissay. High yields of 36.5 and 36.3 t/ha were reported from the 1988 NPK (165/90/110 kg/ha) and N and P (165/90 kg/ha) applications respectively. The results indicated that K had very little effect on yield of potato at Holetta Nitosols.

The results obtained from another experiment that also included cost–benefit analysis, showed that rates of N at 110 and 165 kg/ha and P_2O_5 at 60 and 90 kg/ha gave highest yields in the range 24.0–27.7 t/ha (Table 2.6). Varieties Tolcha and Wechecha benefited more from increased N rates as compared to Awash. More number of smaller tuber sizes (30–50 mm) were produced at the highest rates of N and P_2O_5 (Figure 2.2). Whereas, average tuber number per meter square was affected more by P and with highest values at 90 kg P_2O_5 (Table 2.7). The effect of P was more pronounced as N levels increased and vice versa.

Table 2.6. N and P interaction effects on tuber yield t/ha) of potato on red soil

N (kg/ha)	P_2O_5 (kg/ha) 0	30	60	90	Mean
0	10.0	12.4	13.8	14.0	12.6
55	12.5	18.1	20.5	21.6	18.2
110	13.1	18.9	24.0	24.8	20.2
165	13.8	20.6	24.9	27.7	21.7
Mean	12.4	17.5	20.8	22.0	
$LSD_{0.05}$	:P =1.844; N x P = 2.605				1.606

Table 2.7. Effects of N and P rates on tuber yield and average tuber number of three varieties at Holetta

Fertilizer	Yield (t/ha)		
	Tolcha	Awash	Wechecha
N (kg/ha)			
0	11.5(24.4)*	14.8(28.1)	11.3(25.3)
55	17.8(33.2)	18.3(37.8)	18.4(26.7)
110	20.2(33.8)	19.7(38.2)	20.7(39.2)
165	23.7(35.3)	19.8(39.8)	21.7(39.2)
Mean	18.3(31.7)	18.1(35.9)	18.0(35.1)
$LSD_{0.05}$	Variety =1.30 (1.59); Variety x N = 2.61 (ns)		
P_2O_5 (kg/ ha)			
0	12.7(28.4)	12.1(31.8)	12.3(28.8)
30	18.4(32.6)	16.7(34.2)	17.3(34.6)
60	19.7(32.1)	22.1(38.7)	20.6(36.8)
90	22.5(33.6)	21.6(39.1)	21.9(40.3)
Mean	18.3(31.7)	18.1(35.9)	18.0(35.1)
$LSD_{0.05}$	Variety 1.30 (1.84); Variety x P_2O_5 = n		
CV (%)	25.8 (16.34)		

* Values in parentheses are ATN, i.e., average tuber number per meter square

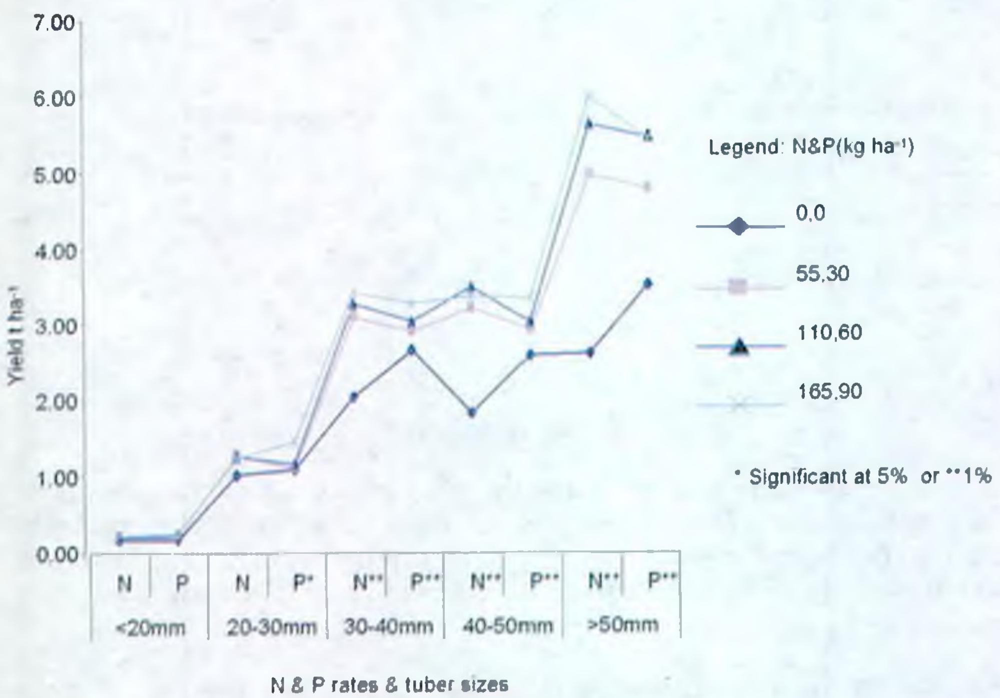

Figure 2.1. Effect of N & P rates on tuber yields of different sizes grades on red soils

For many reasons, the recommendations from research on the use of fertilizers are in most cases not strictly applied by farmers. For instance farmers usually do not have access to inputs such as fertilizer and fungicide. In addition, farmers are discouraged by lack of access or other problems of market for fresh tubers. For instance, the fresh tubers are easily perishable under the prevailing poor post-harvest handling at farm level and urban warehouses. Lack of incentive, lack of access to input and market and poor market infrastructure are therefore some of the problems that prohibit potato growers to aspire for higher production and productivity.

Locations varied in their inherent phosphorus content. However, the interaction effect of nitrogen by phosphorus appeared to be less important. High tuber yields were obtained at higher rates of N and P, 81 and 138 kg/ha, respectively (Table 2.8).

Not many studies were done on the optimum economic applications of fertilizer levels. Even those that were conducted were not comprehensive. For the above study on N, P and K, the partial budget analysis showed that a maximum benefit of 12768.1 birr/ha was obtained from 140 kg/ha N and 130 P_2O_5 kg/ha . However, rates at 195, 130 and 65 kg/ha were found economically feasible to household farmers with marginal costs and rates of return of 1320%, 442% and 920.9% , respectively.

At Adet, a maximum net benefit of 10685.99 birr/ha was attained at 81 /138 kg/ha of N/P. Whereas, the economically feasible rates were 81/0 and 81/69 kg/ha N/P with 1418% and 1316% marginal rates of return, respectively. The rate 81/69 kg/ha N/P was recommended for potato production in Adet and Injibara areas.

Table 2.8. Effect of different N and P rates on total tuber yield in South Gonder Zone, Amhara Region

N (kg/ha)	Yield (q/ha)				
	P_2O_5 (kg/ha)				Mean
	0	69	138	207	
0	7.5	7.2	8.0	8.3	7.7
54	11.0	14.1	14.9	15.0	13.8
81	11.9	15.7	16.3	18.0	15.5
108	13.3	17.1	18.4	17.1	16.5
Mean	10.9	13.5	14.4	14.6	13.4

Studies made elsewhere indicated that to a certain degree a reduced use of fertilizer from the recommended rate could not seriously offset the high yield obtained. Up to 27% reduction in the optimum rate of N could depress not more than 5% of the yield. However, the result depended on the nature and type of soil where the study was conducted.

Under the Ethiopian farmer condition, there are many factors that can affect the yield response of potato to fertilizer application. For instance, most farmers give priority to high yielding crops like potato for using their farmyard manure. This is a common practice among the potato growers in many places. They plant potato in the most fertile ground at the backyard of their houses which receives crop residues, organic manure, and farmyard manure and has become unresponsive to the application of inorganic fertilizer. Nevertheless, the situation is changing because potato is becoming more and more of a field crop being produced in highly impoverished cereal fields that have exhausted their nutrients over many years of continuous production without replacement.

Although production of potato is largely limited to on red soils, some attempt has been made to address fertilizer needs on Vertisols which contain higher levels of P than Nitosols. In 2000-01, soil N and P requirement of potato grown on Vertisols on a camber bed at Ginchi was studied using two varieties (Menagesh and Genet), and four levels of N (80, 110, 140 and 170 kg/ha) and P (32.2, 41.4, 50.6 and 59.8 kg/ha). In 2000, N rates showed increase in yield from 80 to 110 and 140 to 170 kg/ha, while the yield increase due to P was only from 41.4 to 50.6 kg/ha. N x P varietal interactions were not found for tuber yield. The margins of yield increase to successive N or P rates were lower when compared with the increases shown in previous study on Nitosol. The effect on yield due to N rates was more pronounced than P rates. Both varieties were not that responsive for P in both years. Much of the variability in the study was attributed to variety interaction with season followed and N rates that accounted to 12.2 and 10.9% of the total variability, respectively (tables 2:9 and 2.10).

Table 2.9. N and P effects on tuber yield and average tuber number of two Varieties on Vertisol at Ginchi

Fertilizer rate (kg/ha)	Yield (t/ha)		
	Menagesha	Genet	Mean
N			
80	21.6(40.6)*	18.6(45.4)	20.1(43.0)
110	24.8(44.4)	21.0(50.5)	22.9(47.5)
140	26.244.8)	21.9(50.1)	24.1(47.5)
170	27.4(45.7)	23.5(48.1)	25.5(46.9)
Mean	25.0(43.9)	21.3(48.5)	
LSD 0.05	Variety = 1.288		
P_2O_5			
32.2	24.3(42.6)	19.944.9)	22.1(43.7)
41.4	23.5(41.4)	20.4(48.8)	21.9(45.1)
50.6	25.3(44.2)	21.9(49.7)	23.6(46.9)
59.8	26.9(47.3)	22.8(50.6)	24.9(48.9)
Mean	24. 8(43.8)	21.3(48.5)	
LSD 0.05	Variety=2.603 (1.59); Interaction (PxV) =ns (ns)		

* Figures in parentheses are average tuber numbers per meter square

A phenomenon less common on Nitosols but was found somewhat prevalent in Vertisol potato production was tuber growth cracking. The extent of cracking varied with variety. In Menagesha, 35% of all tubers produced were cracked to an average depth of about 2-3-5 mm while variety Genet had 10.3%. There was also a significant year and year x variety interaction for cracked tubers. Conditions that

In a similar study conducted at Adet, ridging frequency had no significant effects on parameters like tuber size, marketable and total yields. The results shown at Adet, however, may not be used to draw a conclusion that can apply to different soils and growing conditions. For instance, the results under Holetta conditions showed that yield and tuber quality can be affected by ridging and at least twice ridging is very necessary. Light soil and heavy rainfall areas require more frequent ridging. Whereas, in thin top soils care has to be taken to reduce insect damage and greening by modifying planting distance and increasing frequency of ridging. In ware potato production, good cover-up of soil does substantially reduce unmarketable tuber yield due to greening.

Table 2.11. Effect of ridging frequency on tuber yield and its components, greening and insect damage, 1994–1995

Ridging frequency	Final ridging (DAE)[1]	ATN[2] (no./m^2)	ATW[3] (g)	Green tuber (no./m^2)	Green tuber yield (t/ha)	Insect damage (no./m^2)	Total yield (t/ha)
0	-	24.9	54.6	3.7	6.7	9.8	12.6
1	10	24.8	64.0	3.5	5.2	8.9	14.2
2	25	24.9	61.2	4.2	5.2	7.1	14.5
3	40	25.5	62.2	5.8	5.2	6.7	15.4
4	55	27.7	60.7	3.7	4.5	7.3	15.4
$LSD_{0.05}$		ns[4]	ns	ns	1.919	Ns	1.966

[1]DAE, days after emergence; [2]ATN, average tuber numbers [3]ATW, average tuber weight,

[4]ns, not significant

Tuber Bulking Rate

Varieties of potato differ in maturity dates and harvesting time depends much on the purpose of production—ware or seed tuber. The method of harvesting in Ethiopia is quite different from that excercised in developed countries where harvesting is fully automated. In Ethiopia potatoes for consumption are not always kept until the crop is fully mature and senesce. The tubers are piece-meal harvested when needed for home consumption, convincingly at some good-sized stages.

Therefore, a study was made in 1991–1993 to evaluate the bulking rate of three varieties with variable maturity group: Menagesha, Tolcha, and Awash. In addition, the study assessed the response of the varieties to N application (165 kg/ ha) either all applied at planting or split in to two equal halves and one half applied at planting and the other half at first cultivation.

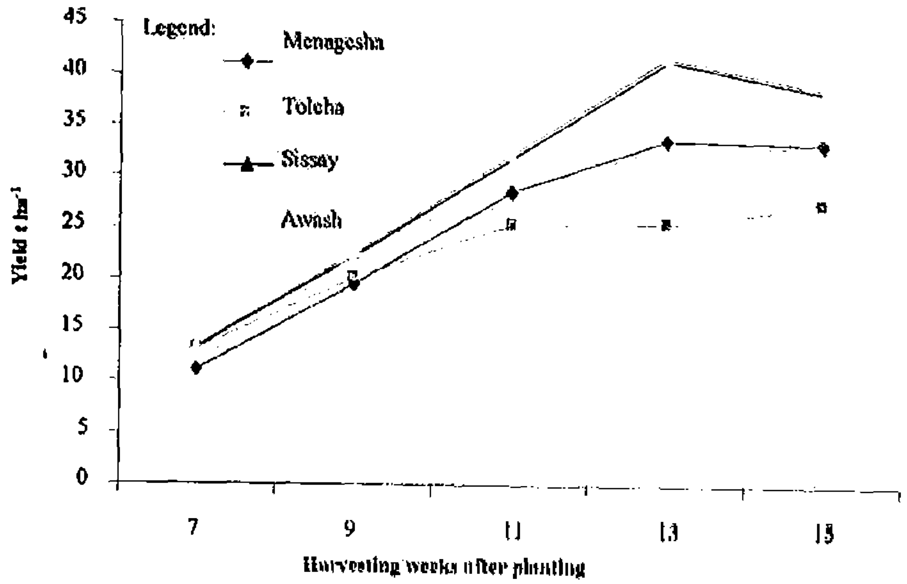

Figure 2.4. Effect of harvesting date on mean tuber yields (t ha-1) of Menagesha, Tolcha, Awash and Sissay varieties

The optimum harvesting time was variable for varieties. For Menagesha and Tolcha, optimum harvest time was at 13 weeks after planting while it was 11 for Awash and Sissay. Between the first and the fourth harvest, mean yield ranged from 11.0 to 41.5 t/ha (Table 2.12 and Figure 2.4). Maximum total tuber yield was obtained between 98 and 105 days after planting (DAP) for all varieties.

Bulking rate (BR) was computed as:

$$BR = \frac{y2 - y1}{T1}$$

where, BR stands for bulking rate; y2 yield per hectare at the last harvest; y1, yield per hectare at immediate previous harvest; T days between two consecutive years.

Bulking was at peak in Awash (3.8 q/ha per day) in about 63 DAP followed by Tolcha 4.95 q/ha per day in about 77 DAP. Whereas in Menagesha, peak bulking was attained after 90 days (Figure 2.4). In all cases, yield increased at a decreasing rate after the peak. Bulking rate increased upto the fourth harvest only in Menagesha, while in Tolcha the rate declined after the second harvest. In Awash, a negative bulking was observed after the third harvest.

Table 2.12. Effect of time of harvest and N application on tuber yields of four released varieties.

	Yield (t/ha) by harvest time					Mean
	1st*	2nd	3rd	4th	5th	
Variety						
Sisay	11.0	19.4	28.4	33.4	32.8	25.0
Awash	13.1	19.9	25.2	25.1	29.1	22.1
Menagesha	13.2	22.3	31.8	41.5	38.3	29.5
Tolcha	14.3	22.2	29.2	34.8	33.3	26.8
Mean	12.9	20.9	28.6	33.7	32.9	
$LSD_{0.05}$	HD = 3.267; VxHD = 5.281					2.21
N application (165 kg/ha)						
All at planting	12.7	19.8	28.7	32.4	31.4	25.0
Split applied*	13.1	22.2	28.5	34.9	34.4	26.6
$LSD_{0.05}$	N = 5.967; Harvest date x N = ns					1.08
CV%	16.4					

* Date of harvest (weeks after planting): first harvest 7, second 9, third 11, fourth 13 and fifth 13.

** Split into two equal halves and applied at planting and at first cultivation

Table 2.13. Effect of N application and harvest time on tuber yields of our cultivars

Fertilizer N application (165 kg/ha)	Variety	Yield (t/ha)	ATW* (g)	ATN/m^{-2}	N mean yield (t/ha)
All at planting	Sissay	25.8	38.1	66.6	25.01
	Awash	22.0	51.1	43.2	
	Menagesha	28.1	85.6	33.1	
	Tolcha	24.1	65.9	36.2	
Split applied**	Sissay	24.2	35.7	66.7	26.64
	Awash	22.1	49.7	44.3	
	Menagesha	30.8	88.8	34.3	
	Tolcha	29.4	69.5	40.1	
$LSD_{0.05}$		2.67	Ns***	ns	1.08
CV(%)		14.35	17.94	10.16	10.16

* ATW, average tuber weight; ATN, average tuber number
** Split into two halves and applied at planting and at first cultivation
***ns, not significant

Intercropping

Intercropping is a cropping system that involves the growing of two or more crops simultaneously on the same piece of land. The practice was originally used as an insurance against crop failure under rain-fed conditions. Nowadays, however, the main objective of intercropping is higher productivity per unit area in addition to stability in production. Small-holder farmers practice intercropping also to obtain several products from the same piece of land, spread the period of peak demand for labor, control soil erosion and maintain or improve the fertility of their land.

In mechanized monocropping culture, intercropping may be considered as less productive, less efficient and probably undeveloped culture. However, the practice can enhance the efficient use of scarce resources and reduce the risk of dependence upon a single crop which is susceptible to environmental and economic fluctuations in farming systems where natural conditions necessitates adoption of the intercropping approach.

On the other hand, intercropping may also lead to soil erosion and yield reduction. It may also create difficulty in cultivation practices if it is not compatible with a system. Therefore, identification of the ideal spatial arrangement in each farming system and socio-economic condition is vital to tap the benefit of intercropping.

The most important intercrop mixtures used by farmers in Ethiopia are cereal with cereal, cereal with legumes and trees with annual crops (Kidane et al. 1990). However, in northwest, south and eastern Ethiopia, mainly at mid-altitude areas of mixed farming zone, farmers widely practice intercropping of potato with maize (Aleligne 1988) and rarely with beans. In addition, farmers practice intercropping without regular pattern. No much study was done on the practice of intercropping in Ethiopia. Rathi (1982) reported that sowing of mustard in place of fourth ridge of potato and maintaining 20 cm distance between plants can provide an additional yield of mustard 15–20 q/ha) with a loss in yield of potato not exceeding 10–15%.

A study on total monetary value (TMV), economic yield and land equivalent ratio (LER) of potato and maize intercropping system was made at Adet during 1997–1998 (Tesfaye et al. *2006*). Maize variety BH660 and late blight tolerant potato variety Tolcha were used. Planting was done at a spacing of 50 x 30 cm for intercrops and 75 cm x 30 cm for sole crops. Fertilizers at 81/69 kg/ha and 80/40 kg/ha of N/P_2O_5 were applied for potato and maize, respectively. Four intercropping levels consisting of three potato to maize row ratios (1:1, 1:2, 2:1) and row of maize and potato, were used along with the farmers intercropping practice.

Higher total monetary value was recorded for the regular special arrangements compared to the farmers' intercropping practice and the sole crops. The highest total monetary value was obtained from potato with maize with 2:1 row intercropping. Potato with maize in followed by 1:1 row ratio (Table 2.14). The LER results also indicated that the 1:1, 2:1 and 1:2 row arrangements had values of 1.51, 1.71 and 1.16.

A related intercropping study of potato and maize was mad at Bako for three cropping seasons. Maize and potato were arranged in 1:1 ratio alternating within a row (15 x 75cm) and between rows (37.5 x 30 cm) including sole planting (75 x 30 cm). The yield of potato in an intercropped field was as high as sole potato in one of the three study seasons. Intercropping was found economically advantageous than sole cropping as the maize grower could get potato yield as bonus in addition to maize yield.

Table 2.14. Total monetary value and land equivalent ratio (LER) of maize/potato intercropping in 1997 and 1998, Adet

Treatment	Yield (kg plot^{-1})		Total monetary value (birr/plot)	LER
	Maize	Potato		
(1:1) One row potato one row maize alternating	11.43	31.16	25.69	1.51
(2:1) Two row potato one row maize alternating	12.48	39.0	30.05	1.71
(1:2) One row potato two row maize alternating	11.97	16.4	20.19	1.16
Farmers intercropping practice	7.7	14.03	14.03	0.83
Sole maize	14.9		16.61	1.00
Sole potato		44.94	18.47	1.00
LSD	2.43	3.73	2.58	

Note: Average market prices were 1.12 birr/kg for maize and 0.41 birr/kg for potato
Source: Tesfaye et al. 2006

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Chapter Three

Potato Seed Management

Endale Gebre, Gebremedhin Woldegiorgis, and Berga Lemaga

Introduction

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 or improved seed. This is true because the usual method of propagating potato throughout the world is using the vegetative seed tuber. 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). Viruses are the major constraints in potato production worldwide occurring wherever the crop is grown. They received particular attention in seed certification schemes because they cause degeneration whereby they accumulate in successive generation via seed tubers and result in diseased plants that produce progressively smaller tuber yield. The growing potato plant is challenged by many factors that affect tuber growth, quality and yield like bacterial wilt, aphids that transmit viruses, potato tuber moth and physiological condition of the mother tuber.

Therefore, potato seed production requires special focus because of its distinct and special problems of degeneration due to mainly viruses and other biotic factors particularly. Potato, like most vegetatively propagated crops, is notorious of gradual yield decline when using continuously the same seed tubers kept from own farm or obtained from unknown sources. Potato is also very bulky and highly perishable crop that requires care in handling, especially under the Ethiopian condition where farmers are forced to keep the seed for more than six months for the next planting season.

Experience from potato growing areas of the world has shown that the development of appropriate seed production techniques and seed system have a very significant impact on the yield of potato, and on the expansion of potato production to new areas with potential to grow the crop. Availability of improved and high yielding varieties will have very little impact without seed production technologies.

Analysis of Potato Seed Production in Ethiopia

The Ethiopian Seed Corporation was established in 1978 with main objective to supply improved varieties to state farms and producer cooperatives. The organization was the only seed enterprise in Ethiopia until 1990. As a result of the market liberalization the role of

Ethiopian Seed Corporation was changed and renamed as Ethiopian Seed Enterprise, it still is the major seed producer in the country (Berga and Gebremedhin, 1994a). However, the seed production and distribution of horticultural crops in general, including potato, is virtually non-existence. The shortage of quality seeds remained to be the most critical problem in the potato production.

Due to the absence of monitoring and certification system, the bulk of planting materials used in the country still is from low quality seed tubers saved from previous harvest. Such seeds are usually inferior tubers that could not normally be sold for consumption. The use of disease-free seed tubers, which is one of the main quality attributes in seed potato production worldwide, is not adequately appreciated in Ethiopia and there is no certification mechanism. Accurate information on the economic significance and distribution of viruses in Ethiopia is not available. Nevertheless, it is reported that a presumably virus-induced potato degeneration significantly reduced potato tuber yield from year to year in various locations of the country. Nearly all viruses considered as major importance in seed certification worldwide are reported to occur in Ethiopia among which potato leaf roll virus (PLRV) (Fig. 3.1) and potato virus Y (PVY) are more predominant (Bekele and Yaynu, 1994).

The major part of potato production is located in high altitude areas that are not suitable for the development of virus and aphid populations. Ethiopia has therefore favorable climatic conditions and a huge potential to produce high-quality and virus-free seed potatoes. Proper utilization of such an opportunity will not only boost the national potato production but also help the country to earn more foreign currency by

Fig. 3.1 Potato leaf roll virus (PLRV) is one of the major virus problems in potato production

exporting quality seed potato to other countries. Seed potato production requires research support to generate useful information in various aspects such as the incidence and geographical distribution of viruses and their aphid vectors.

Moreover, considerable variation exists in the seed size, age and overall handling qualities among potato growers. As potato tubers are predominantly water (75-80%) and are difficult to keep for a long period from one season to the next, the availability of adequate supply of healthy seed is an essential requirement and a backbone for increased productivity. However, growers in Ethiopia mostly use poor quality seed tubers of cultivars, which also are susceptible to late blight (*Phytphthora infestans*), that result in low tuber yield of usually below 10 t/ha (Berga and Gebremedhin, 1994a). Among local farmers, it has also been a common practice to save as seed the small and inferior tubers that they can not normally sale for consumption. This practice has contributed to the build-up of high level of viral and tuber-borne diseases in the locally grown cultivars.

The incidence of virus infection on potato samples collected at and around Holetta for two years, 1993 and 1994, showed that potato virus Y (PVY) was the most prevalent (52.3%), followed by PLRV (45.9%), and PVS (39.3%) (Bekele et al. 1995). Resent reports show up to 100% infection confirmed with enzyme linked immunosorbent assay (ELISA) test, in which PLRV and PVY were the most prevalent (Holetta Agricultural Research Center, Progress Report 2001, unpubl. data) In potato research, clones after staying 7–10 years in the breeding and clonal selection process, were found to have shorter life after release in sustaining their potential yield at the farmers field due to degenerated seed materials. This has greatly hampered the potentially high yield from improved varieties. Thus, degeneration due to viruses and other tuber-borne diseases as well as poor seed management have been the causes for substantial yield losses each year in Ethiopia.

Due to the absence of private or public commercial seed production, there is high interdependence among potato growing areas for seed tuber. The existence of diverse agro-ecology has enabled nearly a year-round potato production. The diverse ecology is also the main factor allowing different and is some cases unique forms of seed flow. Figure.1. Survey results from some of the traditional growing areas reveal an important lesson to understand the phenomenal features of the seed chain for strategic technology intervention. For instance, in East Shewa Zone of Oromiya Region, there is a well-established and highly integrated production, exchange and flow of seed potatoes (Fig. 3.2).

The majority of potato farmers in the Shashemene area do not use potatoes produced in their locality as seed material for their own. This is due to quick disease build-up which results in yield decline and the short period between consecutive planting season whereby the dormancy of the seed does not allow adequate sprouting at the time of planting. Microclimate plays a key role in refreshing seed quality disfavoring disease build-up in one district than the other where exchange of seed between different microclimates each season challenges the survival of the pathogens in the host and the environment.

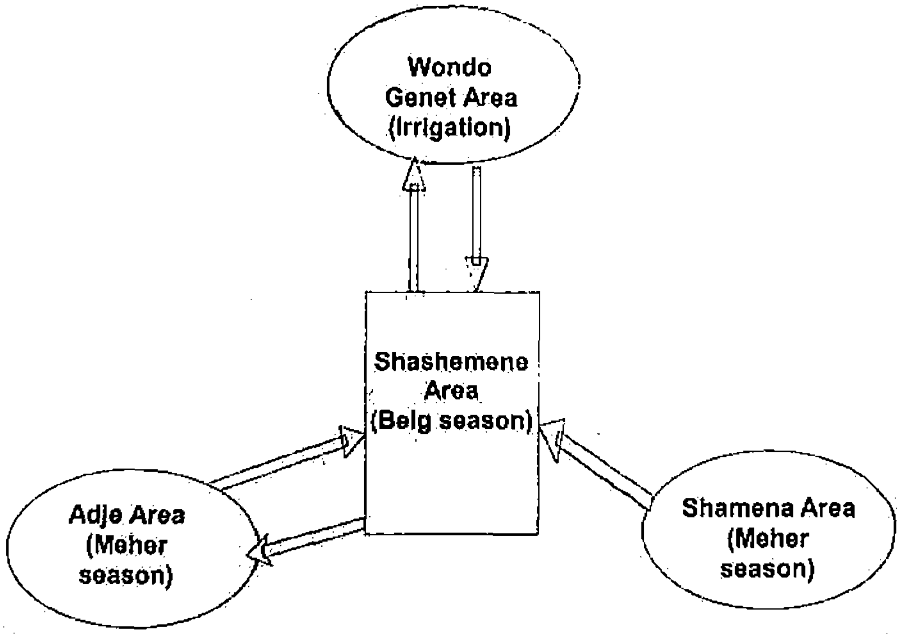


Fig 3.2. Potato seed flow systems in east Shewa Zone

Hence, most of the farmers in the Shashemene area purchase seed tubers produced in other areas in East Shewa Zone: Adje, Shamena and Wondo Genet (Fig. 3.2). For the belg planting (irrigated potato), much of the seed tubers for the Shashemene area come from Adje in Sirraro district and Shamena in Sidamo Zurie district. Likewise, farmers in Shashemene supply seed tubers to Wondo Genet and Adje for the *meher* and irrigated production. Whereas, farmers in Shamena area do not use seed from the other districts but grow own potatoes twice a year.

Similarly, in Jeldu area in the central highland there is no inflow of seed from other districts or regions; but there is outflow of seed by traders from this district to such far places as Wolega, Assosa and other potato growing areas ((Fig. 3.3). The existence of diverse agro-ecology or microclimate is the driving force for a year round potato production and such seed flow experiences. Some areas always preserve their own seeds, but at the same time they are permanent seed sources to other districts.

The cool highland areas that experience little pest pressure are primary seed sources. The areas can be suitable windows for strategic intervention involving integration of improved technologies such as variety with good quality seed production packages and supporting quick dissemination of the technologies to other potato growing regions. That indicates the existence of good opportunities for improving seed quality, and the production and productivity of potato by targeting primary and secondary seed sources.

Moreover, the variety selection program has to strengthen the improvement research for characters such as high yield and late blight tolerance while taking into account length of dormancy, color, taste, cooking quality and wide adaptability to different agro-ecologies. Further about the understanding of the seed flow interdependence of potato growing areas for seed is helpful to get adequate feed-back for the variety selection process for tuber qualities such as dormancy and sprouting conditions.

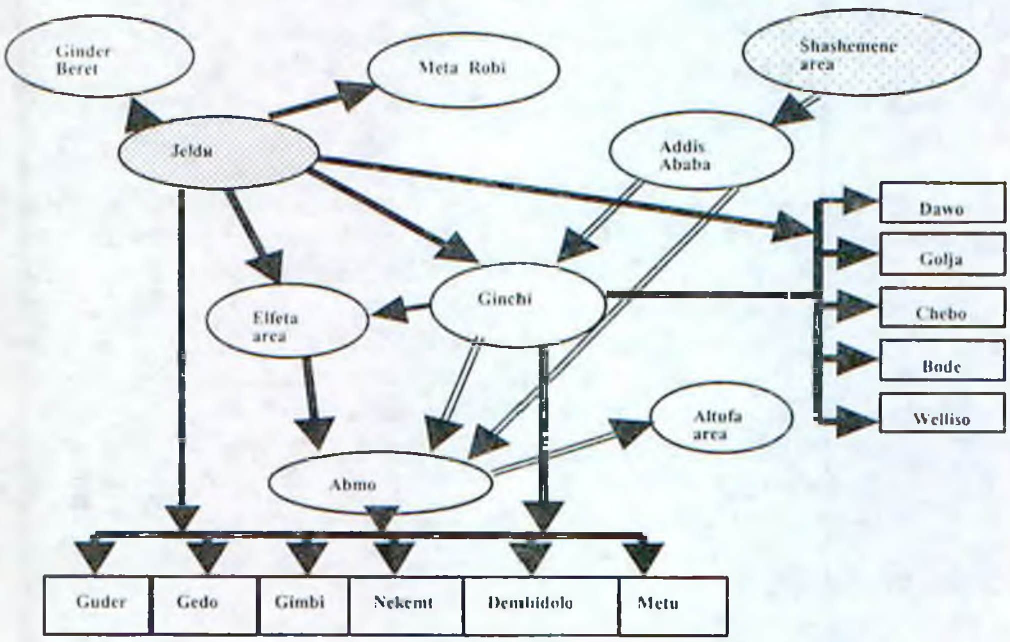


Fig. 3.3. Seed flow channels of potato

Production and Maintenance of Pathogen-Free Seed

Basic seed production is an essential part of a strategy for organizing a potato seed program and involves different methodologies and approaches. A pre-requisite to a successful and sustainable seed scheme is a continuous supply and maintenance of pathogen-free pre-basic seed. In potato, now the In-vitro technology is useful for production, improvement and germplasm handling. In-vitro micro-propagation is a practice that has achieved wide acceptance in order to overcome one of the major limiting factors in the improvement of potato productivity, the shortage of high quality seed tuber.

The conventional clonal propagation method favors disease build-up that drastically reduces productivity. On the other hand, micropropagation using meristems and auxiliary buds as explants can lead to many-fold multiplication and the plantlets can be transferred to pots in screen-houses at higher humidity. It is useful for the breeding program to avail clean seed for variety evaluation as well as production of breeder and pre-basic seed with the desired quality standards (Endale and Sathyanarayana, 2001; Hussey and Stacey, 1981).

Elimination of viruses through chemotherapy or thermotherapy and subsequent meristems culture is the most effective protocol in the establishment of pathogen-free material. Subsequent test for freedom from known viruses is done through ELISA test using monoclonal antibody for known viruses locally (Graebe, 1987). The above process is also found effective for cleaning clones infected with bacterial wilt, which is also an important threat of potato production partioularly in the central part of the country. In-vitro plant lets and plants growing in screen-house and in the field are tested periodically for viruses, and whenever required, for bacterial wilt before further multiplication for basic seed supply. High health standard and purity genetically and physically is maintained for breeder seed.

Once purity is maintained through meristems culture, the use of single nodal cuttings is the most preferred method of propagation that ensures higher propagation rates with maximum genetic uniformity in potato (Chandra and Naik, 1993). The major factors limiting the rates of multiplication in nodal culture are the short height of the plantlets and the low number of nodes on the plantlets obtained. This was improved by addition of growth regulators to the medium. GAs stimulated development of nodal cutting on MS was reported; but, at high concentration it produces narrow and elongated shoots depending on genotypes. Longest main shoot and highest node numbers are reported to be obtained in a medium containing NAA and BAP (Jones, 1994). The limitations, however, are ascribed to the various components of the culture environment and the low photosynthetic ability of the explants or plantlets. Moreover, the vigor of the plantlets depended upon light intensity. A higher increase in stem diameter, leaf area and leaf number was obtained at 16 hours daylight in the laboratory.

Use of Rapid Multiplication Techniques (RMTs)

Rapid multiplication techniques (RMTs) are methods used to increase the amounts of nuclear seed stocks for further multiplication into basic seed. RMTs pro vide a better multiplication method than the conventional method of vegetative multiplication of potato. The conventional method of vegetative propagation, according Mwansa and Mwala (2000), provides a low multiplication ratio (1:3 to 1:15) and may allow of rapid virus infection. Whereas, the RMTs provides high multiplication ratio (1:40 to 1: several thousands/year) and lower rate of contamination particularly from soil and seed-borne pathogens. In addition, the rapid multiplication method is more efficient because it involves integration of different techniques. The techniques include: sprout cuttings, single node cuttings, stem cuttings (Fig. 3.4) and micro-propagation (Fig. 3.5).

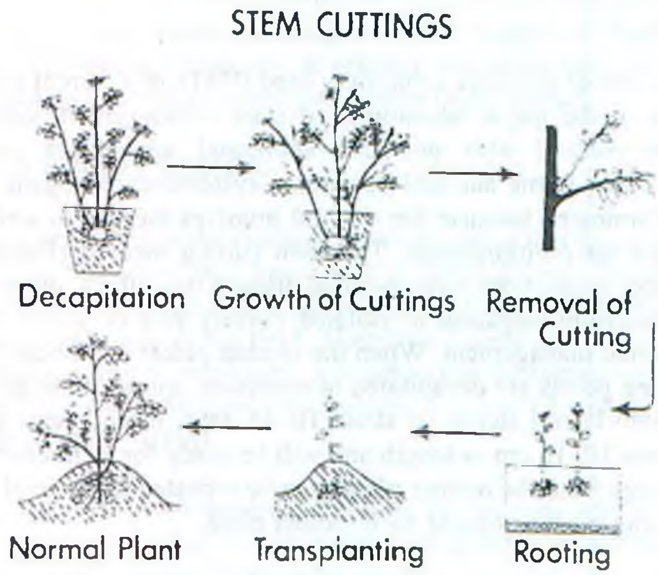


Fig. 3.4. Steps in stem cutting from decapitation of shoot tip to rooting

Fig. 3.5 Laboratory (*in vitro*) and screen house multiplication of virus free tested potatoes is now part of the informal seed system

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. The quantity of seeds of different varieties grown in different localities is presented in Table 3.1.

Table 3.1. Quantity of seed potato production of different varieties at three localities in the central highlands, 2001-2005

	Seed (t)					
Locality	2001	2002	2003	2004	2005	Total
JELDU						
Menagesha	26	44	62	144	0	276
Tolcha	0	0	0	29	175	204
Wechecha	6	44	31	101	155	337
Jalene	0	0	0	0	22	22
Degemegn	0	0	0	0	6	6
WALMERA						
Menagesha	0	0	0	0		
Tolcha	0	0	0	0	238	238
Wechecha	0	0	0	0	224	224
Jalene	0	0	0	0	204	204
Degemegn	0	0	0	0	113	113
Guassa	0	0	0	0	124	124
DEGEM						
Menagesha	0	0	0	4		4
Tolcha	0	0	0	18	154	172
Wechecha	0	0	0	29	170	199
Jalene	0	0	0	0	134	134
Degemegn	0	0	0	0	2	2
Guassa	0	0	0	0	50	50
Total	32	88	93	325	1,771	2,309

Source: Gebremedhin et al. (2006)

Agronomic Management

The production of potato seed crop can be equally affected by the various agronomic management issues and practices of potato ware crop production. However, the effects of some of the agronomic practices may be more important in the production of potato seed crop. Some agronomic practices in particular can have significant influence on the quality, and yield of seed. Therefore, multiplication of seed crops should involve manipulation of some important agronomic practices towards quality and high seed yield results.

In potato seed production, seed health and size are important seed qualities. Adjustment of plant density in the fields is a good practice to produce a high proportion of medium size tubers. The cost of seed potato is estimated to constitute up to 50% of the total cost of production. It may therefore not be economical to use large size tubers as seed.

Rouging and dehaulming are also important agronomic practices that can be used mainly to minimize virus infection and bacterial wilt infestation (Fig. 3.6) in the field and obtain healthier seed tubers. Rotation, use and application of fertilizers and pest management are conventional potato agronomic practices. However, they can be more critical particularly in potato seed production and need to be properly administered to get high quality potato

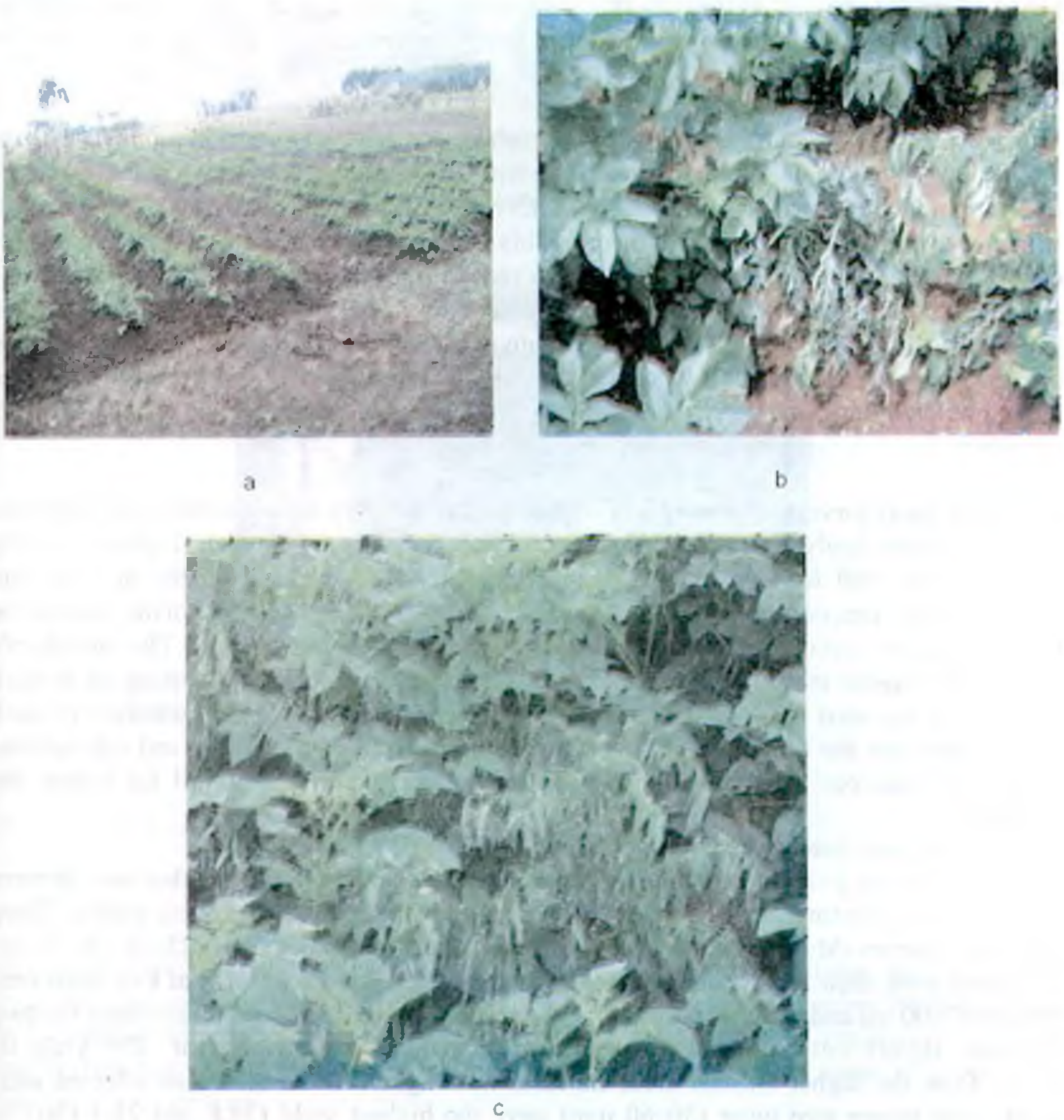
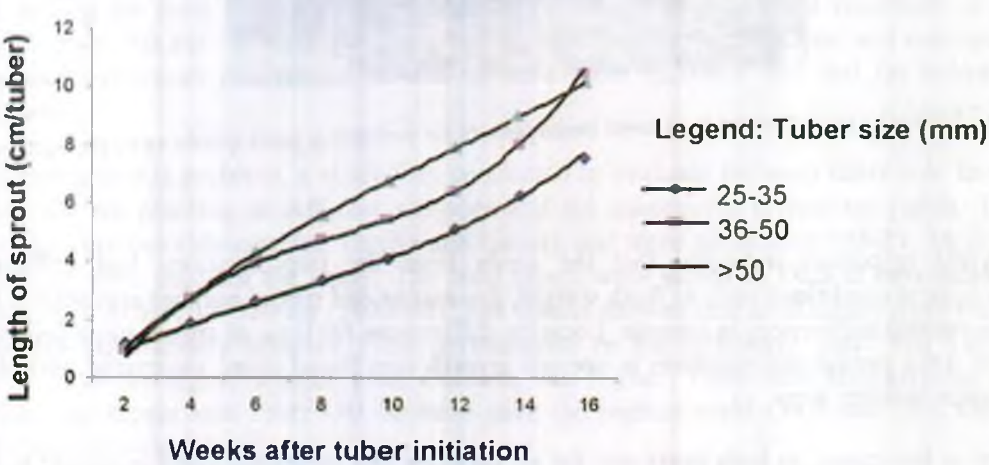


Fig. 3.6 Seed prodcution requires well managed plots (a) with regular inspection to completedly avoid major seed contaminants like bacterial wilt (b and c).

Fig. 3.8. DLS can be made out of cheap locally available materials (a), or can be improved to fit medium scale storage (b and c) maintaining good tuber quality



Effect of tuber size and storage time in diffused light store on sprout growth at Holetta, 2400 m altitude

However, the reduction in tuber weight was variable with tuber size. If tubers are healthy, the differences in performance in the field that is attributed to the locations would be minimal, provided bigger tuber sizes (50-60 mm) are used. It is also important to note that smaller seeds tend to dry after 7-8 month in storage, even at high altitudes as Holetta. Farmers in warm and low humid areas should choose to store rather bigger size seed tubers (>55 mm) that stand long desiccation period due to high vapor pressure deficit that might be encountered in ventilated DLS.

Fig. 3.10 Seed potato treatment after harvest (a), regular inspection (b) and sprouted tubers in good condition after 8 month at 2400 masl (Holetta) (c).

To a large extent sprout growth is a function of light, and percentage inhibition of sprout growth is essentially independent of location, variety and temperature. The growth largely depends on intensity of irradiance falling on the tuber (McGee et al. 1988). The two locations are likely to have little difference in irradiance. But the difference in construction of the DLS in the two sites might have allowed irradiance differences, which could have a cumulative effect for the length of the storage period. Such effects are confounded in the analysis.

The results of partitioning the error variance showed that a larger proportion (35.5%) of the total variability was accounted largely for seasonal variation between the two crop growth periods than the value for seed size (8.2%) and altitude/location (1.5%). The importance of confining seed tuber production in the highland areas is multidimensional mainly from the

Little variation was observed in yield between 25 and 30 cm for all varieties for a fixed row width. The rate of change in yield within a given in-row distance was variable for each cultivar. The yield distribution in seed tuber size showed economical variation among vareities and spacings (Table 3.3 and Figure 3.12).

Table 3.3. Effect of spacing and variety on tuber yield for different tuber sizes, average tuber weight and average tuber number of seed potato crop at Holetta on Nitosol, 1995 and 1996

	Tuber yield (q/ha)											
	Tuber size (mm)											
	<20		20-30		30-40		40-50		>50		ATW* (g)	ATN m²
Variety												
Awash	6.4	(3.5)**	30.8	(17.5)	67.9	(36.5)	64.9	(34.8)	16.2	(8.1)	37.9	55.5
Menagesha	2.2	(0.7)	12.3	(4.1)	35.3	(12.0)	84.2	(27.2)	196.5	(55.6)	94.6	54.2
Tolcha	1.78	(1.0)	12.0	(6.2)	44.8	(22.0)	74.2	(29.2)	82.4	(37.0)	50.9	47.0
LSD 0.05	0.56		2.02		4.93		6.13		9.52		2.1	2.84
Row width spacing (cm)												
45	4.3	(2.4)	21.4	(11.8)	50.2	(26.5)	65.5	(31.4)	73.6	(27.9)	43.4	58.8
60	3.4	(1.9)	17.5	(10.0)	46.5	(24.8)	66.4	(31.7)	84.0	(31.5)	47.4	53.6
75	3.9	(1.4)	21.6	(7.8)	65.6	(22.8)	104	(33.0)	137.3	(34.8)	53.7	58.6
90	2.3	(1.4)	12.5	(7.5)	35.1	(19.4)	81.7	(31.6)	98.8	(40.1)	60.2	37.9
In-row spacing												
20	3.5	(1.8)	20.6	(10.8)	53.5	(25.6)	74.1	(31.6)	91.5	(30.0)	47.7	64.9
25	3.6	(1.8)	18.2	(9.3)	50.6	(23.7)	74.0	(31.4)	100.3	(33.7)	51.1	49.7
30	3.6	(1.8)	18.0	(8.9)	49.2	(22.7)	75.2	(31.5)	101.8	(35.1)	52.0	50.5
35	3.2	(1.7)	16.2	(8.1)	44.1	(21.6)	74.5	(33.6)	99.9	(35.2)	53.4	43.8
LSD 0.05	ns		2.33		5.69		7.07		10.68		2.43	3.28

* ATW, average tuber weight; ATN, average tuber number
** Figures in parentheses represent percentage of the total yield

Most of the yield in Awash (71.4%) was from tubers of 30–50 mm, while in Menagesha 82.8% of the yield came from tubers > 40 mm. In Menagesha and Tolcha the yield from tubers or > 50 mm size accounted for 55.6 and 37.0%, respectively, indicating the possibility for further intensification of planting density with very little yield decline for seed purpose. At 20 cm, tubers >30 mm accounted for 87.4% and tubers >40 mm for 61.8% of the total yield.

Saleable tuber yield was increased at 75 cm and above in Awash and at 60 cm and above in Tolcha. In Menagesha, such yield was already attained at the lowest row width and in-row spacing (Table 3.4) that gave up to 15–16 t/ha of >40 mm tubers. Similar to other studies, the effect on yield in Menagesha was mainly because of less competition in growth and faster and more bulking of the few tubers formed.

Decreasing row width below 60 cm can bring in operational problem, particularly in irrigated potato, on heavy soils and heavy rainfall areas, in addition to increased seed rate and thus cost. The seed rate problem can be managed to a certain degree by using smaller-sized seed tubers.

The varietal differences indicated that optimum spacing for any purpose requires consideration of the maturity type and vegetative growth (vigor) of the crop in addition to other factors such as soil fertility and water availability. For varieties like Menagesha, seed size (30–50 mm) yield may not be maximized even at closer spacing and may require further reduction of in-row distance or use of alternative cultural methods such as dehaulming to control seed size.

Table 3.4. Effect of row width and in-row distance on average tuber weight and average tuber number of three cultivars at Holetta on Nitosol, 1995 and 1996

	Tuber weight (g) and number/m^2			
	In-row distance (cm)			
Row width (cm)	20	25	30	35
45	44.0 (52.4)*	42.9 (52.7)	41.9 (53.0)	47.6 (44.7)
60	44.3 (45.8)	46.4 (45.6)	50.0 (59.0)	49.0 (44.5)
75	48.5 (72.6)	56.5 (58.9)	55.0 (59.5)	54.8 (57.0)
90	56.8 (32.7)	58.6 (36.9)	63.3 (36.1)	62.1 (33.2)
LSD $_{0.05}$ = 4.85 (6.56)				
Awash				
45	30.4 (57.0)	25.3 (69.5)	31.2 (56.5)	34.6 (49.2)
60	33.1 (46.1)	35.3 (52.2)	34.6 (50.5)	38.4 (44.4)
75	37.5 (70.6)	46.3 (56.8)	42.7 (60.6)	44.0 (53.2)
90	42.5 (32.8)	44.0 (34.6)	39.2 (46.3)	48.4 (30.7)
Menagesha				
45	55.7 (52.0)	59.6 (46.1)	55.2 (51.9)	62.7 (45.0)
60	58.5 (51.3)	58.9 (49.7)	64.3 (50.2)	62.1 (47.2)
75	62.1 (75.1)	72.3 (58.7)	69.1 (60.6)	62.6 (70.6)
90	68.9 (36.7)	73.2 (42.7)	78.7 (35.2)	70.0 (42.1)
Tolcha				
45	37.0 (48.3	43.7 (42.6	39.4 (50.5)	45.5 (39.4)
60	41.3 (39.9)	44.9 (34.9)	57.0 (36.2)	46.6 (41.8)
75	45.7 (72.1)	61.0 (61.1)	53.2 (57.2)	57.1 (47.1)
90	59.0 (28.6)	58.6 (33.4)	72.0 (27.0)	68.0 (26.8)
LSD $_{0.05}$ = 4.41 (11.36)				

* Figures in parentheses represent average tuber number per meter square

A study was conducted in 1991-93 to determine the optimum harvesting time for seed potato crops of different released varieties. Five harvesting dates were seed beginning 7 weeks after planting and at two weeks interval. Four released varieties were also used: Menagesha, Tolcha, Awash and Sissay. The varieties had different maturity dates and thus showed variation in optimum harvesting time among them. The maximum total tuber yield was obtained 98 and 105 days after planting for all varieties. Tuber number during all the harvesting stages was higher for tuber size class 30–40 mm followed by 20–30 mm. Tubers with 30–50 mm size in all cases constituted 45 to 55% of the total tuber yield. According to the results, there were differences in seed size, tuber number and yield among varieties. Therefore, seed production schemes need to integrate these attributes to maximize seed tuber yield. There was little or no difference among varieties for yield of smaller tubers (<20 mm, 20–30 mm) in relation to harvesting dates (Fig 3.13).

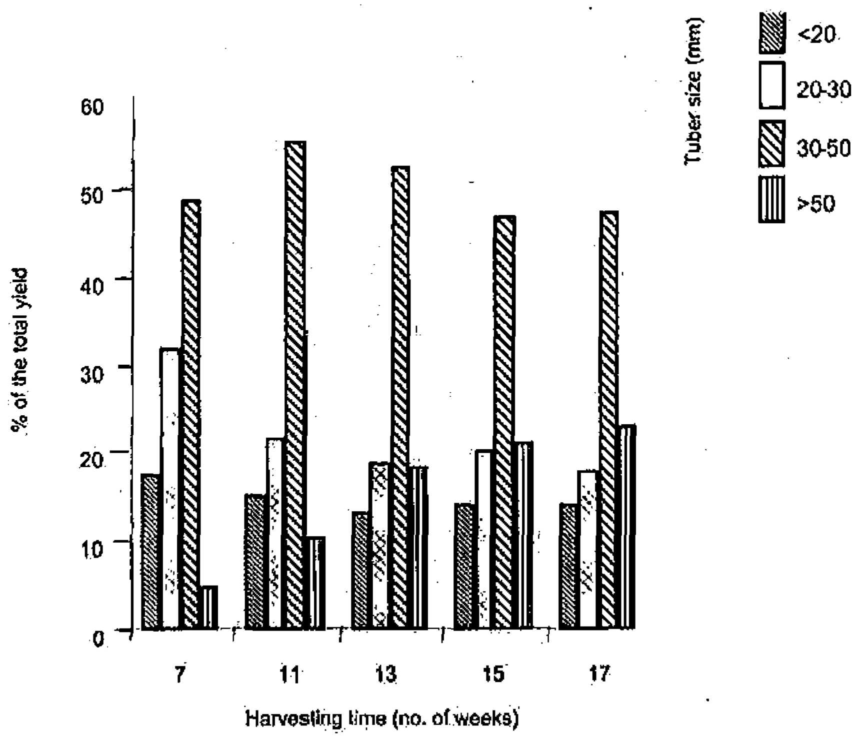


Figure 3.13. Percentage distribution of tuber number by tuber size and harvesting date

Dehaulming

Dehaulming, or preferably called haulm removal, is one of the least practiced operations by potato growing farmers in Ethiopia. Elsewhere it is usually practiced to slow down the development of diseases such as late blight and viruses. Seed growers can also effectively use it to hasten senescence and manipulate seed size tubers. The practice is essential in seed tuber production as it avoids infection late in the growing season and the possible spread of late blight from foliage to tubers. With most of the cultivars this time is reached long before the tuber bulking period is over. In mechanized farming, haulm removal facilitates harvesting.

In an experiment carried out to evaluate the effects of haulm removal on yields, seed tubers of four varieties Awash, Menagesha, Tolcha and Wechecha were planted at the same time and harvested at different dates: 60, 70 and 80 days after planting (DAP). The seeds were stored and replanted at the same time. This cycle was replicated over two years. The combined results showed that nearly three-folds yield increment was recorded when haulm removal was delayed from 60 to 70 DAP for tuber sizes 50–60 mm. Seed size tuber yield could be maximized when delaying dehaulming up to 80 days. There were varital differences (Table 3.5), indicating that growers decisions in controlling seed yield had much to depend on it. Variation is also expected between main and off-season rain crops for time of haulm removal. In early varieties like Tolcha and Awash there was little or no appreciable increases in seed yield for time the haulm is removed (Table 3.6). In Tolcha, tuber weight and yield were reduced due to delaying dehaulming from 70 to 80 days caused by the senescing plant feeding on the stored food. Although not well known under Ethiopian condition, the effect of early harvest on subsequent on set of sprout growth is reported to be so small that it is unlikely to cause problems in age of seed at replanting (Allen et al. 1992).

In general, harvesting must be done after keeping tubers in the soil for up to 10–14 days is for the skin to set. Haulm removal can be accomplished by cutting, pulling, burning, and spraying the haulm with chemicals. However, the first method facilitates transmission of disease and great care must be taken to minimize mechanical damage to tubers during harvest. It is also very important to separate the good tubers from those attached by insects, disease and mechanically injured ones. The good tubers graded into different sizes should be stored under optimum conditions. Storage conditions, especially temperatures, determine the physiological age, which in turn determines the subsequent performance of tubers in the field. Storing in natural diffused light store gives best results in seed dormancy and sprout stimulation.

Table 3.5 Effects of haulm removal on yield and average tuber number

Dehaulming date (AP)	Yield (t/ha)			
	Tuber size class (mm)			
	<50	50-60	>60	Total
60	8.6 (33.1)*	3.4 (5.2)	0.3 (0.3)	12.4
70	10.3 (40.9)	6.0 (7.7)	1.6 (1.2)	17.9
80	5.7 (29.7)	9.9 (17.1)	5.9 (5.7)	21.6
LSD	2.58 (8.9)	1.68 (3.8)	1.41 (1.13)	
CV (%)	34.45 (43.18)			

* Figures in parentheses represent average tuber number per meter square

Table 3.6 Effects of haulm removal 60, 70 and 80 days after planting on yield, average tuber weight (ATW) and average tuber number (ATN/m^2) of some varieties

Variety	Yield (t/ha)				ATW (g)			ATN (m)		
	60	70	80	Mean	60	70	80	60	70	80
Awash	14.1	15.6	17.9	15.9	33.1	28.9	33.6	14.9	13.5	13.3
Tolcha	19.6	24.6	19.8	21.3	45.4	43.9	30.8	21.3	23.1	23.3
Menagesha	4.9	10.6	14.8	10.1	20.1	31.3	48.6	19.9	21.2	20.1
Wechecha	15.2	19.9	26.4	20.5	30.0	38.7	55.1	22.1	25.5	24.2
Mean	13.4	17.7	19.7		52.8	51.2	46.8	19.6	20.8	20.2
LSD	Variety = 10.20, Dehaulming = 4.59				Interaction = 17.31			NS*		

NS not significant

Seed tuber Dormancy

For most varieties seed tubers are dormant at harvest and for some time afterwards even in temperatures conducive to sprout growth. A few early varieties have short dormancies. The timing of the dormancy break and sprout growth is influenced by the crop husbandry.

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Potato Disease Management

Bekelle Kassa and Eshetu Bekele

Introduction

The potato is prone to many diseases caused either by bacteria, fungi, viruses or mycoplasma. Late blight is generally the most important disease wherever potatoes are grown in the country. Traditionally the crop is grown during the off-season using the short rain that falls during February–April and sometimes with supplementary irrigation when available. The main reason for not growing potato during the long rainy season, despite the high yield potential of the main season crop, is the severe threat posed by late blight. The local varieties do not cope with the disease pressure in the main rainy season and often are wiped out particularly in the highlands. Viruses and bacterial wilt are also very important diseases affecting potato production.

Tuber and plant degeneration due to virus and bacterial wilt is becoming very important throughout the potato growing areas. The prevalence of these diseases is high in the low-to-mid attitude areas. The pathogens attack foliage, root systems and tubers, which makes them important throughout the crop cycle. Seed tubers may deteriorate before or soon after planting especially when seed is cut; the growing plant may be weakened by direct attack or systematic infection and become less productive, or the roots of foliage may be attacked directly causing their premature death. Many factors contribute to the survival, spread and damage of the pathogens. The major reasons include use of susceptible local varieties, poor management practices in field and storage, conducive environmental conditions and lack of internal seed certification system.

The current chapter describes the major diseases of potato and their spread and prevalence in the country. In addition, discussions on the management of the diseases are made in light of improved production technologies that have been developed through research.

Survey of Potato Diseases

The incidence and prevalence of the different diseases of potato was studied in the major potato growing districts in central Ethiopia. The diseases were visually identified and assessed based on their typical symptoms. In instances of symptoms for bacterial wilt and viruses, soil and leaf samples were collected for serological test using ELISA kits. According to the results, early blight (*Alternaria solani*), bacterial wilt (*Ralstonia solancearum*), late blight (*Phytophthora infestans*) and viruses were the most widely distributed potato diseases in all the surveyed areas (Table 4.1).

Table 4.1. Mean incidence and prevalence of different potato diseases in central Ethiopia, 1993-94

Disease	Incidence	Severity
Bacterial wilt	11.10 ± 2.60	32.13 ± 6.00
Early blight	11.85 ± 1.21	12.70 ± 2.52
Late blight	9.33 ± 1.63	10.00 ± 2.24
Powdery mildew	3.17 ± 1.41	6.25 ± 1.60
Soft rot	1.00 ± 0.64	___
Viruses	11.92 ± 2.20	0.0
F and P values	$F_{5,62} = 7.55$, $P < 0.0001$	$F_{4,30} = 7.09$, $P < 0.0004$

Source: (Holetta Research Center Potato progress reports, 1993-94, unpubl. data)

Table 4.2. Detection and incidence of bacterial wilt (*R. solancearum*) from soil using ELISA during the off-season, 1993

Locations	No. of samples	Bacterial wilt (%)
Zeway	16	33
Shashemene	16	23
Wondo Genet	18	50
Holetta	44	25

Source: (Holetta Research Center Progress reports 1993-94. unpubl. data)

Severe late blight infection during the main season was the major reason for shifting the production of potato to the off-season in these areas. Late blight also occurred in the off-season in all the locations, but with less incidence and severity than the early blights and bacterial wilt. The occurrence of soft rot and powdery mildew was very much limited.

There was lower or no bacterial wilt severity in the cool highland above 2400 m. At lower altitudes like Wondo Genet, bacterial wilt (*R. solancearum)* was found highly prevalent (Table 4.2). During the survey two major viruses were identified, potato virus Y (PVY) and potato leaf role virus (PLRV). PVY was more predominant on the local (6 to19%) and PLRV on the improved varieties (16 to 32%).

Late Blight and Yield Loss

Yield losses of potato due to late blight infection were estimated during the main rain seasons of 1993 and 1994 at Holetta. The results showed that 2.7 to 67% yield reduction could occur for different varieties that showed different levels of resistance as determined by AUDPC values (Table 4.3).

The varieties consistently showed resistance reaction to late blight. Whereas, the disease pressure was variable from year to year in accordance with the amount and distribution of rainfall received during the main rainy season.

Table 4.3. Late blight pressure and corresponding losses in yield of different potato cultivars at Holetta, 1993 and 1994.

Cultivar	1993 Late blight (AUDPC)	1993 Yield loss (%)	1994 Late blight (AUDPC)	1994 Yield loss (%)
K-59 A (26)/Genet	355.9	14.6	293.0	2.7
CIP-378501.3/ Awash	697.5	36.1	1109.8	5.9
CIP-378367.4	378.0	37.8	1025.1	47.5
Sissay	611.8	37.6	1081.7	22.3
UK-80-3/Tolcha	375.7	17.3	434.1	29.4
AL-624	1451.5	67.1	1184.8	45.5
Mean		35.08		25.55

Source: Bekele and Yaynu (1996)

Variability in Isolates of *P. infestans*

Until the 1980s, only the A1 mating type (an asexual organism) of *P. infestans* was widely and commonly distributed (Goodwin et al. 1994b). Where *P. infestans* exists as an asexual organism it is essentially an obligate parasite. It requires a living host (crop debris or solanaceous weeds) for long-term survival. Whereas, sporangia may survive for days or weeks in soil, they cannot over-winter or over-season. Mycelium of the fungus cannot survive in the absence of a living host cell.

The situation changed dramatically during the 1980s and 1990s. Isolates of P. infestans with the A2 mating type were first reported from Switzerland (Hohl and Iselin 1984) and subsequently from many countries in northern Europe (Fry et al. 1993). Both mating types (A1 and A2) were common in Mexico, but they were apparently not common in other locations. When individuals of opposite mating type (A1 and A2) come into physical contact, sexual structures (antheridia and oogonia) are produced by each thallus. After a period of dormancy for weeks or months, oospores become capable of germination. In locations where sexual reproduction occurs, the resulting oospore can survive for months or years in the absence of living hosts (Drenth et al. 1995). This makes the control of late blight extremely complicated and difficult for smallholder potato farmers in developing countries.

The late blight fungi that prevails in Ethiopia is assumed to be an asexually mating type (A1 type). A study was initiated to verify the type by evaluating the variability of isolates from different agro-ecologies in Ethiopia. Samples were collected from Adet, Galessa, Holetta, Kossober, Shashemene and Wolmera districts by isolating the pathogen from tomato (cv. Money Maker).

According to the results of the study, all isolates produced the typical late blight symptom (Holetta Research Center, Potato Pathology Progress Report, 1997 & 1998, unpubl. data). However, the degree of infection varied with the locations from which the samples were collected. The isolates from Adet and Galess a showed shorter latent period and produced bigger lesions than those from the other districts. In contrast, the pathogen isolated from tomato at Holetta did not infect all the inoculated varieties of potato. It produced minute bright yellow spots on the tested potato cultivars. Generally, the isolates were more aggressive to the host from which they were isolated.

Characterization of P. infestans populations

Further chemical and molecular characterization of the collected Ethiopian isolates was done by Schiessendoppler et al. (2003). The genetic structures of the isolates were analyzed as la mtDNA–haplotype. The result showed all isolates to be A-1 mating type (Table 4.4).

Based on the results of the leaf disc method, 75, 10 and 15 % of the 41 isolates tested were sensitive, intermediate and insensitive to Metalaxil, respectively. Selfing within the isolates was frequent and recorded as 100%. Oospore production was also higher in the tested samples.

Table 4.4. Characteristics of populations and oospore production in selfing of *P. infestans* from Ethiopian isolates

	Characteristics of P. infestans populations					
No. of isolates	Mating type	MtDNA haplotype	Leaf disc test for Metalaxyl insensitivity (%)			Self fertility (%)
			Sensitive	Intermediate	Resistant	
41	A1	1a	75	10	15	100
Oospore production in selfing						
No. of isolate	Percentage of samples in classes					
	0	1 (0-5)*	2 (5-10)*	3 (10-20)*	4 (>20)	
34	0	12	18	35	35	

*Assessment key: number of oospores per microscope field (magnification of 40X, average of 10 observations)
Source: Schiessendoppler et al. (2003)

Chemical Control of Late Blight

The efficacy of different fungicides was evaluated during the main season for two years. All the fungicides controlled late blight and increased yield. The increase was more apparent in the susceptible variety, AL-624 (Table 4.5). The per cent late blight control on this variety ranged from 22 to 90% with a corresponding yield increase from 177 to 485%. Late blight severity on the tolerant variety Tolcha was less than that of AL-624, although the per cent control seemed to be high when compared to the unsprayed control.

The result indicated that spraying the susceptible variety with any one of the fungicides was economically feasible. The net benefit and the marginal rate of return were very high (more than 100%). The two contact fungicides, Chlorothalonil and Brestan 10, could be affordable to farmers for a reasonable control of late blight and good return.

On the other hand, one application of the preventive fungicide, Redomil MZ, followed by two applications of a contact fungicide like Mancozeb, has additional advantage. That is, sustainable control of the disease to protect development of resistance to Metalaxyl due to repeated application.

Table 4.5. Effect of fungicides on late blight control and yield increase of potato varieties Tolcha and AL-624, 1996 and 1997

Treatment	Tolcha		AL-624			
	Disease control (%)	Yield increase (%)	Disease control (%)	Yield increase (%)	Net benefit (Birr)	Marginal rate of return (%)
1996						
Chlorothalonil 50% EC	46.9	63.7	59.3	205.8	5230.0	248
Ridomil MZ 63.5% WP	45.4	61.1	78.8	369.2	7334.0	192
Mancozeb 80% WP	51.9	36.3	43.4	184.6	4650.0	
Ridomil MZ 63.5% WP + Mancozeb 80% WP						
Brestan 10	55.6	50.3	46.8	176.9	4838.0	451
Control	00.0	00.0	00.00	00.0		
1997						
Chlorothalonil 50% EC	52.9	-15.6	75.5	355.1	13292.0	171
Ridomil MZ 63.5% WP	53.3	-0.1	82.3	485.4	14890.0	487
Mancozeb 80% WP	31.9	-25.0	57.8	303.0	1188.0	
Ridomil MZ 63.5% WP + Mancozeb 80% WP	28.9	-8.3	90.2	415.7	13505.0	104
Brestan 10	68.7	-39.1	22.3	217.2	5222.0	198
Control	00.0	00.0	00.0	00.0		

Source: Bekele and Hailu (2001).

Rate and Spray Intervals

The effects of different rates and spray intervals of the fungicide Redomil MZ 63.5% WP on the control of late blight on varieties with different levels of resistance were studied at Holetta in factorial experiments.

Fungicide spray significantly increased yield at all the fungicide rates, spray intervals and varieties (Table 4.6). The higher rates (2 and 3 kg/ha) significantly reduced late blight development, as indicated by lower AUDPC, and increased yield when compared to the rte 1 kg/ha. Therefore, 2 kg/ha Redomil MZ 63.5 % was found effective. Although the AUDPC values increased with the increase in the spray interval, the corresponding increments in yield were not significant suggesting that 10 to 20 days spray intervals could safely be used. Varieties significantly differed in the late blight development (AUDPC) but the yield was not found significant at 5% level. The susceptible variety, Al-624 benefited more than the two relatively resistant varieties from the higher fungicide rates and the shorter spray intervals to have much more disease reduction and yield increments. Fungicide spray increased tuber yield of the susceptible variety AL-624 by about 223%, while the increments in yield of the CIP378005.3 and UK-80-3 were 40% and 59%, respectively.

Table 4.6. *Main effect of rate and spray intervals of the fungicide Redomil MZ 63.5% WP on late blight development and yield, Holetta 1993*

Treatments	AUDPC	Tuber yield (t/ha)
Fungicide (kg/ha)		
0	836.3	13.2
1	214.8	22.8
2	87.5	27.3
3	79.3	26.4
Spray Interval (Days)		
10	44.8	25.9
20	153.5	25.6
30	184.4	24.1
Varieties		
AL-624	403.1	23.9 (7.4)*
CIP378005.3	144.2	23.3 (16.6)*
UK-80-3	83.8	24.6 (15.5)*

* Figures in parentheses are tuber yield of the unsprayed plots of the respective varieties
Source: Summarized from Potato Program Progress Report for 1994 (Holetta Research Center, unpubl. data)

Similar study was done in 2000 main season at Holetta and Galessa using three recently released varietie: Tolcha (moderately resistant), Meanagesha (moderately susceptible) and Awash (susceptible). The fungicide Dithane M-45 was used at a rate of 3kg/ha and sprayed at 7, 14 and 21 days interval.

Spraying significantly reduced late blight development and increased yield in all the varieties and at both locations (Table 4.7). The fungicide Dethane M-45 at a rate of 3 kg/ ha when sprayed at 7 days interval was the best in controlling the disease and in increasing yield. The variety Tolcha tolerated the disease and yielded high at Holetta but not at Galessa. That indicated differences in virulence of the pathogen at these locations and/or in the environmental conditions for disease development. There was significant interaction between varieties and spray intervals. The tuber yield of Menagesha and Awash had increased by about 1105% and 280%, respectively, by spraying the fungicide at 7 days interval at Holetta. Whereas, the increment of that of the moderately resistant Tolcha was only 54%. It is, therefore, necessary to spray susceptible varieties frequently when planted in the main season in disease prone areas like Holetta.

Table 4.7. Main effects of varieties and spray intervals on late blight development (AUDPC) and tuber yield at Holetta and Galessa, 2000

Treatments	Holetta		Galessa	
	AUDPC	Yield (t/ha)	AUDPC	Yield (t/ha)
Variety				
Tolcha	282.6b	16.5a	629.7a	7.9b
Awash	1406.1a	7.3c	701.2a	5.3c
Mwnagesha	1391.8a	11.5b	503.1b	21.3a
Spray Interval				
7 days	529.3d	23.1a	395.0c	14.1a
14 days	857.9c	15.3b	568.9b	12.9ab
21 days	1128.5b	13.3b	665.4b	10.8b
No spray	1591.7a	8.8c	815.9a	8.2c

Source: Extracted from 2000 potato program progress report (Holetta Research Center, unpubl. data)

Integrated late blight management

Varieties, planting dates and fungicide spray

The effect of varieties and planting dates on late blight severity and potato yield was investigated for three seasons without and with fungicide application (Ridomil MZ 63.5% WP at a rate of 2.5 kg/ha). Three varieties representing different level of tolerance, namely Tolcha (tolerant), Awash (moderate), and AL-624 (susceptible), were used in combination with planting dates (June 3-7, June 18-21, July 3-5, and July 18-19).

Late blight appeared as early as 22 days after planting on AL-624, 29 in Awash and 39 in Tolcha (Table 4.8). Similarly, the rate of late blight development was faster in the susceptible variety as indicated by the higher AUDPC.

Although early planting resulted in higher AUDPC, the disease onset was delayed and consequently tuber yield was higher over the three years in the early-planting. In late planting, because of the low initial inoculum, initiation and progress of the disease was slow. This permit only limited number of disease cycles. It is important to note that though late blight development is higher in early June planting, tolerant varieties like Tolcha can give higher yield.

Table 4.8. Effect of variety, planting date and fungicide application on incidence (DOS) and severity of late blight and tuber

	1993			1994			1996		
Treatments	DOS* (days)	AUDPC	Yield (t/ha)	DOS (days)	AUDPC	Yield (t/ha)	DOS (days)	AUDPC	Yield (t/ha)
Variety									
AL-624	27bc	821.5a	8.7c	24b	750.8a	4.6b	22b	1351.4a	5.6c
Awash	32ab	291.9b	16.8b	35ab	615.4a	7.1b	29ab	1181.5ab	11.3b
Tolcha	41a	142.0b	23.4a	43a	462.8a	11.7a	39a	466.6c	21.6a
Planting date									
Early June	42ab	652.8a	25.7a	38a	867.4a	13.4a	40a	1567.0a	20.1a
Late June	45a	570.0ab	23.0ab	35ab	637.5ab	6.1b	29ab	1260.0ab	16.2b
Early July	27c	298.2b	9.2c	26abc	447.3bc	5.5b	23bc	896.4c	8.4c
Late July	28c	251.0c	7.2c	21bc	486.6bc	6.3b	19c	276.1d	6.8c
Fungicide									
No	-	416.1	16.3	-	499.0	7.8	-	998.8	12.8
Yes	-	14.1	23.0	-	55.2	12.5	-	182.9	23.6

* DOS, Disease onset (days from planting)
Source: Bekele and G/Medhin (2000)

Spraying Ridomil MZ 63.5% WP has generally significantly reduced the disease severity and increased yield in all the varieties and sowing dates in the three years. There were significant interactions between the fungicide spray, varieties and planting dates. The yield increase brought about by fungicide spraying on the susceptible variety AL-624 was much higher at the early than late planting dates. Whereas, spraying early planted Tolcha (tolerant cultivar) did not significantly increase yield. Therefore, susceptible varieties can be planted early by protecting them with fungicides. In contrast, tolerant variety such as Tolcha can be planted early with minimum one time application of fungicide.

Varieties, plant density and fertilizer

The effects of plant density and fertilizer on late blight severity and yield of two potato varieties were investigated at Holetta in the main seasons for three years during 1997,1999 and 2000. The effects of variety, plant density and fertilizer levels on late blight severity and yield were generally variable (Table 4.9). Increasing plant population has also increased yield in all the seasons, despite the significant increase in disease severity in 1997.

Despite increased values of AUDPC at higher fertilizer levels, tuber yield showed increment probably favored better by the improvement in soil fertility and higher plant density. That might had contributed to higher bulking of the tuber. To a certain degree, the disease progress was affected by the interactions between the three factors.

Table 4.9. Effect of variety, plant density and fertilizer on late blight severity and yield of potato

	1997			1999			2000		
Treatments	AUDPC	Lesion no.	Yield (t/ha)	AUDPC	Lesion no.	Yield (t/ha)	AUDPC	Lesion no.	Yield (t/ha)
Varieties									
AL-624	196.7	17.5	22.1	-	-	-	-	-	-
Awash	288.2	21.1	19.9	892.6	18.7	6.4	315.4	19.4	12.1
Menagesha	-	-	-	704.5	21.1	8.7	624.8	15.4	18.5
Plant density (tuber no/m^{-2})									
3.3	192.0	18.9	17.3	874.8	18.0	5.9	446.5	16.6	12.8
4.4	212.0	18.3	19.7	734.5	15.1	9.3	494.0	17.6	14.6
8.3	323.3	20.6	25.6	815.9	26.7	7.2	468.5	18.0	18.6
Fertilizer/ha									
111N+89.7P_2O_5	249.9	18.7	24.9	1003.7	19.8	8.8	511.2	17.0	16.3
54N + 138P_2O_5	337.4	17.5	22.8	760.1	18.3	10.0	495.1	17.8	15.6
9N + 23P_2O_5	140.1	21.7	15.3	686.9	21.9	3.8	403.9	17.5	14.0

Source: (Holetta Research Center, Potato Progress Report (1997,1999 and 2000), unpubl. Data)

The economic advantage of integrated use of tolerant varieties, early planting and reduced fungicide was investigated. The partial budget analysis showed that when the three management components were integrated fully, the highest net benefit of 1536% marginal rate of return (MRR) was obtained form Menagesha (Table 4.10). The highest net benefit and MRR was attained using Tolcha at June 3-7 (early) planting supplemented with reduced rate (2 kg/ha) Ridomil MZ. The local variety required repeated Mancozeb application for a moderate benefit.

Table 4.10. Economics of the integrated management of late blight

Management options	Variety	Mean yield (t/ha)	Net benefit (Birr)	MRR (%)
Variety + early planting + fungicide	Local	32.4	22527.98	477
	Awash	18.3	25479.74	
	Tolcha	28.0	40501.62	1023
	Menagesha	31.4	46016.62	2081
Variety + early planting	Local	3.6	415.60	
	Awash	6.4	6062.50	483.0
	Tolcha	25.3	36362.50	1666
	Menagesha	10.3	10597..50[D]	
Variety + fungicide	Local	30.6	25139.78	
	Awash	18.1	20997.98	670
	Tolcha	28.7	39651.62	988
	Menagesha	27.5	41426.66	670

Virus Diseases

At least 36 potato viruses and a viroid have been reported to infect potato naturally (Stevenson, et al. 2001). The potato plant can become systematically infected with viruses following transmission either mechanically or through vectors. Whereas, nearly all of these viruses are transmitted vegetatively through seed tubers. PVY and PLRV, the two economically most important potato viruses, are also horizontally transmitted by aphid vectors under natural conditions. Green peach aphid (*Myzus persicae*) is the most important vector of these two viruses worldwide, while other aphids like potato aphid (*Macrosiphum euphorbae*) can act as less efficient vector.

Unlike diseases caused by bacteria and fungi, once infection has become established development of disease within the plant is not greatly affected by weather conditions. Usually viruses decrease plant vigor by shortening internodes and cause color change in foliage which become mottled or chlorotic. Some viruses may rapidly kill plants while others cause mild or no symptoms. The primary symptoms of some virus infections are mild or, if infection occurs late in the season, plants show no symptoms, but even so tubers from them when planted as seed will produce plants with severe symptoms in the following season.

Evidence on the occurrence of potato viruses was first reported in Ethiopia in 1980's (SPL 1986). Accordingly, PVY, PVX, PVS, PVM and PLRV are found to be viruses encountered in potato. However, the report provided on their distribution and relative importance.

Another survey was made in 1992/93 off-season and 1993 main season using visual inspection of characteristic symptoms of the common viruses and the enzyme linked immunosorbent assay (ELISA) method, respectively. The survey revealed that in the off-season the combined incidences of PVY, PVX and PVS reached 51% and that of PLRV alone 11% of the total plants checked. In the visual assessments PLRV was detected in 7 to 88% of the plants inspected from each clone. ELISA test showed that 47, 40, 15 and 5% of the tested clones were infected by PVY, PLRV, PVX and PVS, respectively. The result of the 1992 off-season visual assessments and 1993 ELISA tests are summarized in Table 4.11.

Some clones were found free of any virus infection, indicating the possible existence of different level of tolerance in the existing germplasm. High aphid population usually found in association of potato in the field and storage might have contributed to the high incidence of viruses in some cases. In any case, varieties should be cleaned from viruses before they are distributed to users. Capacity has to be strengthened to ensure sustainable supply of clean seed to growers.

Table 4.11. Virus infection level in different potato clones determined visually 1992 off-season, and by ELISA test, 1993 main season

Clones	PLRV (%)	ELISA Positive Samples (%)			
		PLRV*	PVY	PVX	PVS
AL-624	0.0	-	-	-	-
Sissay	78.9	-	-	-	-
CIP 378501.3*	-	25.0	12.5	0.0	0.0
CIP 378501.3	15.7	83.3	100.0	41.7	0.0
CIP 384298.56	77.5	-	-	-	-
CIP 387014.16	0.0	-	-	-	-
CIP 382147.18	87.5	-	-	-	
CIP 387346.13	8.4	-	-	-	-
CIP 387028.1	21.5	-	-	-	-
CIP 387346.2	7.4	-	-	-	-
CIP 388367.4	0.0	-	-	-	-
CIP 383120.14	0.0	-	-	-	-
CIP KU-80.3	-	0.0	50.0	0.0	0.0
Krolisa	-	50.0	0.0	0.0	0.0
K-59-A (26)	-	50.0	62.5	0.0	0.0
BR-113-112	-	0.0	100	50.0	0.0
CIP 382121.	-	100.0	50.0	50.0	0.0
CIP 384321.3	-	0.0	75.0	50.0	0.0
CIP 374080.5	-	50.0	100	0.0	0.0
CIP 384298.56	-	100.0	0.0	0.0	0.0
CIP 384321.18	-	0.0	0.0	0.0	0.0
CIP 387315.2	-	50.0	0.0	0.0	100.0

*PLRV = Potato leaf roll virus, PVY = Potato virus Y,
PVX = Potato virus X, PVS= Potato virus S
Source: Bekele Kassa and Berga Lemaga (1996)

Degeneration of seed tubers

As potato is usually propagated by vegetative means, virus diseases could easily disseminate and accumulate in tubers causing degeneration of varieties and subsequent reduction in potato yield. Potato viruses such as PLRV, PVY and PVX are the major causes of degeneration of many potato varieties (Progress Report 2000, Holetta).

A study was made at Holetta using initially virus-free seeds of 6 varieties produced through a rapid multiplication technique and subsequently grown for 4 consecutive years using seeds from the previous harvest. The results indicated that the incidence of PLRV drastically increased in all the varieties during the 4 consecutive years (Table 4.12). The rate of increase of the virus incidence in varieties such as Tolcha and AL-624 was slow as compared to the increase in Awash and Menagesha. Consecutive use of tubers from the previous season as a seed source caused accumulation of viruses, particularly PLRV, and caused degeneration of seeds as evidenced by the decrease in marketable tuber yield. Accordingly, per cent yield reduction of 62, 45, 44, and 41 was recorded for Tolcha, Genet, AL-624 and Awash, respectively, accountable to degeneration by viruses. Therefore, according to the study findings, seed sources have to be replenished periodically with virus-free seed stock.

Table 4.12. Increasing trend of PLRV incidence and marketable yield decline of six potato varieties planted at Holetta from 1997 to 2000

Variety	PLRV incidence (%)				Marketable tuber yield (t/ha)			
	1997	1998	1999	2000	1997	1998	1999	2000
Awash	3.3	5.8	12.3	43.7	20.5	8.0	26.2	12.0
Tolcha	3.3	3.8	4.7	18.3	40.2	24.3	14.1	15.2
Genet	2.1	4.5	12.3	38.5	27.0	12.5	17.1	15.1
Al-624	1.0	2.3	12.3	16.4	40.6	18.2	28.3	22.9
Menagesha	5.0	8.6	9.3	41.5	33.1	26.1	20.8	28.0
Wechecha	-	7.5	13.7	23.7		18.9	16.6	15.7
Mean	**2.9**	**5.4**	**10.8**	**30.4**	**32.3**	**18.0**	**20.5**	**18.2**

Source: Holetta Research Center, Potato Progress Report 2000. unpubl)

Bacterial Wilt

Bacterial wilt caused by *Ralstonia solanacearum* is widespread in tropical, subtropical and warm temperate areas throughout the world. Its occurrence has now also been reported from temperate zones. Many factors influence disease incidence and yield loss. Cutting potato seed seriously increases the risk of high losses. When seed potatoes are cut, disease incidence was found to increase by 250% and yield was reduced by 40% (Vijayakumar et al. 1985). The disease had become one of the major biotic constraints of potato production in the country. Its distribution was limited to the low and mid altitude areas like Shashemene and Alemaya. Recently it is expanding to the highland, including the major potato growing areas of the central and northwestern highlands where the disease was not reported previously. However, the loss incurred by the disease has not been quantified. Incidences of up to 63% have been recorded (Bekele 1996) in some potato growing regions. Infected plants are completely destroyed by the disease, and the tubers produced, if any, are considered a complete loss since they cannot be used particularly for seed purpose.

Integrated management of bacterial wilt

Potato growers in areas like Mutulu, Guder, in West Shewa were provided with improved package that integrated improved variety, healthy seed, recommended fertilizer rate at planting, planting, roughing of diseased plants, weeding and use of clean tools for hilling. The improved practice was compared with farmers practices replicated up to 6 bacterial wilt infested farmers' fields in 1999-2000 seasons. The improved package gave good control over bacterial wilt incidences in both years (Table 4.13)

Table 4.13. Percentage incidence of bacterial wilt under improved and farmer' practices in Guder

Management practices	Bacterial wilt incidence (%)	
	1999	2000
Farmer's	21.6	10.8
Improved	0.2	5.6

Source: Holetta Research Center, Potato progress report 2000, unpubl

To determine the effect of proceeding crops (maize, beans, wheat and potato), an experiment was conducted in 1996-97 at Ambo using two varieties having some degree of difference in tolerance to bacterial wilt. The result showed that wilt incidence was influenced by type of the preceding crop. Susceptible potato variety planted after wheat and maize exhibited mean wilt incidence of 8.3 and 9.3%, respectively.

Wilt incidence on the susceptible variety was 23.0% as opposed to 0% on tolerant variety (Table 4.14). Per cent tuber rot at harvest differed with variety, but not with type of preceding crops and cultivation (hilling). Incidence of tuber rot after 3 weeks in diffused light storage was affected by type of preceding crops and variety. There was a negative correlation (r = -0.86) between tuber yield and wilt incidence and a coefficient of determination of r^2 = 0.74. Therefore, use of maize and wheat as a preceding crop and relatively tolerant potato varieties are important to control wilt.

Table 4.14. Effects of preceding crop and post emergence cultivation on bacterial wilt incidence and yield of potato

Preceding crop	One times hilling			Two times hilling		
	Incidence (%)	Rotten tubers DLS (%)	Yield (t/ha)	Incidence (%)	Rotten tubers DLS (%)	Yield (t/ha)
Awash (tolerant variety)						
Wheat	0.0	24.9	24.33	0.0	3.6	31.67
Beans	0.0	8.9	31.67	0.0	7,.1	31.33
CIP-384321.3	0.0	15.4	30.33	0.0	20.5	35.67
Awash	0.0	3.7	31.00	0.0	3.2	32.00
Maize	0.0	9.0	34.00	0.0	7.1	32.67
CIP-384321.3 (susceptible variety)						
Wheat	7.2	6.1	31.67	9.4	7.3	34.00
Beans	31.0	3.5	31.33	29.9	1.7	29.33
CIP-384321.3	18.8	4.1	35.67	31.9	1.2	24.33
Awash	40.9	1.9	32.00	42.9	1.8	25.33
Maize	14.1	3.6	32.67	4.5	0.0	44.33

Source: Bekele and Berga (2001)

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Chapter Five

Potato Pest Management

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Introduction

Potato is attacked by a number of insect pests. In the last two decades or more, the major insect pests that stay on potato did not shift and include: cutworms (*Agrotis* spp. and *Euxoa* spp.), red ants (*Dorylus spp.)*, potato epilachna (*Epilachna hirta*), metallic leaf beetle (*Lagria vilosa*), potato aphid (*Macrosiphum euphorbiae*), green peach aphid (*Myzus persicae*) and the potato tuber moth, *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae) (Bayeh and Tadesse 1992). Among these insects, the potato tuber moth received more attention than all the other potato insect pests on potato combined.

Potato Tuber Moth (PTM)

The potato tuber moth, PTM (*Phthorimaea operculella* (Zeller)) originated in the eastern Andes (South America) where its main solanaceous hosts, potato and tobacco, are thought to have originated (Finney et al. 1947 and Rothschild 1986). It was distributed throughout the world following the spread of potato and is presently regarded as a major pest of potato in almost all tropical and subtropical regions (Finney et al. 1947). Sixty plant species have been recorded worldwide to host PTM; 52 of them belong to the Solanaceae. Although PTM shows a certain degree of specificity for the genus *Solanum*, it also perpetuates itself on alternative hosts, which include cultivated tomato (Das and Raman 1994).

The pest is important in its larval stage and causes direct damage by eating the stem and turning the inside to brown, mining the foliage between the leaf sheaths or tunneling developing tubers. It either pupates in damaged stems, by making enfold from the mined leaves or near the end of the crop cycle by hiding in the surrounding soil.

Towards the end of the crop season, the larvae find their way down to the soil through cracks in the ground. They burrow into developing tubers, create galleries, and deposit their excrements at the outlets. They move into stores with the harvested crops, where they spread rapidly within the heap and hence rendering the damaged potato unusable. In Ethiopia, this pest was recognized as important first in the warmer areas where potato is grown. However, lately it has established itself as an important pest in major potato growing areas. The importance of the pest will continue to increase because of the long distance movement of seed tubers from limited source locations mainly in the cool highlands of North and West Shewa to many places across the country.

PTM biology

PTM has four larval instars. The adult moth is small with narrow gray and mottled wings. The lighter hind wings are fringed with long hairs (McKinley et al. 1992). It is most active on warm nights. During the day adults seldom fly, unless disturbed. The sexes occur in an equal ratio. Mating takes place soon after emergence from the cocoon (Finney et al. 1947). The potential fecundity, according to a review of the literature by Rothschild (1986), is more than 200 eggs per female and mated females lay most of their eggs within 3 to 5 days of emergence, in very low light intensity or complete darkness (Broodryk 1971). Warm weather favors the moth's reproduction (Kroschel and Koch 1996). There is no evidence of true diapause (Whiteside 1985 cited in Rothschild 1986).

Population dynamics of PTM

The activity of male adults of PTM was monitored using sex pheromone baited traps at Holetta both in seed tuber stores and in production fields. The field results showed that the months when PTM activity peaks were January February and June. The January and June peaks were mainly attributed to the population that had been multiplying on left-over tubers in fields from the main season and irrigated potato harvests. The catches in February were more important because the off-season planted potato was green in the field and liable for PTM attack. Whereas, in the seed tuber stores' the population never showed peaks, the number caught remained low the all year round.

In contrast, in one of the monitoring years the seed from irrigated fields stayed longer than usual in fields which allowed PTM population to increase. Thus, a particularly higher PTM population in seed tuber store was obtained, indicating the importance of keeping the right harvesting time. The usual high population in fields had not been contributing much for infestations that had been occurring in stores. One possible reason for this might be the proper timing of vine killing, which might had contributed for the reduction in the movement of more larvae into the soil to infest developing tubers (Bayeh and Tadesse 1992).

In a similar study, the activity of male adults of PTM were monitored using sex pheromone baited traps in the major potato growing areas of West Amhara Region Adet, Debre Tabour and Tillili — during the potato-growing seasons from 1998 to 2000. Data were recorded at a weekly interval. In Tilili, the PTM was present all the year round because of the three potato growing systems existing in the area. Whereas, at Adet the diffused light store present nearby the seed multiplication farm probably contributed for the year round activity of PTM in the field.

At Adet, the peak period was between June and October, while in Tillili it was from July to October. At Melkassa Agriculutral Research Center, too, the activity of male PTM adults showed an increase towards the end of the crop maturity period (Figure 5.1).

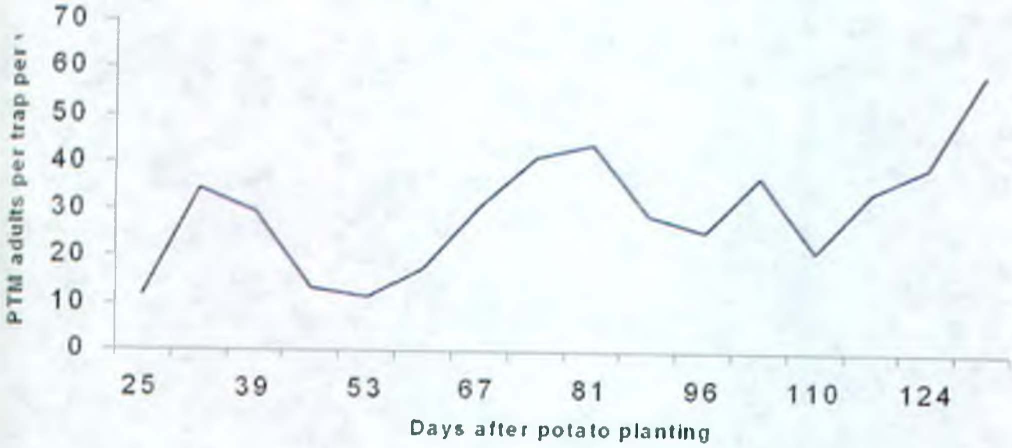

Figure 5. 1. Sex pheromone baited trap based monitoring of PTM in potato field in 2000/2001 at Melkassa

A weekly monitoring study was done to assess trends in the population of PMT larvae and the damage the cause on leaves of potato plants until the time of vine clearing, which normally is done at leaf senescence. On each sampling day, 25 potato plants were sampled at random per plot per week and inspected for PTM larvae and their damage. Both larval population and the leaf damage they caused increased with time and started declining when most of the potato leaves entered senescence (Figure 5.2).

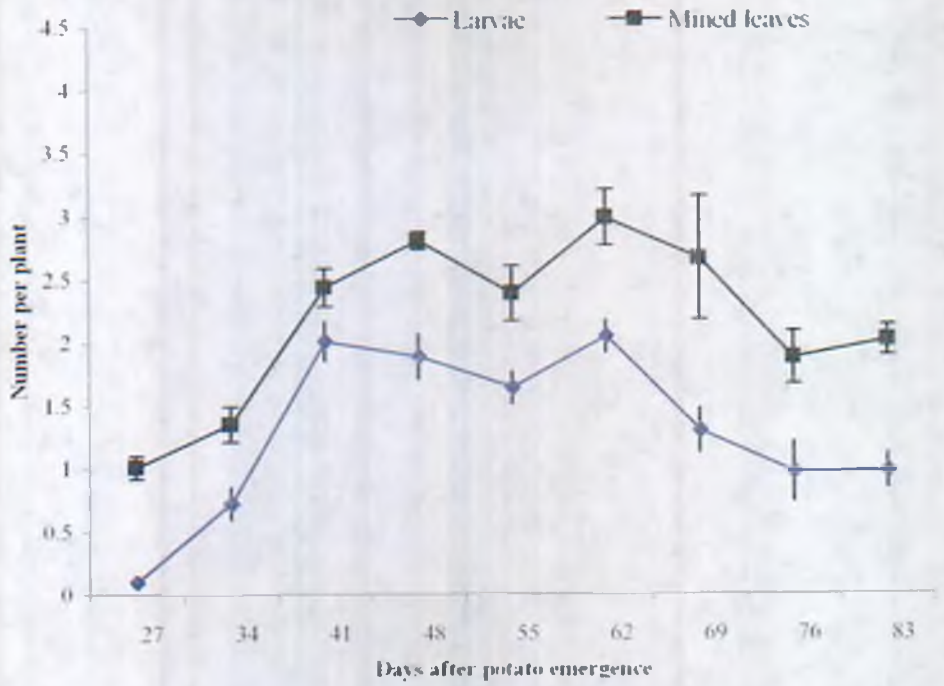

Figure 5.2. Monitoring of PTM. larval population and leaf damage they inflicted on potato in 2000/2001

Performance of PTM on potato foliage

The population of PTM that builds upon potato foliage has a direct importance on the infestation level that may occur on developing tubers in the rhizosphere. When potato leaves start senescing, the larvae that develop in leaves find their way down to developing tubers by passing through cracks in the soil. Field-infested tubers in turn serve as the seed for the multiplication of PTM in stores and for the subsequent carry-over of the insect back to the field in the next cropping season. All these depend on the survival and development of PTM larvae in the foliage of potato plants.

Therefore, a study was made on the survival and development of PTM larvae in potato foliage at Melkassa under a controlled condition in a growth chamber. The survival test was done on newly borne larvae, which were individually transferred into individual petri dishes containing healthy leaves taken from potato plants in the preblossom or blossom stage. Daily follow-up was made to measure the survival and development of the test larvae (n = 80 at each plant phenology).

In general, larval survival was better on the foliages of potato sampled at blossom stage (Figure 5.3). This compliments the results of the above study in which the larval population and the damage caused on potato leaves was higher during blossoming period (Figure 5.2). On potato foliages at the preblossom stage PTM had significantly longer larval and larva-adult development time than at the blossom stage (Figure 5.4).

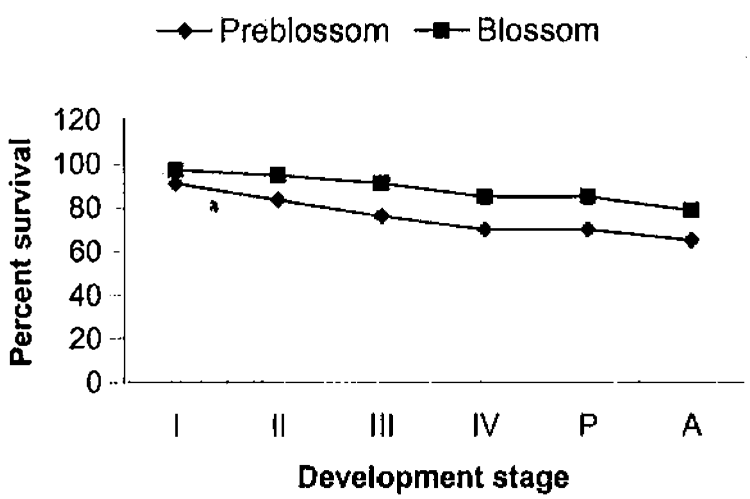

Figure 5.3. The mean percentage survival of PTM four larval instars, pupae (P) and adults (A) in the leaves of potato plants sampled during preblossom and blossom stages

PTM in diffused light stores

Improved production of seed potato tuber using diffused light store (DLS) has been demonstrated for a number of years in many districts of the central highlands. However DLS can never guard off insect pests from coming in from any source.

The major source of infestation often comes from tubers transported to DLS and stored for seed. Since there is high accumulation of seed tuber per unit area in DSL than in an open field, the loss of tubers due to the PTM is correspondingly high.

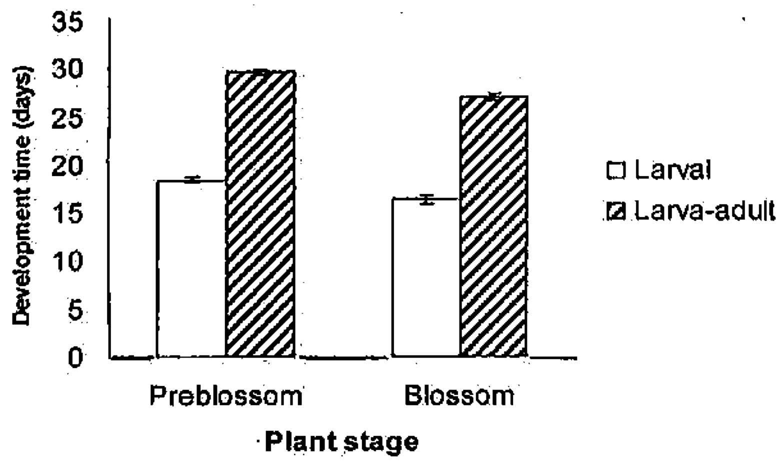

Figure 5.4. Larval and larva-to-adult development time of potato tuber moth on leaves of potato taken at preblossom and blossom plant stages

Therefore, monitoring the PTM situation in DLS was carried out at Holetta Research Center for three years (1988-91) using sex pheromone baited traps. Then the activity of PTM adult males in the DLS was common. The count in July was significantly higher than in the other months which was attributed to the accumulation of tubers in DLS for about six months after harvest (Bayeh and Tadesse 1992). This showed the potential carry-over of significant population of PTM back to the field.

Seed potato production by small-holders, informal seed system, has become the best alternative over the years. This might have created an ideal environment for the multiplication and further spread of the insect to parts of the country where it was not reported before as a threat for the production of potato. With this realization, on monitoring study was carried out to assess PTM infestation levels in DLS constructed by smallholder farmers in four weredas in west and northwest Shewa, which have become the major sources of seed potato for the country. Well-handled DLS selected from each wereda were used for fortnightly monitoring. Ten tubers per shelf were randomly selected fortnightly and inspected. Healthy and damaged sprouts per tuber were counted.

The infestation of seed tubers was higher in DLS in Walmera wereda followed by Jeldu. There were no damaged tubers in DLS in the other two weredas (Figure 5.5). Seed tuber production has a relatively longer history of about 15 years in Walmera and 6 years in Jeldu compared with Dandi and Degem. In general, the results indicated that PTM could become a threat in diffused light stores following the increase in the production of seed tubers and the number of DLS that will be put up by more small farmers that may join the existing seed potato producers.

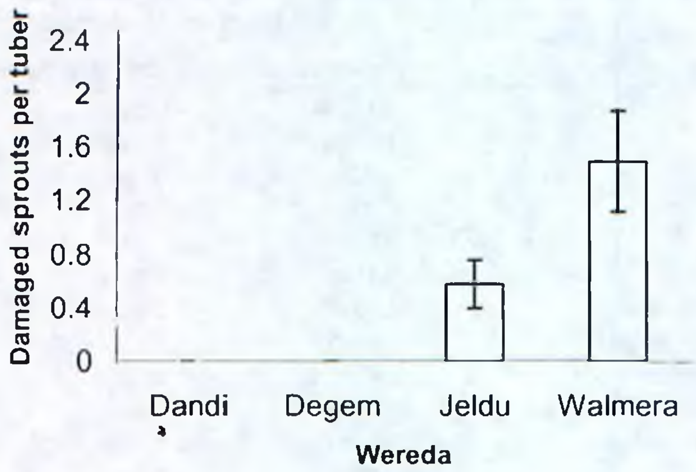

Figure 5.5. Mean number of PTM damaged sprouts per tuber in DLS built by farmers in four weredas in west and northwest Shewa

PTM control

Use of botanicals

The efficacy of some botanicals was studied using a test crop variety Wechecha in a replicated experiment applying all treatments to natural PTM infestation in DLS between April and November 1997 and between April 1998 and March 1999 at Holetta (2400 masl) and Shashemene (1800 masl). Powdered flowers of pyrethrum (*Chrysanthemum cineraraefolium*) and leaf powders of neem, (*Azadirachta indica)* endod (*Phytolocca dodecandra*), Lantana Camara and few more plants were dusted on potato tubers at 35g/50 tubers and tubers were coated uniformly.

Neem seed extract at 5% concentration and Diazinon 60% EC (5 ml in 10 liters of water) solution were prepared. The aqueous neem seed extract was prepared from 500 g dried and crushed seed that was suspended in a bucket of water tied in a cloth. After 12 hours, the seed debris were squeezed and removed. The solution was taken up to 10 liters. The test tubers were dipped for about one minute before storage. After 120 days, rotted tubers and those damaged by PTM were recorded. Powders from seeds of neem and Phytholaca and flower of pyrethrum effectively reduced tuber damage (Table 5.1).

Table 5.1. Control of PTM using different botanicals in DLS, 1997

Treatment	% damage after 120 months	
	Damaged sprouts	Damaged tubers
Pyrethrum flower	0.31.b*	3.3ab
Endod seed	1.62ab	8.0ab
Endod leaf	8.23ab	3.3ab
Lantana Camara, leaf	2.36ab	3.3ab
Neem seed	0.57ab	1.3b
Neem leaf	5.41ab	1.3b
Eucalyptus globules leaf	8.83a	2.0b
Croton macrostachys, leaf	2.69ab	4.7ab
Piper capense, Pepper leaf	2.85ab	4.0ab
Tagetus Minuta L. *Mexican marigold* leaf	2.85ab	4.0ab
Basudin (Diazinon) 60% EC	3.86ab	4.7ab
Control	5.02ab	7.3a
CV%	55.3	34.4

*Means followed by different letters with in columns are significantly different ($p < 0.05$)

The above botanicals and entomopathogenic bacteria were evaluated for the control of PTM both in field and store in the main and off-seasons at two locations. The concentrations of the dipping solutions were: clean water, and Basudin® 60% EC solution (standard) at 5 ml/10 liter of water, 500 g powder of neem seeds (NS), 70 g powder of pyrethrum flower (PF), 70 g powder of neem leaf (NL), Bt solution 5 g all diluted at 10 liter of water. Clean tubers were dipped for 10 minutes and stored in DLS at Holetta and Shashemene. Among the treatments, aqueous solution from pyrethrum flower gave best protection to the seed tubers (Figure 5.6). Both pyrethrum flower and neem leaf powder were effective in reducing sprout damage by the PTM in the two locations.

A similar procedure was followed in the field. Extracts prepared from neem seed, pyrethrum flower and neem leaf and solutions of Basudin 60% EC and *Bacillus thuringiensis* Kurstaki. The aqueous solutions were applied after a pre-spray count was made. Post-spray counts were made after 96 hours. This experiment was carried out in 2000 and 2002 at Holetta and Shashemene. The results obtained from the experiment carried out at Holetta in 2000 and in both years at Shashemene were incomplete and hence were not considered in this review. In 2002, the post-spray counts made after 96 hours showed significant difference and were higher for Diazinone 60% EC treated plots than all the other treatments (Figure 5.7).

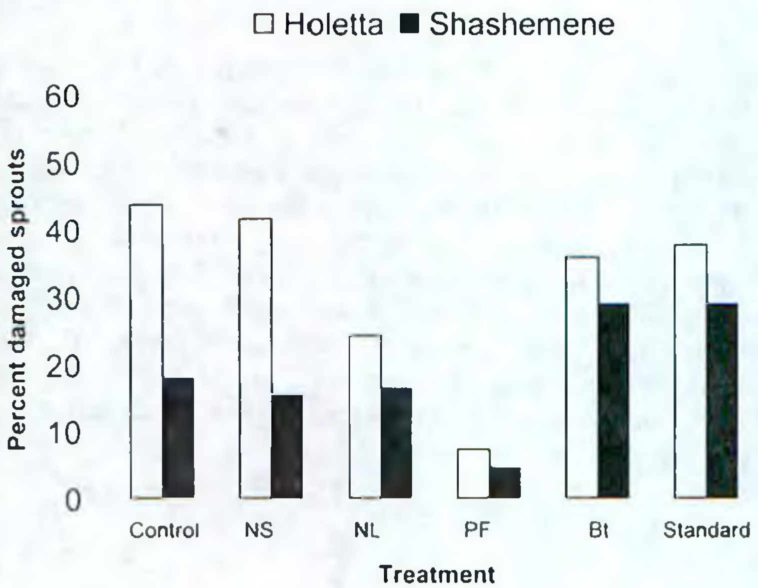

Fig.6. Efficacy of botanical on sprout damage by PTM in DLS (NS = Neem seed, NL= Neem leaf, PF = Pyrethrum flower, Bt = Bacilus thuringiensis and Standar =Diazinone EC)

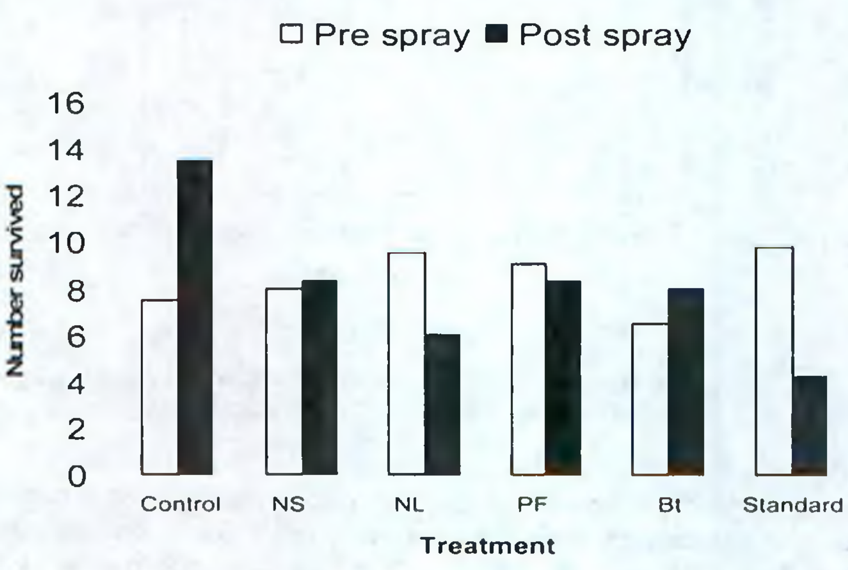

Figure 5.7. Effect of spray of different botanicals and *Bacillus thuringiensis* on the population of PTM at Holetta during off-season, 2002 (NS,= neem seed; NL, neem leaf; PF, pyrethrum flower;Bt, *Bacilus thuringiensis;* and Standar, Diazinone EC)

PTM parasitism

The potato tuber moth originated in the Eastern Andes where potato has originated (Graves, 2001). In its native places, it is associated with a particularly rich complex of parasitoids that attack mainly eggs and larvae on foliage and exposed tubers (Finney et al. 1947, Oatman and Platner 1973, Rothschild 1986, Trivedi and Rajagopal 1992, Coll et al. 2000 all cited in Bayeh et al. 2004). The PTM followed the spread of potato around the world and has a much wider geographic range on potato including in Ethiopia. This spread might have also been accompanied with its parasitoids or otherwise. The parasitoids that live on PTM in Ethiopia have not been documented. A survey was conducted in potato production fields in the rift valley, and controlled experiment involving deliberate exposure of PTM larvae in situ in potato plants to natural pressure of its natural enemies were made (Bayeh 2003). It was found that PTM parasitism takes place in potato in Ethiopia. However, the parasitism level was not different among the two plant stages and the unspecified plant stage of potato in farmers' fields (Figure 5.8).

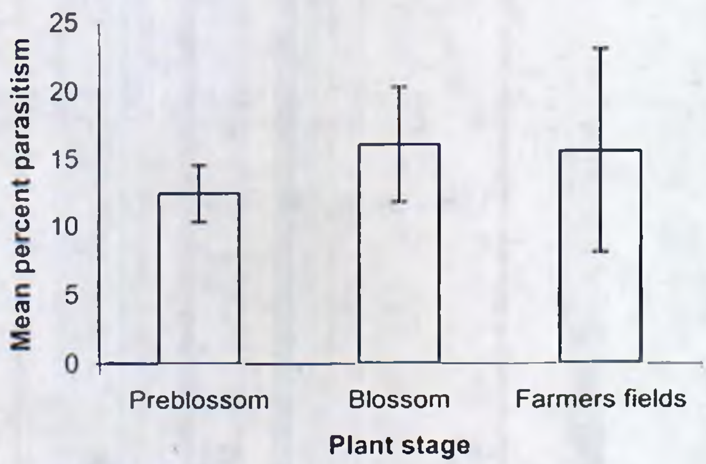

Figure 5.8. Mean per cent parasitism of larvae of potato tuber moth in the foliage of potato plants at preblossom, blossom and unspecified stages

Five parasitoid morphotypes were reared from PTM larvae recovered from mines in potato leaves both in the experiment plots and in farmers' fields. The most common was the ichneumonid, *Diadegma mollipla*, which was composed of the 66.2% of recovered parasitoids.

Red Ants

Crow and Shitaye (1977) and Crow et al. (1977) reported that the red ant (*Dorylus spp.*) was a very serious pest on vegetable crops grown at high altitudes. Red ants damage potato plants by scraping phloem tissues off the roots and destroying root hairs. Such potato plants wilt and die. If the insect appears late in the season while potato tubers are in the field, they bore hole and eat out the starch from the developing tubers. The damaged tubers cannot be used for market and the loss incurred by the insect is direct. So far, red ant has not been reported as a damaging insect pest by farmers at lower altitudes including Awassa (1680 m), Shashemene (1800 m) Shamena and (2120 m).

Surveys carried during crop growth in Walmera, Jeldu and Dandi weredas indicated that red ant was more serious in dry soil. Whereas, farmers in Degem responded that the pest was more serious in wet conditions. Farmers' estimated different levels of damage on potato by red ants (Table 5.2). According to the survey results, (damage caused by) red ant on potato was estimated between 0 and 50%. The results from systematic survey did not correspond with the farmers' estimations (Figure 5.9).

Table 5.2. Farmers' Estimations of red ant damage on potato plants, 2001

Damage level (%)	Respondants (%)			
	Galessa	Jeldu	Walmera	Degem
0	0	0	9.5	22.0
≤25	67.0	54.6	28.6	12.0
≤50	33.0	31.8	23.8	15.0
≤75	0	13.6	28.6	22.0
≤100	0	0	9.5	29.0

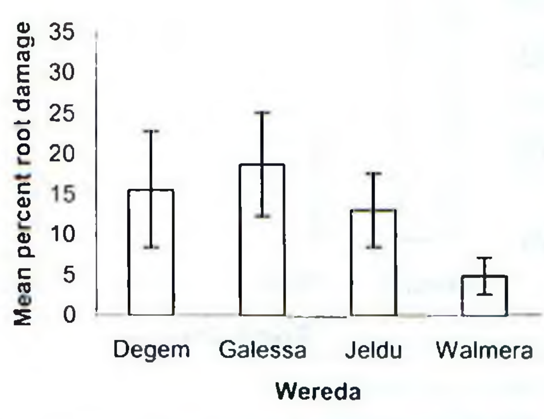

Figure 5.9. Mean per cent damage on roots of potato plant by red ants in four weredas in the central highlands of Ethiopia

The botanicals screened for the control of potato both in the field and stores showed that pyrethrum flower powder is very promising for use in seed stores. In the field, the results lack consistency between the two test locations. Thus it was difficult to recommend which one of the botanicals or Bt for PTM control in the field. However, there were some indications in the results obtained that showed the synthetic insecticide Basudin 60%EC was still effective to control PTM in the field.

Besides the potato tuber moth, the red ant has become a consistent menace in the cool highlands of central Ethiopia. Further study on control, of red ant should be made in the immediate future. Therefore, the focus should be in developing management strategies to contain both the potato tuber moth and red ant.

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Chapter Six

Potato Post-Harvest Management

Endale Gebre, Gebremedhin Woldegiorgis, Dagnachew Bekele and Berga Lemaga

Introduction

Post-harvest management in potato or any other crop is a set of operations and functions between crop production and consumption. Potato is inherently perishable. During the process of harvesting, storage, distribution and marketing, substantial losses are incurred which range from a slight loss of quality to substantial spoilage. Post-harvest losses may occur at any point in the marketing process, from the initial harvest through assembly and distribution to the consumer. The causes of losses are many: physical damage during handling and transport, physiological decay, water loss, or sometimes simply because there is a surplus in the marketplace and potatoes are kept longer under inconvenient condition for some time.

The tuber, once harvested, is susceptible to environmental influences and requires proper handling and processing in to value added products that have longer shelf-life. The increasing market demand for quality is requiring growers and others engaged in the industry to strictly follow appropriate principles and standards to ensure higher productivity and quality with reduced losses and minimum cost all along the potato value chain. Quality of fresh horticultural commodities is a combination of characteristics, attributes and properties that give the commodity value for food (Hickson, 2004).

There is a huge estimate of post-harvest losses for fruits, vegetables, roots and tuber crops that sometimes reaches as high as 50% (Solomon 1987). So far there are limited marketing options for the individual farmer in the major production regions and there are almost storage facilities (Figure 6.1) to help producers stabilize the low price during peak production. From the estimated potato acreage of over 160,000 ha, a total of 1.3 million tones of potatoes is produced annually. About 30–50% of the annual production is a post harvest loss.

In Ethiopia most of the potato produced is mainly consumed as boiled, salad and stew preparations. Potato is consumed throughout the year, but with higher consumption during harvesting. Use of alternative recipes like crisps, french fries, flakes, pre-peeled potatoes and various snack food items has not developed well. This in combination with the high post-harvest losses is believed to have limited the overall consumption of potato in the country to be one of the lowest for per capital consumption in Africa.

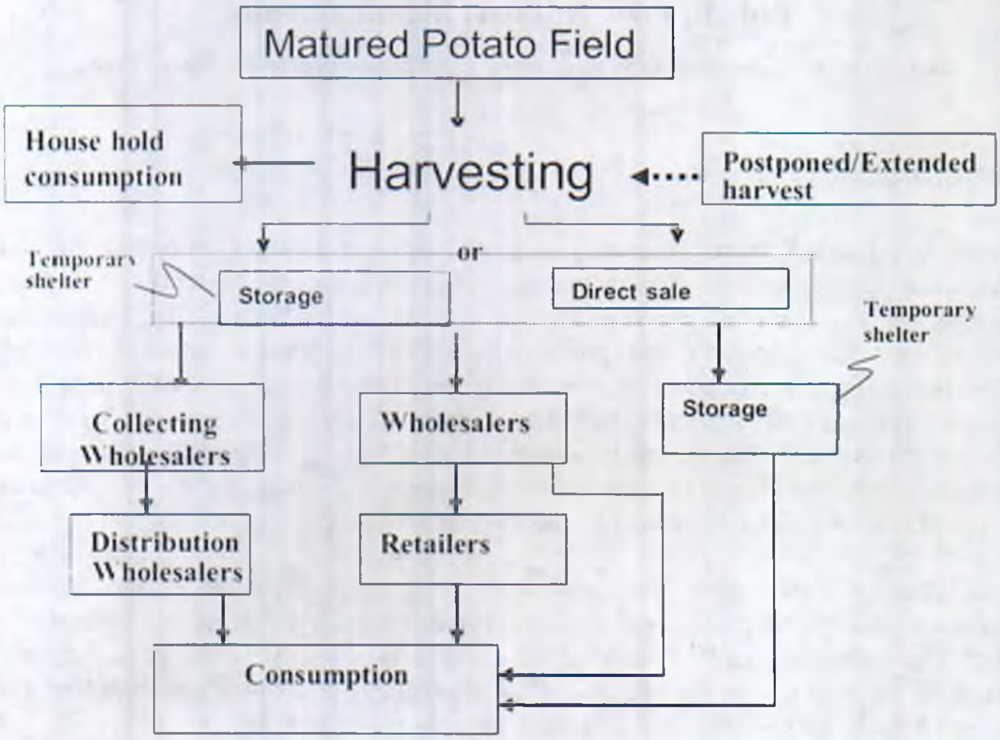

Figure 6.1. Potato storage and marketing systems in Ethiopia

Nutritional Value

Potato produces more energy and protein per cultivated area and per unit of time than most of the major food crops (Table 6.1). It contains less fat but provides significant amount of protein, vitamin C, carbohydrate and iron. The carbohydrate which constitutes about 75% of the total dry matter is the main energy source (Table 6.2). It is also considered as an important source of dietary fiber. The balance among the more important amino acids in protein, the level and the spread of minerals, makes potato second only to eggs in nutritional value as a single source (Crisosto and Crisosto, 2001). Hence potato has high potential to provide significant nutritional and economic benefits to both rural and urban communities in Ethiopia.

Specific gravity of potatoes is used to determine its processing quality. High specific gravity potatoes are preferred for potato chips, crisps, and dehydration. On the other hand, potatoes of low specific gravity are preferred for canning, because they fall apart less during processing than potatoes of high specific gravity.

In Ethiopia so far there is only very limited work done in the area of post-harvest handling and management. The chapter therefore, discusses the subject using the available little works that were done in the past few years.

Table 6.1. Nutritional composition of potato compared with some other crops

Crop	Water	Protein (g/100 g)	Energy (Kcal/100 g)	Fat (g/100 g)	Calcium (mg/100 g)	Protein (g/100 g DM)	Energy (Kcal/100 g DM)
Barley	12.0	11.0	332	1.8	33.0	13.6	377
Beans	11.0	27.7	348	3.0	116	25.5	391
Chicken pea	11.0	20.10	258	4.5	149	22.6	402
Enset	50.0	0.73	213	0.15	82	1.5	426
Lentils	11.0	24.2	346	1.8	56	27.2	384
Maize	12.2	9.5	356	4.3	7	10.8	405
Potato	77.8	2.05	87	0.11	9.5	9.2	392
Sorghum	11.0	10.1	343	3.3	39	11.4	385
Sweet potato	69.2	1.63	124	0.6	35	5.3	403
Tef	11.2	9.1	353	2.2	110	10.2	398
Wheat	12.00	12.2	334	2.3	36	13.9	380

Table 6.2. Comparison of potato with other top ranking food crops in each of dry matter, edible energy and protein production

DRY MATTER		EDIBLE ENERGY		PROTIEN	
Crop	Dry matter (t/ha)	Crop	Energy (MJ/ ha/day)	Crop	Protein (kg /ha/day)
Cassava	3.0	Potato	216	Cabbage	2.0
Yam	2.4	Yam	182	Broad Bean	1.6
Potato	2.2	Carrot	162	Potato	1.4
Sweet potato	2.1	Maize	159	Dry peas	1.4
Rice	1.9	Cabbage	156	Egg plant	1.4
Carrot	1.7	Sweet potato	152	Wheat	1.3
Cabbage	1.6	Rice	151	Lentils	1.3
Bananas	1.5	Wheat	135	Tomato	1.2
Wheat	1.3	Cassava	121	Chickpea	1.1
Maize	1.3	Egg plant	120	Carrot	1

Major Potato Post-harvest Losses

Estimates of the production losses in developing countries are hard to judge; but some estimate the losses of potatoes, sweet potatoes, plantain, tomatoes, bananas and citrus to be very high. About 30–50% of the total produce (1.3 million tones) is lost after harvest. Globally, horticultural crops postharvest losses have been reported at 19% for theUSA at an estimated annual loss of $18 billion (Kantor et al., 1997).

Higher losses have been reported for African countries ranging between 15%–30% of the harvested product (Buys and Nortje, 1997).

Post-harvest losses are mainly caused by different physical, environmental and biological factors which include mechanical injuries, extreme temperatures and pathogens (Clark et al., 2004). The causal factors enhance post-harvest losses through changes in the chemical composition and physical properties of the tuber in the process of respiration, loss of moisture from the tuber, sprouting, and spread of diseases. In the light of the little information generated on the major factors of post-harvest losses in Ethiopia, some of the principles in post-harvest management and the basic environmental and physiological causes of post-harvest loss are discussed as below.

Physical, biochemical and physiological losses

Physical losses include the various responses of tuber to excessive or insufficient heat, cold, or humidity. Proper storage is required to allow ventilation and heat exchange to maintain proper temperature level, to reduce the air and gas exchange (oxygen, carbon dioxide, and ethylene) and to minimize water loss.

Losses caused by mechanical injury are usually overlooked. Physical injury is a loss by itself, and it can result in secondary physiological and pathological losses. Mechanical injury can occur at hilling, harvesting, and handling operations such as grading, transporting and marketing.

Heavy clods and angular and pointed stones increase damage levels. Among tubers from the same cultivar, the degree of damage is influenced by the dry matter content and turgidity of the tubers. High dry matter content causes higher braising. Good level of care is needed during harvesting and handling operations to minimize damage caused on tubers. The damaged tuber always has a shorter post-harvest life than the undamaged tubers.

Respiration

Potato tubers respire using sugars converted from starch. Therefore, respiration reduces the starch content of the tuber. During respiration, the tubers use oxygen from the air and produces water, and carbon dioxide and heat. The most important effect of tuber respiration is the production of heat and its subsequent effect on storage temperatures and the action required to control it. If the respiratory heat is not removed, the temperature of the potatoes rises by 0.25 ^{0}C per 24 hours. The rate of respiration is dependent on the temperature and is minimum at about 5 ^{0}C. Tubers that are stored at relatively higher temperature lose their moisture after some time and become unfit for consumption or for prolonged storage as seed for the coming season planting.

The problem was observed in seed potatoes stored in diffused light store (DLS) at Shashemene area. Fresh weight of tubers is considerably reduced in storage both due to respiration and water loss. It was observed that mean tuber weight loss as high as 23% was recorded when potatoes were stored in naturally ventilated storage for 120 days (Table 6.3). The tubers were dry due to excessive moisture loss and they were not suitable for planting after 6 months. This was due to relatively higher temperatures and dry air that enhances respiration and consequently desiccates the stored tuber.

Table 6.3. Mean weight loss of tubers of four cultivars stored in naturally ventilated ware storage

Days in store after harvest	Mean fresh weight loss (g/kg)	% loss on fresh weight bases
30	33.5	3.4
60	133.2	13.3
90	183.5	18.3
120	233.7	23.4

Loss of moisture

Water is lost from tubers by evaporation. The rate of loss of water is highly affected by the weather condition of the location and it is proportional to the water vapor pressure deficit, i.e. the drying power of the surrounding air. The potato will lose moisture rapidly if it is immature, wounded and unhealed and sprouted. Immature tuber loses water more rapidly because of its more permeable skin and increase in water loss when sprouting starts because the surface of sprouts is more permeable to water vapor.

Loss in dry matter content

Tuber respiration during storage results in dry matter losses. This amounts to 1–2% of fresh weight in the first month and about 0.8% per month thereafter until sprouting is well advanced when dry matter loss will amount to 1.5% per month. Temperature and humidity of storage have an effect on the dry mater in relation to the water content and changes in specific gravity of the tubers. Potatoes stored at relative humidity of 83–84% show increase in specific gravity during storage at both 4.4 and 12.8 °C. At 90% relative humidity, however, the specific gravity of tubers remain practically unchanged in storage up to 6.5 months at 4.4 °C and 10 °C (Smith 1987). Similar result was obtained in a ventilated ware storage with internal temperature for 120 days ranging between 3.6 and 7.8 °C and relative humidity of 86.6–87.0% at Holetta (Table 6.4). Nevertheless, respiration, sprouting, loss of moisture from the tuber and pathogenic losses have mostly a direct influence on the dray matter content and thus on the use or processing quality of the tuber (Elazar, 2004).

Table 6.4. Change in specific gravity after 120 days in naturally ventilated ware potato storage at Holetta

Days in ventilated ware store	Variety					
	Jalene	Tolcha	Zengena	Menagesha	Gorebella	Mean
0	1.095	1.098	1.090	1.071	1.090	1.090
45	1.096	1.103	1.102	1.071	1.088	1.092
120	1.103	1.099	1.102	1.086	1.095	1.098
Mean	1.098	1.100	1.098	1.076	1.091	1.093

Sprouting

Generally, tubers are dormant at harvest. A very important point related to successful storage is an understanding of dormancy and sprouting. The tuber has a definite life cycle. Following field maturity, the tuber remains dormant for a specific period of time which varies with variety and the influence of the crop growing and storage conditions. Maturity at harvest time influences the degree of sprouting. Stresses at any of these stages reduce tuber natural dormancy. Damaged and diseased tubers sprout sooner than healthy ones. It has already been noted that once dormancy ends, sprout growth leads to increased respiration and moisture loss from the tuber via sprout tissue. The higher the temperature over a range of about 4 ^{0}C to 21 ^{0}C, the shorter the dormancy period. The most critical temperatures are between 4 ^{0}C and to 10 ^{0}C. However, it is possible that tubers stored first at low temperature followed by storage at 10^{0}C, could have a shorter dormant period than following continuous storage at 100 ^{0}C.

The number of sprouts per tuber, which determines the number of main stems per plant, is influenced by variety, tuber size and the degree of apical dominance. In a given variety, the degree of apical dominance is influenced by storage conditions, particularly temperature (Table 6.5). Sprouting directly affects quality of ware potato presumably due to its enhancing effect on water and respiratory loss.

Pathogenic Losses

Post-harvest attack by microorganisms can cause a serious loss. Post-harvest diseases can start prior to harvesting in the field, at or following harvesting through wounds. Insects and rodents may cause additional pathogenic losses. The potato tuber moth causes the most serious damage in the store. The larval damage causes direct weight loss and the wounds lead to secondary infection by microorganisms. During storage, aphids can attack the young sprouts and shoots, and they can disseminate certain virus diseases, especially potato leaf roll virus (PLRV). Quantitative pathogenic losses result from the frequently rapid and extensive breakdown of tissue for example, fungal and bacterial attack which is followed by massive attack by secondary organisms. This mostly is the prime importance in storage and can cause substantial damage.

Table 6.5. Estimated storage life of ware and seed potato

Storage temperature (°C)	Storage life (no. of months)		
	Ware	Seed	
	Dark	Dark	Indirect light
4	10	10	11
10	5	6	9
15	4	5	8
20	3	4	6
25	2	3	5
30	1.5	2	3
35	1.0	1	2

Storage Methods

Traditional storages

In Ethiopia potatoes are basically stored for two reasons: ware and seed. Farmers use different traditional potato storage system depending on the use. However, these storage facilities are not proper to keep the quality of tuber for more than 1–2months. As a result, farmers are forced to sell their potatoes at low prices during harvest. They buy seed potatoes at a very high price at planting. Some farmers store seed potatoes either in burlap sacks or in dark rooms, which result in the formation of long and etiolated sprouts that break easily while handling and during planting. Storing seed potatoes in diffused light stores (DLS) results in the formation of shorter and sturdier sprouts than storing in the traditional dark storage method or in burlap sacks. Potato seeds stored in DLS have better emergence, more uniform growth and better plant establishment, resulting in higher tuber yield than seed stored in the traditional storage.

At Holetta, potatoes stored in burlap sack produced smaller sprouts and lost higher weight than those stored in either 2, 3 or 4 layers on shelves of DLS. Potatoes stored in multi-layered burlap sacks produced less number of sprouts per tuber. These results were confirmed by research carried out at Alemaya where storage of seed tubers in dark resulted in a higher weight loss than storage in DLS.

Field (under ground) storage is commonly used in the highland area. Farmers leave their potatoes underground for prolonged use by piece-meal harvest which also helps regulate the low market price they often encounter at peak times and improve their use for consumption. This is the most common storage system of farmers both for ware and seed potatoes, but it is preferred most for ware due to high dry matter. It can keep up to 4 months in cool highlands. However, this extended method is challenged by untimely rainfall that hastens tuber rotting, tuber moth problems causing considerable yield loss, and tuber infectious diseases that degenerate the tubers. Floor storage (piling potatoes in the room on the floor) is used both for ware and seed purpose which helps to keep the potato up to 2–3 months in cooler areas.

Storage on raised bed, locally called *ko't or alga*, is usually used to keep potatoes for seed. Storing potatoes in pit in which the wall is made from mud and roofed with straw is exercised to keep ware potato for 1–2 months.

All the methods used by farmers had considerable quantity and quality loss (Table 6.6) to ware and seed potatoes. Nearly all the major physical, physiological and disease problems that cause loss were not effectively controlled or regulated adequately. The problem is very critical in affecting seed quality and subsequent performance of the crop in the field. The seed quality is thus the most pressing factor in the potato enterprise. In general, farmers have no appropriate facility for package, transport, and storage. Thus, they cannot keep stock to reduce post-harvest loss and reduce price fluctuation in order to obtain better price.

Table 6.6. Effect of extended harvest on yield of potato, average of three years

Treatments (Days in ground after 1st harvest)	% unmarketable tuber (3 years average)
Harvest at maturity (control)	-
15	65.7
30	71.1
45	78.7
60	83.1
75	84.5
90	81.0
105	88.1

Diffused light stores (DLS)

The potato tuber which is to be used as seed has to be stored and prepared for planting so that it retains its vigor, remains healthy and in insect-free condition up to the time of planting. Although this can be done in costly refrigerated storage, the need of the household and small-scale producer or enterprise demand a low -cost alternative technology. After complete growth of the potato crop in the field and before ready for planting, the tuber enters a period of rest known as dormancy.

During dormancy the tuber is relatively easy to store. However, once dormancy ends and sprout growth commences, unless planting is done shortly after wards, sprouting must be controlled to protect the tuber from becoming exhausted, infecting with virus and damage by insect. Seed tuber storage must include, therefore, a way of controlling the growth of the sprouts and other pests.

The diffused light storage is a very simple and low cost structure (figure 6.2 and 6.3) which allows the diffusion of daylight and free ventilation (air circulation) inside the storage that helps to suppress the elongation of sprouts as opposed to dark storage. It helps to maintain seed quality for a long time in areas where prolonged storage is a must. Observations made at Holetta indicated that tubers could be stored a long as 7 months without considerable depreciation of seed quality. The storage performance, however, was noted to vary depending on variety.

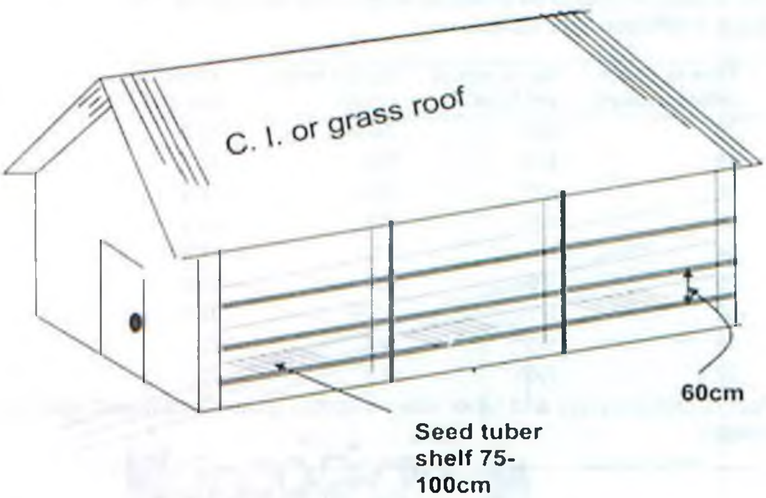

Figure 6.2. Side view of medium sized diffused light store (DLS)

Figure 6.3. Seed tuber in a well managed diffused light store

According to the results, tuber weight loss, time of dormancy break (sprout initiation), sprout number and length varied depending on variety (tables 6.7 and 6.8). In general, decisions and actions on weather or not to store potatoes and how to store them must depend up on circumstances of individual cases. Therefore, the

Figure 6.5. Hose hold level ware potato storage at Jeldu

Table 6.9. Percentage tuber weight loss of different potato varieties in naturally ventilated store at two different seasons

Variety	Weight loss (%)	
	Nov.-Feb. storage	Jun-Sep storage
Jalene	12.5	10
Wechecha	15	12.5
Digemegn	10	5
Tolcha	12.5	10
Zengena	15	12.5
Guassa	12.5	10
Menagesha	17.5	15
Gorebella	15	10
Mean	13.7	10.6

The above-describe naturally ventilated ware potato storage has two compartments. Potatoes are stacked at the height not exceeding 1.5 m. The wall is made up of mud with a thickness of not less than 10 cm. To avoid crack formation, the mud must be well fermented and stabilized with straw. Following the night wind direction, the stores are constructed with air inlet and outlet openings. These are opened during the night from sunset to sunrise to allow air circulation, exhausting the day's heat due to respiration of the stacked potatoes and cooling it with the lower night temperature. The roof slope in one direction and covered with straw.

Matured potatoes are much more desirable for home consumption as well as processing than less matured ones. Therefore, ware potato should be harvested at full maturity stage when the soil is slightly moist to prevent tuber abrasion and to avoid tuber damage. All potatoes showing greening, any decay or damage are rejected for storage.

Tubers showing disease symptom and any other mechanical damage are unfit for storage; therefore, such tubers are carefully separated and avoided. The harvested potatoes must be cured to repair any skin injuries and to promote the formation of stronger epidermis to reduce water loss. Good quality potato tubers, that are suitable for storage can then be kept and stored.

Evaluation of ware quality of potatoes stored in locally made household level naturally ventilated ware potato storage with 2 m x 1.5 m x 2 m size was made for eight potato varieties with stack height (1.5 m) recommended for naturally ventilated ware potato stores at Holetta. The walls were made up of mud having a thickness of not less than 10 cm and roofed with grass to protect temperature build-up and direct sunlight. The cool night wind of the highland is employed using an air inlet and outlet openings which remained opened at night (from sun set to sun rise) to avoid the entrance of hot air into the stored potatoes.

The result (Table 6.9) showed that potatoes from both main and off-season production could be stored for about four months (120 days) with losses ranging 5-17.5% depending on the potato variety and the internal and external storage temperature and relative humidity. At Holetta, with temperatures and relative humidity presented in Table 6.10, potatoes could be stored for four months. Variety Digemegn had got the minimum and Menagesha the maximum storage weight losses (Table 6.11). The other potatoes varieties showed storage weight losses between 10–15%. Potato produced in the off-season and stored from May to August showed the lowest storage weight loss.

The evaluation included quality changes in terms of tuber firmness, emaciations, crisp quality and sprouting from storage sample every 15 days. The results related to processing and utilization are discussed in the following section.

Table 6.10. Environmental conditions of naturally ventilated stores for ware potato stored for 120 days at Holetta

Environmental factor	Storage period: Main-season harvest (Nov -Feb)		Off-season harvest (Jun-Sep)	
	Internal	External	Internal	External
Temperature (°C)	3.6	22.7	7.83	19.84
RH (%)	86.6	53.8	87.09	75.81

Table 6.11. Mean tuber weight loss of four cultivars in naturally ventilated ware storage at Holetta

Treatments (days in ground after 1st harvest)	Mean fresh weight loss (g/kg)	% loss on fresh weight bases
30	33.5	3.35
60	133.25	13.32
90	183.5	18.35
120	233.7	23.37

Processing and Utilization

In Ethiopia most of the potato produced is consumed as boiled potato and frequently prepared in local dishes sauced or mixed with other vegetables and spices. The per capital consumption of potato in Ethiopia is probably the lowest in Africa (Solomon 1987 and Workafes 2006). The main reasons for the low consumption of potato are poor post-harvest handling and supply, unavailability of processing industries, lack of improved varieties with appropriate processing quality (chips, crisps, dehydrated potatoes and several potato-based snack food products), and lack of awareness of the different uses of the crop (Sapers, 2003).

In recent years, the demand for potato chips and crisps is increasing very rapidly in urban areas. However, the focus of the variety improvement in the last two decades was more on improving productivity. Therefore, evaluation of existing potato varieties for their processing quality like chips and crisps has since recently been an important exercise. Although the overall tendency to the processing qualities of potato is a heritable varietal character, it is also influenced by storage environment such as period of storage (Fallik and Aharoni, 2004). Quality assessment of released potato varieties for crisps, chips, dry matter content, and specific gravity was made to study seasonal and varietal effects.

The results of the study showed that potatoes produced in the off-season had higher dry matter content and specific gravity than from the main season potatoes for most of the varieties (Table 6.12). In the main season, variety Digemegn followed by Jalene, Zengena and Tolcha had the highest dry matter and specific gravity. In the off-season production, variety Digemegn, Jalene and Tolcha showed the highest dry matter content, 25.5%, 24.7% and 23.97%, respectively. Both in the main and off-season production variety Digemegn gave the highest dry matter content and specific gravity, while Menagesha had the lowest (Table 6.12). The result indicated that even if there was a difference among varieties and seasons, except for Menagesha, stored potatoes from main and off-season production had acceptable dry matter and specific gravity for processing.

The specific gravity of the tubers was calculated using the formula:

Specific gravity = Weight in air x 100 / (Weight in air – weight in water)

Table 6.12. Seasonal and varietal effects on dry matter and specific gravity for varieties improved

	Main season		Off-season		Over seasons	
Variety	Dry matter (%)	Specific gravity	Dry matter (%)	Specific gravity	Dry matter (%)	Specific gravity
Digemegn	24.93	1.105	25.49	1.107	25.21	1.113
Zengena	23.08	1.098	23.52	1.098	23.30	1.097
Jalene	23.29	1.096	24.72	1.103	24.01	1.099
Gorebella	22.43	1.093	22.36	1.093	22.40	1.093
Guassa	22.07	1.091	22.85	1.095	22.46	1.093
Menagesha	18.87	1.078	18.97	1.075	18.72	1.076
Tolcha	22.95	1.096	23.97	1.097	23.45	1.098
Wechecha	22.91	1.094	23.44	1.097	23.18	1.096
	22.57	1.094	23.17	1.096	22.84	1.096
S.e.	0.602	0.002	0.467	0.002	0.380	

Potatoes with a dry matter content of 20–24% are ideal for making French fries, while those with a dry matter of upto 24% are ideal for preparing crisps. Moreover, good quality potatoes should have a specific gravity value of more than 1.080. Potato tubers with specific gravity values of less than 1.070 are generally unacceptable for processing (kabira and Berga, 2003). Potatoes stored at relative humidity of 83–84% increase in specific gravity during storage at both 4.40C and 12.80C. At 90% relative humidity, the specific gravity of tubers remained unchanged in storage to 6 and half months at 4.40C and 100C (Smith 1987).

Trained panelist evaluation was alto made for quality of chips and crisps using characters colour, flavour, color, flavor, texture and overall acceptability. The results indicated that in main season production variety Jalene followed by Tolcha, Zengena, Guassa and Wechecha were highly preferred for their crisping; but all varieties had acceptabe quality (Table 6.13). For chips in the main season production, the most preferred potato variety was Jalene, followed by Zengena, Guassa and Tolcha. Jalene from both main and off-season production had the most preferred crisps and chips. As noted above, Jalene was also the second, next to Digemegn, in its dry matter content and specific gravity both in the main and off-season production. Varieties Tolcha, Zengena, Guassa and Wechecha were equally preferred for their crisping quality. Variety Digemegn, although it had the highest dry matter and specific gravity, was not preferred as much as Jalene.

Table 6.13. Trained panelist evaluation of chips and crisps quality of potatoes after 120 days in naturally ventilated storage

Evaluation (Score on 1–9 scale)*						
Variety	Main season		Off season		Over seasons	
	Crisps	Chips	Crisps	Chips	Crisps	Chips
Jalene	6.9	6.3	7.2	6.7	7.0	6.5
Wechecha	6.6	5.9	6.5	6.2	6.5	6.1
Tolcha	6.6	6.2	6.8	6.7	6.7	6.5
Zengena	6.6	6.2	6.7	6.4	6.6	6.3
Guassa	6.6	6.2	6.6	6.4	6.6	6.2
Gorebella	5.9	5.9	6.2	5.8	6.1	5.6
Menagesha	5.5	5.8	6.2	5.8	5.9	5.8
Digemegn	4.5	4.2	5.6	4.6	5.0	4.5
s.e	0.367	0.404	0.302	0.321	0.239	0.253

*Scores on 1–9 scale with extreme values of like or dislike

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Potato Socioeconomics and Technology Transfer

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Introduction

Potato is one of the economically most important crops in Ethiopia that play key roles as source of food and cash income for small-holder producers. There is huge potential for potato to contribute for the national economy of the country especially via its value-added products. Potato production, marketing and utilization in Ethiopia is not well developed. Natural, economic, technical, and institutional factors are responsible for the low performance of the potato sector. Regarding economic limitations, for instance, inefficient and unfavorable credit conditions, price fluctuations, storage loss of marketable products, and inefficient marketing infrastructure are among the highly influential factors limiting potato development.

There is little or no information on various socio-economic factors related to the potato crop. Characterizing the potato production practices and indigenous knowledge of potato growers has been one of the areas that needed to be addressed. To date, some socio-economic studies were conducted on potato production and marketing, transfer of production technologies and adoption and impacts of the technologies. This chapter, therefore, to discusses important socio-economic issues and findings on potato.

Potato Production and Marketing

The low productivity of potato could be addressed by generating appropriate technologies for potato producers. Investigation of the production and marketing of potato is one of the priority areas of focus to generate baseline information that could contribute for subsequent research and development interventions.

Since potato is a perishable product, immediate marketing is crucial to sustain its production and improve productivity. Therefore, as part of the national potato improvement research program, socio-economic studies are made to assess potato production marketing practices: identify and prioritize constraints; and suggest appropriate research, extension, development and policy intervention options. This section, therefore, reviews the studies conducted thus far and presents the findings on the production and marketing scenario of potato in the country, with particular emphasis on the major potato growing areas in the northwestern, central and southern parts.

Potato production systems

In the potato growing regions and zones of Ethiopia, there are three major seasons of potato production systems. These are the main rain season, irrigation and short rain season production systems. A minor production of potato is also exercised in some areas using residual moisture. Planting time varies with season of production, on-set of rain and agro-ecology.

Main season potato production

Potato production in the main rain (number) season is the dominant system the in highland and mid-altitude areas. The main season potato is planted from March to June and harvested from July to October. The main season crop is grown both as sole crop and intercropped with other crops. Sole cropping is widely practiced in the highland areas, while intercropping is common in the mid altitudes. Farmers intercrop potato with maize, linseed, rapeseed, faba bean, and haricot bean after the last cultivation of potato in May or June. For instance, in 1996 cropping season, 54% of the farmers in the northwestern region intercropped potato with other crops potato production is the dominant main seasonsystem in the northwest region.

In Shashemene and Shamena districts of East Shewa and Sidamo zones and their vicinities, potato is also produced in the main rainy season. However, due to severe incidence of late blight, potato production in the main season had not been encouraging to farmers. Early planting is preferred to escape the late blight pressure as the intensity of the rainfall increases and humidity rises. To minimize the loss, farmers usually apply 2–3 sprays of fungicide. Farmers in these areas are encouraged for high input production they have better access to market.

In the highlands of West and North Shewa, potato is mainly grown in short rain season. However, due to intensive intervention work by the research system with effective technologies, most farmers in the area are now successfully growing potato in the main season in larger acreages than before as a field crop. The area coverage of the crop, however, differed from one location to another. Areas close to market outlets allocated more land to potato production and intensified production using different inputs as compared to areas far away from the market.

Short season production

The *belg* (short rain) season begins in Jauary–February and ends in May–June depending on locations. Late blight pressure is less problematic during this season due to relatively low intensity of rain and humidity and higher temperatures. Planting late in the season from March to April needs frequent fungicide spraying to control late blight. Potato is the first crop planted in the belg season immediately following the on-set of rains in February. This is a common practice in many parts of the central and eastern highlands of the country. In areas like Shashemene district and its vicinities, the major crops grown in the belg season include potato, maize, tef and haricot beans.

In the central highlands, such as Jeldu and Dendi, the major crop grown is potato. Whereas, in the northwestern region, the belg potato is not as important as irrigation potato. For instance, in 1997 cropping season, only 5% of the farmers grew belg season potato (unpublished survey). Belg season potato production in the region is limited to the cool high land climate zones where sufficient moisture is available in the off-season.

Irrigated potato production

Irrigated potato production has been limited to specific areas where there is adequate access to irrigation facilities. Irrigated potato crop is planted any time from October to March depending on location and occurrence of frost. Recently this practice is increasing in area coverage across almost all-agro ecologies such as the southern, central, eastern and northern regions. The major growing areas include Wondo Genet, Shashemene, Ambo, Harumaya, Wolmera, Wukro and Awi.

Irrigation potato is highly productive because it has low disease pressure, produces large-sized tubers, and fetches relatively good price than rain-fed potato (Table 7.1). Moreover, farmers believe that there is no marketing problem for irrigation potato. Hence, they attempt to expand production of irrigation potato by renting additional land either in cash or share-cropping. Yields of up to 48 y/ha and above can be obtained from irrigation potato. In some areas of irrigated production, frost is economically the important problem.

Table 7.1. Comparison of irrigated and rain-fed potato production system by farmers in Jeldu District, West Shewa Zone 2001

Attribute	Irrigation potato	Rain-fed potato
Tuber size	Large	Relatively smaller
Productivity	High (48 t/ha)	Low (8 t/ha) when improved technologies are not used
Disease incidence (fungicide requirement by no. of sprays)	Low (1 spray)	High (2 sprays or more)
Frost incidence	High for Oct.-Dec. planting	Low
Taste preference	More palatable	Palatable
Ware market price (Birr/kg)	High (65–120)	Low (10.00–50 100)
Marketing problem	Low (sold at farm gate)	High (sold at the market)

Source: Potato production and marketing survey, 2001, unpub. data

In the northwestern region, irrigation potato is the second most important production system next to main season potato. It is grown in both cool highlands and warm temperate climates zones. In 1997, 36% of the farmers on average grew irrigated potato. Farmers of Yilmana Densa (88%) and Farta (69%) districts were the leading irrigation potato producers. Irrigated potato production in the mid-altitude areas is a recent and highly expanding practice due to availability of water, high yield and market opportunity. In general, there is a trend of shift from extensive rain-fed agriculture to intensive irrigation system in the region (unpubl. survey data).

In most regions, there is very limited production using residual moisture from the main rainy season. Planting is done in September through October after early-maturing barley or other crops are harvested and in few instances on fallow lands. When there is high moisture deficiency, farmers supplement their crops with irrigation water if available. But, productivity is low and production is declining due to intensification of the other systems.

Potato cropping calendar

Land preparation for belg and irrigated cropping seasons commences in October through January. Frequency of plowing is three times on average. Planting is done in straight-line furrows or irregular dropping with a spacing of 10–15 cm between tubers and 40–60 cm between furrows. According to the recommended practice, however, spacing between tubers is 30 cm and between furrows 75 cm. Land preparation for main season begins in January through May. Frequency of plowing is three times on average. Planting is similar to that of the belg season.

In most potato growing parts of Ethiopia frequency of land preparation ranges 3–5 (tables 7.2 and 7.3). Land preparation is affected by factors like season of production, precursor crops and on-set of rainfall. Barley, faba bean, potato and tef are the main precursor crops of main season potato in the northwester region. Whereas, in the central, southern and eastern mid altitude areas dominant precursor crops are maize, beans and tef.

Table 7.2. Assessment of belg potato production in some districts of the central highlands, 2001

Specifics	Jeldu	Ginchi/Galessa	Ambo
Frequency of land preparation	3-4	5	4
Planting time (common)	Feb - Mar	Jan – Feb	Feb - Mar
Potato varieties (local)	Diredawa (major), Jilema (red potato) (minor)	White potato (major), Diredawa (minor)	Shashemene (Maj), Diredawa, Netch Abeba & Elfeta (minor)
Improved varieties grown	Menagesha and Wochecha	Genet, Tolcha, Wochecha and Menagesha	Wochecha
Seed rate (t/ha)	0.8-1.0	1.2	0.8 -1.2
Fertilizer rate (kg/ha)	60	80	60
Yield (t/ha):			
Local	8.0	12.0	6.0
Improved	24.0	24.0	Data not available
Harvesting	Jun - Dec (Piecemeal harvest)	Jun - Nov (Piecemeal harvest)	June – Aug
Fungicide (Ridomil) application (No. of sprays)	1-2 times	1-3 times	Not common
Seed source (commonly)	Own harvest	Own harvest	Purchasing
Method of planting (common)	Opening furrows with oxen	Opening furrows with oxen	Opening furrows with oxen and opening holes
Method of preserving seed	Leave in the soil, DLS	Leave in the soil, few DLS	
Potato consumption (months/year)	8	8	3

Source: Potato production and marketing survey, 2001 (unpubl.)

The farmers' spacing practice is different in different parts of the northwestern region. In Awi Zone, farmers use about 100 cm spacing between rows and 10–20 cm between seed tubers. On the other hand, in Debre Tabor Zone, about 70–80 cm spacing between rows and 30 cm between seed tubers is used. The difference in cultivation practices between the two zones is that some farmers in Debre Tabor ridge each plant separately where as, in Awi they ridge in rows. Farmers use small-sized seed tubers and plant 2-4 per hole within row. However, the recommended practice suggests that seed tubers should be medium in size and healthy and a single tuber per hole.

Table 7.3. Potato cropping calendar by season of production in the northwest region

Activity	Main season	Irrigation	Residue
Time of land preparation	Nov –Apr	Sept– Dec	Aug–Sept
Average frequency of land preparation	3 times	3 times	3 times
Planting time	Mar–May	Dec– Jan	Sept–Oct
Time of hoeing / ridging	May–Jun	Mar–Apr	Nov– Dec
Hoeing/ Ridging frequency	3 times	3 times	3 times
Harvesting time	Jul–Oct	Apr–Jun.	Jan-Feb

Source: Potato production and marketing survey, 1997 (unpubl.)

Fertilizer application

In some areas like Shashemene and Wondo Genet districts, the farmers consider that the use of chemical fertilizer is indispensable for potato production. The rate used ranges 80–300 kg/ha of DAP depending on soil fertility, fertilizer availability and wealth status of the farmers. None of the farmers in these areas reported having planted potato without chemical fertilizer.

In the central highlands such as Jeldu, Dendi and Wolmera districts, fertilizer application on potato has recently become a common practice. This was because of extension efforts demonstrating the use of fertilizer on potato (Table 7.2). However, due to unavailability of fertilizer during the short rain season and high price, farmers are forced to using alternative option such as application of manure and compost. In the northwestern region, farmers fertilize potato fields with application of manure, household residues, inorganic fertilizer and use crop rotation systems. Night parking of cattle on crop fields is the most common practice to maintain and improve the fertility of the soil.

Varieties

In the south of the country, a number of potato varieties are grown: Nechi Abeba (White Flower), Key Abeba (Red Flower), Agea, Durame, Awash and Genet (Table 7.4). The naming of potato varieties was mainly based on flower colors. Of these varieties, Nechi Abeba is grown by most of the producers. Genet and Awash are improved and released varieties while the others are either imported or local. Farmers reported that the importance of local varieties Agea and Durame, has declined due to low productivity and susceptibility for late blight.

Table 7.4. Recognized characteristics of major potato varieties in Shashemene district and its vicinities

Character	White Flower (England)	Red Flower	Genet	Awash	Agea	Durame
Length of maturity (months)	3- 4	6	3-4	3	3	3
Yield	High	Medium	Medium	Low	Low	Medium
Disease tolerance	Susceptible	Susceptible	Tolerant	Tolerant	Susceptible	Highly susceptible
Marketability	High	High	Medium	High	High	High
Taste	Best	Good	Fair	Good	Best	Best

Source: Potato production and marketing survey, 2001 (unpubl.)

In the central highlands, varieties such as Diredawa and Elfeta are dominant (Table 7.4). Improved potato varieties mainly grown include: Menagesha, Wochecha, Tolcah, and recently Jalene and Degemegn.

In the northwest region, there are different local varieties, depending on the localities, such as Aba Adamu, Enat Beguaro, Janahla, and Key Abeba in Dega Damot and Bibugn areas while Aballo is popular in Banja, Farta, Yilmana Densa, Lai-Gaint, Dabat, and Chilga dstricts (Table 7.5). Farmers prefer Aballo, Enat beguaro, and Janahla for their yield, taste and good market price; but they are highly susceptible to disease. Most of the local varieties are abandoned due to disease, pest, moisture stress, and soil fertility problems. According to the farmers, the recently introduced improved varieties Tolcha and Wochecha are outstanding in yield and disease resistance.

Table 7.5. Some characteristics of local potato varieties grown in northwest Ethiopia

Variety	Size	Status	Taste	Color	Yield	Maturity	Disease resistance	Storage quality	Cooking quality
Aballo	Medium	Widely grown	Good	Fed red	Good	Medium	Susceptible	-	Good
Aba Adamu	Large	Common	Poor	White	Good	Medium	Moderate	-	-
Afechat	Large	Rare	Good	Red	Good	Early	Susceptible	-	-
Amorie	Medium	Common	Good	White	Good	Early	Susceptible	Poor	Poor
Enat- Beguaro	Medium	Widely grown	Tasty	White	High	Late	Susceptible	Good	-
Habesha	Small	Abandoned	Tasty	White	High	Late	Susceptible	Good	-
Janahla	Medium	Common	Good	White	-	Medium	Susceptible	-	-
Key Abeba	Medium	Widely grown	Good	Red	High	Early	Resistant	Poor	-
Shikuarie	Big	Rare	Tasty	Black	Low	Late	Susceptible	High	Good
Sisay	-	Rare	Bitter	-	-	-	Resistant	-	-
Agew Dinch	Medium	Rare	Poor	Fed red	Low	Too late	Resistant	High	Poor
Ayitima	Medium	Rare	Good	Black	Good	Too late	Moderate	Poor	Poor
Kuchibye	Small	Abandoned	Good	White	Low	Early	Susceptible	High	Good
Jiga	Big	Common	Poor	White	Good	Early	Susceptible	Good	Good
Sumura	Medium	Abandoned	Poor	Red	Good	Late	Moderate	Good	Poor
Demie	Medium	Common	Good	Red	Low	Medium	-	-	-

Note: Market demand for most except Ayitma and Kuchibye is good to high

Source: Potato production and marketing survey, 1997 (unpubl.)

Seed sources

In the south, the potato seed system is very complex. There is a well-established and highly integrated production, exchange and flow of seed potatoes between different districts and regions (see Chapter 3). In recent years, as potato becomes increasingly a cash crop, the need for quality and high yielding potato varieties has become apparent. As a result, farmers pay more attention to the production of seed potato mainly in the central highlands of the country. Potato meant for seed is planted on the best piece of land on isolated fields. Harvesting is done selectively and carefully by hand.

In the northwest, nearly half of the farmers run out of seed every year due to lack of appropriate storage systems. For instance, in 1997 cropping season, 50% of the farmers used their own harvest while 44% purchased from the market, 5% purchased from other farmers and 1% obtained from extension demonstration (Unpublished survey data, 1997). Farmers practice different storage systems for seed potato, such as leaving in the soil and storing on shelves in the house and in storage granary.

Disease management

Late blight followed by bacterial wilt are the most important diseases that cause significant yield losses in potato production. The severity of late blight on potato production depends mainly on variety and planting time. Planting in turn is influenced by on-set distribution and intensity of rainfall, temperature and humidity. In some years, when the rainfall intensity is higher than the average, 1-2 sprayings of fungicides are applied for a better crop.

Fungicide application is crucial to control late blight especially for the main season production. Early planting supplemented with minimum chemical application is one of the important farmers' strategies to control late blight. In most cases, two sprayings are considered to be effective for early-planted main season potato.

Ridomyl and Mancozeb are the commonly known fungicides for the control of late blight. Ridomyl is said to be more effective and persistent than Mancozeb. In most cases, the rate of chemical fungicide is 4 cups each dissolved in 16 liters of water for a quarter of a hectare. For effective control, Ridomyl is sprayed every 15 days while Mancozeb is sprayed every 7 days. Farmers complain above the high price of fungicide (about 265.00 Biurr/kg).

Harvesting

Harvesting of potatoes ranges from 90 to 120 days after planting depending on variety, season, purpose of the crop and market. Harvesting of a crop may be done in bulk at once or in a piecemeal depending on the market situation. In piecemeal harvesting, the crop may stay up to six months in cool highlands (central and northwest) where insect infestation is very low. Bulk harvesting is done when farmers believe that potato prices are reasonably high and further price increase is unlikely. Otherwise, harvesting could be delayed protracted until the subsequent crop. In the central highlands, harvesting of belg season potato for instance in Jeldu, starts in June and extends up to December. Farmers leave potato in the soil until prices improve and there could be continuous harvesting either for sale or for consumption. In Dendi district, the harvesting period also starts in June, but it extends up to November.

Storage

Potato is stored for three purposes: family consumption, sale and seed. In the mid-altitude areas, potato growers reported that at times of low late blight incidence, potato harvested in a dry and sunny day could be stored for two months without loosing its quality for consumption. After two months, however, the tubers start sprouting and become no longer fit for consumption. In the cool highlands, harvested potato can stay up to 4 months with little loss.

Most farmers store in the traditional granary locally called *gotera*. In the highland areas, potatoes are also left in the soil unharvested. In addition, since recently, the use of improved seed tuber storage (diffused light stores, DLS) is becoming popular. Potato could be stored in DLS for about 6–8 months depending on the locality without major losses in its quality.

In general, traditionally, farmers store potato using different practices. These include storing potato in local granary *gotera*, on bed-like structures in their house, and on the floor of their house. The other local storage practice is simply leaving potato in the soil unharvested. That allows a simple storage by delaying harvesting for some time until the stored potato is needed for immediate sale when prices increase and for consumption.

Farmers store potato on the floor of their house by sparing in their living room adequate space for that purpose. The storage space is prepared on a clean ground with a large mat made of bamboo splits and tef straw placed on over the mat. The potato tubers are piled and spread on the straw. Tef and/or wheat straw is placed on the tubers. As insulating material. If vailable, a large plastic sheet or canvas is placed over the straw. Otherwis, more tefor wheat straw is placed to maintain the temperature at a certain level.

Potato tubers stored in such condition sprout within a short time and involves high post-arvest loss. Hence, lack of appropriate storage systems for seed and ware potato was reported to be the most pressing problem. Hence, the problem should be addressed well by research.

Potato marketing systems

Potato marketing apparently is not a serious problem in the central part of the country due to access to market and good demand in Addis Ababa and other towns. As a result, the traders purchase a large proportion of potato mostly on the field before harvesting. Some proportion of potato is harvested and transported immediately to the nearest market for sale. In some cases when prices are too low, the farmers are forced to sell only part of the produce in order to meet immediate cash needs and store the remaining produce until prices improve. The highlands of Shashamene district and its vicinities, the largest potato producing areas in the region, supply much of the ware potato to Addis Ababa and other places including far market places such as Kenya Moyale.

Farmers in the central highlands generally follow three marketing strategies. These include selling at the farm gate before harvest, at local market and in other towns.

Selling at the farm gate before harvest

Most of the farmers sell their produce right at the farm before harvest. According to the farmers, this strategy has many advantages. For instance, all costs related to harvesting and marketing (packaging, loading, unloading, brokerages and transportation) are covered by the trader. In addition, there is no risk of quality deterioration for the farmers. The farmers are also sure that market is reliable, and they are thus encouraged for more production.

Brokers play key roles in potato marketing especially in Shashemene areas. Upon agreement on price and type of volumetric package with farmers, the broker takes the responsibility on behalf of the trader and hires daily laborers and supervises for the harvesting and bagging process of the produce. Potato purchased directly from farms reaches the terminal market within 24 hours of harvest without major loss of quality.

Selling at local market

Selling of potato in the nearby markets is another option to farmers. In such situations, farmers harvest part of the field and transport the produce with a cart drawn by a donkey or horse and by pack animals. Once potato is harvested, the farmer is price taker and has no bargaining power. In most cases, market prices at the local market are too volatile depending on the supply (amount of potato offered for sale) and the demand manifested by traders willing to buy. Often prices vary considerably within a day depending on supply and demand irrespective of the prices in the terminal market. Farmers sell their produce directly to consumers, brokers or wholesalers.

Selling in other towns

This strategy is adopted by few enlightened farmer-traders as a part time job. These farmer-traders collect their own and neighbors' produces and transport it to the district towns where they can get good marketing margin. However, the farmer-traders mostly face fierce competition from wholesalers. The major obstacles faced by farmer-traders include: high marketing costs, discriminatory practices by retailers and lack of capital.

Farmer-traders have higher average marketing costs due to the low volume of potato marketed in a given time. In addition, farmers and wholesalers sell their potato to retailers on credit basis. The retailers repay their credit mostly in the evening after they sell potato. However, the retailers in most cases prefer wholesalers who can provide them with assured supply and less tightened credit than the farmer-traders.

Farmer-traders do not have adequate capital to increase their volume of sale and be competitive with wholesalers. Besides, they do not have access to formal credit services. Most of them collect the produce of their neighbors and relatives to pay the money afterwards while others borrow money from money lenders at very high interest rates (120% per year) as compared to the formal sources of credit (10.5% per year at the time of the study).

Especially in Shashemene district, brokers play a crucial role in the marketing of potato both at the point of collection and the terminal market. There are about three types of brokers involved in potato marketing based on the stage at which they are involved and location. These are field brokers, local market brokers and commission agents.

Field brokers, locally known as *massa dellala*, are engaged in potato brokering at field level before harvest. Most of the field brokers operate in the area from which they have close ties because of blood relationship or ethnicity. They have a good knowledge of the area in which they operate and provide security to the collecting traders who may come from other regions or belong to other ethnic groups. Fees to the brokers range from Birr 1:00 to 5:00 per package of potato depending on the type of package. The larger the package the higher the fee.

Local market brokers are brokers that operate at the local market. They are involved in purchasing potatoes on behalf of the collecting traders. Some of these brokers also play the role of field brokers involving on-farm-gate potato purchasing.

Commission agents operate based at terminal markets. The commission agents act on behalf of the collecting traders. In most cases, collecting traders are based at the point of collecting sites such as Shashamane and send truckloads of potatoes to Addis Ababa with a written note to the broker specifying the number of bags of potatoes and other related information through the truck driver. The commission, agent on behalf of the trader, sells the potato, collects the money from retailers and transfers the money to the collecting traders via the nearest bank. The commission agents also provide price information, collect the used bags, purchase new bagging materials and send them to the collecting traders.

Unlike Shashemene, the major potato markets in West Shewa Zone are located within the districts. The price of potato falls at harvesting and rises at planting. Customers of farmers include wholesalers, retailers, consumers, and other farmers. Government and NGOs are also customers for seeds of improved varieties.

For seed, potato is transported to distant areas like Tigray, Gondar, Gojam, Harer, Nekemt and Assosa. Consumption, it is supplied to near-by markets. The price of seed is set by producers while that of ware potato is by traders. If the supply is high and demand is low, traders fix low price. The major marketing problem faced by farmers is low price of ware potato.

There is also no reliable market especially in the rainy season due to poor road conditions and associated high marketing costs for wholesalers. Since there is competition among traders, brokers play pivotal roles in collecting/purchasing potato on behalf of traders. Even the brokers go to the farm and negotiate with farmers before potato is harvested. The farmer is given down payment until all the harvesting is completed.

In northwest, there is severe problem of market even though the region has a huge potential for potato production. A large proportion of potato is produced in areas where transportation and marketing systems are not well developed. In these areas, the price for 100 kg of potato ranges from Birr 20.0 to 60.0. Because of limited access to markets, farmers exchange potato with other crops such as maize and barley. They also exchange potato with handcrafts such as basket (kimba) and rush matting (Atena). In districts like Chilga, bordering Sudan, where there is market outlet to neighboring countries, potato is sold at higher price (up to Birr 150.00 per 100 kg). The price of potato peaks from February to April. At this time, the supply is low but the demand is high because of the fasting period for followers of the Orthodox Church. In some areas, marketing days for potato and shallot are different from the regular marketing days of other crops.

Packaging systems

In Shashemene district and its vicinities, unlike grain, potato prices at the farm gate are set on volume basis. The farmer and the trader have to agree on the type of package before they start negotiating prices. Once they agree on the volumetric package and the price, potato is harvested and packed. About six types of volumetric units or bags are commonly used. Each type of bag has a local name identified by its shape (Table 7.6). On the other hand, in most areas of he central highlands, farmers use simple packaging systems, such as sacks.

Table 7.6. The most common types of volumetric packages, approximate weight of a bag of potato and their target terminal markets

Bag	Approximate weight (kg)	Terminal market
Weha Mulet (Derlbab)	90-110	Local market
Dello	130-140	Southern Ethiopia (Moyala and surrounding areas)
Shinkurt Mulet	140-175	Meki, Modjo
Saris	230-250	Addis Ababa (Saris, Plassa, Kerra, Zenebe Work, Kolfe, Shiro Meda)
Timbo (Two Wessilla and Ilbashi)	550-600	Addis Abeba (Merkato, Akaki, Mesaleamiya) and Debret Zeit
Timbo (Three Wessilla)	650-700	Addis Ababa (Merkato)

Potato consumption

Potato is mostly consumed boiled and in the form of sauce or stew. In some cases, ried potato is consumed using cooking oil. Consumption of potato by urban dwellers in various forms has increased in recent years. In some major growing areas in the central highlands like Jeldu and Dendi, farmers consume potato 8–9 months in a year. However, in mid-altitudes, the consumption period is shorter, 3 to 4 months in a year.

In northwest highland areas, potato constitutes the major food diet in the family. Farmers depend much on potato for food and cash. Boiled potato is a good supplement and substitute of injera at the time of food shortage. Some farmers in the highland parts have also started preparing injera from potato mixed with barley or tef. The practice is criticized by community elders and some people though it seems innovative.

Major Potato production and marketing is challenged by many constraints. The major ones include:

- Unavailability of clean and adequate seeds of improved varieties,
- Unavailability and high costs of inputs, (fertilizer, fungicide and seed)
- Late blight incidence
- Bacterial wilt warmer areas.
- Low soil fertility
- Climatic variability: unreliable rainfall
- Perishability of the produce
- Poor market information linkages
- Farmers are price takers in ware potato sale
- Poor packaging
- Shortage of land
- Poor storage facility and lack of technologies
- Lack of access to irrigation water
- Poor transport facility

Technology Transfer

In potato, like in all other areas, the conventional research and the current extension system were for so long operating mainly based on a linear model. The top-down approach was used in generating and transferring technology, with little or no involvement of farmers and without proper consideration of their priorities and capacities. Adoption and impact of potato technologies through transfer efforts that followed the linear model were very slow and not profound. That has resulted in a shift of emphasis towards participatory approaches. Effective participation has been sought as essential element in the development of site-specific technologies that address farmers' felt needs.

Improving the exchange of ideas and information among farmers, research and extension services is crucial to improve the technology development and dissemination process, especially in complex, diverse and marginal environments with limited resources. Thus, a participatory potato technology development and dissemination process has been undertaken for several years in the central highlands of Ethiopia since 1998 (Gebremedhin et al. 2006). The methods used to disseminate the available technologies included individual farmers; farmer field school (FFS) farmer's research group (FRG); replicated on-farm technology adaptation trials including variety, agronomic practice, and integrated disease management (IDM); informal seed production and training.

On-farm variety adaptation studies of released varieties and promising clones have been evaluated under various on-farm conditions in different agroecologies of the country. The evaluation process was participatory and ranking of varieties was done using various parameters (Table 7.7). This approach has been very instrumental in providing farmers with the experience of evaluating and selecting appropriate technologies. Farmers' evaluation of the varieties for quality revealed that attributes such as appearance, taste and texture were the most important parameters used to compare varieties/clones.

Seed is among the key problems particularly in potato and other root and tuber crops. Because the current capacity of the formal seed system in Ethiopia; the Ethiopian Seed Enterprise is limited to supplying seeds of mainly cereals such as maize and wheat. In most parts of Ethiopia, farmers usually used to save as seed the small and ungraded potato tubers that they cannot normally sell for consumption. Hence, farmers were given adequate trainings on informal seed production. Informal seed production has now become a major practice that helps farmers to get relatively clean and sufficient seed for the next cropping season. In addition, the seed potato growers benefit from the high price of the seed market. The informal seed technology transfer involved integrating the use of diffused light store (DLS) and management of pests like the potato tuber worm (*Phthorimaea operculella*). That helped considerably to the establishment of a sustainable informal seed system that can provide relatively healthier seed throughout the country.

Table 7.7. Technologies evaluated and number of farmers involved in different weredas through the FFS-FRG participatory research approach, 2004-05

Wereda	Technology	PR approach	No. participating farmers
	IDM-LB	FFS + FRG	25 +15
	Post-harvest	FFS	75
Jeldu	INM	FFS + FRG	50 +15
	IDM-LB	FFS + FRG	24 +15
	Post-harvest	FRG	15
Dendi	INM	FFS +FRG	25 +/15
	IDM-LB	FFS + FRG	25 +15
Degem	INM	FFS + FRG	25 +15
	IDM-LB	FFS + FRG	25 +15
Wolmera	INM	FRG	15
	Post-harvest	FFS	25
	INM	FFS + FRG	25 +15
Alemaya	Post-harvest	FRG	15

Source: Gebremedhin et al. (2006)

The training focused on upgrading farmers' skills to compare the performance of improved technologies over traditional practices. The training included improved potato production packages for seed and ware potatoes and post-harvest handling and utilization technologies. Trainings using the FFS and FRG approaches also helped to reach more farmers rapidly (Table 7.7). In addition, the trainings enhanced the transfer of knowledge-intensive technologies such as late blight management providing detailed and specific information.

Adoption of Improved Technologies

Since the early 1970s, several improved technologie; have been generated by the national agricultural research system These include late blight resistant varieties, agronomic practices, crop protection measures and post-harvest handling techniques. Various technologies have been successfully demonstrated and disseminated to farmers through collaborative outreach efforts. A survey by Holetta Agricultural Research Center (2003, unpublished) was made on the adoption and impact of technologies particularly in some major potato growing areas of the central highlands. The survey results are reported below.

Sources of information

According to the above-mentioned survey, the key sources of information about improved technologies were Holetta Research Center (HARC) and farmer-to-farmer exchange (Table 7.8). The outreach programs of HARC, such as demonstrations, adaptation, popularization of technologies, and training and farmer-based seed (informal) production considerably contributed for awareness creation and success of adoption. The methodologies used in the process include farmers field schools (FFS), farmers research group (FRG) and individual farmers.

Table 7.8. Major sources of information used by farmers in three weredas on improved potato production technologies, 2003

Source of information	% farmers Jeldu	Dendi	Degem	Mean	X^2
Holetta Research Center	55	66	76	62	6.62
Farmer-to-farmer exchange	42	30	6	33	16.59
Office of Agriculture	1	3	21	4	26.40

Source: HARC (Adoption and impact survey, Holetta, 2003, unpubl.)

Improved varieties

Due to adoption of the improved varieties, farmers expanded area under potato at the expense of barley and wheat. The most important factors that encouraged farmers to expand area under improved potato varieties were increased productivity, sources of good incomes and increased demand at the market (Table 7.9). The most important problem that limited further expansion of improved varieties was shortage of clean seeds (Table 7.10).

Fertilizer and fungicide application

About 86–99% of the farmers in Jeldu, Dendi and Degem districts adopted fertilizer application on improved potato varieties. Fungicide application is also a recent phenomenon in the farming systems of these areas. About 39–94% of the farmers adopted application of fungicide. They apply only once for tolerant varieties and three times for local.

Table 7.9. Factors influencing adoption of improved varieties, 2003

Factors	% of farmers				X^2
	Jeldu	Dendi	Degem	Mean	
Increased productivity	36	50	70	46	25.39***
Sources of good incomes	34	34	30	34	6.26^{NS}
Demanded at the market	31	27	27	29	4.99^{NS}
Preferred for consumption	8	5	30	9	20.19***
Adaptability	21	27	30	24	5.36^{NS}
Resistant to diseases	12	24	24	18	10.51^{NS}

Source: HARC (Adoption and Impact survey, Holetta, 2003, unpubl.)

Table 7.10. Factors limiting availability of seeds of improved potato, 2003

Factors	% farmers				X^2
	Jeldu	Dendi	Degem	Mean	
Lack of cash	32	64	4	42	51.98***
Expensive and unaffordable price of improved seeds	42	38	14	36	56.71***
Lack of quality seed	0	8	14	5	52.97***

Source: HARC (Adoption and impact survey, Holetta, 2003, unpublished)

Ware and seed storage

In recent years, farmers' awareness about the use of DLS has increased dramatically. Among the participant farmers, about 71–99% have adopted DLS technology (Table 7.11). high adoption rate of DLS indicated that the use of DLS greatly contributed for the expansion of improved potato varieties.

Table 7.11. Percentage of farmers that were aware about and adopted storage technologies, 2003

Study districts	DLS (% farmers)		Ware potato storage (% farmers)	
	Aware	Adopted	Aware	Adopted
Jeldu	100	99	49	5
Dendi	97	71	29	3
Degem	100	85	79	0
Total	99	87	44	4

Source: HARC (Adoption and impact survey, Holetta, 2003, unpubl.)

Land preparation, planting date and method

According to research recommendation, potato should be planted on fine seed-bed. Accordingly, all the farmers practiced on average four times plowing for planting of improved potato varieties.

The recommended planting date of improved potato varieties, which is the first week of June, was adopted by 15–60% of the farmers (Table 7.12). Even though improved potato varieties were recommended to be planted in the wet (long) season, farmers have also started planting in the short rain season in March–May. In some districts, majority of the farmers using improved varieties modified the recommended planting date depending on their agro-ecologies. Hence, farmers have started diversification of planting dates and, as a result, they are benefiting from potato through several months in a year.

Table 7.12. Proportion (%) of planting date adoption by farmers, 2003

Districts	1st of June	2nd of June	3rd of June
Jeldu	60	14	10
Dendi	31	17	1
Degem	15	9	6
Total	44	15	6

Source: HARC (Adoption and impact survey, Holetta, 2003, unpubl.)

Mostly local potato is planted in irregular rows. However, farmers now are adapting in row planting in most areas. Moreover, research recommendation suggests the use of medium-sized tubers as seed. Accordingly, 94–95% of the farmers in Jeldu, Dendi and Degem district adopted planting of such tubers.

Cultivation

Two to three times cultivation is recommended for potato production. The first is done one month after emergence, the second and third before canopy closure. Depending on location, soil type and other factors, adoption of the recommendation was very variable (Table 7.13).

Table 7.13. Frequency of cultivation of potato in west and north Shewa zones, 2003

	% farmers cultivating		
District	2 times	3 times	>3 times
Jeldu	44	34	22
Dendi	84	16	0
Degem	3	70	23
Total	55	31	14

Source. HARC (Adoption and impact survey, Holetta, 2003, unpubl.)

Dehaulming and harvesting

Dehaulming potato foliage 10–15 days before harvesting is the recommended practice to protect disease transfer from foliage to tubers and regulated seed tuber size. Even though farmers dehaulmed at different times before harvesting, 41% in Jeldu, 39% in Dendi and 54% in Degem adopted the recommended dehaulming, i.e., two weeks before harvesting. In that case, it does not necessarily imply that seed and ware potato were planted in separate plots. However, farmers commonly dehaulm some part of the potato field that is reserved as seed.

Price trends

Four years price trends of local potato variety indicate that price is declining from year to year for both ware and seed potato (Figure 7.1). This might be because of the shift from local to improved varieties and the resulting decline in the demand.

On the other hand, the price of improved seed potato is increasing from year to year (Figure 7.2). This was because of increasing demand as a result of considerable economic benefits derived from improved potato.

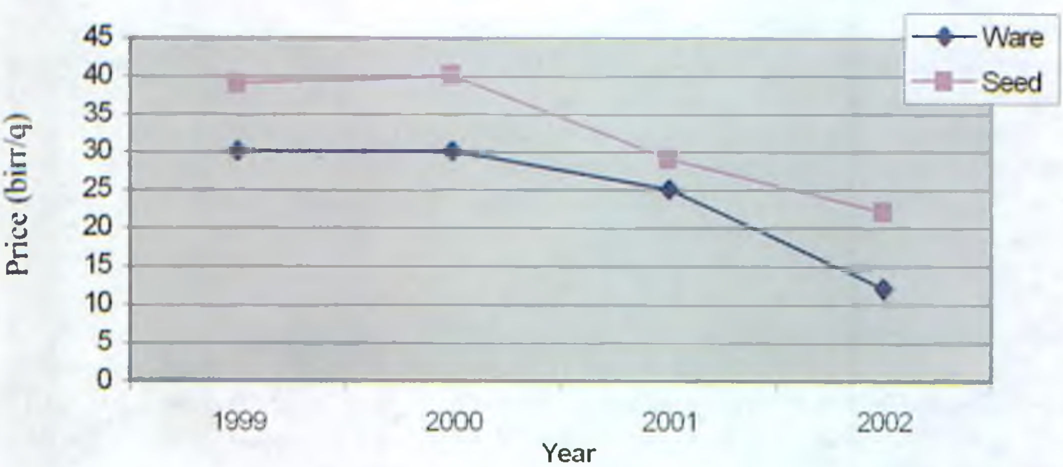

Figure 7.1. . Price trends of ware and seed local potato in west and north Shewa zc
Source: Adoption and impact survey, Holetta, 2003, (unpublished)

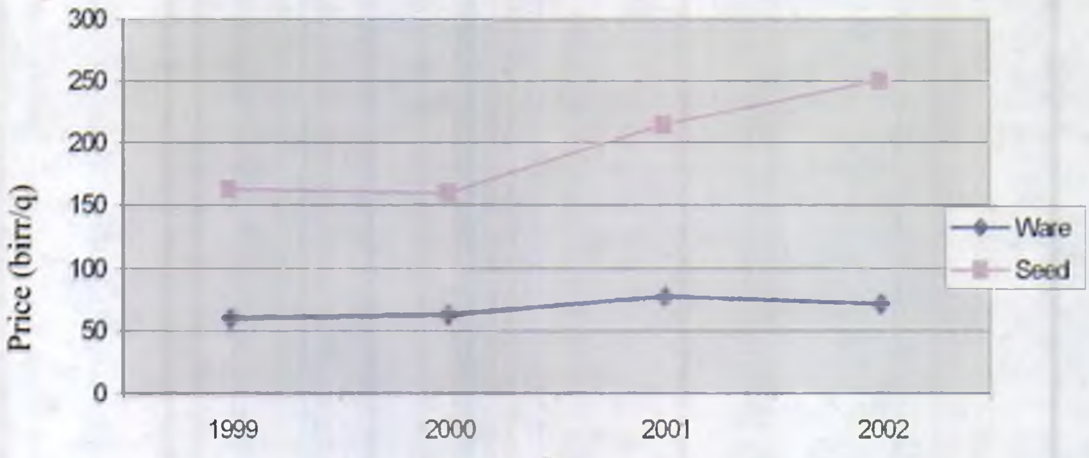

Figure 7.2 Price trends of ware and seed [illegible] potato in west and north Shewa zones
Source: Adoption and impact survey, Holetta, 2003, (unpubl.)

Impacts of Improved Technologies

Adoption and impact studies were made particularly in the major potato growing areas of the central high lands (Gebremedhin et al. 2006; Holetta Research Center, Adoption and impact survey, Holetta, 2003, unpubl.) The findings showed that the farmers obtained considerable economic benefits and impacts in their livelihoods from the use of improved potato production technologies. The impact indicators for the use of improved potato production technologies were identified by farmers themselves. In general, the use of improved potato production technologies made a considerable impact on the livelihoods, asset ownership and economic status of farmers.

Impacts on Asset Ownership

One of the most important impact areas observed from the use of improved potato production technologies was asset ownership. The two most important assets of farmers were livestock and land.

According to the survey results, 75% of the farmers purchased oxen, 64% cows, 52% heifers and bulls, 43% using the income they obtained from using improved potato technologies (Table 7.14). Moreover, nearly half of the farmers increased their cultivated land either by share-cropping or contracting additional land.

Table 7.14. Percentage of farmers reporting impact on asset ownership from use of improved potato production technologies in three districts in the central highlands

Impact areas	Jeldu	Dendi	Degem	Mean
Purchased oxen	79	75	71	75
Purchased cows	65	60	63	64
Purchased heifers	48	80	50	52
Purchased bulls	46	40	42	43
Purchased sheep	68	100	70	74
Purchased donkeys	28	50	58	46
Purchased horses	71	83	11	52
Purchased chicken	63	86	57	63
Cultivated more land	43	71	41	46

Source: Gebremedhin et al. (2006)

Impacts on livelihoods

In the last few years, considerable economic benefits by farmers were observed from the use of improved potato varieties and associated packages. According to the marginal analysis done for seed growers, the marginal rate of return reached up to 1109% in some central highland areas (Table 7.15). The results of the marginal analysis indicated that for every 1.0 Birr that as the farmers invested on improved potato varieties, they could obtain 1.0 birr and additional 11.09 Birr.

The impacts of improved potato technologies on the livelihoods of farmers were broader involving considerable changes in the lives of thousands of families in the intervention areas (Table 7.16). For instance, about 71% of the farmers in Jeldu and 39% in Degem districts constructed new corrugated houses using the incomes derived from the new technologies.

Moreover, 69% of the farmers in the above areas increased the number of houses owned. The most important impact of improved potato varieties was improvements in food security at household levels. Farmers emphasize the improvement in food provision to their families since through out the year. Moreover, more number of children enrolled to school as a result of economic improvement.

Table 7.15. Partial budget and marginal analysis of local and improved potato varieties, 2003

Benefit/cost (Birr/ha)	Local variety	Improved variety
Gross benefit	4800.00	40000.00
Costs of labor:		
Labor to plant potato	175.00	175.00
Labor to apply fertilizer	10.00	10.00
Labor to apply fungicide	5.00	5.00
Labor to cultivate	200.00	200.00

Labor to harvest	235.00	235.00
Oxen labor to harvest	40.00	40.00
Total labor cost	665.00	665.00
Costs of inputs:		
Fertilizer	280.51	354.53
Fungicide	187.00	224.40
Seed	1200.00	4000.00
Total input cost	1667.51	4578.93
Total cost of production	2332.51	5243.93
Net benefit	2467.49	34756.07
Marginal cost	2911.42	
Marginal benefit	32288.58	
MRR (%)	1109	

Source: (HARC Adoption and impact survey, Holetta, 2003, unpubl.)

Table 7.16. Percentage of farmers reporting impacts on their livelihoods from use of improved potato technologies, 2003

Impact areas	Jeldu	Dendi	Degem	Mean
New corrugated house	71	-	39	51
Increased number of houses	65	80	70	69
Improved food security	55	100	97	88
Improved settling debt	22	86	25	33
Improved input use	48	89	48	55
Use of hired labor	28	75	46	41
More children to school	62	88	76	71
Improved clothing	74	100	87	87
Saving	13	75	43	34
DLS	78	88	77	79
Health service	54	91	79	72

Source: Gebremedhin et al. (2006)

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Part II

Enset

Introduction

Mesfin Tessera and Gebremedhin Woldegiorgis

Enset (*Ensete vertricosum*) belongs to the order *Scitaminae*, the family *Musaceae* and the genus *Ensete*. The plant species was referred by various scientific names given at different times, such as *M. ventricosum*, *M. davyae*, *M. ensete*, and *Ensete davyae / Ensete edule*. Finally enset was given the name by which it is currently known, i.e., *Ensete vertricosum*.

In the genus *Ensete*, about 25 species are equally distributed in Asia and Africa. Out of these, enest (*E. vertricosum*) is cultivated as a primary, secondary and tertiary food crop in different parts of Ethiopia. It is also grown as an ornamental plant in some parts of the country. Enset is a single-stemmed, monocarpic, perennial and herbaceous plant. It grows up to 7 m height depending on clone type and management. In appearance, the enset plant resembles banana; however, there are certain variations between the two plants. The major parts of the enset plant are inflorescence, pseudo-stem, leaf-sheath, corm, flower, fruits and seeds.

Enset grows at a wide range of altitudes from well below 500 m in Omo Ratae under irrigation (Personal observation, Ermiyas T., 2004) to 3200 m. The plant grows luxuriously at elevations between 2000 and 2750 m under rain-fed condition. The average temperature of the major enset-growing areas is between 10 to 20^{o}C (Huffnagil, 1961). The relative humidity is reported to be between 63 and 80%. The crop grows well on most soil types if they are sufficiently fertile and drained. However, the plants prefer Nitosols to Vertisols. The production of enset in Vertisols is not common. Manure is used as an organic fertilizer in most homesteads. The soils in enset-growing areas are moderately acidic to alkaline (pH 5.6–7.6) and contain 2–3% organic matter (Westphal, 1975).

Enset-based farming systems play an important role in food security of Ethiopia. Some of the densest rural populations of the country are located in regions that practice enset farming system. It is indicated that the human carrying capacity of enset and enset-based farming system is reported to be high and likely greater than any other crop and cropping system for the same agro-ecology and inputs (Almaz, 2001).

According to Central Statistics Authority (1997), the total area covered with enset crop is 224,400 ha. The largest proportion of the area is in southern (145,860 ha) and Oromiya (78,600 ha) regions. About 15–20% of the Ethiopian population depends on enset as a staple and co-staple food source.

The enset plant has multiple uses for farmers. Each part of the plant has a crucial advantage for the grower in the day-to-day activities. However, enset is primarily cultivated for food. The major types of local food made from enset are kocho, bulla and amicho (cooked corm).

Kocho is a bulk of the fermented starch obtained from a mixture of decorticated leaf sheath and grated corm and true stem. Bulla is a high-grade dehydrated product solidified from squeezed materials of scrapped parenchyma tissue of leaf sheath, true stem and corm. It is mainly obtained from fully mature plants.

Fiber is the byproduct of the leaf sheath after decortications. The fiber has an excellent structure, and its strength is found to be equivalent to world fiber crop abaca (Godfrey 1985). In addition to raw material for factories, the fiber is used to make bags, ropes, twines, cordage, mats and as tying material.

The 'kocho' yield per unit space and time, is much higher in terms of weight and energy than the yield of any other crop grown in Ethiopia. Therefore, the cultivation of enset in densely-populated areas under low input conditions can sustain the population better than any other crop (Admasu, 2002).

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Chapter One

Enset Variety Development

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Introduction

There are many enset clones in different agro-ecologies. Farmers classify their landraces and give them different names based on several attributes that distinguish the landraces from one another. The crop is known by different Local names in different ethnic groups. These include enset or koba in Amhara, asset Gurage , weisae Hadiya, wesse Kembata, workie Oromo, wessie Sidama, uta Wolayita and guna-guna Tigray (EARO, Horticultural Crops Research Strategy, 2000, unpubl.)

The names given by farmers to the different clones distinguish different clones linguistically, phenotypically and in terms of their utilization values. They often plant the different clones they have in mixture. According to a survey, about 97 vernaculars are estimated in Sidama, 42 Gedio, 77 Wolaita, 196 Gamo Goffa, 142 Kembatana Hadiya, 28 Borena and 70 Gurage.

Since enset is endemic to Ethiopia, a significant level of variability in its population is expected. This definitely offers ample opportunities for the genetic improvement of the crop even through classical selection methods from the germplasm pool.

Variability in Food and Fiber Yield

Since 1994, clones were collected from six major growing parts of the southern region: Waka, Wolita, Gamogofa, Kembata, Sidama and Gurage. The clones were established and evaluated for kocho, bulla and fiber yields at Areka Agricultural Research Center. The produces from each clone were processed and yield data were recorded using the formula in (Tsedeke et al. (1996).

The formula which considered the spacing used at different stages and the year taken by the plant until flowering (harvesting), was:

$$\text{Yield (kg/ha/year)} = \frac{\text{Actual yield (kg)} \times 10000\ m^2}{\sum \text{Year} \times \text{Spacing}}$$

Based on their maturity, clones were grouped into three sets of early, intermediate and late materials (annexes 1.1-1.8). From the early set, 14 clones gave kocho yields of 31–60 t/ha per year (Table 1.1a). Particularly, clones Digomerza and Goseria gave high average yields of 54.9 and 52.2 t/ha per year kocho, respectively. From the late set, the clones named Eskurkis and Manduluka gave 36.75 and 31.53 t/ha per year kocho yield.

The best bulla and fiber yielders were obtained mostly from the early set. From the early set, only six clones were good bulla yielders. Whereas, most of the clones that yielded better kocho were also good fiber yielders (Table 1.1b). Only six of the fourteen clones were found promising for all the three usages (Table 1.2).

Table 1.1a. Grouping of enset clones planted at Areka based on kocho

Yield Range	Number of accessions		
	Early set	Intermediate set	Late set
Kocho (t/ha/yr)			
1-15	37	NA	75
16-30	27	NA	21
31-45	12	NA	2
46-60	2	NA	0
Bulla (q/ha/yr)			
1-15	39	88	84
16-30	15	16	3
31-45	4	5	0
46-60	2	0	0
Fiber (kg/ha/yr)			
1-200	38	104	95
201-400	33	26	6
401-600	7	0	0

Source: Atnafua B. and Endale T. (Areka Research Center, unpubl. data)

Table 1.1b. Elite enset clones selected from early set collection based on their kocho

Usage	Clone
Kocho	Digomerza, Goderia, Henuwa, Zebro, Kembata, Gena, Keberiya, Weshmeda, Shedodinya, Akacha, Ginawa, Siskela, Dirbowa, Disho
Bulla	Digomerza, Henuwa, Zebro, Weshmeda, Disho, Siskilla
Fiber	Hekacha, Gena, Shedodinya, Ginawa, Kembata, Goderia, Digomerza

Source: Atnafua B. and Endale T. (Areka Research Center, unpubl. data)

Among the selected 13 clones in the intermediate set, most were qualified for the three usages. However, only one clone was in the highest kocho and bulla yield categories (tables 1.1a and 1.3). The superior clones selected in the late set could not be in the highest yield category for kocho, bulla and/or fiber.

Only two of the selected clones were in the second highest kocho yield category. In this set, four more clones were selected only for their fiber yield. The yields were, however, much lower than clones selected for fiber yield in the early and intermediate categories (tables 1.1a and 1.4).

Table 1.2. Selected superior enset clones from early set based on kocho

Clones	Kocho (t/ha/yr)	Bulla (t/ha)	Fiber (kg/ha/yr)
Digomerza	55.0	5.7	406
Goderia	52.0	–	424
Henuwa	44.0	4.3	317
Zebro	42.0	4.7	363
Kembata	41.0	–	447
Gena	41.0	–	554
Keberia	40.6	–	270
Ginawa	32.0	–	449
Shedodiniya	34.0	–	498
Weshmeda	34.4	3.1	372
Akacha	33.6		195
Siskilla	31.5	1.8	269
Dirbowa	31.5	–	319
Disho	31	2.3	247

Source: Atnafua B. and Endale T. (Areka Research Center, unpubl. data).

Table 1.3 Selected superior enset clones from intermediate set based on kocho

Clones	Kocho (t/ha/yr)	Bulla (t/ha)	Fiber (t/ha/yr)
Wellanchie	48	4.1	372
Boela	26	1.6	320
Shelekie	35	2.2	319
Ashura	51	3.1	301
Bishato	41	3.2	290
Weina	25	2.6	282
Ossogurzo	–	–	280
Kuchaarkia	–	–	278
Zeriyle	41	3.9	273
Kikiro	–	–	272
Heilla	40	–	–
Maria	–	3.2	–
Gimbo	–	2.6	–

Source: Atnafua B. and Endale T. (Areka Research Center, unpubl. data).

Selected superior enset clones from late set
›ased on kocho

Kocho	Bulla	Fiber
37	2.3	177
32	1.3	162
30	–	230
30	–	–
26	–	–
22	–	–
21	0.7	40
20	–	187
20	–	198
20	0.5	66
–	2.1	–
–	1.7	–
–	1.4	–
–	–	223
–	–	219
–	–	211
–	–	204

ıracterization

nnial plant to Ethiopia. Depending on some conspicuous s and locality of cultivation, there are identified several ırmers. There are some clones with different vernacular ·'vpic appearance. Almaz (2001) made a molecular ·d from several locations. According to the genetic Chena and Decha shared similar genetic profile. ach other than any of the other collections.

·idered in the comparison. One of the essa, a clone from Hadiya. The other ·nes (Hichewi and Kapicho) (Table · genetic base enset might have ' to be different.

ʾa that requires an immediate ·l clones collected so far to a lar means.

Table 1.5. Duplication groups of Enset clones based on identical AFLP finger printing profiles

No.	Clones
1	Chale arkio (C) and Tuti arkio (C)
2	Bajo. Yahi bajo (D), Woiro (D)
3	Ganji bocho (C), Chele bocho (D)
4	Ael nobo (C), Chele bocho (D), Gebi nobo (C), Machi nobo (C), Neche nobo (C), Goshno (C), Omo (C),Chongo(D)
5	Ketano (C), Katino (D), Akibero (C),Kachichi (C), Choro (D)
6	Bekecho (C), Shelako (C), Bokucho (H)
7	Shimo (C), Chamero (D)
8	Gayo (D), Wango (D)
9	Geno (D), Utino (D)
10	Kekero (D), Utro (D)
11	Agade (H), Mariye (H)
12	Beneja (H), Kombotra (H)
13	Manduluka (H), Orada (H)
14	Onlya (H), Toroa (H), Wordes (H)
15	Woshamaja (H), Zobra (H)
16	Ofichi (C), Shelako (c)
17	Gamchala (S), Warukore (S)
18	Hichewi (C), Kapicho (C), Chichia (W)
19	Tayo (D), Birbo (S), Made (S)
20	Bedadeda (H), Dirbo (H), Hayiwona (H), Shewite (S)
21	Eshamwessa (H), Shalakumia (W

Keys: C = Chena, D = Decha, H = Hadiya, S = Sidama, and W = Wolayita

Enset Morphogenetic Characterization

Classification through morphometric method involved clones that were collected from six major enset growing areas (namely, Kembata and Hadiya, Wolayita, Sidamo, Gurage, Gamu-gofa and Waka), standard instruments and measurements on vegetative characters. Leaf length and width, pseudo-stem height and circumference, weight of corm, flowering time and finally heights of the true stems were evaluated. After emergence of inflorescence, the bract color and type of compactness and after removing bracts, the emerging flowers were classified under female, male or hermaphrodite types. At the late stage of flowering, enset fingers (almost similar to banana) are formed on the inflorescence. These fingers are green first and later become yellow at ripening. Texture of fruit cover and size, number of seeds per fruit, and floral morphology were also closely observed to identify the mode of pollination.

The time taken from sucker transplant on permanent field to flowering was considered as maturity period of the clone. The descriptions given (tables 1.6-1.12) provide a general picture on the important morphogenetic features of enset plant and the degree of variability.

Leaf

Enset leaves are two-rowed, their shape oblong or lanceolate and are arranged spirally. The leaf consists of lamina (leaf), petiole, midrib and vein (Figure 1.1). At harvest, the average number of leaf per plant is 5-21. The length and width of matured leaf is in the range of 2-5 m and 0.4-1.0 m, respectively.

Midrib is the continuous growth of petiole, which gives pronounced support to lamina. Enset midrib is multi-colored including brown to red, green, yellowish, red, light red, light green, pink to red, dark brown, black and brown. The mid-rib coloration in some clones cover the whole parts, whereas in others it is concentrated at the base of the midrib and tinged with red or light red at tip.

The lamina or blade is found at the left and right of the midrib. It consist veins, which are nearly parallel with each other and run in along S-shaped course from midrib to margin. Few centimeters from the margin, the veins are curved towards the tip of the leaf and gathered together in the marginal vein. The new leaves continuously grow up through the center of the pseudo-stem. At emergence, the young leaf (heartleaf) is enrolled and is erected vertically but latter it unfurls gradually and at the same time stretches out and lean back and away from the heartleaf and finally it hangs down and dies. Generally, matured leaf has green and whitish green color at the abaxial and adaxial sides, respectively.

Figure 1.1. Enset leaves are two rowed, oblong or lanceolate in shape arranged spirally having a petiole, midrib and vein

Pseudostem

Pseudo-stem (false stem) consists of a system of tightly clasping or loose and overlapping leaf sheaths. Leaf sheaths are nearly hollowed or cone, the older being out side and younger inside. The height and circumference of pseudo-stem were in the range of 1-2.8 m and 0.77-1.7 m, respectively. The number of harvestable leaf sheaths was in the range of 9-23 per plant and the weight soon after harvest is in the range 11-95.9 kg per plant (tables 1.7-1.12). Pseudo-stem is the main source of kocho, bulla and fiber. It is swollen at the base, and made up of succulent spirally arranged leaf bases surrounded by outer leaf bases.

The pseudostem circumference of enset plants from clones of different areas ranged from 1.5 to 3.0 m.

The height, number and the weight of leaf-sheaths per plant that can be decorticated ranged from 1.5 to 5 m, 12 to 16 and 18 to 70 kg, respectively (tables 1.7-1.12). Surfaces of the leaf sheaths are shiny, wall of the epidermis is heavily thickened with cellulose, and the top of the sheath is gradually contracted into the petiole.

Enset pseudo-stem is multicolored. The colors observed are dark-green, green, light-green, deep-red, yellowish-green, red, light-red, brown, purplish, bronze to red, pink with tinged-red, and red with tinged- green. There were also black and brown streaks and strips on the outer side of the leaf sheaths.

Corm

Enset corm is typically tuberous (fleshy) and underground growing structure (Figure 1.2a). It bears lateral and apical buds at the center of the junction of corm and pseudo-stem. In the cross section of corm, there are two distinct layers, the cortex and central cylinder. Enset corm is the source of kocho and Amicho. It weighs on average about 12.5-75.0 kg/plant.

a

b

Figure 1.2. Enset corm: a typical tuberous (fleshy) and underground growing structure: it produces an apical bud (a); cross sectional view (b)

The corm of enset is flat at the top and bottom. It produces an apical bud (Figure 1.2b) near the top and usually withers after flowering. Therefore, corm rather than rhizome could be the more appropriate botanical term, which describes the underground stem of Enset. Corm weight possibly varies with respect to clone, management and environmental condition. The weight of grated corm was in the range of 12.5 to 75.0 kg per plant. The circumference of enset corm was in the range of 1.5 to 2.5 m and the length was in the range of 0.7 to 1.8 meter (tables 1.7-1.12).

True stem

True stem is the generative organ of the enset plat. In vegetative state, the true stem is short at the base of central growing shoot. As the plant enters its generative stage, the true stem grows fast. True stem is white and soft. As enset enters its generative stage, it develops into peduncle and inflorescence (Figure 1.3a). The peduncle (stalk of inflorescence) is green. The inflorescence is consisting of bracts and flowers (Figure 1.3b1). Flowers develop into fruits and seeds (Figure 1.4). The inflorescence is upright on emerging then horizontal and later pendulous.

Fig. 1.3a Enset peduncle and inflorescence with its numerous bracts

Fig. 1.3a Enset peduncle and inflorescence with its numerous bracts.

Bracts

Bracts are leafy structures (Figure 1.3b1), which are oval and pointed, spirally arranged around the axis. They overlap each other closely. Clonal variations on bract color were clearly distinguished. The colors varied from reddish-brown, purple, bronze, yellowish- green to yellow. In some clones, brown bracts with yellowish steaks were also observed.

1 2 3

Fig. 1.3b Enset inflorescence and bracts consist of numerous flowers: bracts (1), female flowers with elongated stylates and swollen stigma (2) and male flowers (3).

Flower

Flowers are many in each bract and are in two rows. Those at the lower inflorescence are mostly female (Figure 1.3b2), the middle are hermaphrodite and those at the upper inflorescence are male (Figure 1.3b3).

Unisexual flowers were observed at the bases and upper parts of inflorescence while bisexuals are in the middle. The flowers are arranged in nodal clusters, bifurcatedly. Several groups of flowers were observed on one inflorescence. Each flower group was enclosed in a bract comprising two rows. On average 19 to 33, male flowers and 9 to 22 female flowers were observed per axis. The floral arrangement of Enset is similar to that of banana flowers.

On most clones, the male and female flowers differed in many aspects. The female flowers are large and bare well-developed ovaries, which have elongated style with swollen stigma at the tip (Figure 1.3b2). In the female flowers, the staminate remain short at the base of the style and they are light- purplish. Female flowers are creamy white and develop fruits in clusters. Whereas, in the male flowers the ovaries are smaller, the style and the stigma are slender but anthers are well developed and longer than the style (Figure 1.3b3). At early stage, the anthers have white and purple strips, but at maturity, the color changes from purple to brown. In hermaphrodite flowers, both sexes develop to functional size. Prior to opening both the male and female flowers were covered with white perianth.

Figure 1.4 Enset flowers developing into fruits and seeds

Fruits and seeds

The fruits of enset resemble those of banana but are smaller and inedible (Figure 1.4). At the early stage, the fruits are whitish and then turn dark- green followed by yellowish at maturity. They are leathery, dry or with very scanty pulp, and small (7-12 cm). Under Areka condition, vernaculars Gishera, yielded 43, and Fugatesa and Mariya 18 to 33 fruits per bunch, respectively. Seeds vary in size and weight among clones. They are irregular, hard and black. On Fugatesa and Mariya, seeds about 86 and 96, were recorded, while Gishera gave 238 seeds. Seeds per fruit ranged 1-14, 1-13 and 1-5 for Fugatesa, Mariya and Gishera, respectively.

Mode of pollination

Since *Ensete* is indigenous to Ethiopia, much is expected on the basic science from research. Based on simple observation on the floral morphology of an Enset plant, there is a possibility of self as well as cross-pollination. The presence of female flowers on the upper part and male flowers on the lower part of the plant hinders self- pollination. Nevertheless, the presence of hermaphrodite flowers between the male and female flowers could facilitate self- pollination. On the other hand, bees and other insects were observed visiting the flowers in search of food, which can facilitate cross-pollination. Additionally, fruits and seeds are mostly found on the inflorescence part where there are only female flowers. Therefore, to avoid such confusion, the mode of pollination needs further investigation.

Year to flowering

There is clear clonal variation on maturity period at one location under similar management practices. Under Areka condition, at an altitude of 1830masl, clones took 1.23 to 6.29 years from last transplanting to flowering (tables 1.7-1.12).

The differences in the maximum leaf sheath and grated corm weights, among the locations is wide. This was highest for the Kembata clones followed by the Guraghe collections. The maturity period ranges were narrower at Wolayita and Kembata. The other parameters do not seem to discriminate the clones better than grated weight and maturity period. For each of the locations the grated corm weight of the collected clones were plotted against their maturity periods. A consistent pattern was observed over the locations where grated corm weight yield was independent of maturity period (figures 1.5a-1.5f).

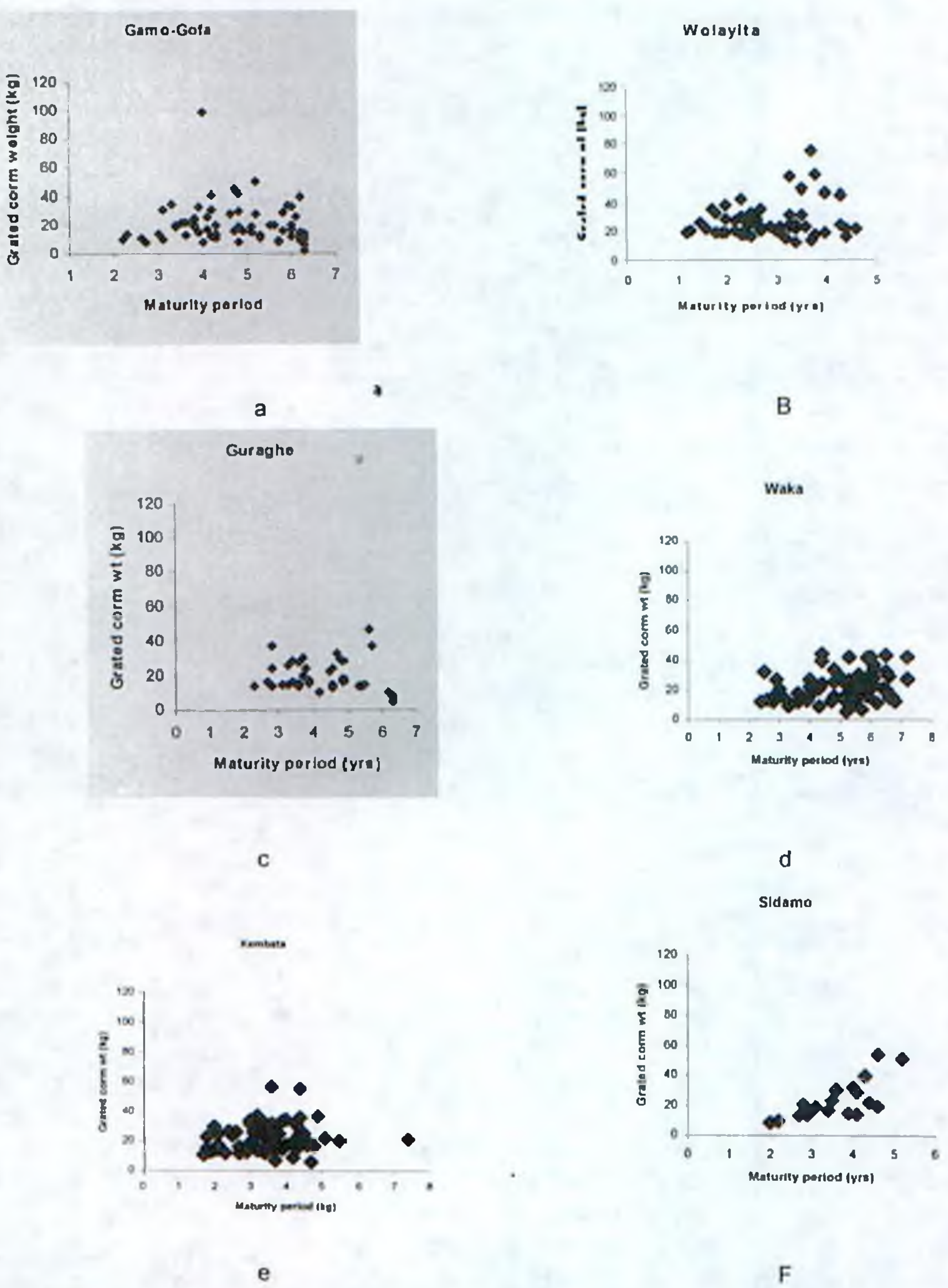

Figure1.5. Scatter plots for grated corm yield (kg/plant) by maturity period (years) for enset clones from six locations evaluated at Areka

Table 1.6. Values for different morphometric parameters used to characterize Enset clones collected from six growing areas

Parameter	Gamo-Gofa	Guraghe	Sidamo	Waka	Kembata	Wolayita
Plant height (m)	2.9-7.5	2.5-7.5	5.4-7.3	2.4-7.4	----	2.97-6.82
Pseudostem height (m)	0.7-3.4	0.6-2.2	1.7-2.7	1.1-3.3	----	0.95-2.36
Pseudostem circumference (m)	0.5-2.0	1.0-2.0	1.0-1.9	0.8-1.9	----	0.89-2.27
Number of green leaves/plant	6.5-14.5	8.0-27	8.8-12.3	6.3-15.2		8.0-15.8
Weight of leaf sheath (kg)	20-127	14.0-157	30-101	31-136	21-238	----
Central shoot weight (kg)	8.5-44.3	7.5-28	13-32	2.4-43.5	3-51	----
Grated corm weight (kg)	2.5-49.9	4.0-46.5	8.4-54	5.6-44.4	6-56.7	12.5-74.8
Maturity period (yrs)	2.2-6.3	2.3-6.3	2-4.6	2.4-7.2	1.8-4.7	1.2-4.6
Number of clones	64	39	20	69	68	57

Table 1.7. Yield components of enset clones from Wolayita

Clones	Plant hgt (cm)	Psd. Cir. (cm)	Psd. hgt (cm)	No. green Leaves/plant	No. leaf sheaths	Wt. of corm grated (kg)	Maturity period (yr)
Erasha	362.5	107.5	96.3	11.0	12.5	17.5	2.3
Chamia	362.5	107.5	96.3	11.0	12.5	17.5	3.8
Shelekumia	466.7	99.7	163.3	9.0	12.0	22.7	3.3
Keberia	617.5	142.5	160.0	14.8	19.0	42.5	2.3
Felluwa	428.3	99.3	125.0	11.0	13.3	23.5	2.7
Lembo	435.0	121.5	145.0	11.0	17.0	21.5	4.4
Tituwa	540.0	90.0	180.0	10.0	11.0	19.0	3.1
Halla'a	685.0	126.3	226.3	11.0	27.0	24.8	4.3
Ketenia	387.5	93.0	152.5	7.5	9.0	21.0	2.4
Sesa	450.0	83.7	150.0	10.3	13.0	19.7	4.0
Adinona	470.0	99.5	145.0	9.8	14.3	15.4	3.2
Akacha	525.0	121.3	141.3	15.5	15.5	38.5	2.0
Bulla	511.3	127.5	151.3	13.8	18.5	30.0	2.3
Gena	668.8	172.5	168.8	12.0	20.5	32.5	1.8
Siyuti	502.5	96.3	170.0	9.5	10.0	16.5	2.5
Kuchaarkia	601.3	142.5	176.3	11.0	18.5	35.8	2.7
Fenku	535.0	105.0	95.0	13.0	7.0	25.9	1.5
Aniko	540.0	155.5	172.5	10.5	17.0	45.8	4.0
Mochie	465.0	137.3	153.8	12.3	17.8	23.4	3.6
Sanka	373.3	106.0	123.3	9.3	11.7	23.2	3.3
Tuzuma	545.0	113.7	177.7	13.3	13.7	27.7	2.2
Tuffa	420.0	132.5	140.0	10.0	16.0	22.5	4.6
Locha	460.0	107.3	136.8	10.8	14.8	18.5	2.0
Argama	455.0	106.0	165.0	8.5	15.5	16.5	4.4
Dirbowa	600.0	142.5	201.3	10.0	16.0	28.5	2.0
Bedadiya	458.8	111.3	160.0	10.0	14.0	24.3	3.3
Bukiniya	621.3	141.3	223.8	9.8	16.3	49.1	3.5
Keltentia	535.0	112.5	187.5	11.0	13.5	21.0	3.0

Agena	337.5	105.0	107.5	9.8	8.3	19.8	2.7
Mattia	615.0	132.5	206.3	9.8	11.8	19.3	1.9
Ossogurzo	631.3	127.5	205.0	12.0	19.3	28.0	2.4
Kikiro	647.5	153.5	236.3	12.0	18.8	56.8	3.3
Botinia	470.0	123.7	148.3	11.7	13.3	23.5	3.1
Delullya	505.0	109.5	150.0	11.3	13.5	18.3	2.4
Banga	578.8	138.8	187.5	11.5	13.5	28.5	2.6
Posho	585.0	151.3	177.5	12.5	15.3	33.0	2.5
Shemoroy	590.0	115.0	203.8	11.8	18.3	31.1	3.3
Shedodinlya	501.3	135.0	122.5	12.8	16.5	19.0	1.2
Ginawa	506.3	136.3	121.3	12.8	16.3	19.8	1.3
Gensa	517.5	133.8	139.0	10.3	16.3	21.3	1.6
Ankuwa	488.8	132.5	138.8	10.5	12.3	19.3	1.8
Dokozuwa	453.8	116.3	128.8	11.3	14.5	18.5	1.9
Eslamia	503.3	119.0	190.0	10.3	18.3	23.3	2.9
Goderia	682.5	150.0	211.3	11.3	17.0	41.6	2.3
Woisha	500.0	131.3	147.5	11.5	16.3	20.3	2.2
Hoeya	450.0	107.0	145.0	11.0	12.5	26.3	2.5
Kualia	571.3	125.5	187.5	13.3	18.5	31.4	3.5
Pena	630.0	168.8	233.8	15.8	22.8	74.8	3.7
Kembata	585.0	145.8	164.5	12.0	16.3	35.8	1.7
Tersekla	297.5	89.3	95.0	9.3	9.5	12.5	3.4
Gezeite	595.0	120.0	178.8	11.3	15.3	27.6	2.4
Genawasa	525.0	145.0	167.5	10.0	21.0	45.5	4.3
Onia	473.3	107.0	166.7	11.0	16.0	21.3	3.4
Meshiria	585.3	144.3	226.7	11.3	20.0	59.0	3.8
Balla	505.0	100.0	180.0	9.0	19.0	13.0	3.7
Felekia	566.7	124.3	170.0	10.3	16.0	24.8	2.6
Lalukla	540.0	125.0	200.0	8.0	19.0	25.0	3.4

Table 1.8. Yield component of enset clones from Gamogofa

Clone	Plant hgt. (cm)	Psd stem Cir. (cm)	Psd stem hgt. (cm)	No. of green Leaves/plant	Green leaf wt. (kg)	Central shoot wt. (kg)	Grated Corm Wt. (kg)	Maturity period (yr)
Shibr	7.2	2.2	1.6	10.8	67.1	16.4	30.9	4.2
Bobiso	4.6	1.4	1.1	10.8	47.0	19.0	25.6	6.1
Kelene	5.8	2.1	1.1	8.3	54.6	14.5	11.5	2.6
Dolla	3.6	1.2	0.9	6.5	23.3	8.5	13.0	3.6
Deilia	5.3	1.7	0.9	13.7	57.8	14.8	9.7	2.2
Bergude	5.9	1.6	1.4	10.0	63.0	27.5	7.8	4.0
Halleko	3.2	0.7	0.9	9.5	18.0	11.5	6.5	6.3
Gorantesa	6.6	1.4	1.5	13.5	53.8	22.5	31.0	3.1
Della	5.5	1.9	1.1	11.0	47.5	12.4	8.4	2.7
Ayssade	5.9	1.8	1.4	9.0	34.0	10.0	19.0	4.8

Shalda	4.2	1.3	1.0	9.7	33.7	14.3	11.7	4.2
Ame	4.5	1.3	1.1	8.8	27.0	9.8	14.8	5.1
Gena	6.6	2.0	1.4	9.7	83.7	28.2	40.8	4.2
Chicho	4.0	1.1	0.9	14.5	40.0	14.0	12.0	6.2
Bino	4.8	1.5	1.3	9.0	51.5	13.8	17.0	6.0
Bulta	6.8	2.4	1.3	8.7	70.0	17.3	25.5	3.8
Kerta	5.0	1.1	2.0	12.5	99.8	23.5	40.0	6.2
Tsisse	6.3	2.2	1.2	8.0	60.3	17.5	24.3	3.8
Bossa Genna	6.9	2.1	1.7	10.3	89.7	20.5	30.0	4.8
Pallo	6.6	2.3	1.4	11.5	61.3	18.6	19.8	4.3
Chawille	5.5	1.4	1.3	11.0	38.0	13.0	28.5	5.2
Dellulle	6.7	2.1	1.3	12.8	74.0	19.0	20.3	3.8
Hallako	5.0	1.1	1.4	11.5	57.5	15.3	15.5	6.2
Mesho Gema	6.3	1.8	1.3	11.7	67.2	18.2	21.6	3.5
Wa-ano	4.6	1.3	1.4	10.7	48.0	10.5	34.5	5.9
Zinke Bkemo	5.8	1.8	1.0	10.5	43.0	13.1	10.6	4.3
Mone	5.8	1.8	1.1	10.2	43.7	12.7	12.7	5.3
Bonga	7.5	3.4	1.6	12.3	110.6	22.4	21.9	3.6
Chochi	4.5	1.2	0.9	11.5	36.3	18.0	8.8	6.2
Mezie	6.9	2.3	1.6	10.3	127.3	25.4	35.0	3.3
Mosso	4.3	0.9	1.1	9.5	32.3	15.3	15.8	5.8
Bukuma	4.6	1.0	1.2	10.0	26.5	9.5	12.5	6.0
Tuffa	4.3	1.0	1.0	9.8	37.4	18.0	8.3	5.7
Gollaa	5.4	1.7	1.2	9.8	47.8	14.9	15.4	3.9
Akisha	4.8	1.5	1.4	8.8	31.2	12.3	13.6	4.3
Zinkie	3.7	0.7	1.0	10.3	25.7	20.7	11.3	6.3
Kesseta	5.8	1.6	1.5	11.8	108.0	19.8	33.5	6.0
Weriza Mocho	5.4	1.6	1.2	9.0	52.4	13.0	16.5	4.9
Dimo	7.3	2.1	1.0	10.5	84.6	20.1	14.1	2.3
Shelekumla	2.9	1.2	1.2	12.0	25.5	11.5	9.8	6.3
Fello	6.1	1.9	1.2	9.5	54.1	15.3	16.3	4.7
Zoa Zinke	4.5	1.9	0.8	5.8	20.0	8.9	8.4	4.8
Keteme	4.3	1.3	0.9	8.0	25.3	8.8	11.5	5.3
Boda	4.1	0.9	1.4	10.8	45.0	10.0	19.6	6.0
pello-2	5.8	1.8	1.3	12.0	59.3	16.1	20.0	5.5
Bokoze	6.9	2.0	1.7	9.3	118.0	18.3	42.0	4.8
Morketa	5.2	1.8	1.2	9.0	107.0	11.0	45.0	4.7
Felekle	4.7	1.7	1.4	11.0	32.9	9.7	20.1	5.6
Sorte	6.3	2.2	1.5	10.3	98.8	20.3	19.0	5.1
Kelise	5.3	1.7	0.5	9.8	61.0	24.7	17.3	4.1
Hampape	3.5	0.8	1.3	12.0	55.0	15.3	14.3	6.3
Bundo	4.6	1.7	1.1	7.3	26.5	16.0	17.3	4.1
Geno-2	6.4	1.8	1.4	9.5	84.0	29.5	28.5	4.6
Yilla	3.7	1.0	1.1	11.5	27.0	33.9	9.4	5.7
Fosho	5.0	1.7	1.2	8.5	38.0	19.5	26.5	4.1

Beshera	5.0	2.3	2.0	13.0	118.2	44.3	98.8	4.0
Wassa Aylto	4.7	1.2	1.2	10.7	52.7		29.5	5.8
Argozo	6.7	1.9	1.8	9.0	79.0	19.5	33.3	3.9
Berzie	5.1	1.4	1.4	13.0	50.3	13.3	9.9	5.2
Zongo	3.3	0.9	1.0	13.0	27.5	27.5	2.5	6.3
Kekero	6.8	2.1	1.3	11.7	101.7	19.3	20.5	3.4
Pemla	5.3	1.8	1.2	11.5	63.5	14.8	19.4	3.8
Harambo	5.4	2.6	1.1	11.0	34.5	12.3	10.5	3.1
Checho	6.0	2.0	1.2	9.8	46.6	15.0	19.4	3.4
Chechu	5.5	1.8	1.1	13.7	48.7	14.3	14.5	3.0

Table 1.9. Yield components of enset clones from Gurage

Clones	Plant hgt. (m)	Psd stem hgt. (m)	Psd stem clr. (m)	No. of green Leaves	Green leaf wt. (kg)	Central shoot wt. (kg)	Grated corm wt. (kg)	Maturity period (yr)
Nechewe	6.1	2.0	1.1	10.0	60.1	13.9	14.0	3.8
Gufenlye	2.5	0.6	1.1	14.0	20.0	11.5	5.0	6.3
Temoyise	6.4	2.0	1.5	12.0	99.5	25.5	28.1	3.4
Mishlrate	6.1	1.8	1.6	12.3	105.7	12.8	29.7	4.8
Demorjate	2.8	62.0	1.7	11.0	14.0	15.0	4.0	6.3
Keweretiye	5.5	1.9	1.4	10.3	58.8	11.5	15.1	3.1
Slnwet	3.9	1.1	1.1	11.3	25.3	7.7	10.7	4.2
Glmbuwe	5.7	1.8	1.5	11.3	133.8	15.3	22.8	4.5
Agadle	5.7	2.1	1.3	10.5	97.0	16.0	24.0	4.6
Mayimole	4.9	1.4	1.1	13.0	61.3	13.5	16.7	2.7
Ayewegene	7.4	2.3	1.3	11.0	134.8	20.0	29.8	3.7
Ameratlye	4.3	1.2	1.3	9.8	60.3	13.3	13.6	5.3
Gezewet	6.7	2.2	1.4	13.0	119.3	25.3	28.0	3.6
Ylrglye	3.5	0.8	1.2	11.0	55.5	9.0	9.0	6.3
Engedawork	5.4	1.7	1.2	9.3	77.5	26.7	15.5	3.9
Yegendlye	3.9	1.1	1.3	11.7	41.5	9.7	13.7	5.4
Guare Bshelega	7.5	2.2	1.0	12.5	148.8	26.5	37.0	2.8
Yekimech	5.1	1.8	1.3	10.0	59.0	18.8	28.5	4.9
Yesherafire	5.9	1.9	1.3	8.8	44.6	13.8	16.3	3.4
Shifire	6.7	2.1	1.6	12.5	94.9	18.4	24.6	2.8
Kanchewe	6.0	2.0	1.0	11.0	54.5	14.8	14.2	2.3
Astara	5.5	2.2	1.2	8.0	46.0	13.0	17.5	3.9
Sebara	5.7	1.7	1.4	12.0	94.5	16.3	32.9	4.7
Gumbar	6.4	1.7	2.0	14.0	156.5	24.0	36.8	5.7
Teriye	6.5	1.9	1.3	11.8	75.3	15.9	25.9	3.3
Lemat	3.8	1.3	1.3	11.3	46.7	12.7	15.0	5.5
Ankifye	5.3	1.5	1.3	13.0	48.4	13.5	14.6	3.6

Achora	6.1	1.9	1.9	13.5	110.0	27.5	46.5	5.6
Guariye	5.5	1.7	1.0	9.8	40.8	12.8	15.9	3.6
Yebiye	4.3	1.1	1.2	10.5	67.5	17.0	13.3	4.6
Weka	5.9	1.9	1.5	14.0	61.0	20.5	18.5	4.9
Tobiro	6.6	2.1	1.4	12.5	79.3	14.4	23.8	3.8
Shertiye	2.8	0.6	1.0	12.7	40.7	11.3	10.3	6.2
Bezeret	5.4	1.7	1.2	8.7	49.0	12.0	13.5	2.8
Bishakanchewe	4.9	1.6	1.1	8.7	35.2	7.5	14.5	4.6
Wered	2.5	0.6	1.0	13.5	29.0	10.0	7.0	6.3
Weret	6.1	1.5	1.6	27.0	58.5	3.8	16.5	4.9
Dere	5.9	1.8	1.1	10.3	45.5	14.9	14.6	3.3
Bisha Amerad	6.0	1.8	1.4	12.0	73.3	9.5	19.7	3.7

Table 1.10. Yield components of enset clones from Sidamo

Clones	Plant hgt. (cm)	Psd. Cir. (cm)	Psd hgt. (cm)	No. green leaves	Leaf sheaths wt (kg)	Central shoot wt (kg)	Grated corm wt (kg)	Maturity period (yr)
Hekacha	5.4	1.9	1.0	11.5	45.1	14.6	8.4	2.0
Sanka	5.9	1.7	1.9	9.3	79.5	19.2	39.7	4.3
Serane	5.4	2.3	1.5	9.3	97.6	30.6	54.0	4.6
Sodiso	6.4	1.9	1.3	10.0	50.8	18.5	19.5	4.6
Gerayicho	5.8	2.0	1.0	11.5	43.0	13.0	23.5	3.5
Sidiramo	6.7	2.1	1.2	10.5	63.6	22.9	32.0	4.0
Gemechala	6.2	2.3	1.3	11.8	64.3	13.8	19.0	3.1
Gerbo	6.0	2.2	1.3	13.8	72.0	17.1	13.5	2.9
Sraro	5.8	1.8	1.5	12.0	86.0	31.7	51.3	5.2
Hekeche	6.1	2.0	1.2	10.3	67.8	17.3	14.9	3.9
Ado	5.9	1.8	1.5	10.3	65.7	20.3	22.0	4.4
Gena	6.6	2.1	1.5	12.3	94.7	30.0	30.0	3.6
Adameado	6.9	2.3	1.5	10.7	80.0	23.7	32.3	4.0
Guseto	6.0	2.1	1.2	8.8	41.7	19.3	16.7	3.4
Betetie	6.6	2.2	1.1	11.3	81.3	19.8	21.0	2.8
Kullo	5.7	1.6	1.0	11.8	46.3	15.5	9.5	2.2
Mindiraro	5.0	1.7	1.1	10.0	30.0	25.0	14.0	4.1
Welenticho	5.9	2.0	1.1	10.3	66.5	17.5	13.5	2.7
Cheleako	5.5	1.7	1.4	10.0	88.0	20.5	31.0	3.6
Midasho	7.3	2.7	1.4	10.5	101.0	28.3	29.0	4.1

Table 1.11. Yield components of enset clones from Waka

Clones	Plant hgt. (m)	Psd stem hgt. (m)	Psd stem cir. (m)	No of green leaves	Green leaf wt. (kg)	Central shoot Wt (kg)	Grated corm wt. (kg)	Maturity period (yr)
Bosena	6.0	3.3	1.2	11.2	53.8	23.2	23.3	6.1
Shasha	5.4	1.7	1.2	11.4	64.6		28.0	7.2
Azuma-Boza	7.3	1.9	1.4	11.3	97.2		42.3	7.2
Budunswa	92.0	1.6	1.1	10.5	52.0		27.3	7.2
Shuchatia	5.7	1.7	1.6	11.2	68.5	26.5	28.6	5.9
Yesha-Mezia	5.5	1.7	1.3	10.8	70.0	15.1	24.5	4.4
Anko-Meziya	5.3	1.3	1.3	9.7	46.3	10.7	17.8	5.7
Shado-Diniya	6.6	2.0	1.6	14.5	101.7	25.2	42.3	6.0
Tuzuma	6.3	2.0	1.6	11.5	109.7	17.6	37.2	6.1
Mecha-Boza	6.9	1.9	1.3	11.0	117.5	27.3	26.8	5.3
Berjiya	6.6	1.9	1.4	11.0	103.8	24.5	22.3	5.3
Agunsata	5.7	1.7	1.0	8.5	59.0	14.6	12.6	4.7
Deliya	6.1	1.9	1.6	10.8	77.7	16.3	27.2	5.7
Gena	7.3	51.8	1.7	12.2	136.2	32.6	44.4	4.4
Erentiya	5.5	1.9	0.9	10.0	35.3	11.8	13.1	3.9
Mezia	6.5	1.9	1.6	10.7	57.0	22.0	27.3	2.9
Busuriya	3.3	1.1	0.5	6.8	39.8	4.8	6.9	5.7
Bota-Meziya	3.6	1.1	0.9	8.0	35.3	9.7	11.0	5.5
Dika	4.6	1.5	1.0	7.3	56.3	14.8	9.0	4.3
Feleke	5.5	1.7	1.2	8.3	53.3	16.3	20.1	5.9
Ketenlya	2.4	1.1	0.8	8.5	35.0	2.4	5.6	5.2
Nekaka	6.0	1.9	1.4	11.8	102.0	24.5	27.4	5.9
Chichiya	6.2	1.7	1.5	12.5	74.8	20.1	30.5	5.6
Shemera	6.0	2.1	1.1	10.0	55.4	15.5	13.7	3.2
Mecha-Shododinya	6.6	1.9	1.6	13.0	101.2	30.1	42.0	5.9
Chemarotiya	5.2	1.6	1.3	10.3	81.0	14.0	29.4	6.6
Bukuniya	4.7	1.5	1.1	9.7	45.2	12.6	12.3	5.2
Hasa-Bedadiya	4.9	1.4	1.2	10.0	60.3	15.5	28.8	6.1
Hoedniya	5.4	1.8	1.3	9.3	68.7	21.7	18.0	3.6
Zergesa	4.4	1.2	1.5	8.5	41.5	13.0	15.8	4.8
Gimira-Arkiya	5.1	1.4	1.2	8.0	80.0	13.0	16.0	5.9
Aeluwa	5.7	1.7	1.2	12.5	100.8	17.8	22.2	4.0
Argema	7.2	2.5	1.3	12.2	115.6	29.8	32.6	2.5
Delullya	6.0	1.9	1.4	11.8	105.3	18.6	21.3	4.3
Dorta	5.4	1.5	1.2	15.2	91.7	19.8	12.2	2.4
Kekere	6.4	1.8	1.2	12.8	73.7	15.9	17.3	2.9
Shelekumla	5.8	1.8	1.6	13.4	115.2	22.8	34.0	4.8
Shengia	5.8	1.9	1.2	10.8	59.8	15.6	12.2	2.8

Kozia	6.3	2.0	1.3	11.2	82.1	19.6	13.8	2.6
Yeka	6.8	2.0	1.3	8.5	83.5	13.5	26.0	5.1
Bergodia	6.0	1.7	1.2	9.3	41.5	12.7	23.0	5.3
Gezsa	5.7	1.9	1.2	9.5	77.5	18.1	21.4	6.4
Lochingie	5.3	1.7	1.1	11.0	64.0	13.8	15.8	4.8
Banga	5.6	1.7	1.4	10.6	91.8	16.3	25.8	4.8
Sanka	5.6	1.7	1.3	10.2	57.8	20.4	22.7	5.7
Matsa	5.5	1.5	1.1	9.0	56.3	11.5	15.3	6.6
Akachiya	5.1	1.7	0.9	7.8	33.7	9.9	11.5	6.2
Elore	5.4	1.7	1.4	13.8	92.2	18.6	22.3	5.6
Tseela	5.1	1.7	0.9	9.2	35.2	9.0	12.4	6.8
Hala-Meziya	5.7	1.6	1.3	9.8	59.8	15.6	18.3	5.5
Banga-Arkiya	6.5	1.8	1.4	13.8	101.5	22.0	27.4	4.0
Buba	5.2	1.6	1.0	9.0	74.5	11.5	19.0	5.5
Adinona	5.5	1.6	1.4	10.7	67.0	18.2	32.7	6.5
Tena	6.3	1.8	1.4	15.8	93.5	27.0	20.8	3.0
Trey	4.9	1.7	1.1	10.0	31.0	17.8	9.3	3.3
Bumbe	7.4	2.4	1.9	12.8	126.5	28.8	43.5	6.5
Bota-Bukuniya	6.2	1.7	1.4	12.0	86.3	19.2	34.8	6.1
Fechariya-Yepa	6.3	3.1	1.4	11.8	113.4	27.6	42.4	5.3
Goshindiya	4.9	1.5	1.2	10.0	60.8	16.3	29.0	5.0
Donkolola	5.5	1.7	1.0	12.4	57.4	14.6	12.0	3.6
Ayina	7.4	2.2	1.7	12.8	156.5	30.3	39.8	4.4
Tasurga	4.8	1.7	1.1	6.3	30.0	11.3	20.7	6.5
Utula	3.9	1.2	0.8	6.5	42.5	8.5	15.5	6.7
Gea	5.1	1.6	1.3	12.5	39.5	22.8	17.0	4.0
Yesha	5.0	1.6	1.2	10.6	48.4	15.0	15.2	5.1
Halla'a	4.8	1.4	1.1	7.8	47.8	14.9	29.8	
Okashiya	5.4	1.8	1.2	9.3	78.7	16.0	20.8	
Anko-Gena	5.0	1.6	1.3	7.8	74.8	11.8	25.0	
Gulumo	5.8	1.5	1.2	10.7	55.7	16.0	20.7	

Table 1.12. Yield components of enset clones from Kembata

Clones	Green leaf wt. (kg)	Central shoot wt. (kg)	Grated corm wt. (kg)	Maturity period (yr)
Goderitta	95.0	20.0	19.0	3.7
Goemerrie	97.1	20.5	31.5	3.0
Disho	66.8	15.5	14.3	2.0
Shelekie	213.0	26.3	32.0	3.6
Mesemesa	98.3	21.0	22.3	3.4
Heilla	141.0	24.7	27.3	3.3
Goemersa	85.0	19.3	29.0	3.7
Gimbo	169.0	22.4	28.8	3.5
Mariya	127.3	23.3	32.3	3.1
Wohie	35.0	10.0	16.0	4.3
Kerbo	78.0	18.0	24.5	4.5
Dirbo	69.0	17.0	12.5	2.9
Gishira	94.8	17.0	17.5	3.1
Abatemerza	112.3	26.3	32.3	3.4
Serpie	168.0	18.3	30.8	4.3
Weina	128.7	17.7	26.7	2.4
Tororie	35.0	11.5	19.0	4.6
Etinie	89.8	14.8	15.3	1.8
Tessa	129.0	22.0	25.0	2.1
Weshmeda	68.0	26.5	13.0	1.9
Kuene	85.0	17.0	16.3	2.7
Zeriyie	173.0	35.5	27.8	3.2
Onjamo	49.3	15.0	14.7	2.1
Abato	111.5	30.0	26.3	2.6
Kessitet	40.0	13.5	11.0	1.7
Koina	39.3	9.5	13.8	3.2
Zebro	124.0	32.5	24.0	2.5
Wellanchie	160.0	29.0	34.0	3.1
Fechachie	96.0	20.5	12.0	2.7
Henuwa	69.3	15.8	23.0	1.8
Ashura	237.7	26.7	56.7	3.6
Sisikilla	76.0	17.3	17.5	2.1
Bishato	134.1	21.6	33.8	3.0
Kebenichie	76.5	18.3	24.5	3.2
Boela	166.0	23.4	33.5	3.9
Oniya	149.8	24.5	37.2	3.2
Lekka	106.5	51.0	31.5	3.3
Digo-merza	130.5	29.6	29.8	2.0
Bikamo	50.0	16.0	9.0	4.2
Fugicho	58.0	12.5	6.0	4.7
Kembata	73.3	17.7	14.7	3.9
Wenadie	109.8	18.0	32.5	3.4

Kinwar	65.0	3.0	34.5	4.0
Eskurkis	160.5	34.0	55.5	4.4
Nechewe	87.7	21.2	37.0	4.9
Tebuttie	89.3	15.8	25.0	3.8
Ored	33.0	6.0	17.0	4.8
Manduluka	103.9	25.1	35.9	4.4
Airo	72.0	11.0	17.5	4.6
Agadie	49.8	14.8	22.0	5.1
Bedediet	31.0	14.0	22.0	4.3
Bossei	55.5	28.0	12.0	2.3
Dengicho	85.0	40.3	25.3	4.5
Gureza	56.7	11.7	15.0	4.3
Ferchesa	120.7	23.0	30.0	3.4
Fugatesa	53.7	13.0	17.7	4.0
Senkutie	86.0	14.0	25.0	3.8
Kerkrie	29.0	10.0	12.0	3.4
Gulfa	29.3	6.3	19.1	3.0
Hankuchie	62.3	13.0	16.7	3.6
Mena	76.0	17.0	18.0	3.5
Becherotu	46.5	18.5	20.5	5.5
Azenora	21.0	7.0	14.0	3.7
Korttie	51.0	18.0	21.5	7.4
Cherka	121.0	24.0	23.0	3.7
Gozeza	79.0	20.0	26.0	3.1
Hargamo	19.0	6.0	7.0	3.7
Belka	80.0	15.3	25.3	4.4

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Annex 1.1. Performance of early maturing enset clones for yield of kocho

Clones	Mean yield (t/ha/yr)	DMRT
Digo-merza	54.9	A
Goderia	52.2	AB
Henuwa	43.8	A-C
Zebro	42.0	A-D
Kembata	41.0	B-D
Gena	41.0	B-D
Keberia	40.6	B-E
Weshmeda	34.4	C-F
Shedodiniya	34.0	C-F
Akacha	33.6	C-F
Ginawa	31.8	C-G
Sisikilla	31.5	C-G
Dirbowa	31.5	C-G
Disho	30.9	C-H
Onjamo	30.3	C-I
Kuene	30.0	C-J
Fenku	29.9	C-J
Abato	29.2	C-K
Kessitet	28.2	D-L
Bulla	27.9	D-L
Shifire	26.0	E-M
Fechachie	25.8	E-N
Woisha	25.4	F-O
Ankuwa	25.2	F-O
Mattia	25.2	F-O
Etinie	24.1	F-P
Gensa	23.6	F-Q
Mezie	23.2	F-R
Argema	22.7	F-R
Dokozuwa	22.1	F-S
Dimo	21.9	F-T
Guare_Bshelega	20.1	F-U
Locha	20.1	F-U
Kanchewe	20.0	F-U
Tuzuma	20.0	F-U
Bossei	19.7	F-U
Becherotu	19.5	F-U
Betetie	17.9	G-U
Erasha	17.2	G-U
Gorantesa	17.0	H-U
Dellia	15.9	I-U
Gemechala	15.1	I-U
Hekacha	15.1	I-U
Gerbo	15.1	I-U
Chechu	14.8	I-U

Mayimote	14.4	K-U
Tessa	13.948	K-U
Bezeret	13.94	K-U
Kullo	13.53	L-U
Yesherafire	13.039	L-U
Meria	12.647	L-U
Kekero	12.112	M-U
Harambo	12.067	M-U
Kelene	11.714	M-U
Koria	11.617	M-U
Tena	11.549	M-U
Welenticho	11.472	M-U
Dorta	11.211	M-U
Hohedinya	10.454	M-U
Shengia	10.407	M-U
Teriye	10.405	M-U
Gezewet	10.274	N-U
Donkolola	10.077	O-U
Nechewe	9.786	O-U
Checho	10.042	O-U
Dere	9.89	O-U
Mesho Gema	9.814	O-U
Trey	9.697	O-U
Bonga	9.172	P-U
Keweretiye	9.106	P-U
Della	8.808	P-U
Erentiya	8.393	P-U
Ankifye	8.155	Q-U
Kekere	7.586	R-U
Shemera	7.435	R-U
Dolla	6.452	S-U
Temoyise	6.196	T-U
Guariye	5.892	U

Annex 1.2. Performance of early maturing enset clones for yield of fiber

Clones	Mean Yield (t/ha/yr)	DMRT
Hekacha	557.42	A
Gena	554.17	A
Shedodinya	498.3	A-B
Ginawa	448.74	A-C
Kembata	446.53	A-C
Goderla	423.70	A-D
Digo-merza	405.59	A-E
Etinle	388.69	B-F
Weshemeda	372.32	B-G
Zebro	362.85	B-H
Ankuwa	343.75	B-I
Tessa	322.46	C-J
Dirbowa	318.73	C-K
Gensa	317.14	C-K
Henuwa	316.83	C-K
Fenku	299.28	C-L
Tuzuma	277.78	C-M
Keweretiye	276.59	C-N
Dokozua	269.744	D-O
Bulla	269.52	D-O
Keberle	269.49	D-O
Sisikilla	269.43	D-O
Kesitet	267.92	D-P
Wolsha	266.8	D-O
Gure Beshelega	248.54	D-R
Disho	247.42	D-R
Shifire	245.23	E-R
Donkolola	242.88	E-R
Mesho Gema	242.42	E-R
Fechachle	239.07	E-Q
Delila	230.04	E-S
Argema	229.33	E-S
Betetle	224.83	F-S
Abato	219.62	F-S
Kuene	206.64	G-S
Tena	204.33	G-S
Locha	204.21	G-S
Becherotu	203.8	G-S
Dorta	201.16	G-S
Maltla	200.45	G-S
Akacha	195.23	G-S
Welenticho	194.24	G-S
Mayimoe	189.12	H-S
Kiyo	184.79	H-S
Onjamo	183.02	H-S
Korla	181.09	I-S
Della	165.62	I-S

Shengia	5.42	G-J
Guarie	5.156	H-J
Dere	6.52	F-J
Nechewe	6.43	F-J
Ankifye	6.35	F-J
Kekere	6.1	G-J
Checho	4.54	H-J
Harambo	3.67	IJ
Donkolola	3.54	IJ
Erentiya	3.26	IJ
Shemera	3.23	IJ
Dolla	1.89	J

Annex 1.4. Performance of intermediate maturing enset clones for yield of fiber

Clones	Mean Yield (t/ha/yr)	DMRT
Wellanchie	372	A
Boela	320	AB
Shlekie	318.58	AC
Ashura	301	A-D
Bishto	290	A-E
Weina	282	A-F
Ossogurzo	280.2	A-F
Kuchaarkia	278	A-F
Zeriyie	273	A-G
Kikiro	272	A-G
Ferchesa	270.5	A-G
Gimbo	270	A-G
Mariya	262.5	A-H
Felekia	262.34	A-H
Gezeit	243.54	A-I
Gea	241.6	A-V
Heilla	235.58	A-K
Mena	235.5	A-K
Oniya	235	A-K
Dirbo	227.6	A-L
Lekka	223.9	A-M
Gishira	222	A-M
Goderitta	209	B-N
Cherka	208.72	B_N
Zoa Zinke	202	B-N
Abatemerza	201	B-N
Weroza Mocho	193.63	B-N
Tebuttie	193	B-N
Goemersa	192.5	B-N
Eslamia	185.6	B-N
Goemerrie	183.34	B-N
Keltentia	182.5	B-N
Banga-Arkiya	177.6	B-N
Mesemesa	176	B-N

Senkulle	175.2	B-N
Sinweta	172.24	B-N
Shemoroy	168.5	B-N
Goliaa	164.76	B-N
Hankuchle	162	B-N
Ketenia	161	B-N
Tituwa	160.4	B-N
Zergesa	158	B-N
Kebenichie	157.53	B-N
Bota Meriya	154	C-N
Banga	153.6	C-N
Shibr	84.24	I-N
Shaida	84.16	I-N
Butta	83.5	I-N
Akisha	83.27	I-N
Agena	82.73	I-N
Gulfa	81	I-N
Agunsata	80.39	I-N
Hoeyla	80.25	I-N
Agadle	79	I-N
Pelio	78.79	I-N
Guseto	78.69	I-N
Yesha	78.39	I-N
Bisha Amerad	77.57	I-N
Ayewegane	75.91	I-N
Delluile	75.64	I-N
Hala-Meziya	75.31	I-N
Bokoze	74	J-N
Gimbuwe	72.32	K-N
Buba	72.29	K-N
Geraylcho	72.21	K-N
Bedadiya	153.6	C-N
Ketise	152.14	D-N
Dika	151	D-N
Botinia	151	D-N
Felluwa	149.22	D-N
Elore	146	D-N
Midasho	142.6	D-N
Gena	139.3	D-N
Adinona	138	D-N
Deluliya	137.56	D-N
Beshera	136.2	D-N
Korttle	132	E-N
Wenadie	131.5	E-N
Kembata	128.52	E-N
Posho	126.25	E-N
Gozeza	124.34	E-N
Geno-3	123	E-N
Mecha-Boza	119.25	F-N
Keteniya	118	F-N
Geno-2	117.64	F-N
Onla	109.34	G-N

Beriiya	107.54	G-N
Yebiye	102.45	H-N
Sidiramo	102	H-N
Hekeche	101.58	H-N
Fosho	100	H-N
Yeka	99	H-N
Lochingie	99	H-N
Adameado	98	H-N
Ayina	96.41	H-N
Pemia	95.75	H-N
pello-3	94.09	I-N
Bergodia	93.57	I-N
Yesha-Mezia	92.31	I-N
Aeluwa	90.76	I-N
Shelekumia	90.35	I-N
Siyuti	90	I-N
Bergude	90	I-N
Sanka	88	I-N
Fechariya-Yepa	88	I-N
Goshindiya	87.68	I-N
Bukuniya	87	I-N
Astara	86.56	I-N
Koina	86.09	I-N
Argozo	85.72	I-N
Engedawork	71	K-N
Mishirate	71	K-N
Morketa	70.7	K-N
Weka	68.87	K-N
Sebara	68.5	K-N
Mindiraro	67.37	K-N
Tobiro	65.77	L-N
Fello	65.5	L-N
Bundo	65.21	L-N
Weret	61.28	L-N
Hargamo	60.27	L-N
Azenora	60.27	L-N
Tsisse	58.14	M-N
Bossa Gena	58	M-N
Ayssade	57.57	M-N
Zinke Bkemo	55.62	M-N
Yekimeche	55	M-N
Bishakanchewe	52.76	N
Kakire	51.6	N
Tersika	49.41	N

Annex 1.5. Performance of intermediate maturing enset clones for yield of bulla

Clones	Mean Yield (t/ha/yr)	DMRT
Wellanchie	41.2	A
Zerlyie	39.43	AB
Bishato	32	AC
Mariya	31.67	A-C
Ashura	30.55	A-D
Oniya	30.1	A-D
Gimbo	27.8	B-E
Goderiita	27.16	C-F
Welna	26	C-G
Lekka	24.26	C-H
Cherka	22.13	C-I
Shelekle	21.9	C-I
Goemerrie	20.71	C-J
Abatemerza	18.95	C-K
Hellla	18.7	C-K
Wenadie	18.63	D-L
Kebeniche	18.1	D-M
Kembata	16.03	D-N
Mena	16.54	D-O
Boele	16.28	E-P
Ferchesa	16	E-Q
Mesemesa	14.53	E-R
Goemersa	14.38	F-S
Bota-Meziya	13.8	G-T
Gishira	13.6	G-T
Hankuchie	13	H-T
Dirbo	13	H-T
Aylna	12.9	H-T
Gozeza	12.74	H-T
Koina	12.37	H-T
Sebara	12.08	H-T
Engedawork	12.68	H-T
Gea	11.39	H-T
Gulfa	11.37	H-T
Beshera	11.22	H-T
Shelekumia	10.67	I-T
Midasho	10.5	I-T
Gena	10.22	I-T
Delullya	9.7	I-T
Banga Arkiya	9.48	I-T
Senkutie	9.32	I-T
Elore	9.12	I-T
Ketise	9.11	I-T
Bukuniya	8.61	J-T
Yeka	8.42	J-T
Mecha-Boza	8.28	J-T
Bokoze	7.73	J-T

Keteniya	7.02	K-T
Pello	3.23	P-T
Bishakanchewe	3.2	P-T
Shalda	2.78	Q-T
Bundo	2.54	R-T
Akisha	2.42	R-T
Yekimech	2.3	ST
Sinwet	2.287	ST
Korttie	7	K-T
Fechariya Nepa	6.84	K-T
Sidiramo	6.71	K-T
Ayewegene	6.684	K-T
Pemla	6.7	K-T
Yesha-Mezla	6.7	K-T
Banga	6.63	K-T
Dellulle	6.43	K-T
Berliya	6.37	K-T
Bisha-Amerad	6.2	K-T
Tebuttle	6.19	K-T
Azenora	6.1	K-T
Gimbuwe	6.06	K-T
Hekeche	5.96	K-T
Bergodla	6	K-T
Geno-2	5.83	K-T
Shibr	5.78	K-T
Bossa Gena	5.73	K-T
Tobiro	5.69	K-T
Gerevicho	5.66	K-T
Astara	5.54	K-T
Weka	5.5	K-T
Argozo	5.4	L-T
Morketa	5.27	L-T
Agadie	5.25	L-T
Buba	5.21	L-T
Tsisse	5.2	M-T
Lochingle	5.04	N-T
Bergude	5	N-T
Goshindiya	4.83	N-T
Mishirate	4.77	N-T
Adameado	4.757	N-T
Butta	4.73	N-T
Geno-3	4.72	N-T
Yebiye	4.64	N-T
Aeluwa	4.55	O-T
Fosho	4.49	P-T
Kerkire	4.36	P-T
Hala-Meziya	4.33	P-T
Hargamo	4.23	P-T
Zergesa	4.18	P-T
Dika	4.16	P-T
Agunsata	3.8	P-T
Werza-Mocho	3.72	P-T

Goliaa	3.6	P-T
Pello-3	3.56	P-T
ZinkeBkemo	3.48	P-T
Yesha	3.41	P-T
Weret	2.204	ST
Guseto	2.033	ST
Mindiraro	2.019	ST
Ayssade	1.725	ST
Zoa Zinke	1.179	ST
Fello	0.722	T

Annex 1.6. Performance of late maturing enset clones for yield of kocho

Clones	Yield mean (t/ha/yr)	DMRT
Eskurkis	36.76	A
Manduluka	31.52	AB
Pena	30.2	A-C
Meshiria	30.11	A-C
Bukinlya	26	B-D
Genewasa	22.15	C-E
Gumbar	20.81	D-F
Lalukia	20	D-G
Kualla	20	D-G
Kinwar	19.7	D-G
Kerbo	19.6	D-H
Aniko	19.3	D-I
Agadie	18.5	D-J
Belka	17.94	D-J
Nechewe	17.77	D-J
Halla'a	17.34	D-K
Chamla	17.1	D-K
Semie	16.8	D-L
Mecha-Shododinya	16.71	D-L
Shado-Dinya	16.62	D-L
Bumbe	16.32	E-M
Mochle	16	E-N
Uzuma	15.78	E-O
Dengicho	15.183	E-P
Nekaka	15	E-P
Nekaka	15	E-P
Airo	14.68	ER
Sodiso	14.6	E-R
Fugatesa	14.44	E-R
Airo	14.68	E-R
Sodiso	14.57	E-R
Fugatesa	14.44	E-R
Bededlet	13.5	E-S
Kerta	13.3	E-S
Shchatia	12.86	E-S
Bededite	13.5	E-S

Kerta	13.3	E-S
Shuchatia	12.86	E-S
Deliya	12.7	E-S
Deliya	12.7	E-S
Fugicho	12.31	F-S
Bota-Bukuniya	12.1	F-T
Wohie	11.82	F-T
Bikamo	11.66	F-T
Gezsa	11.62	F-T
Sraro	11.16	F-T
Chichya	11.1	F-U
Busuriya	5.21	P-U
Argama	5	Q-U
Tseela	4.87	R-U
Zinkie	4.31	S-U
Shelekumia	4.16	S-U
Bino	4.1	S-U
Chemerotiya	10.84	F-U
Balla	10.8	F-U
Gimira-Arkiya	10.5	F-U
Ado	10.2	F-U
Adinona	10.11	G-U
Azuma-Boza	9.81	H-U
Tororie	9.78	H-U
Gureza	9.75	H-U
Senka	9.62	J-U
Berzie	9.54	J-U
Sorte	9.45	J-U
Bosena	923	J-U
Serane	9.1	J-U
Felekie	8.80	J-U
Hasa-Bedadiya	8.56	J-U
Feleke	7.7	K-U
Bobiso	7.65	K-U
Hallako	7.12	L-U
Bukuma	7.1	L-U
Pello-2	7.1	L-U
Kesseta	7.03	L-U
Boda	6.96	L-U
Ored	6.96	L-U
Mosso	6.94	L-U
Ameratiya	6.85	L-U
Shasha	6.61	M-U
Lemat	6.31	N-U
Mone	6.22	N-U
Tuffa	6.14	N-U
Metsa	6.1	N-U
Wa-ano	6.04	N-U
Ame	6	N-U
Shertyie	5.96	N-U
Anko-Meziya	5.95	O-U
Sesa	5.94	o-U

Wassa-Ayito	5.90	O-U
Utula	6	O-U
Chawille	5.88	O-U
Tasurga	5.835	O-U
Budunswa	5.8	O-U
Lembo	5.77	O-U
Yegendiye	5.7	P-U
Akachiya	5.63	P-U
Keteme	5.62	P-U
Yilla	5.41	P-U
Hampapae	5.31	P-U
Yirgiye	5.31	P-U
Halleko	4.05	S-U
Chicho	3.74	S-U
Chochi	3.65	S-U
Zongo	2.12	TU
Gufeniye	2.12	TU
Demorjate	1.06	U

Annex 1.7. Performance of late maturing enset clones for yield of fiber

Clones	Yield mean (kg/ha/yr)	DMRT
Pena	230.24	A
Ameratiya	223	A-B
Yilla	218.62	A-C
Serpie	211.24	A-D
Aniko	210.57	A-E
Meshiria	204	A-F
Kualia	197.5	A-G
Lalukia	187	A-H
Pello-5	177	A-I
Eskurkis	177	A-I
Hallaá	176.6	A-I
Halleko	173.5	A-J
Bikamo	173	A-K
Kerbo	172	A-L
Manduluka	162	A-M
Mochie	162	A-M
Belka	156	A-N
Hampape	155	A-N
Chicho	152	A-O
Bukinyia	151.1	A-O
Nekaka	141.34	A_O
Genawasa	140.94	A-O
Tuffa	138.79	A-O
Nechewe	135.11	A-O
Wassa Avito	127	A-O
Bumbe	126.43	A-O
Agadie	124.51	A-O

Balla	120	A-O
Bota-Bukuniya	117.2	A-O
Felekie	116.87	A-O
Deliya	116	A-O
Chichiya	115	A-O
Tuzuma	114.24	A-O
Gimira-Arkiya	112.5	A-O
Fugatesa	107.7	B-O
Chamia	107.4	B-O
Shuchatia	106.8	B-O
Serane	99	C-O
Achora	56.99	I-O
Anko-Meziya	56.8	I-O
Hasa-Bedadiya	55.41	I-O
Yegendie	55.1	I-O
Keteme	53.95	I-O
Yirgiye	53.15	I-O
Lemat	51.86	J-O
Sorte	51.4	J-O
Zinkie	50.22	J-O
Tororie	49.48	J-O
Kerta	49.1	J-O
Gufeniye	48.73	K-O
Shertiye	47.8	L-O
Dengicho	93.5	D-O
Gureza	91.2	D-O
Adinona	91	D-O
Shado-Diniya	88.6	E-O
Pello-4	88.56	E-O
Sraro	88.4	E-O
Budunswa	88.2	E-O
Busuriya	87	F-O
Feleke	85.22	F-O
Tseela	84.54	F-O
Azuma-Boza	83.78	F-O
Bosena	83.60	F-O
Mone	83.29	F-O
Chemerotiya	78.43	G-O
Wohie	77.64	G-O
Argama	75.84	G-O
Sanka	75.53	G-O
Tasurga	74.06	H-O
Kesseta	73.93	H-O
Sodiso	72.71	H-O
Aim	72.57	H-O
Fugicho	71.62	H-O
Berzie	71.45	H-O
Ored	70.19	H-O
Akachiya	69.72	H-O
Shasha	69.24	H-O
Ado	66.9	H-O
Kinwar	65.97	H-O

Ame	65.67	H-O
Bededite	65.33	H-O
Gezsa	65.23	H-O
Chawille	64.01	H-O
Lembo	63.43	H-O
Mecha-shododinya	62.93	H-O
Matsa	62.57	I-O
Hallako	62.32	I-O
Shelekumia	62.02	I-O
Utula	58.14	I-O
Bino	45.87	M-O
Bobiso	45.38	M-O
Boda	44.57	M-O
Bukuma	44.4	M-O
Demorjate	44.23	M-O
Wa-ano	44	M-o
Pello-2	41.75	M-O
Mosso	40.52	M-O
Gumbar	39.59	MO
Sesa	39.48	M-O
Zongo	35.48	NO
Chochi	28.77	N

Annex 1.8. Performance of late maturing enset clones for yield of bulla

Clones	Yield mean (q/ha/yr)	DMRT
Eskurkis	23.4	A
Serana	20.59	AB
Sernie	16.61	A_C
Kerbo	13.52	B-C
Manduluka	12.66	B-E
Nechewe	11.02	C-F
Airo	10	C-G
Tuzuma	9.77	C-G
Shado-Dinya	8.4	C-G
Mecha-Shododinya	8.4	C-G
Bumble	8.14	C-G
Nekaka	8.11	C-G
Shuchatia	8.1	C-G
Bikamo	7.7	C-G
Bededite	7.5	C-G
Chichiya	7.377	C-G
Fugatesa	7.089	D-G
pello-5	7.076	D-G
Deliya	7.062	D-G
Hampape	6.990	D-G
Gumbar	6.979	D-G
Belka	6.868	D-G
Bota-Bukuniya	6.85	D-G
Chemerotiya	6.690	D-G

Tororie	6.606	D-G
Busuriya	6.21	D-G
Sorte	6.2	D-G
Agadie	5.96	D-G
Gezsa	5.87	D-G
Ored	5.85	D-G
Kesseta	5.85	D-G
Bosena	5.81	D-G
Sodiso	5.55	D-G
Dengicho	5.53	D-G
Bukuma	1.92	FG
Pello-4	1.7	FG
Yirgiye	1.66	FG
Bino	1.64	FG
Chawille	1.57	FG
Keteme	1.53	FG
Bobiso	1.46	FG
Pello-2	1.38	FG
Chicho	1.35	FG
Tuffa	1.258	FG
Ado	5.1	D-G
Sanka	4.94	D-G
Adinona	4.92	D-G
Knwar	4.92	D-G
Azuma-Boza	4.7	D-G
Gimira-Arkiya	4.58	D-G
Hasa-Bedadiya	4.570	D-G
Gureza	4.553	D-G
Wassa Ayito	4.468	D-G
Yilla	3.998	D-G
Tasurga	3.958	D-G
Felekie	3.903	D-G
Fugicho	3.841	D-G
Sraro	3.61	E-G
Mone	3.611	E-G
Wohie	3.242	E-G
Berzie	3.23	E-G
Ameratiye	3.230	E-G
Feleke	3.21	E-G
Tseela	3.04	E-G
Achora	3.01	E-G
Boda	2.954	E-G
Matsa	2.83	E-G
Utula	2.74	FG
Anko-Meziya	2.73	FG
Yegendie	2.72	FG
Budunswa	2.71	FG
Wa-ano	2.64	FG
Shertiye	2.58	FG
Lemat	2.42	FG
Akachiya	2.37	FG
Ame	2.37	FG

Kerta	2.17	FG
Shasha	2.08	FG
Shelekumia	1.24	FG
Hallako	1.201	FG
Chochi	1.17	FG
Zongo	0.92	G
Mosso	0.918	G
Gufeniye	0.814	G
DEMORJATE	0.74	G
Halleko	0.64	G
Zinkle	0.591	G

Chapter Two

Enset Agronomy

Mulugeta Diro, Mikias Yeshitila, Ermiyas Tesfaye and Endale Tabogie

Introduction

Enset *(Ensete ventricosum* (Welw.) Cheesman) is propagated conventionally by vegetative means while growers rarely raise seedlings from seeds though wild enset propagates from seeds. In the conventional vegetative propagation, corms from two to six-year old plants are used only at the vegetative phase. At an initial stage of the reproductive phase, a true stem begins elongating from the base of the pseudo-stem to form an inflorescence that bears fruits and seeds. Once the true stem is initiated the corm cannot be used for propagation. Apical buds should necessarily be removed from corms to induce growth of lateral buds. On average 50–60 suckers emerge from a parent corm or corm pieces in one to two months after planting.

Enset can also be propagated *in vitro* under aseptic condition on nutrient media. After emergence, suckers usually grow in groups attached to parent corm for about a year. Thereafter, suckers are established in nursery or main field using different spacing and cultural practices. In the current chapter, the propagation and establishment of enset plantation will be discussed based on experiences of different enset growing areas and research results.

Propagation

Seed propagation

Enset is a diploid and produces 5-15 seeds per fruits, 10-18 fruits per hand and 5-20 hands per bunch (Taye 1996). Enset seeds are 6 mm or more in diameter (Cheesman 1947, Purseglove 1972), and the seeds are enclosed by hard seed coats (Figure 2.1). However, there are enset clones such as *Lochinge* that do not produce seeds. The seed coat generally causes dormancy in two ways, mechanical and physical dormancy (Hartmann and Kester 1990). Seed enclosing structures that are too strong to allow embryo expansion during germination, though water may be absorbed, imposes mechanical dormancy. According to Graven et al. (1996), hard seed coat of Musaceae (*Musa* and *Ensete*) offers protection to the embryo during maturation, dispersal and dormancy; but, it hampers germination because the embryo requires strong forces to rapture the seed coat. Seed coverings that are impervious to water produce physical dormancy. Therefore, the hard seed coat of enset imposes mechanical dormancy.

Hot water treatment (at 40 °C for 24–48 hour) with scarification around micropylar opening of intact seed of enset was reported to promote seed germination to over 90% which was only about 10% without the treatment (Tesfaye 1992). In other experiments, the hot water treatment of intact seeds did not result in germination (Almaz et al. 2000, Mulugeta and van Staden 2003). However, by rupturing the seed coat, two months after application of the hot water treatment, elongation of embryos was observed in some seeds placed on wet filter paper in petri dishes or on sucrose medium in jars (Mulugeta and van Staden 2003). This suggested that the elongating radicle-epicotyl parts of the embryos could not push the strong micropylar collar of the hard seed coat.

Similarly, Stotzky and Cox (1962) reported a condition where embryos of banana seeds emerged in an abnormal way from the bottom of the seed, where the chalazal mass was removed, rather than through the micropylar canal. This indicates the imposition of mechanical dormancy by the hard seed coat in enset and bananas (Musaceae). Poor embryo development within the seed may be another factor that contributes to poor germination of the intact seeds of enset.

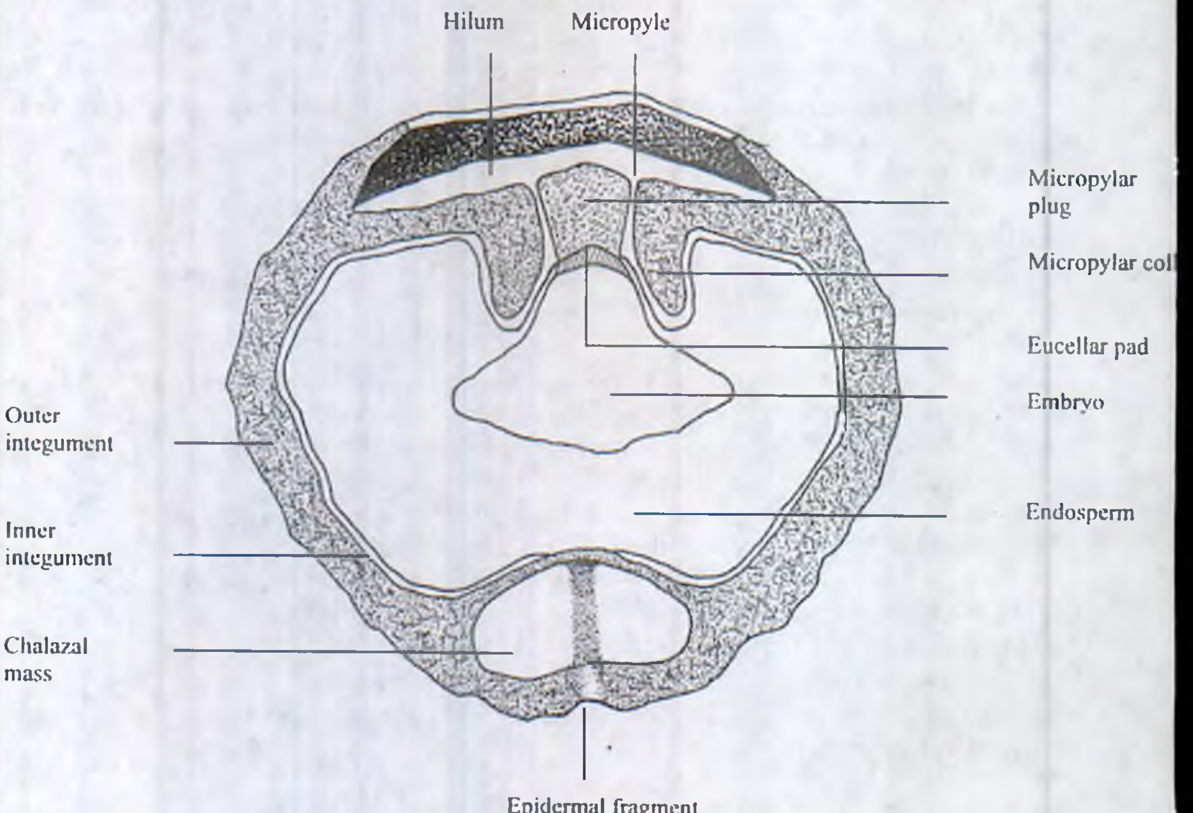

Figure 2.1. Longitudinal cross section of the seed of enset (*Ensete ventricosum*)
Source: adapted from Mulugeta, 2003

Wild species of enset propagate from seed (Kefale and Sandford 1991, Taye 1996, and Shigeta 1996). Some farmers from some areas such as Gardulla highlands in southern Ethiopia also propagate enset from seeds (Kefale and Sandford 1991). Cultivated enset produces seeds after a long juvenile period and seed germination is also very low because of seed dormancy. Moreover, since enset utilizes its stored carbohydrate during fruiting and eventually dies, it is harvested before or shortly after flowering, reducing viable seed production. Culturally, growers in some areas do not want to consume products from enset plants grown from botanical seeds. In the Shaka area, for instance, farmers believe that enset plant obtained from the seed reverts to its wild relatives in behavior and it is not consumed. Therefore, propagation by seed is not common in enset cultivation.

Conventional vegetative propagation

Enset under cultivation is usually multiplied vegetatively and grown as clones. Enset corms send multiple suckers only after removing apical bud from corm. New side shoots of *Musa* (bananas and plantains) arise from a sympodial rhizome. Whereas *Ensete* does not produce new side shoots; *Ensete* is thus monopodial (Price 1995). That is, growth of lateral buds is completely inhibited in enset. The exceptions in *Ensete* are clones Awsako and Welgela (HSIU 1972) and those which were collected and maintained at the Phu Ho field germplasm bank in Veit Nam (Khoi and Valmayor 1995).

In the conventional vegetative enset propagation, a corm, with growing meristem portion, is used. To ensure the presence of meristematic portion, 10–15 cm pseudostem part is cut with the corm. Apical buds must then be removed before planting to break apical dominance. The corm is planted whole (Taye and Asrat 1966) or it is longitudinally split into two or four parts and each part is planted separately (Kefale and Sandford 1991, Terefe et al. 1994, Mulugeta et al. 2002). If planted without removing the apical buds, only one sucker emerges from the whole corm and a few suckers from the split corm. Adventitious buds differentiate from meristematic portion on the top of a corm, around junction of corm and pseudostem, after removing apical bud. The adventitious buds grow into multiples of suckers. There are different approaches to vegetative propagation of enset in different enset growing areas.

Vegetative propagation methods

Different methods and corm types are used in different areas to vegetatively propagate enset (Kefale and Sandford 1991, Mulugeta and Endale 1994). When the whole corm is used, well-grown, three to six years old mother plant is uprooted, corm is cut with 10–15 cm pseudostem and apical bud is removed. The cut surface is exposed for about a day to cure plant material. A cup like hollow space is created with knife on the top of a whole corm where apical bud is removed. This hollow space is traditionally filled with clod or gravel and planted at a spacing of about 1 x 1m. However, research results showed that there was no difference in sucker production whether or not clod or gravel is filled in a hollow space made up on removal of the apical bud from whole corm (Mulugeta and

Endale 1994). The size of planting holes depends on the size of corm. For whole corm, about 30-50 cm wide and 30–40 cm deep hole is traditionally used. The use of whole corm is largely practiced in Gurage, Kambata, Hadiya, Southwest and West Shewa zones. In these areas, planting of corms for sucker production is mainly done from late December to January. The use of whole corm is also practiced in parts of Sidama Zone, where planting is carried out from January to April.

When split corms are used, vigorous, two to three years old parent plant is uprooted; corm is cut with about 10-15 cm pseudostem. The corm is split longitudinally into two or sometimes four parts, and apical bud is removed from each part and the parts are planted. Split corms are sometimes left for a day or so for curing. This practice is commonly used in Wolaita, Gamo Gofa and Keffa zones. Planting in these areas is done mainly in January and may be extended up to March.

Suckers can also be initiated at original position of mother plant. In this case, two to three-years-old plants with better growth are selected in enset field. The parent corm is not uprooted this time. The above ground part is removed leaving about 10–15 cm pseudostem with corm; apical bud is removed and the corm is covered with soil and manure. Suckers with the parent corm are uprooted 6–8 months after apical bud removal. The parent corm is then split into two or four parts with suckers, and then planted in two or four holes. This method is predominantly practiced in Gedio and Gardulla areas. However, growers in different areas use this method believing that it is better for areas or season with low-moisture stress, as plant-soil relation is not disturbed from the beginning.

Moreover, suckers can also be produced without uprooting the parent plant and removing its above-ground parts but the apical bud is wounded to break apical dominance. Suckers grow as side shoots while the parent plant is still growing. According to farmers, suckers produced in this way are few in number but vigoros. The method is practiced in different enset growing areas. From local experience, the method has also an advantage in maintaining soil–plant relationship to use in dry area or season (Training manual at Kucha Woreda, 2004, unpublished).

Corm age, type and size for sucker production

The influence of parent enset plants on sucker production was reported by Mulugeta et al. 2001). Two to five years old parent plants gave comparable suckers in number and vigor over the two year One year old parent plant also gave some suckers (6–15 suckers per corm) but fewer in number and weaker. Therefore, two to three years old enset plants can be used as parent plants. The use of four year old-plants as sources of corm for sucker production did not show any disadvantage in terms of both number and vigor of suckers produced except that the cycle of propagation would be longer.

The use of halved corm resulted in earlier emergence of suckers that led to more vigorous suckers than whole or quartered corms (Table 2.1) (Terefe et al. 1994, and Mulugeta et. al. 2002). When suckers were categorized into undersized, small and medium to large size groups, more number of medium to large suckers were obtained from halved corms

(Mulugeta et. al. 2002). The lower number of vigorous suckers from the whole corms could be partially due to some suckers, which emerged earlier from the whole corm, taking over apical dominance on the late emerging buds, as explained by Edmond et al. (1977). Therefore, growers are advised to use halved corms under favorable environmental conditions to produce suckers.

Table 2.1. Effect of corm type on sucker emergence and plant height, 1989–1991 at Areka,

Corm type	No. suckers emerged per corm				Plant height (cm)			
	1989	1990	1991	Mean	1989	1990	1991	Mean
Whole corm	31.3	8.7	27.0	22.3	188.1	112.4	95.8	132.2
Half corm	94.5	57.7	74.3	75.8	191.3	156.3	81.7	143.1
One-fourth corm	59.3	128.7	119.6	102.4	169.7	159.5	79.0	136.1
CV(%)	49.6				19.9			
LSD (0.05)	39.6				31.7			

Source: Terefe et al. (1994)

Table 2.2. Number and vegetative growth of enset suckers as influenced by different corm sizes

Corm size	No. of suckers	Sucker height (cm)	Psuedostem diameter (cm)	No. of green leaves
75% of full size	110	132.0	5.2	4
50% of full size	122	151.3	7.1	4
25% of full size	102	99.5	3.8	4
Whole corm (full size)	124	98.5	4.2	4
Mean	114.5	120.3	5.1	4

Source: Terefe et al. (1994)

Planting whole corm or 25% of the whole size gave comparable suckers in number and height (Table 2.2). However, longer and thicker suckers were obtained from the 50% of full size corm. Lower parts of corms were removed to attain 25, 50 and 75% of full size corms. Removing half of the corm did not affect bud differentiation and sucker growth; it rather improved. The removed part can be fed to animals.

As planting material, enset corm is transported from one place to another, but not known how long it could stay without losing its viability. In enset growing areas mother corms are planted one day after keeping in an open shade for suberization. Observation made to identify how long corms (whole and split), obtained from 2–3 years old mother plants, could stay under shade before planting showed that split corms were more liable to lose viability. The number of sucker obtained from split corm reduced sharply when stored for 15 days and nil at 25 days or more. High moisture loss in split corms contributed to the low emergence of suckers when storage was prolonged (Figure 2.2).

Generally, it is possible to store whole corm up to 30 days without losing the sucker initiation potential. Corms did not lose their viability under shade for a month when they remained whole. Therefore, corms should remain intact when a time gap between uprooting and planting for sucker production is longer. On the other hand, split corm planted in one or two days gave reasonably higher number of suckers (Figure 2.2). Splitting longitudinally into two upon planting would help to initiate more suckers. Therefore, this is in agreement with earlier reports where half corm is recommended for sucker production.

Hole size for corm planting

Farmers plant corms in holes of irregular sizes, which may affect the emergence and growth of suckers. In most growing regions, depths and widths of holes are mainly dependant upon size and type of corm to be planted.

Studies done to investigate optimum depth and width of corm planting for sucker production (Endale et al. 1995 Unpub) indicated that emergence and growth of suckers is considerably affected by depth of hole. Except for number of emerged suckers, hole depth of 30 cm is found to give better performance for all the parameters considered (Table 2.3).

Table 2.3. Effect of corm planting depth on emergence and height of sucker

Hole depth (cm)	No. of suckers	Sucker diameter (cm)	Sucker height (cm)	Psuedostem height (cm)	Psuedostem diameter (cm)
20	54.9	4.4	71.6	8.8	2.5
30	36.2	4.2	85.3	14.8	3.4
40	30.8	3.2	71.0	11.6	2.5
50	10.5	2.7	33.7	5.1	0.8
Mean	27.2	3.3	55.3	8.3	1.9

Source: Endale et al. (1994, unpublished)

Corm planting time

In most enset growing areas, corm planting for sucker production is exercised during the dry season. It is not known weather farmers practice is the optimum for optimum growth and development of the planting material. Information was generated through planting corm on the 25th date of every month for two years (1991–1993) and under farmers own management practices such as applying farm yard manure, cultivation weeding. Higher number of suckers are produced from March, May and June (Figure 2.3). The performance of suckers was generally high from corms planted; in January.-March and May-June. The results show that January to June can be appropriate time of planting corms for good establishement and subsequent growth of suckers (Endale et al. 1994, unpublished).

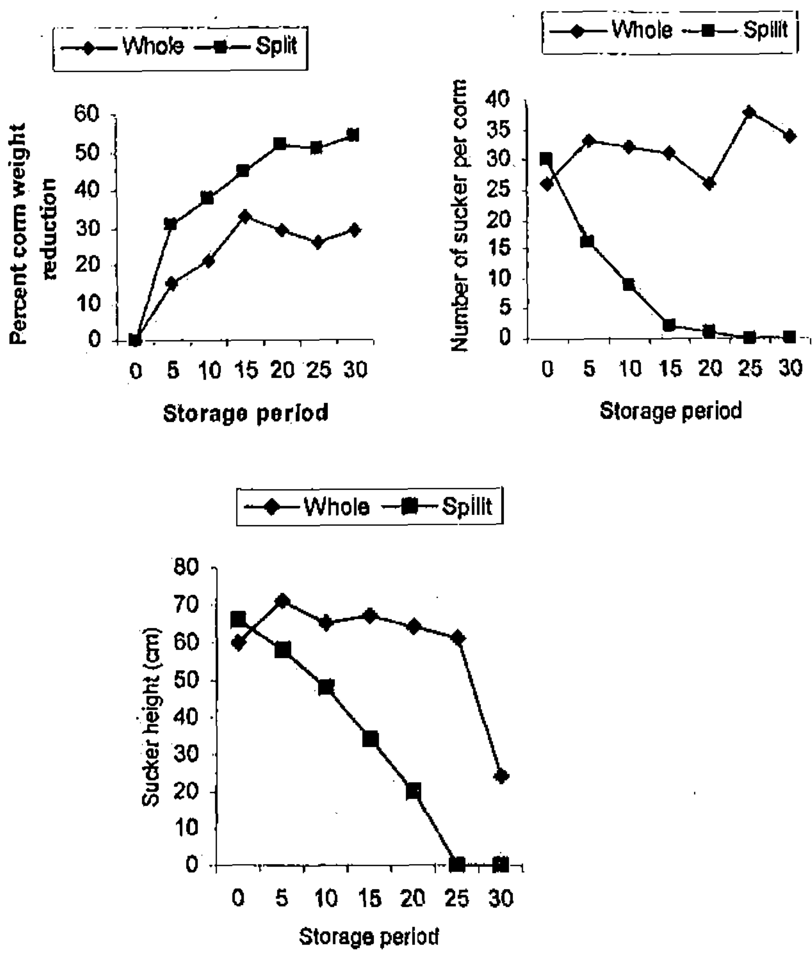

Figure 2.2. Effect of storage time on corm weight, number of suckers and suckers height of planting corms used whole or split

For sucker multiplication, application of 1.5 kg farm-yard manure at the time of corm planting and 1.5 kg after suckers emerge resulted in more number with good growth at Areka condition (Training manual at Kucha Woreda, 2004, unpublished).

In vitro enset propagation

Plant propagation in vitro can be achieved by zygotic embryo culture, organogenesis, or somatic embryogenesis. Organogenesis relies on the production of organs, either directly from an explant or from a callus culture. Somatic embryogenesis is plant regeneration through a process analogous to zygotic embryo germination. Various combinations of nutrients, plant growth regulators and environmental factors for different species or genotypes may stimulate the propagation of plants in vitro. Some important efforts were made to establish in vitro requirements of enset explants for propagation.

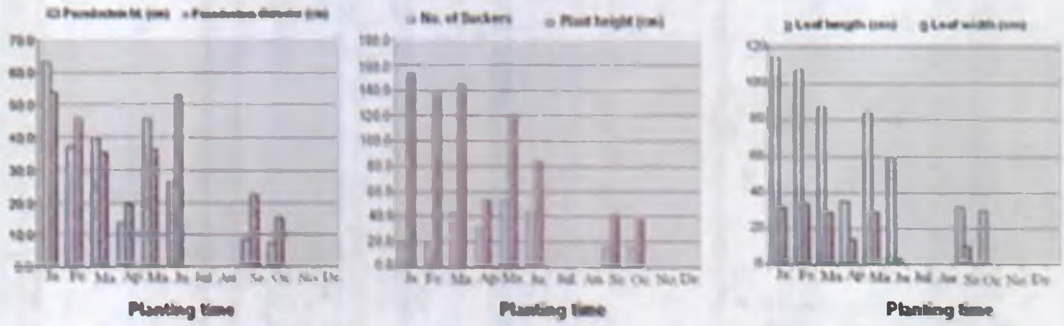

Figure 2.3. Effect of planting time (month) on vegetative growth of suckers

Zygotic embryo culture

Germination of intact seeds of the *Ensete* is very poor. Thus, in vitro germination of excised mature zygotic embryos was used as an alternative pathway to regenerate plants from seeds (Taye 1980, Almaz et al. 2000, Mulugeta and van Staden 2003, and Mulugeta and van Staden 2004).

Depending on genotypes, Murashige and Skoog (1962) (MS) medium without plant growth regulators (PGRs) when used with 5 g per liter activated charcoal (AC) resulted in higher germination percentage of zygotic embryos of enset (Mulugeta and van Staden 2004). The results indicated that inclusion of AC was a remedy for failure of root formation and growth, browning and unwanted callus formation in enset zygotic embryo culture (Figure 2.4), which were reported as constraints by Taye (1980).

A separate rooting stage is not needed when AC is added to the media. Charcoal can assist in absorbing toxic substances, and it provides dark environment that has beneficial effects when used in tissue culture (George and Sherrington 1984 and Collin and Edwards 1998). Thus, in order to regenerate healthy seedlings from zygotic embryos of enset, the use of AC is very beneficial.

Shoot tip culture

In the micropropagation of *Ensete*, shoot tips (corm tissues with some leaf primordia) of mother plants that were grown in greenhouses (Afza et al. 1996, Morpurgo et al. 1996, Tilahun 1997, Bizuayehu 2002, and Mulugeta 2003) and in vitro germinated seedlings (Almaz et al. 2001, Mulugeta 2003) have been used as a source of explants. There was a high risk of having contaminated culture when field-grown suckers were used as source of explants (Mulugeta 2003).

Figure 2.4. Effect of activated charcoal (5 g/liter) (b) on growth of shoots and roots of in vitro seedlings from zygotic embryos of enset cultured on MS medium without plant growth regulators, note the white roots in the presence of activated charcoal

Source: Mulugeta and van Staden (2004)

To initiate aseptic culture, six months old suckers from the greenhouse were trimmed to 2–3cm long shoot tips. The shoot tips were decontaminated in 1.5–3.5% sodium hypochlorite solution with two drops of Tween 20 for 15 minutes and rinsed three times with sterile distilled water (Tilahun 1997 and Mulugeta 2003). The shoot tips were then reduced to 8–10 mm in length and inoculated intact onto MS medium supplemented with 2.5 mg/liter benzyladenine (BA) + 1 mg/liter indole-3-acetic acid (IAA). Initiation of sterile shoot tips of *E. ventricosum* was difficult due to blackening of the explants that caused swelling and callusing and contamination of culture especially when mothers plants grown in the field were used as a source of explant. However, inclusion of activated charcoal (5 g/liter) in the media reduced blackening of the shoot tips in vitro. Whereas, growing mother plants in the greenhouse in soil and sand pot mix reduced contamination of culture. Blackening problem was lesser with shoot tips from in vitro germinated zygotic seedlings.

For multiplication of propagules of *E. ventricosum*, a combination of 2.25–5 mg/liter BA and 0.1–1 mg/liter IAA was used (Afza et al. 1996, Tilahun 1997, Almaz et al. 2000, and Mulugeta 2003). Afza et al. (1996) reported comparable rate of multiplication between in vitro and in vivo, which was about 400 plantlets per year while Almaz et al. (2000) reported the regeneration of about 30 shoots per corm explant in four months, which is better than that from conventional propagation. Bizuayehu (2002) reported that on an average about nine shoots per explant were obtained on MS medium containing 3.5 mg/liter IAA and 1.5 mg/liter BA with recovery of about 50%. In another work, three to five shoots per shoot tip were produced when in vitro-grown zygotic seedlings of enset genotype *Oniya* were used as donor plants and the shoot tips split longitudinally through the apex into two and cultured on basal MS medium supplemented with 2.5 mg/liter BA + 1 mg/liter IAA (Mulugeta and van Staden 2005). If three shoots per shoot tip are considered normal, it is possible to multiply six cycles in a year with two months for a multiplication cycle and obtain over 700 normal shoots per year from a single shoot tip.

The use of high concentration of cytokinin (up to 100 mg/liter BA) did not result in multiple shoot formation from intact shoot tip (Mulugeta and van Staden 2005). Therefore, wounding the apical dome by splitting may be necessary to release lateral buds from apical dominance of the tip of the monopodial corm of enset during micropropagation. The greater response in the production of multiple shoots by zygotic seedlings cultured in vitro could be due to the absence of blackening and the juvenile nature of the explants. The problem associated with in vitro-grown seedlings is that seeds from cross pollination can be genetically heterogeneous. In vitro multiplication of enset can be beneficial when new cultivars are introduced and plant material from disease and pest resistant clones is needed to produce large numbers of plantlets. Hyperhydricity appeared to be one of the problems of enset propagation in vitro.

The rate of in vitro multiplication for *E.ventricosum* is lower than that of bananas which is over four million shoots per shoot tip per year for bananas, depending on the stooling properties of the individual clone (Cronauer and Krikorian 1988). The lower multiplication rate of enset in vitro can be explained by the monopodial morphology of enset corms where side shoot formation does not occur in the field. Whereas, corms of banana have sympodial morphology where suckering occurs in the field.

The plantlets from *Ensete* showed high rooting capacity on MS medium without plant growth regulators in the presence of activated charcoal (Tilahun 1997, Bizuayehu 2002, and Mulugeta 2003). There were cases in which indole butyric acid (IBA) was used to induce rooting (Almaz et al. 2000). Young, 5–10 cm long in vitro enset plants that had 3–5 whitish roots were removed from the culture vessels, washed with tap water and planted in pots filled with compost and soil. About 98% of the planted plantlets grew into full plants when put directly in greenhouse than when put initially in mist chambers (Bizuayehu 2002). Mulugeta (2003) acclimatized in vitro - generated plantlets in a mist house where moisture was provided by automatic misting system. Depending on the vigor of the plantlets, 70–100% establishment was achieved.

Enset Establishment

Suckers of about one year are uprooted with mother corm, detached and sorted out in size groups. All are planted in a nursery, bigger ones individually and weaker ones in a group. Transplants are uprooted and replanted in the nursery by changing plots every year in mid-altitude areas and every two years in some parts of high-altitude areas, until the plants attain an age of four or more. Spacing increases with age and size of the transplants. After transplanting from one plot to another in the nursery, plants are given different local names. Transplanting is practiced two to three times in the nursery and then to the main field in Kembata-Hadiya and in Gurage.

In Gurage, many times transplanting is practiced in nursery. The mother corm is planted at a spacing of about 1.5 x 1.5 m. Suckers emerge in 2–3 months after mother corm planting and stay with the mother corm for about a year. The suckers are called *Fonfo*. Suckers from *Fonfo* stage are sorted out into size group: smaller and bigger. The smaller ones are called *Ariye* and replanted in a group for further growth and development. The bigger ones are transplanted into *Simmua*. Thus, *Simmua* are suckers that have been transplanted once and can be planted in rows with 2–3 suckers in group or in rows of single plants (Spring 1996). The author further explained that spacing between rows is 1 m and between plants 0.2 m. The spacing between grouped plants of *Simmua* stage is about 1 m x 1 m and within the group 0.2 m. Planting of this type of sucker is carried out on the onset of rainy season, usually in February and March.

After staying for one year in *Simmua* stage, suckers are uprooted and transplanted into the next stage, *Tiket*. Thus, *Tiket* are suckers that have been transplanted twice. The spacing used at this stage is about 1m x 1m between rows and plants. At the end of one year, either the suckers are transplanted to the next stage or the leaves are defoliated mainly to intercrop maize. The defoliated plants in *Tiket* stage are called *Girdem*. Suckers stay in *Tiket* stage for one or two years and transplanted for the third time to *Hiba* stage. Plants stay in this stage for one or two years and transplanted to the main field, where it is left until maturity. Spacing used at this final stage is about 2.5 m x 2 m, between rows and plants, respectively. Plants in this stage are called *eset* and need about 3–4 years to be harvested. The total time required from propagation to harvesting is 7–8 years in the mid-altitude areas and even more than 12 years in cold high-altitude areas. As shown in Table 1, repetitive transplanting within nursery and change of names with stages of plant growth and development is practiced in different enset growing areas.

Enset suckers transplanted only once, from sucker production stage to main field, flowered earlier than those transplanted twice or thrice (Bezuayehu et al. 1996, and Admasu and Struik 2000). Admasu and Struik (2000) further stated that enset plants transplanted once flowered in 104 weeks, plants transplanted twice in 234 weeks and those transplanted thrice in 260 weeks. In terms of yield, at 104 weeks after separating the suckers from the corm, the production per hectare per year from transplanting enset plants once was 148 and 25% of kocho dry matter more than transplanting twice and thrice, respectively.

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Chapter Three

Enset Diseases Management

Mesfin Tessera, Gizachew W/Michail and Kidist Babosha

Introduction

Enset (*Ensete ventricosum*) is the backbone of the southern, central and southwestern parts of Ethiopia. This perennial crop mostly covers the densely populated area. Had it not been to Enset, the livelihood of the inhabitants would have been greatly threatened in the past many decades. The high yield per unit area coupled with its ability to withstand drought makes enset an ideal and strategic crop for the populace.

Various diseases of enset have been reported. Some of these are leaf damaging fungal diseases, corm rot, sheath rot and dead heart leaf rot of enset with unknown causal agents. Root knot, root lesion and black leaf streak nematode diseases are also known (Quimio and Mesfin, 1996). There are also viral diseases of enset known as mosaic and chlorotic leaf streak diseases. However, based on the distribution and extent of damage, Enset bacterial wilt disease caused by *Xanthomonas campestris pv musacearum* is known to be the most threatening and important problem to the Enset production system. In this chapter the major research findings involving the most important diseases will be discussed.

Enset Bacterial Wilt

Yirgou and Bradbury (1968) reported the disease to be caused by the bacterium, *Xanthomonas campestris pv*. musacearum. The typical symptoms are wilting of the heart-leaf at the early stage and a follow-up wilting of the neighboring leaves. As the petioles and leaf sheaths are dissected, pockets of yellow or cream colored bacterial matter are clearly observed in the air pockets.

A bacterial slime oozes from cut vascular tissues. This bacterium is a motile, gram negative rod possessing a single polar flagellum and has the following characteristics: oxidase and tyrosinase negative, does not reducenitrate or hydrolyse starch or gelatin and does not accumulate poly-β-hydroxybutyric acid (Thwaites et al., 2000). Cultivation of banana trees as intercrops or border plants as a fence is a common practice in the enset farm. Damage of banana plants around the plant with Xcm is a common observation and once there was an epidemic of bacterial wilt of banana (Dagnachew and Bradburey, 1974).

Distribution

Enset bacterial wilt incidence and distribution was surveyed in1997/98 and 1998/99 main rainy seasons from plants ageing 3 years old and above. Twenty-eight sample sites were selected from enset producing agro-ecologies (Table 3.1). The average area under each agro-ecological zone is presented in Table 3.2.

Table 3.1. Sampled sites from different enset producing agro-ecology

AEZ	No. of sites	Site name
H2	7	Shebe, Bonga, Aletawendo, Hagereselam, Geresa, Gazer, Jinka
SH2	6	Gera, Sunlu (Jima), Angacha, Limu, Leku, Agena
SH1	5	Areka, Gunchere, Waka, Tocha, Dedo
M2	4	Yirgalem, Feshagenet, Cholelektu, Solemo
PH2	1	Shewa-Gimira
PH1	1	Mizan-Teferi
SM1	1	Gedeo

Table 3.2. Acreage of enset producing agro-ecologies

AEZ	Agro-ecology description	Area ('000 ha)
H2	Tepid to cool Humid Mid to high altitude	1844
SH2	Tepid to cool sub humid Low to high altitude	1688
SH1	Hot to warm sub-humid Lowlands to mid altitude	1684
M2	Tepid to cool moist Mid to high altitude	712
PH2	Tepid per-humid, low to high altitude	372
PH1	Hot to warm per-humid Low land to mid altitude	204
SM1	Hot to warm sum-moist Lowlands and plateau	128
Total		6632

The bacterial wilt incidence was not influenced by agro-ecology and sampling year. However, sampling locations were compared and wilt incidence was different among some of the locations. The highest incidences recorded in Waka and Gera was not different from most other places (Table 3.3).

Table 3.3. Enset bacterial wilt incidence in different major enset producing areas

	Mean Incidence (%)	
Sample site	Log_{10}(n + 1) transformed	Back transformed
Agena	0.048 ± 0.048	0.2 ± 0.20
Aleta Wondo	0	0
Angacha	0.06 ± 0.04	0.20 ± 0.13
Areka	0	0
Bonga	0.13 ± 0.10	1.10 ± 0.99
Chelelektu	0	0
Dedo	0	0
Fesehagenet	0.09 ± 0.06	0.40 ± 0.30
Gedeo	0	0
Gera	0.42 ± 0.15	4.20 ± 0.15
Gerese	0.06 ± 0.06	0.30 ± 0.30
Gunchur	0.21 ± 0.12	1.60 ± 1.05
Hagereselam	0	0
Jinka	0	0
Leku	0	0
Limu	0	0
Mizan	0	0
Shebe	0.21 ± 0.09	1.00 ± 0.47
Shewa-girma	0.095 ± 0.064	0.40 ± 0.27
Solemo	0.18 ± 0.11	1.30 ± 0.99
Suntu	0.19 ± 0.15	2.90 ± 2.68
Tocha	0.26 ± 0.11	1.40 ± 0.62
Waka	0.53 ± 0.13	3.80 ± 0.1.27
Yirgalem	0	0
F- and P-values	$F_{23,218}$ = 3.61, P < 0.0001	

Characterization

Morphological and biochemical characteristics of over 90 bacterial ooze samples from diseased plants collected from Sidama, North Omo, Kembata and Guraghe zones were analyzed for hypersensitive reaction. Based on colony color and hypersensitive reaction on tobacco leaves, 25 isolates were discarded for not fulfilling the character of pathogenic *Xanthomonas campestris pv. Musacearum* (Xcm).

The results showed that yellowish colony color with mucoid growth was exhibited by all isolates of Xcm (Table 3.4). Gram negative nature of the bacterium and its motility was quite evident for all Xcm isolates. Carbohydrates utilization by Xcm isolates is shown in Table 3.5. All Xcm isolates did not use lactose, maltose and manitol. There was no variability for pathogenicity found among the isolates from different locations and clones (Table 3.6).

Survival in plant tissue and soil

Survival studies on Xcm in the soil were done using pure pathogenic Xcm from Awassa laboratory. Data on recovery of Xcm under different conditions indicated that Xcm was recovered from samples buried in soil (below 6 inch) after a month only, 3 months on laboratory bench and after 2 months from top of soil (Table 3.7). Xcm was recovered until 12 days of sampling on YPSA amended with streptomycin but not thereafter (Table 3.8).

Table 3.4. Results of morphological and biochemical characteristics of Xcm isolates from different locations

Biochemical test	Negative (-) or Positive (+) reaction					
	Mareka	Loma	Bpoloso	Chacha	Yasana Welene	Gumer
Gram reaction	-	- a	-	-	-	-
Motility	+	+	+	+	+	+
Yellow colony on YPSA	+	+	+	+	+	+
Mucoid growth	+	+	+	+	+	+
Citrate utilization	-	-	-	-	-	-
Gelatin liquefaction	+	+	+	+	+	+
Nitrate reduction	-	-	-	-	-	-
Starch hydrolysis	-	-	-	-	-	-
Casien hydrolysis	+	+	+	+	+	+
Malonate utilization	+	+	+	+	+	+
Indole production	-	-	-	-	-	-
Hydrgen sulfide production	+	+	+	+	+	+

Table 3.5. Mode of utilization of carbohydrate by *Xanthomonas campestris pv. musacearum* isolated from naturally wilting enset plant

Carbohydrare source	Negative (-) or Positive (+) reaction					
	Mareka	Loma	Bpoloso	Chacha	Yasana Welene	Gumer
Fructose	+	+	+	+	+	+
Galactose	+	+	+	+	+	+
Glucose	+	+	+	+	+	+
Glycerol	+	+	+	+	+	+
Mannose	+	+	+	+	+	+
Sucrose	+	+	+	+	+	+
Lactose	-	-	-	-	-	-
Maltose	-	-	-	-	-	-
Manitol	-	-	-	-	-	-

Table 3.6. Enset bacterial wilt incidence for 12 clones isolated from different location under artificial inoculation

Enset clone	Incidence (%) by isolates				
	North Omo (23)*	Sidamo (13)	Guraghe (23)	Kembat (23)	Mean
Ag	85.78	95.78	100	100	97.89
As	91.55	100	100	91.55	95.76
Ay	100	87.44	100	100	96.86
Ba	100	100	100	95.78	98.95
Bo	95.78	95.78	100	95.78	96.84
Ch	100	95.78	100	100	98.95
De	100	95.78	100	100	98.95
Di	91.44	100	100	100	97.86
Er	91.44	100	100	91.44	95.72
Ne	100	100	100	95.78	98.95
Su	100	95.78	100	100	98.95
Yi	100	100	100	100	100
Mean	97.17	97.2	100	97.53	

*no. of isolates

Table 3.7. Recovery of Xcm isolates on YPSA medium from diseased tissues kept under different conditions at ambient temperature

Treatments	Inoculation period (months)						
	1	2	3	4	8	12	24
Laboratory condition	+	+	+	-	-	-	-
Top of soil	+	+	-	-	-	-	-
6 inch below soil	+	-	-	-	-	-	-

Keys:- +/- = Absence/Presence of Xcm

Table 3.8. Recovery of Xcm isolates on YPSA medium from different soil types that are kept for various days

Treatment	Recovery* after incubation period (days):																
	3		6		9		12		15	18	21	24	27	30	40	50	60
	S	NS	S	NS	S	NS	S	NS									
Kembata Black soil	+	-	+	-	+	-	+	-	- -	-	-	-	-	-	-	-	-
North Omo Red Soil	+	-	+	-	+	-	+	-	- -	-	-	-	-	-	-	-	-
Sidamo Black Soil	+	-	+	-	+	-	+	-	- -	-	-	-	-	-	-	-	-
Sidamo Red Soil	+	-	+	-	+	-	+	-	- -	-	-	-	-	-	-	-	-

*+/- = Presence/absence of Xcm on YPSA medium; S = I[th] Streptomycin; NS = No Streptomycin

Resistance to Xanthomonas campestris

Twelve enset clones from Kembata and Hadiya, 89 clones from Sidama and Guraghe and 12 mixed enset collections from kembata, Sidama, Hadiya Wolayita and Guraghe were evaluated for their resistance against Xcm. Forty banana cultivars were also collected from Melkasa Research Centre for the study. Inoculation of test plants was done using virulent Xcm strain.

Various levels of reaction were observed for the different clones collected from various locations (tables 3.9, 3.10, 3.11 and 3.12). Reaction of banana cultivars is presented in Table 3.13. Clones like Serena and Wonigoro from the Sidama collection had an infection rate as high as 43% (Table 3.10), while from the Guraghe clones Nechew, Bazeriet and Dere had 10% infection after 120 days. Recovery after wilting should be a critical issue as the recovery at that stage might not be due to real resistance. An enset plant that recovers from wilting may not reach for harvest. Wilting is seen as lack of resistance gene against the disease and the recovery by producing a new heart-leaf might be misleading. Protection of the apical meristem from being rotten by Xcm must exist somewhere in such enset cultivars. In general, there is a need to make further investigation to better understand the host–pathogen interaction in enset in a comprehensive approach in order to generate reliable information.

All the banana cultivars were found susceptible to bacterial wilt. Wilt symptoms did not develop until 30 days of inoculations. About 95% of the test cultivars showed 100% wilt incidence after 90 days of inoculation with Xcm (Table 3.13).

Table 3.9. Enset bacterial wilt incidence on Sidama collections under artificial inoculation

Clone Name	Incidence (%) after evaluation period (DAI)* of:							
	15	21	30	45	60	75	90	120
Hekecha	14	28	57	71	71	71	88	100
Sediso	0	0	50	57	57	57	71	71
Siraro	0	0	50	57	57	57	71	71
Ado	0	0	50	57	57	57	71	71
Gena	10	57	71	88	88	88	88	88
Adame ado	14	28	50	57	57	57	71	71
Kullo	28	28	88	100	100	100	100	100
Astara	28	71	71	88	88	88	88	88
Gulumo	20	50	50	100	100	100	100	100
Chelako	20	50	67	67	67	67	67	83
Bulla	28	80	60	100	100	100	100	80
Tunako	20	50	50	67	67	83	83	83
Sidinamo	20	57	57	88	88	88	71	57
Gemechalo	20	57	57	88	88	88	88	100
Gerbo	0	0	14	50	50	50	50	50
Waniwassa	14	20	20	80	80	80	80	80
Hekicha	14	28	28	43	57	57	71	71
Gusselo	0	14	14	88	88	88	88	100
Derassa dimella	14	14	33	67	67	67	67	67
Cinicho dubane	14	50	50	67	67	50	50	67
Halso	20	57	57	67	100	100	100	100
Hawe	0	71	71	100	100	100	100	71
Senana	0	0	33	83	88	88	88	83
Alenticho	14	20	20	20	75	100	100	100
Buffare	20	50	50	100	100	100	100	100
Bulle	14	33	33	83	88	83	83	83
Genticho	0	0	50	71	88	88	88	88
Geraicho	0	71	71	88	88	88	88	88

Betete	20	57	57	88	88	88	88	88
Buacho	14	43	43	100	57	57	71	45
Wolanticho II	20	20	50	71	71	88	88	100
Sedisse	0	43	43	71	71	71	88	88
Kerase	14	14	20	43	43	43	57	57
Borba da	0	20	20	60	60	60	80	80
Wolanticho I	20	75	75	75	75	75	75	75
Astara	20	57	57	88	86	88	88	88
Gena	20	57	57	88	88	100	88	57
Ontasha	28	28	28	43	43	57	57	57
Demella	14	28	28	57	71	71	100	100
Wonigoro	0	0	28	43	43	43	71	43
Astara	0	0	16	100	100	100	100	100
Gedime	0	71	43	88	88	88	88	57
Serena	0	43	43	43	43	43	43	43
Wolancho	0	33	50	83	83	83	88	100
Berjo	0	16	16	83	83	67	67	67
Ewisho	0	0	16	71	88	88	88	88
Dinke	20	67	50	83	83	83	83	83
Ketene	20	50	50	83	83	83	83	83

DAI = Days after inoculation

Table 3.10. Enset bacterial wilt incidence on Guraghe collections under artificial inoculation

Clone name	Incidence after evaluation period (DAI)* of:							
	15	21	30	45	60	75	90	120
Nechwe	0	0	0	20	20	20	10	10
Temayse	0	0	38	62	75	88	88	88
Esmaele	0	7	50	88	88	88	88	88
Maymote	0	0	50	83	75	75	75	75
Aylwegene	0	7	75	88	88	88	88	88
Amaratye	0	7	50	88	88	88	88	88
Geziwet (1)	0	0	50	62	62	50	50	50
Geziwet (2)	0	7	71	100	100	100	100	100
Wered	0	7	62	83	88	71	71	71
Yegendiye	0	7	50	83	88	71	71	71
Yeshirafre	0	7	43	62	62	38	38	38
Kanchiwe	0	0	20	50	37	38	75	75
Astara	0	0	20	43	43	38	38	38
Separa	0	0	13	37	37	75	75	75
Teriye	0	0	38	50	75	50	71	62
Anikefye	0	0	13	14	28	38	38	38
Achana	0	0	38	62	62	71	71	38
Yibriye	0	0	38	62	62	71	71	71
Weka	0	0	13	25	25	38	71	38
Jabiro	0	0	75	83	88	88	88	88
Chekimad	0	0	62	83	88	88	88	75
Bazeriet	0	7	38	50	25	10	10	10
Wereze	0	7	25	50	50	50	50	71

Bodles Altafort	50	75	100	100*	100
Matoke	50	100	100	100	100
Ginir-2	50	100	100*	100	100
Kenya-1	50	100	100*	100	100
Williams-1	50	100	100	100*	100
Williams-2	50	50	100	100	100
Valery	50	75	100*	100	100
Prata	50	50	75	100	100
Chibulangome	50	50	100*	100	100
	45	60	75	90	120
Kibungo-1	25	50	100*	100	100
Figue Sucree	50	75	100*	100	100
Saba	25	75	100	100*	100
Silk	50	75	100	100	100
Red	50	100	100	100	100*
Gitty	50	100	100*	100	100
Wondogenet-2	50	50	100	100*	100

* = uninoculated/ control plants that showed wilt symptoms

Fungal Diseases

Foliar and corm diseases

Fungal diseases of enset are not as such threatening to crop production. They only affect the crop at the early stage of growth. As the crop plant gets older, it resists most of the fungal pathogens. Most of the foliar fungal diseases cause leaf spotting and blighting which later coalesce and severely affect the photosynthesis mechanism of the crop.

Among the fungal diseases, corm and root-rot diseases were found as devastating especially on young seedlings. Three fungal pathogens were detected from diseased leaves, while one was isolated from the flower. The fungal pathogens identified from the Areka collections were *Deightoniella leaf spot, Drechslera leaf spot, Pyricularia leaf spot, Sclerotium root rot, Sclerotium corm rot and Cephalosporium Inflorescence spot* (Tezera and Quimio, 2000).

Viral disease

Leaf narrowing, stunting and chlorotic leaf streaks are the typical symptoms of enset leaf streak disease. Preliminary investigation done at the department of virology, Wageningen Agricultural University, The Netherlands, revealed the causal agent to be the Bacilliform DNA (BaDNA) virus (Tessera et al., 1996). Since this viral disease stunts enset plants very severely in the highlands, the impact on yield is quite serious.

Diagnosis of leaf streak virus

Diseased leaves harvested from plants grown in a greenhouse at Wageningen University were used for purification. Leaves incubated at -70°c in a deep freezer were checked at weekly interval. Incubated diseased leaves (50g) were extracted using 1:3 (w/v) in a blender using cold 0.1M Tris-Hcl, pH.6, containing 0.5% (w/v) Na_2So_3, 0.5%(v/v) 2-mercaptoethanol, 0.25%(w/v) maceroenzyme and 0.25%(w/V) cellulase. Dot-blot ELISA revealed the causal agent of enset leaf streak disease as BaDNA virus (Tessera et al., 1996). Partial purification of the virus from diseased leaves gave bacilliform viral particles with mean dimensions of 118-125 X 29.5-30nm (Tessera et al. 1998). The result agrees with measurements reported for the BaDNA genus group (Brunt et al., 1990). Liberation of the viral particles was only found from leaves incubated at -70° c for a minimum of 4 weeks (Table 3.14).

Table 3.14. Incubation period of diseased leaves at -70°c for diagnosing BaDNA virus particles

Incubation period	Positive	Negative
One Week		X
Two Weeks		X
Three Weeks		X
Four Weeks	X	
Five Weeks	X	

Distribution of leaf streak virus

Distribution of leaf streak virus was assessed using samples taken from twenty-five sites in seven major agro-ecologies based on their area coverage. Sample areas were divided into 20 X 20 km grid in order to select individual districts. This method was adopted from banana nematode survey work done by IITA group (Jagtap, 1993).

Enset leaf streak virus was found widespread in all the seven agro-ecologies of the country (Table 3.15). Symptoms of the streak virus are very clear in the highlands where cool temperature and humidity are common features. Stunting of enset plants is severe in the highlands compared with middle and lower altitude areas.

Moist agro-ecology zone gave the highest incidence while in per-humid zone the disease record was the lowest (Table 3.15).

Impact of leaf streak disease

Comparison of yield data between healthy looking and severely stunted plants manifested a yield reduction of 93 and 98% for Midesho and Pena cultivars, respectively. Circumference reduction of 74 and 77% was observed for Midesho and Pena clones, respectively. Height reduction of 73 and 64% was also noted in the same manner (Table 3.16).

Table 3.15. Distribution of enset leaf streak virus in Ethiopia

AEZs	Enset leaf streak virus incidence (%)	
	Transformed mean	Original mean
Tepid to cool Humid Mid to high altitude (H2)	50.02	58.69
Tepid to cool sub humid Low to high altitude (SH2)	45.45	50.80
Hot to warm sub-humid Lowlands to mid altitude (SH1)	49.86	58.40
Tepid to cool moist Mid to high altitude (M2)	54.08	65.50
Tepid per-humid, low to high altitude (PH2)	51.95	60.80
Hot to warm per-humid Low land to mid altitude (PH1)	38.62	39.20
Hot to warm sum-moist Lowlands and plateau (SM1)	47.80	54.80

Table 3.16. Impact of ESV on various parameters of enset

Variety	Age	Parameters	Disease severity		Reduction	SLCC(r)*
			0	5		
Midesho-HS	6	Fresh yield (kg)	165	12	93	- 0.972
		Circum (m)	1.9	0.5	74	- 0.933
		Pseud. height (m)	2.6	0.7	73	- 0.923
Pena-AK	4	Fresh yield (kg)	45	1	98	- 0.978
		Circum (m)	1.5	0.35	77	- 0.983
		Pseud. height (m)	1.4	0.5	64	- 0.909

SLCC (r), Simple linear correlation coefficient

Nematode Diseases

Enset black leaf streak disease

Successful enset production is dependent on healthy sucker emergence and growth. Black leaf streaks on young leaves cause immature leaf death of seedlings. The causal agent of this leaf disease is found to be *Aphelenchoides sp.*, a leaf nematode (Quimio and Tessera ,1996). Further investigation of the nematode revealed the identity as *A. Ensete sp.* n. (Nematoda: *Aphelenchoididae)* (Swart et al., 2000). Dissecting of diseased leaves on slides with water revealed the swimming out of these nematodes from the leaf tissue.

Pathogenicity test made on healthy seedlings confirmed the above leaf nematode to cause the black leaf streak disease (Quimio and Tessera, 1996). Without the control of the disease, it is difficult to get enough seedlings for transplanting.

Survey work done across all enset producing agro-ecological zones revealed the widespread of the leaf nematode disease. The bulked nematodes from leaf nematode samples from each agro-ecology zone gave positive reaction on inoculated test plants. Control plants did not respond to water spray (Table 3.17).

Hence, *A. Ensete sp.*n. was widespread in all the producing zones of the country. Without the control of this leaf disease, it is quite evident to face shortage of propagules. That may enhance food shortage in the area.

Table 3.17. Distribution of *A. Ensete* sp.n. in enset producing agroecologies

	Disease reaction	
Sampled Agro-ecologies	Positive	Negative
H2	3/3	-
SH2	3/3	-
SH1	3/3	-
M2	3/3	-
PH2	3/3	-
PH1	2/3	1/3
SM1	3/3	-
Control (pure water)	0/3	3/3

Parasitic nematodes

The distribution and density of major plant parasitic nematodes of enset form about twenty-five sites selected from seven agro-ecology zones were determined (Table 3.17). The dominant root nematode was found to be lesion nematode (*Pratylenchus goodeyii*) found in all sampling sites followed by *P. zeae*. Highest numbers of *P. goodeyii* were recovered from Agena (Guraghe Zone) and Tocha (Dawro Zone) (Table 3.18). The range of *P. goodeyii* was 800-15020 nematodes per five grams root.

The finding supported earlier survey results of O'Bannon (1975) and Peregrine and Bridges (1992). The nematodes were known to cause toppling of enset plant during windy days due to severe root rotting and damage of roots. The nematodes may increase the susceptibility to bacterial wilt by damaging the roots. They also play a role in the transmission of the wilt disease (Quimio and Tessera, 1996).

The clones highly differed in their susceptibility towards the lesion nematode (Table 3.19). It seems very important to further screen promising clones against this important root pathogen under the greenhouse condition using artificial inoculations.

Table3.18. Distribution and density of plant parasitic nematodes on enset in Ethiopia

Site	Altitude (m)	Nematode species*			
		Pg	Pz	Aph	Melo
Agena	2330	15020	5208	108	0
Tocha	2390	14050	2180	130	0
Waka	1710	8280	604	0	0
Jinka	1560	8170	2170	0	5
Areka	2011	7910	375	280	5
Dedo	2386	7606	1366	329	0
Shebe	1939	7538	393	1287	4
S.Gimira	2117	7329	531	253	4
Agaro(gera)	2065	6672	332	60	0
Jimma	2075	5208	1744	472	24
Angacha	2284	3921	212	45	208
Limu	2386	3913	258	173	367
Solemo	2538	3890	665	65	0
Gunchure	2159	3640	205	50	20
Gazer	1523	3545	70	85	45
Leku	2061	2595	268	100	33
Bonga	1840	1784	36	48	4
Gerese	2145	1550	1883	30	0
Fesehagenet	2544	1350	225	20	30
Yirgalem	1967	1300	88	36	0
Hagereselam	2797	1147	136	12	0
Mizan	1658	1128	54	60	25
Aletawendo	2248	1110	75	0	20
Gedeo	2061	1036	156	28	28
Chelelektu	1863	800	105	15	0

Pg. = Pratylenchus goodyei; Pz. P.zeae; Aph. Aphelencoides sp.; Melo. Meloidogyne spp.

Table 3. 19. Nematode species densities per 100 g fresh root weight of 71 cultivars encountered in 25 sites.

Cultivar	Nematode species*			
	Pg	Pz	Aph	Melo
Semwa	36700	18140	0	0
Gesa	33680	2160	0	0
Korkori	24700	960	300	0
Adinona	18740	640	760	0
Janjiro	17800	8720	0	0
Bukma	15590	4230	0	0
Misir	15520	1300	3410	0
Anchiro	12790	3230	1150	0
Shododen	11730	2160	85	0
Gayo	11540	1440	1780	0
Heila	10620	0	220	0
Nechoa	9810	2150	120	25
Kucha	9540	660	280	0
Tibla	9340	280	0	0
Amiya	9280	80	180	0

Ferezia	8420	240	140	0
Merza	8400	300	0	333
Mergu	8400	0	0	0
Guariyen	8200	0	260	0
Lekaka	8160	0	140	0
Yore	7540	860	0	0
Gimbo	7120	310	90	1480
Geno	5730	200	95	0
Girbo	5180	1960	60	0
Bocho	5173	240	67	7
Molge	4570	0	60	20
Midasho	4480	460	0	180
Mai	4440	200	120	0
Disho	4200	530	20	0
Nobo	4088	309	409	14
Sapara	3960	140	580	0
Gulumo	3840	460	20	0
Bededet	3740	360	240	0
Utero	3580	20	0	0
Benezhe	3540	0	140	0
Tebere	3500	0	0	0
Arpha	2680	0	340	0
Agade	2560	70	0	0
Ado	2460	234	80	0
Astara	2200	0	70	60
Zinke	1760	560	0	0
Ameratiyen	1740	560	0	0
Genticho	1656	196	34	11
Jinka	1620	0	0	180
Melo	1430	2110	0	0
Kerese	1400	80	40	40
Dego	1400	0	0	100
Intado	1300	220	0	20
Kineb	1300	140	140	340
Kancho	1300	0	0	0
Gena	1[illegible]0	33	0	0
Sikubai	1060	0	60	0
Litso	880	3260	90	0
Gonasa	880	333	0	0
Ungame	865	60	65	475
Torabe	840	100	0	0
Boss	760	0	0	160
Dirbo	600	40	0	40
Dalank	587	40	147	0
Tuzuma	560	200	80	20
Ark	420	0	0	0
Nipho	360	0	0	0
Xhori	280	0	120	0
Barxhe	220	60	20	30
Guferek	200	0	0	0
Argama	180	0	0	0
Amarat	120	0	0	60

Bumbo	100	0	0	0
Ginimbuwa	100	0	0	40
Yedi	60	0	0	0
Sisskel	40	0	240	0

Pg, Pratylenchus goodyei; Pz, P.zeae; Aph, Aphelencoides sp.; Melo, Meloidogyne spp

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Biology

Although enset root mealy bug was first reported in Ethiopia in 1988 (Tsedeke, 1988), much was not known about its biology. Enset root mealy bug has an elongate, oval body covered with thin layer of wax on the dorsal and lateral sides that gives the insect the appearance of a cottony, spine-like projection (Figure 4.1d). The waxes are not part of the insect's body but they are incorporated into the new wax secretions at each successive molting.

The enset root mealy bug has different development stages: (1) bright-orange to yellow-orange colored "crawlers" or rapidly moving first-instar (Figure 4.1a), (2) second- and third-instars that begin to develop distinct lateral and posterior cerarii, increase in body size, and start to produce large amounts of honeydew (Figure 4.1b and 1c), and (3) the pre-ovipositing adult female (Figure 4.1d). Males are unknown for *C. ensete*.

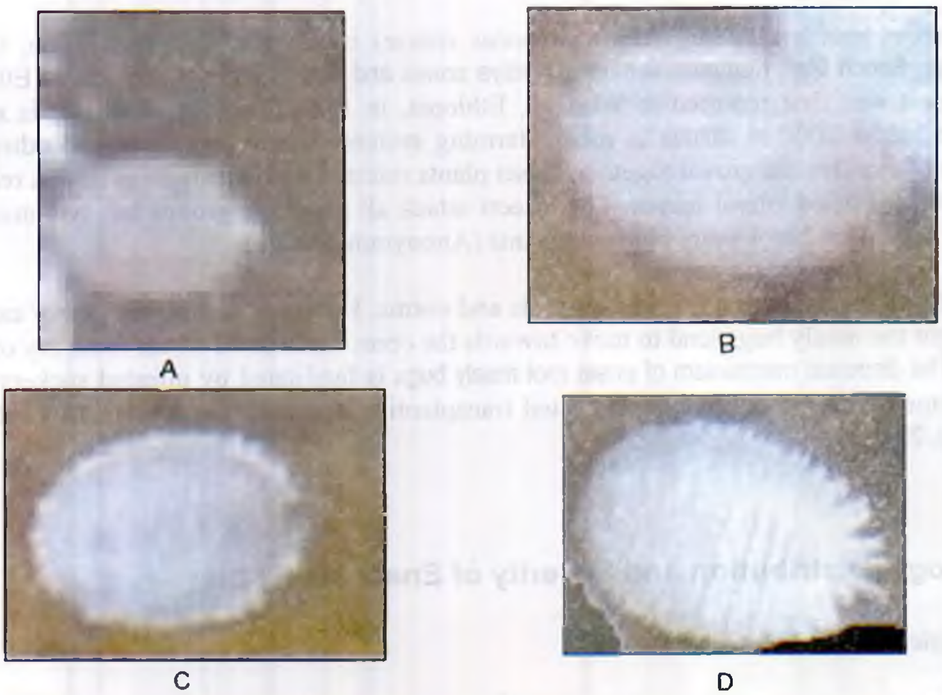

Figure 4.1. Development stages of enset root mealy bug (*Cataenococcus ensete*)

Studying the biology of this important pest is still demanding. The natural enemies of the insect have not been known. Association with ants is observed quite often, but the nature of the association has never been studied. In few instances, ant colonies are observed invading the rhizosphere of enset plants, consuming the mealy bugs.

Survival

The first-instar nymph of *C. ensete* is susceptible to starvation. Whereas the adults are better in tolerating starvation. However, all stages succumb to death within three weeks when exposed to continuous starvation.

Distribution

C. ensete was recorded from Gedeo, Sidama, Bench, Hadyia, Gurage, Kembata Tembaro, Keffa zones and Yem and Amaro districts. However, surveyed enset farms in Wolayita, Silte, Maji, Gamo Goffa, Sheka, West Showa, and Jimma were found free from enset root mealy bugs.

Out of the 163 farms surveyed, more than 30% were found infested by the mealy bug. According to Addis et al. (2006) most of the enset farmers (78.6%) produce their own suckers for planting. The survey also indicated that the mealy bugs are found up to a soil depth of 80 cm from the corm decreasing with reducing root density and increasing soil depth. In addition, about 90% of the mealy bugs were found within 60 cm radius from the plant (Figure 4.2).

In areas where there is frequent exchange of planting materials like Amaro, Gedeo, Sidama and Bench, there is high level of infestation by *C. ensete* (57–100%). But in Hadyia, Gurage, Kembata Tembaro, Keffa and Yem where there was limited exchange of planting materials, the infestation was relatively low (8–29%). The findings indicated that exchange of infected planting materials was the major cause for the expansion of the insect.

Infestation is severe between 1400 to 2200 m the highest infestation (53.6%) being recorded between 1600–1800 m and the lowest above 2200 m and below 1400 m.

Severity

The highest weighted average Infestation (WAI) of *C. ensete* so far is recorded in Gedeo Zone and Amaro district (58.33%). Observations showed that severe damage is recorded in areas where farmers exercise mixed cropping despite the expectation for high pest density in monocropping compared to mixed cropping system, i.e, (niche suitability theory). According to some reports, severity is also higher on Nitosols (Ethiopian Mapping Authority, 1988).

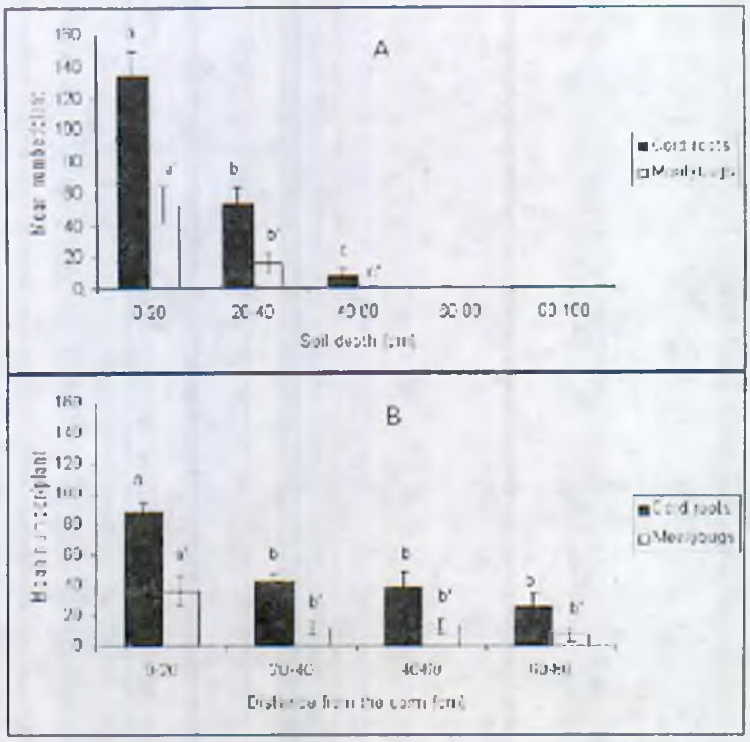

Figure 4.2. Vertical (A) and horizontal (B) distribution of enset cord roots and enset root mealybugs (n = 10).

Bars with same letter are not significantly different (Tukey's test at $p \leq 5\%$)

Damage and symptoms

C. ensete is found exclusively on the roots and corm of enset plant. Plants damaged by the insect encountered retarded growth, lacked vigour and subsequently die, especially when there is moisture stress. Visible effect of root mealy bugs on their host plants is not easy to observe on the aboveground part of the plant until the damage is extensive (Hara et al., 2001) and often too late to remedy the plant.

Control

Insecticides

The effects of different insecticides on enset mealy bugs in Gedio and Sidama Zones were studied for three years during 1997-1990. According to the results, the insecticides evaluated had different protective effects. Because of the difficulty to monitor the mealy bug population due to their subterranean habit, the efficacy of the insecticides was evaluated using indirect ways, i.e., based on changes in stem diameter and length of the central shoot. The insecticides were carefully applied to the rhizosphere of each plant where the insects take homage. The formulations included EC forms, dry flowable, dusts, fumigant releasing tablets and granules applied manually into dugouts that had to be prepared around the root system. All insecticides increased central shoot height and circumference of the pseudo stem indicating the overcoming of the insect damage as compared to control (Table 4.1). All the insecticides evaluated enhanced the growth of the plants and caused high level of mealy bug mortality.

Table 4.1. Effect of different insecticides and their forms on enset mealy bugs in Gedio and Sidama zones, 1997–1999.

Treatments	Mean height of central shoot (cm)	Mean pseudo-stem circumference (cm)
Phyrinex 48% EC	123.09	52.34
Phostoxin tablet	110.11	42.23
Sellecron 720 EC	110.62	40.06
Decitab tablet	97.30	39.24
Deltanet 200 EC	93.99	36.77
Actellic 50% EC	92.22	36.77
Basudin 10 G	90.96	36.53
Miral 10 G	89.84	36.31
Thionex 35%	89.29	36.15
Basudin 600 EC	82.76	36.14
Cyron 56	82.41	35.44
Mitigan 10 G	82.13	35.19
Karate FW	79.54	35.14
Fenom 100% EC	66.81	32.73
Sevien 2.56 G	64.10	27.95
Untreated check	52.00	20.00
CV (%)	36.76	25

In addition, a study was made in 2000-2001 to evaluate alternative application of chemicals using phostoxin tablet and locally formulated insecticides in dust and EC forms. Phostoxin tablets were included only for comparison purposes. Ethiotrothion (Fenitrothion) gave the best protection as observed from the higher stem diameter of treated plants. Whereas, plants treated with Ethiolathion (Malathion) EC form gave the highest central shoot height (Table 4.2). Although both leaf and stem of enset are marketable, plants with big stem diameter are preferred for maximum kocho yield. Therefore, Ethiotrothion EC form was recommended to farmers.

In another study, the efficacy of different synthetic insecticides was tested under greenhouse condition. Diazinon and Chloropyrifos caused the highest mortality and killed more than 95% of the root mealy bugs (Table 4.3).

Table 4.2. Effect of different insecticides on enset mealy bugs and on plant circumference and shoot length (2000-2001)

Treatment	Rate of application	Mean performance	
		Stem circumference (cm)	Central shoot length (cm)
Ethiolathion 5% Dust	37.5 g/plant	4.56 ± 0.66	8.53 ± 0.2.70
Ethiolathion 50% EC	1.5 lt/ha	5.94 ± 0.54	23.62 ± 2.40
Ethiosulfan 5% dust	6.5 kg/ha	4.30 ± 0.24	10.72 ± 0.14
Ethiothiole 40% EC	1.5 lt/ha	4.92 ± 0.59	16.33 ± 1.64
Ethiotrothion 50% EC	1.5 lt/ha	6.60 ± 0.38	16.46 ± 1.23
Ethiozinon 60% EC	1.5 lt/ha	3.91 ± 0.40	12.33 ± 2.40
Phostoxin tablet	3 tablets/plant	3.83 ± 0.86	11.61 ± 1.64
Untreated check		4.74 ± 0.22	9.66 ± 0.79
P values		P = 0.02	P = 0.0005

Table 4.3. Mortality of enset mealy bug due to different synthetic insecticides under greenhouse.

Treatments	% mortality	
	Observed	Corrected
Diazinon 60% EC	100 ± 0.0	84.13
Chloropyrifos 48% EC	97.6 ± 1.0	80.23
Malathion 50% EC	83.2 ± 1.9	67.3
Fenitrothion 50% EC	76.8 ± 2.3	60.89
Endosulfan 50% EC	74.4 ± 4.1	58.53
Dimethoate 40% EC	64.8 ± 3.4	48.87
Control (untreated)	16.0 ± 3.5	---
CV%	16	

Botanicals

With the aim of developing alternative and safe control measures, different botanicals were tested for their toxicity against enset root mealy bugs. Among the botanicals, *Millettia ferruginea* was found to be the most effective (Table 4.4). *M. ferruginea* provides multipurpose uses to the farmers and it is the most abundant and dominant component of the agro-forestry system in the study area. Therefore, seed-water suspension of 10% of the plant can be used to control enset root mealy bug in the enset root mealy bug prone area.

Further screening of *M. ferruginea* at different rates of concentrations showed that *M. ferruginea* caused higher mortality reaching 100%. Lower concentration of up to 5% of *M. ferruginea* extract caused more than 50% mortality within 72 hours (Table 4.5). The effective dose that killed 50% of the population (LD_{50}) was found to be 40.39 mg, while that of the LD_{90} was 77.62 mg.

Table 4.4. Mortality of enset root mealy bug due to water suspensions of different plant materials in Petri dish experiment

Treatment	% mortality at different hours after treatment:					
	24		48		72	
(4 ml/5 cm^3 soil in Petri dish)	Observed	Corrected	Observed	Corrected	Observed	Corrected
Chenopodium ambrosiodes	6.7^{d}	0.1	13.3^{d}	3.4	19.9^{d}	9.61
Maesa lanceolata (leaf)	10.0^{d}	3.4	13.3^{d}	3.4	23.3^{cd}	13.01
Maesa lanceolate (seed)	16.7^{d}	10.11	23.3^{cd}	13.41	29.9^{cd}	19.62
Azadirachta indica	16.7^{d}	10.11	23.3^{cd}	13.41	29.9^{cd}	19.62
Phytolace dodecandra	10.0^{d}	3.4	23.3^{cd}	13.41	39.3^{c}	29.03
Melia azederach	16.6^{d}	10.11	23.3^{cd}	13.41	34.0^{c}	23.72
Schinus molle	13.3^{d}	6.7	36.6^{b}	26.73	43.3^{c}	33.03
Tephrosia vogelii	16.7^{d}	10.11	29.9^{cd}	20.02	53.3^{b}	43.04
Nicotine tabacum	63.4^{c}	56.83	88.6^{b}	78.77	96.6^{a}	85.78
Millettia ferruginea	80.0^{b}	73.42	100.0^{a}	90.02	---	---
Diazinon 60% EC	100.0^{a}	93.45	---	---	---	---
Control	6.6^{d}	---	9.9^{d}	---	10.3^{d}	---
CV (%)	21	---	18.4	---	14.5	---

Table 4.5. Toxicity of *M. ferruginea* seed-water suspensions to enset root mealy bug

Concentration:	% mortality at different hours after treatment					
(g /5c m^3 soil in Petri dish)	24		48		72	
	Observed	Corrected	Observed	Corrected	Observed	Corrected
10	80.00^{b}	80	100.00^{a}	96.72	-	---
7	63.33^{c}	63.33	69.66^{b}	68.34	85.66^{a}	82.37
5	53.33^{c}	53.33	63.33^{b}	60.01	66.33^{b}	63.02
3	26.00^{c}	26	30.33^{c}	27.04	36.66^{c}	33.37
1	3.00^{d}	3	6.00^{d}	2.7	18.66^{d}	15.36
0.5	3.00^{d}	3	6.00^{d}	2.7	9.33^{d}	6.03
0.1	0.00^{d}	0	3.33^{d}	0	6.66^{d}	3.36
Control	0.00^{d}	---	3.33^{d}	---	3.33^{d}	---
Diazinon 60 % EC	100.00^{a}	100	---	---	---	--
CV (%)	24.8	---	13.9	---	11.9	---

Hot water treatment

Hot water treatment of enset suckers for the control of enset root mealy bugs was conducted in 2006 at Awassa. One year old infested enset suckers were exposed to hot water treatment at temperatures of 100 ^{0}C (boiling water), 75 ^{0}C, 55 ^{0}C and control for 10, 30, 60 seconds and 5 minutes. About 5 mm of the outer most layer of the corm and all discolored (i.e., not white) tissue of enset suckers, were peeled off (pared) with knife before treatment. Non-pared enset suckers immersed in boiling water for 10 to 30 seconds and pared suckers treated for 10 seconds resulted in complete control of enset root mealy bugs without affecting the growth and establishment of the suckers.

The nature of enset cultivation, which is intensive and often around the homestead, makes the use of chemical insecticides difficult. Therefore, many alternative and safe control measures need to be considered. These include, for instance, the use of botanicals, clean planting materials, improved sucker management before and after transplanting, and use of natural enemies such as solely carnivorous ants. In addition, community mobilization should be a key approach to create awareness on the biology and distribution of the pest and on safe control measures to minimize the problem.

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Chapter Five

Post-Harvest Management of Enset Products

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Introduction

Enset products have great nutritional importance. The nutritional value of enset products is comparable to other starchy products such as sweet potato, taro and yam. The fat and carbohydrate contents of enset products are even better compared to sweet potato and yam. The enset food contains more Ca and Fe than most cereals, tubers and root crops (Admasu 2002). The protein yield from enset is 50% higher than that of cereals. The protein yield is also higher when compared with that of other root and tuber crops such as sweet potato and Irish potato. When animal products or leguminous plants are incorporated in the diets of enset consuming households, the only shortage preventing a balanced diet is that of vitamin A (Pijils et al. 1995).

Enset plant has multiple uses for the farmers. However, it is primarily cultivated for food. There are three important types of food products.The main food product is processed by fermenting the mixture of scraped pulp of the pseudostem, pulverized corm and stalk of the inflorescence and is locally known as 'Kocho'. The other two types of food from enset are amicho and bulla. Amicho is prepared from the enset corm (root) and is consumed after it is boiled, i.e, similar to sweet potato. Bulla is a purified product of kocho. Fiber is the non-edible product of enset left after decorticated leaf sheath at harvesting time. According to Godfrey (1985), enset fiber has an excellent structure, and its strength was found to be equivalent to world fiber crop abaca.

Generally, women are responsible for enset-processing activities. Although there are slight differences, the methods of harvesting and fermentation process are similar for all enset-growing regions. The main processes of harvesting are scraping the pseudo-stem pulp (parenchymatous tissue) and pulverizing the corm. The mixtures of the two products, scraped pseudo stem pulp and pulverized corm including stalk of the inflorescence, are buried in a pit for fermentation and storage purpose. The pit is dug at the side of a tree or inside dense enset plantation in order to prevent it from heavy rain and strong heat. The product will be fermented and is ready for consumption after 2–3 months. However, it can be consumed after one month of fermentation time if there is urgent need for more food.

The traditional harvesting and post harvesting procedures are tedious, highly labor intensive, unhygienic and associated with great yield losses. Therefore, further research should be geared towards development of appropriate processing technologies and reducing the associated pre- and post-harvest losses. Although fermentation is unavoidable, the traditional methods of fermentation that allows a large loss of soluble material through leaching and prolonged and repeated fermentation needs to be improved (Admasu 2002). Leyuwork (1996) stated that the hygiene of kocho seemed to improve without affecting its nutrient content and food quality by using new kocho storage (burying) methods. Better storage methods and optimum fermentation period for good quality kocho are described here.

The containers used to store the harvested enset plants were white (Figure 5.1a) and black Jeri-can perforated at the bottom (Figure 5.1b), plastic sheet buried in the pit (Figure 5.1c), perforated concrete pit (Figure 5.1d), dried enset leaf sheath and enset leaf with its midrib (farmers' practice) in the pit (Figure 5.1e). The trial was laid in complete replicated design with two replications. The storage time of kocho in each storage method was one to ten months, and measurements were taken at an interval of three months. For each treatment, which is for different sampling time and type of storage, decorticated enset product from one clone of Halla was used.

Figure 5.1. Different containers used for storage of processed enset in pit: a) white containers; b) black containers; c) polyethylene sheet; d) green enset leaf sheath; e) dried enset leaf sheath and enset leaf with its midrib (farmers' practice)

The containers used for the present study were black and white Jeri-cans (perforated at the bottom), plastic sheet, perforated concrete pit, only dried enset leaf sheath and as farmers practice; the enset leaf, its midrib and its leaf sheath at the same time. In the case of Jeri-can, the harvested plant was stored directly in it and the Jeri-cans were kept in a room. Wheereeas, the harvested plant was stored in the pit in the case of plastic sheet, dried enset leaf sheath, and farmers practice by covering the harvested plant with these materials. In the case of perforated concrete pit, the harvested plant was stored in it by covering the harvested material with enset leaves.

The study was carried out at Areka Agricultural Research center. Nutritional analyses of samples were done at the Institute of Biodiversity Conservation (IBC). Sample was taken for nutritional analysis from each treatment.

At the time of sensory evaluation which included kocho color, texture, taste and odor farmers were consulted and the values were coded as: fair = 1, good = 2, very good = 3 and excellent = 4. Ten farmers were included in a group for the evaluation purpose.

Quality evaluation of kocho

The farmers' method of storage showed a highly significant difference for kocho color compared to other methods except the plastic sheet buried in the pit at one month of storage and dried enset leaf sheath at all storage periods. On the other hand, a significant difference was recorded for plastic sheet buried in the pit to the rest of storage methods except perforated concrete pit at one month of storage (Table 5.1). The very good color maintained by the plastic sheet buried in pit even after 10 months of storage reduces losses during fermentation.

Table 5.1. Kocho color evaluation after 1, 4, 7 and 10 months of storage in different storage structures

	Color quality (scores in 1–4 scale)*			
Storage structure	After 1 month	After 4 month	After 7 month	After 10 month
White Jeri-can (perforated)	1.00C	1.00C	1.00C	1.00C
Black Jeri-can (perforated)	1.00C	1.00C	1.00C	1.00C
Plastic sheet buried in pit	3.00AB	3.00B	3.00B	3.00B
Perforated concrete pit	2.00BC	1.00C	1.00C	1.00C
Dried enset leaf sheath	3.50AB	3.50AB	3.50AB	3.50AB
In the pit (farmers practice)	4.00A	4.00A	4.00A	4.00A
CV%	24.43	12.83	17.61	13.20

*Scoring for sensory evaluation for kocho color made in a scale of 1–4, where 1 is good, 2 better, 3 very good and 4 excellent

Kocho stored in the traditional way practiced by farmers gave the highest quality kocho texture compared to all other storage methods after 10 months of storage. But it did not show a significant difference with plastic sheet buried in pit, which in turn was not significantly different from dried enset leaf sheath covered kocho and kocho stored in perforated concrete pit. Plastic sheet buried in the pit revealed a significant difference from storage structures made of plastic, the white and black Jeri-cans, perforated, for all months of storage time.(Table 5.2).

Table 5.2. Kocho texture evaluation after 1, 4, 7 and 10 months of storage, in different storage structures

	Texture (score in 1–4 scale)*			
Storage structure	After 1 month	After 4 months	After 7months	After 10 months
White Jeri-can (perforated)	1.00C	1.00C	1.00C	1.00C
Black Jeri-can (perforated)	1.00C	1.00C	1.00C	1.00C
Plastic sheet buried in pit	3.00B	3.00AB	3.50AB	3.00AB
Perforated concrete pit	3.50AB	2.00BC	2.00BC	2.00BC
Dried enset leaf sheath	3.50AB	2.00BC	2.00BC	2.00BC
In the pit (farmers practice)	4.00A	4.00A	4.00A	4.00A
CV (%)	13.69	28.77	21.01	15.00

*Scoring for sensory evaluation for kocho texture in a scaled of 1–4, where 1 is good, 2 better, 3 very good and 4 excellent

Kocho stored in farmers' method exhibited taste at excellent a highly significant difference from the other storage methods with two exceptions. These were plastic sheet and dried enset leaf sheath buried in the pit at storage time length of seven and ten months (Table 5.3). The two storage structures did not give significantly better taste than perforated concrete pit.

Table 5.3. Kocho taste evaluation after 1, 4, 7 and 10 months of storage in different storage structures

	Taste (score in 1–4 scale)*			
Storage structure	After 1 month	After 4 month	After 7 month	After 10 month
White Jeri-can (perforated)	1.00C	1.00C	1.00C	1.00C
Black Jeri-can (perforated)	1.00C	1.00C	1.00C	1.00C
Plastic sheet buried in pit	3.00B	3.00B	3.50AB	3.50AB
Perforated concrete pit	3.00B	3.00B	3.00B	3.00B
Dried enset leaf sheath	3.50AB	3.50AB	3.50AB	3.50AB
In the pit (farmers practice)	4.00A	4.00A	4.00A	4.00A
CV (%)	11.17	11.17	13.14	13.40

*Scoring for sensory evaluation of kocho taste in a scale of 1–4

Kocho odor did not show a significant difference for storage methods of plastic sheet buried in the pit, dried enset leaf sheath, perforated concrete pit and farmers practice after storage of 4 and 7 months. Whereas, plastic sheet buried in the pit gave comparable performance with dried enset leaf sheaths and farmers practice after storage period of 10 months (Table 5.4).

Kocho stored in different methods did not show a remarkable difference from their mean in nutrient composition (Table 5.5). Although the white and black Jeri-cans were found to affect the color, texture, odor and taste of kocho, they did not yield nutritionally less quality kocho.

Table 5.4. Kocho odor evaluation after 1, 4, 7 and 10 months of storage in different storage structures

	Odor (score in 1–4 scale)*			
Storage	After 1 month	After 4 month	After 7 month	After 10 month
White Jeri-can (perforated)	1.00C	1.00B	1.00C	1.00C
Black Jeri-can (perforated)	1.00C	1.00B	1.00C	1.00C
Plastic sheet buried in pit	3.00B	3.00A	3.50A	3.00AB
Perforated concrete pit	3.50AB	3.50A	3.00AB	2.00BC
Dried enset leaf sheath	3.50AB	3.50A	3.50A	3.50BC
In the pit (farmers practice)	4.00A	4.00A	4.00A	4.00A
CV (%)	13.69	16.77	14.15	10.12

*Scoring for sensory evaluation of kocho odor in a scale of 1–4, where 1 is good, 2 better, 3 very good

Table 5.5. Nutrient composition of kocho stored in different storage structures

	Nutrient composition (%)				
Storage	Protein	Fat	Crude fiber	Mineral ash	Moisture
White Jeri-can (perforated)	1.99	0.16	5.13	3.74	7.38
Black Jeri-can (perforated)	2.38	0.31	5.63	3.71	8.32
Plastic sheet buried in pit	1.90	0.13	6.68	3.90	7.56
Perforated concrete pit	2.18	0.31	6.67	5.23	9.44
Dried enset leaf sheath	2.37	0.20	6.97	5.23	9.44
In the pit (farmers practice)	2.47	0.34	5.73	3.74	8.96
Mean	2.21	0.24	6.13	4.09	8.19

Conclusion

In farmers' storage method of kocho, maggots were observed. The maggot number decreased when the fermentation time of kocho increased. This may be due to acidity increment of kocho because of prolonged fermentation period. On the other hand, maggots were not observed in any of the other storage methods.

Kocho stored in the perforated concrete pit did not show good color except at one month. Farmers comment was more towards sensory evaluation. The evaluation values were also scored based on their assessment of fermentation period. This might be due to the perforated concrete pit storage method that was not closed well and allowed the circulation of air inside the pit. Based on the investigators' observation, the sealed containers that allow the loss of water are preferred for kocho storage. The kocho stored in the plastic sheet had white color and good texture and gave a significant difference in almost all values for sensory evaluation. Therefore, based on the result of the present study, white plastic sheet was recommended to use rather than other storage methods. In addition, plastic sheets were not expensive to be used by most farmers.

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Chapter Six

Socioeconomics and Technology Transfer

Million Taddesse

Introduction

Enset has many different uses and contributes in securing food for smallholder farmers even at times of drought. Enset has, therefore, paramount importance in the household economy. However, adequate attention was not given in research and extension interventions to improve the production and productivity of the crop. Socio-economic studies were conducted on enset production and technology transfer. The studies used standard survey approaches and technology transfer techniques. The current chapter presents and discusses the results of the studies.

Production Systems

Depending on the environmental conditions and farming systems of a given area, different enset production, processing, storage and management practices exist in the Southern region (Anita et al. 1996). However, these practices were not systematically studied and documented. Identification of such practices and indigenous knowledge in enset production is of paramount importance for farmers, researchers, and policy makers. That would help to facilitate further research and other intervention options to generate and disseminate appropriate enset production technologies.

With that realization, a diagnostic survey was made to characterize enset production practices, identify constraints, and suggest appropriate intervention options to overcome the constraints. Representative enset growing zones and districts from the Southern and Oromiya regions were selected for the study. These included Masha district of Sheka Zone in Southern region and Wenchi and Tikur Enchini districts of Oromiya region.

Production trend

In the south, the farming systems of Masha District is dominated enset by enset products such as kocho and bulla are the major staple food types followed by maize. However, 58% of the sample farmers reported that the area allocated for enset production showed a declining trend in the last 20 years because of various environmental and socio-economic factors. Whereas, 32% of the sample farmers reported increasing trend, while 10% reported observing no change. The three most important factors responsible for the decline in acreage were bacterial wilt (47%), mole rate (13%) and moisture stress (16%). Enset bacterial wilt was the most severe problem of all the major enset growing areas of the country. Although many efforts were made to find a solution through research, no successful outputs have been delivered yet. Farmers use traditional control means such as discarding and burning the infected plants. To control mole rat, farmers use traps and flooding water into mole rat holes.

In West Shewa Zone of Oromiya region, the major activities in a typical enset farm include planting, propagation, subsequent transplanting, harvesting, processing and storage. Land preparation starts, like for other crops, following the early onset of rain and ends in July. Weeding, though not a serious problem for enset, is practiced mostly following the on-set of rainfall and right after the cessation of the rainy season (in May and September). Enset matures in almost eight years. Development of inflorescence is the sign of maturity, and high quality and quantity yield is produced from enset crop harvested at this stage. There are five age structures of enset, named locally as Naddo, Dalgee, Masiyee, Iyyibaa and Warqee. Each stage has its own spacing requirements.

Enset clones

According to local names given by farmers of Masha District, the most common clones in the area include: Gudro, Bosso, Gedo, Beresho, Shuri, Nobo, Gemmo, Yeko and Beradi. Farmers reported that clones such as Shuri and Bosso have medicinal values. Shuri corm is boiled and dispensed to a women after delivery of a child to facilitate the expulsion of placenta and to ease stomach discomfort that may be felt after delivery. The extract of leaf sheath of Bosso is boiled and drunk to get relief from back pain. Farmers also claim that clones *Nobo and Gudro* relatively tolerate enset bacterial wilt disease. Apart from its food value, the fiber from the enset plant is also used in construction. Because of these benefits, farmers are interested to expand production with clones that are high yielders and have good kocho, bulla and amicho quality. In addition, early maturing clones for amicho are preferred.

In West Shewa Zone, more than 20 cultivars were identified by farmers based on the colors of the pseudostem, mid rib of the leaf, thickness of the pseudo stem, height and strength. Some are grown mainly for food while others are for medicinal value. Cultivars such as Badadetti, Awwangii, Farasiyee, and Sabaraa are mainly grown for food. Whereas, cultivars Warqee Biddu, Astaraa, and Xaxaratt are grown both for food and medicinal value.

Method of propagation

Enset cultivation starts with the production of suckers. Although it is possible to sexually produce *enset* seedlings, all farmers in Sheka and West Shewa zones produce suckers by vegetative propagation methods. Enset plants produced from seeds are not consumed mainly because the color of kocho which is dark and have bad taste. To produce suckers, most farmers bury a quarter of the corm, while some bury half of the corm in the soil as a method of propagation. Few farmers combine both methods.

About 83% of farmer transplant three times per year, while the rest twice. The first transplanting is usually done in October and the second in January to February. In Masha district, there are five stages of enset before maturity. The first is the sucker stage locally called Beko. After six months, suckers reach Acho stage where they stay mostly for six months before they go to the next stage Ummo (Geddo). The Ummo stage lasts for one year. After this, the planting materials are again transplanted (Derashino stage). After two to three years, enset matures to produce inflorescence and reaches Gundo stage.

Crop management

In the south, farmers apply farmyard manure at the very early growth stage of enset. In the first stage, animals are penned for about 4–12 months in a temporary barn planned for enset planting field until enough manure is collected for the intended plantation. Then, the first transplant (Acho) is planted on the field. Generally, farmyard manure is applied only before planting. Only few farmers apply farmyard manure repeatedly on enset field, and there is no experience in the use of inorganic fertilizer.

Result of the survey in West Shewa showed that there is an interaction between livestock ownership and growing enset. Livestock is very important for providing farmyard manure to improve soil fertility and yield. The higher the number of livestock a farmers owns, the more likely to have a higher number of enset plantation. Enset, in turn, is important for livestock; the leaves and other parts are good sources of livestock feed especially during feed shortage.

Weeding is usually done at early stages of Acho and Ummo. Farmers usually remove dry enset leaves. Green leaves are also taken for different purposes such as aeration, mulching, and composting. This is done mostly at Derashino stage. However, most farmers remove enset leaves after two years of growth.

Drying of leaf and outer leaf sheath are indications of maturity. Inflorescence is another good indicator of maturity. But farmers practice early harvesting whenever the need arises. Most farmers usually harvest enset plants before flowering. Enset harvesting is usually done three years after attaining Ummo (Geddo) stage. Harvesting and processing may be done either weekly or twice a week. It is possible to extend harvesting time after flowering by removing the inflorescence. The practice helps to delay harvesting for about six months.

Processing is mainly the responsibility of women. Men are responsible for planting and uprooting at harvest. Farmers use traditional processing devices to decorticate or pulverize enset products such as kocho, bulla and amicho. Improved processing devices are not introduced to Masha district to improve the traditional, difficult and laborious method. Only limited numbers of farmers are aware of improved processing technologies. However, there is a growing interest to adopt processing technologies such as devices for decortications and corm pulverization. Most farmers use family labor for harvesting and processing while few exchange labor from their neighbors. Once processed, kocho is stored in pit from one month to four years depending on various climatic factors and the socio-economic status of the household.

Farmers realized that enset clones such as Yeshirakinke in Cheha and Kembat in Gumer, are tolerant to enset bacterial wilt attack. Next to enset bacterial wilt, leaf sheath rot or Ziro and corm rot were economically important diseases threatening the production of enset in the study areas. Mole rat and porcupines were also identified to be important pests damaging enset plant.

Farmers perception of bacterial wilt disease

Although some farmers believe that wind is the cause of the disease, many still believe supernatural power as the cause for the disease and the control measures practiced were related to this cause. Almost all farmers in the highland zone reported that the disease causes more damage during the dry season. In the mid-altitude zone the disease was reported to become serious in the rainy season. Whereas, some farmers believed that the disease becomes serious when the moon rises, locally known as c*hegino*.

The survey findings indicated that farmers have different perceptions about the dissemination mechanisms of enset bacterial wilt (Table 6.2). According to the majority of the farmer in mid altitude (57%) and highland (77%) zones, contaminated farm tools are believed to be the most important dissemination mechanism of wilt from infected to healthy plants. Livestock movements inside enset fields is also the second most important means of disease dissemination.

Farmers also reported that chicken and a bird locally known as kura or *ibarafech* were also serious disease dissemination mechanisms especially in the highland zone. During dry season, chicken and the bird attack the pseudostem part of enset in search of water, thereby facilitating disease dissemination. Because of the associated disease problem, therefore, farmers were not interested to keep chicken in their farms.

Farmers usually apply sanitary control measures when the severity of the disease is mild. As the disease becomes severe, farmers become desperate and stop applying sanitary control measures. According to the perception of 79% of sample farmers, sanitary control measures were not effective in controlling enset bacterial wilt attack.

Through training, demonstrations and popularization efforts, the perception of growers seem to have changed considerably. Farmers noticed that careful application of sanitary control measures helps to control enset bacterial wilt attack. Assessment on adoption of sanitary measures indicated that 64% of the sampled farmers use sanitary control measures according to advices given. However, there were also farmers who did not apply the measures strictly because of various factors, such as labor shortage, especially for female-headed households. Moreover, migration of some households to towns to look for off-farm employments has discouraged collective actions to apply sanitary control measures on each farmer's fields.

Table 6.2. Farmers' perceptions about wilt dissemination mechanisms in the mid-altitude and highland areas of Gurage Zone, 2001

Dissemination mechanisms	Farmers perception (% of respondants)	
	Mid altitude (n = 14)	High altitude (n = 13)
Contaminated farm tools	57	77
Livestock movement in enset field	43	77
Human movement in enset field	7	15
Insect pests like Jassid fly	21	8
A kind of bird "kura" and /or "Ibarafechi"	7	62
Flood	7	-
Wind, causing contact between healthy and infected plant	-	39
Harvesting infected plant	-	8
Chicken /hen attack	-	31
Dung	-	8
Human waste material	-	8
Pulling infected plant in the farm while discarding	-	8
I don't know	14	-

Adoption of improved processing devices

Some traditional devices that are commonly used to process enset products are time consuming, unhygienic and impose a lot of inconvenience to the working women. In order to improve the processing of enset products, some devices such as kocho scraper and bulla extractor were introduced and disseminated to farmers in *Wolayita*, Kembata-Tembaro and Gurage zones between 1987 and 1992 (Deribe, 1996). Assessment made on the adoption indicated that nearly half of the sample farmers use the improved devices. Among the adopters, 88% suggested the need for further improvement (Table 6.3). Half of the non-adopters also indicated that the devices need further improvement to suit their needs and circumstances. The other half of the non-adopters reported the devices to be convenient but they could not adopt them due to financial problems.

The farmers' decision to adopt or reject improved enset processing devices was influenced by the simultaneous interaction of technical, socio-economic, physical, and institutional factors. Out of 16 explanatory variables hypothesized to affect farmers adoption of improved enset processing devices, 9 were found to be statistically significant. The significant variables include: farm size, number of enset plants in a field, frequency of processing per year, extension information, farmers perception of the devices, taste of processed kocho or bulla, thin hole of bulla extractor, training and expensiveness of the devices (Table 6.4).

Table 6.3. Farmers reasons for adopters and non-adopters of improved *enset* processing devices in Gurage Zone, 2001

Farmers reasons	Non-adopters		Adopters		X^2 statistic
	n	%	n	%	
The devices need further improvement	24	48	38	88	16.96***
The devices are complex	34	68	39	91	5.18***
The devices are expensive	13	28	34	79	20.6***
Extension information	39	78	39	91	2.76*
Availability of credit	8	16	18	42	7.67***
Improved devices preserve the usual taste	19	62	31	72	10.81***
Thin hole of bulla extractor prevents easy passage of bulla	8	16	11	26	2.67 (NS)

Table 6.4. The maximum likelihood estimates of the binomial logit model

Adoption (dependent variable)	Estimated coefficient	Odds ratio	Wald statistics	Significance level
Age	-0.030	0.971	0.765	0.382
Education	-0.926	0.396	1.245	0.264
Adults	-0.146	0.864	0.389	0.533
Farm size	1.016	2.762	3.676	0.055*
No. of enset plants in a field	0.054	1.056	3.103	0.078*
Processing frequency pear year	3.368	29.026	2.941	0.086*
EXTENINFOR	2.629	13.859	4.365	0.037**
PERCPNTRAD	-0.722	0.486	0.904	0.342
PERCPNIMP	-1.934	0.145	4.703	0.030**
COMPXTY	-1.045	2.844	1.534	0.216
ABLEPURC	-0.306	0.736	0.096	0.757
Taste of processed Kocho or bulla	-1.592	0.203	3.801	0.051**
Credot	1.015	2.759	0.886	0.347
Thin Hole of bulla extractor	-1.004	0.135	3.420	0.064*
Training	2.102	8.185	3.933	0.047**
Expensiveness	-1.582	0.028	11.776	0 .001***
Constant	-1.405	0.033	1.794	0.180
Pearson-χ^2		69.1***		
-2 Likelihood ratio		159***		
Correctly predicted		88.2[a]		
Sensitivity		88.4[b]		
Specificity		88.0[c]		

*, **, *** = Significant at less than 10, 5, and 1% probability level, respectively

[a] Based on a 50-50 probability classification scheme

[b] Correctly predicted adopters based on a 50-50 probability classification

[c] Correctly predicted non-adopters based on a 50-50 probability classification scheme

The adoption of improved enset processing devices was positively influenced by farm size. Farm size is a common variable examined in adoption studies and is often a good proxy for wealth. It is often assumed that farmers with large farm size are more likely to adopt a technology, especially if the technology requires more financial investment. The number of enset plants in a field also positively influenced adoption of improved processing devices. Farmers who have relatively large number of plants in their fields are more likely to use the devices than those who have small number of plants. Because it is economically feasible for farmers who have large number of plants to purchase the devices. The frequency of enset processing per year, access to information and training positively influenced adoption of improved enset processing devices. Whereas, many other factors negatively influenced the adoption of improved processing devices. These include: farmers' earlier perception about the devices as problematic, taste or quality of processed kocho or bulla (device changes taste and quality) and the thin hole size of bulla extractor has thin hole preventing easy passage.

Conclusion and Recommendations

Enset is the most important food security crop. However, the production of the crop is challenged by many many problems. The most important problem in all enset growing areas of the country is bacterial wilt disease. Hence, more and more and integrated efforts should be made through research and other intervention options to generate appropriate technology to mitigate the disease problem. Farmers use traditional enset processing techniques which are laborious, hardy and time consuming. Improved technologies should be promoted through demonstration, popularization and training to boost production, productivity and quality of the produce. Research and development interventions should also focus on value adding technologies for industrial applications both for domestic and export markets. In addition, research efforts should be focused more towards the collection, characterization, and evaluation of enset genetic resources; varietal screening for resistance to major diseases; improving clones for desirable characters; development of integrated pest and disease management; and generation and promotion of gender sensitive technologies.

The adoption of improved technologies for processing enset products by farmers is hindered by socio-economic, technical and many other challenges and problems. Therefore, efforts to facilitate adoption of the technologies should be strengthened. For instance, it will be economically feasible to form small groups of farmers so that they can collectively purchase or borrow the devices. The introduction of improved enset processing should also consider the food habit of the society in a given area. Improving the current quality and number of extension agents also crucial for the successful transfer of improved technologies to farmers. Some of the defects of the kocho scraper must also be minimized to increase the acceptance of the devices. It may also be advisable to manufacture the devices from locally available non-metallic raw materials. Designing optimum size of bulla extractor hole may alleviate the current problem and increase farmers' adoption rate. Before large-scale introduction of the devices in a given area, practical training should be given to farmers in order to increase the adoption rate of improved enset processing devices.

Early detection, prompt destruction and proper disposal of wilt-infected plants reduce the chance of disease spread and thereby suppress development of bacterial wilt at acceptable level. All enset growers at community level should take collective actions on regular basis. If this is not done strictly, an infested field will be a source of inoculums for that area. Cultural practices such as deep tillage and turning over the soil to expose to sunlight during dry season prior to planting, proper spacing and spot rotation of infested sites would reduce disease spread. Farmers need to be trained on strict and procedural application of sanitary control measures to reduce the threat of enset wilt in major inset growing areas. Moreover, extension services need to focus on practical field demonstration of sanitary control measures to farmers.

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Part III

Sweet Potato

Part III — Sweet Potato

Introduction

Assefa Tofa, Endale Gebre and Gebremedhin Woldegiorgis

Among the root and tuber crops, sweet potato is one of the world's major crops especially in developing countries, where it ranks third in value of production and fifth in calorie contribution to human. Sweet potato is a member of the family *Convolvulaceae*, in which there are over 400 *Ipomoea* species distributed throughout the tropics. It is distributed between 40^0N and 40^0S latitude of the equator at up to 2500m.a.s.l. Although some of these species have fleshy roots, they are not usually edible except sweet potato. A very large number of sweet potato cultivars are known to exist. They differ in tuber skin (usually white, brown, yellow or reddish purple); color of the tuber flesh (usually white or yellow); shape of the tuber and weight of the tuber. On the basis of tuber texture after cooking, sweet potato cultivars can be classified generally into three groups: 1) those with firm dry, mealy flesh; 2) those with soft, moist, gelatinous flesh and 3) those with very coarse tubers which are suitable only for animal feed or industrial use (Onwueme, 1978).

As a crop sweet potato combines a number of advantage which give it an exciting potential role in combating the food shortages and malnutrition that may increasingly occur as a result of population growth and pressure in land utilization.

In many parts of Ethiopia as population growth, fertile arable land available per head diminishes. This tends to create a shift to the use of marginal land in those densely populated areas where low incomes allow only modest investment in land improvement and crop production. Therefore, crops like sweet potato which yield greatest amount of food per unit area per unit of time, and which are capable of yielding evening marginal conditions will have to be accorded their rightful place in the Ethiopian food production system. The crop also provides significant amount of energy and protein. Its production efficiency of edible energy and protein are outstanding in the developing world.

Sweet potato does best in areas with 750-1000 mm of rainfall per annum; with about 500mm falling during the growing season at altitudes of 750-2500 m and in areas where average temperature is 24°C. Sweet potato is essentially a warm weather crop. Growth is best at temperatures above 24°C; when temperature falls below 10^0c, growth is severely affected. A soil pH of 6 is most favorable for optimum growth. Though sweet potato is vegetatively propagated, it is a short day plant and photoperiod of less than 11 hours induces flowering.

Sweet potato performs well on sandy loam soil and does poorly on poorly drained clay soils. Drainage is essential since the crop cannot tolerate water logging conditions. Where the water table is high, the crop should better be planted on ridges. Although the crop can withstand drought conditions, it appeared that yield can be considerably reduced if drought occurs within the first six weeks after planting.

The tuberous roots are boiled or steamed and consumed directly. Even though it is not accustomed eating its leaf part at green stage in Ethiopia, it has high protein, vitamins and mineral content. They are used as vegetable food in many parts of the tropics. The leaves are also feed for livestock. Recently, yellow fleshed sweet potatoes are becoming recognized for their high beta-carotene (precursor of vitamin A) content.

Sweet potato has been cultivated in Ethiopia for the last several years. However, it is not known when it was first introduced in to the country. The crop became well established in the regions of Hararghe, Gamugofa, Wolayita, and Sidamo, all at low land or intermediate elevation with a reasonable amount of rainfall (Doku, 1987). Endale et al., 1992 reported that over 95% of the crop produced in the country grows in south-western, eastern and southern parts, where it has remained as one of the major subsistence crops, especially in the periods of drought. In Ethiopia approximately 90% of sweet potato is cultivated between 1500 and 2010 m (Terefe, 1994).

Yield of sweet potato varies with cultivar, locations and production practices. Despite the importance of the crop in Ethiopia yields per unit area at farm level under different management practices are generally below the potential. Based on CSA report of 1993/94 the national average yield of sweet potato was 7 tons per ha. However under research condition root yield using improved varieties and available technology ranges from 30-50 tons per ha. There are a number of biophysical and socio-economical constraints that hinder the productivity of sweet potato under farmers' circumstances. Among others, lack of high yielding and acceptable quality, and pest resistant /tolerant varieties and agronomic practices has been the limiting factors. In the following chapters the major production constraints are discussed, intervention efforts, and progresses made in the past are discussed.

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Chapter One

Sweet Potato Variety Development

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Introduction

The variety improvement research on sweet potato focuses on the collection, introduction, maintenance, characterization and adaptability studies to selected agro-ecologies. In addition, development of early, medium and late maturing, high yielding and disease and insect pest resistant varieties to different agro-ecological zones underlies the main targets for generating the package technologies for improving the productivity of the crop.

Following the introduction, collection and classification work into maturity groups, preliminary yield trials and variety trials for each maturity group are conducted with the objective of identifying high yielding, pest resistant/tolerant varieties to various agro-ecological zones (Table 1.1) as per the National Variety Release Policy. This process takes about 6-8 years before releasing an outstanding variety to growers.

Table 1.1. Some characters of the environment for selection of sweet potato at different locations

Research center	Latit.	Longit.	Altit.	Temp (^{0}C) Max.	Min.	Rainfall (mm)	AEZ*	Major soil type
Awasa	7^{0}05'N	38^{0}29'E	1700	12.1	26.9	1044	SH2	Fluvisols
Areka	7^{0}09'N	37^{0}47'E	1830	13.7	25.6	1528	SH2	Nitosols
Melkassa	8^{0}24'N	39^{0}21'E	1550	14.0	24.8	763	SM$_2$	Ertisols, Cambisols, Yemisols
Bako	7^{0}06'N	37^{0}09'E	1650	13.2	27.9	1210	SH$_2$	Nitosols
Jima	36^0'E	7^{0}46'N	1753	11.3	25.9	1554	H$_2$	Nitosols, Cambisols
Adet	11o16'N	37o29'	2240	12	24	1250	M2	Nitosol, Cambisol

*Agro-ecological zone

Clonal Selection and Stability Studies

Variation is the basis for exercising selection in crop improvement undertakings. The extent of variability among the population and the association between vield and yield components in sweet potato is not yet carefully studied.

Early stage evaluation

A wide genetic base of germplasm were introduced from CIP and other sources and screened under Ethiopian condition. The introductions were made in the form of clones and varieties which are then planted and grown in isolated quarantine field under supervision for one year. Evaluation at this stage focuses on quarantine diseases as well as tolerance to major pests.

Beginning from the second year, clones are evaluated to characterize the clonal accessions in to maturity groups, and tuber qualities like tuber morphology, color, taste, and reaction to diseases and insect pests such as sweet potato butterfly, sweet potato weevil and for abiotic stresses such as drought. Early stage selection, as has been seen for Irish potato, relies on an overall visual appraisal, which would take many of these characters in to account to a certain degree. At a later stage, more objective methods are used to assess the relevant characters (Table 1.2). In some cases, varieties and commercial cultivars are also introduced and evaluated for their yield and tolerance to the major diseases and insect pests of the crop.

Table 1.2. Typical characteristics to be considered in variety evaluation and selection

Characteristics	Specifics
Agronomy and yield	Maturity, marketable yield, number of roots, root size, weight, root yield, vine length, top fresh weight,
Tuber morphology	Flesh color, root growth, shape
Quality	Dry matter, appearance, taste and texture, color, storage characters
Resistance	sweet potato butterfly, sweet potato weevil

Adaptability studies

Sweet potato, among other root and tuber crops, has become the daily traditional food components in the south, west, east and also the north parts of the country. Its contribution for household food security is growing vital. Therefore, efforts have been made to develop improved technologies such as varieties that are high yielding, resistance to diseases and pests, good flesh and post harvest qualities, high above ground biomass for livestock feed. The shape and size of the root are considered to be the most important horticultural qualities. The increasing familiarity of the roots by rural and urban dwellers has opened a growing market for the crop but with a demand for improved quality.

Thus, in recent years the research has focused on evaluating adaptability of sweet potato clones and varieties under diverse environments for specific and wider adaptation. Efforts in the past had concentrated in the south and east part of the country. However, with expanding trend of the crop the crop to other parts has encouraged the respective regional research institutes to strongly involve in the variety development research. The focus of the research as also broadened to include quality aspects that have high market demand that can turn the sweet potato production in to a profitable enterprise for the house hold farmers and for the emerging private growers.

Specific adaptation

To some extent, the agro-ecology for sweet potato production is presumably limited to certain places. However, evaluation of clones/genotypes or varieties for different environments for yield, tolerance to sweet potato butterfly, sweet potato weevil and other biotic stresses have clearly been demonstrated beneficial for the selection of right genotype for a given locality. Several years of variety testing across different environment indicated the presence of interaction between different clones/genotypes and the environment for various characters particularly root and above ground biomass yields and pest incidences.

Southern Ethiopia

Evaluation for yield, quality and adaptability of 11 clones was conducted for three years (1993-95) at two locations, Awassa and Areka. Roots are graded in to marketable roots which usually include those not diseased and damaged, but with different sizes that are grouped under, small sized (100-200 g), medium sized (201-350 g) and large sized (351-500 g). Whereas, unmarketable roots include those, which are very small (<100 g), and oversized (>500 g), with symptoms of disease, rotting, damaged by insect and mechanically and cracked. The superior clones from each group were verified on farmers' fields in different agro ecological zones where farmers also assessed the clones for root size, root skin and flesh color, marketability of roots, taste and above ground cover were considered on top of stability, uniformity and resistance to pest. The overall performance of the tested clones over the years at Areka was very poor probably indicating the unsuitability of the location for sweet potatoes production.

The mean total root yield indicated that clones TIS-1499, I-4444 and TIS-3017 (2) were the most promising (Table 1.3). These three clones released by the name Kudade, Dubo and Feleha, respectively in 1996/97. Clone TIS-3017 (2) gave rather low yield at Areka in all seasons. Its use is restricted around Awassa and similar agro ecologies to maintain good yield.

Table 1.3. Mean total root yield (t/ha) of early maturing sweet potato varieties evaluated at Awassa and Areka for three years (1993-1995)

Clones	Awassa	Areka	Overall mean
TIS1499	32.4	15.8	24.1
I-444	29	13.6	21.7
TIS-3017 (2)	25.1	8.2	16.7
Koka 18	24.1	10.3	17.2
393	20.8	7.3	14.1
Cemsa	16.8	9.3	13.0
TIS-2498	11.0	7.0	9.0
Wadada	10.6	2.4	6.5
CN-1032-16	7.0	2.8	4.9
Koka 9B	6.1	3.8	4.9
Bucaraso	3.8	2.7	3.3
Mean	17.0	7.6	

Similarly, medium maturing clones were evaluated along with a standard check (Koka 6) where varieties AJAC-I, Guralowlow, and 375 were found superior in total root yield performance with values of 35.4, 30.7 and 29.6 t per ha, respectively (Table 1.4). These varieties were released by the name Guntute, Damota and Bareda in that order during 1996/97.

Table 1.4. Yield performance (tons ha^{-1}) of medium maturing sweet potato varieties at Awassa and Areka in 1993-95.

Cultivars	Awassa	Areka	Overall mean
AJAC-1	51.8	18.9	35.4
Guralowlow	43.4	18.0	30.7
375	42.5	16.8	29.6
Koka-6	40.7	13.1	26.9
Koka-26	21.4	12.0	16.7
AIS-35-2	17.9	12.0	14.9
Carales	14.9	6.6	10.8
368	13.4	5.8	9.6
CN-1108-13	12.2	8.1	10.1
Bekule	11.8	10.2	11.0
377	9.2	5.7	7.4
Baracuty	4.6	6.0	5.3
Mean	21.1	10.4	

Among the late maturing clones evaluated, Awassa 83 gave the highest mean total root yield of 36.6 tons per ha at Awassa and an over all mean of 20.8 tons per (Table 1.5). This variety was released in 1998 for Awassa and similar agro ecologies.

Table 1.5. Mean total root yield (t/ha) of late maturing sweet potato varieties evaluated at Awassa and Areka

Cultivars	Awassa	Areka	Overall Mean
Awassa-83	36.6	4.7	20.8
311	26.3	11.2	20.2
374	21.9	6.1	15.6
405	21.7	5.2	15.1
Local Check	17.5	9.1	14.1
Koka-14	16.3	7.9	13.0
Erergota	18.2	4.4	12.7
Mean	20.3	7.3	

It can be observed that the two locations (Awassa and Areka) that have been used as varying agroecology to evaluate the sweet potato clones display contrasting environment with regard to adaptability and yield in all the maturity groups. Most of the clones at Areka could not express their potential for yield and the location mean in most case never exceeded the national average. It might be important to consider the relevance of using this location as a testing site in the variety development scheme in the future.

In 1997-2000 selected 12 early maturing clones, a standard and local check were evaluated at Awassa, Belella, Areka and Humbo with the objective of selecting adaptable, early maturing and high yielding varieties. Combined analysis of over years and locations revealed remarkable differences compared with the local check (Table 1.5). The variety 192040-I gave 13.3 tons per ha of marketable and 18.4 tons per ha total root yield, which was the highest compared with the others. On top of this, the sensory evaluation put this variety the best (data not shown) and as a result it was released under the name "Belella" in the year 2002. The other variety (192009-VIII) was released under the name "Temesgene" after verification in the year 2004 for its comparable yield to the standard check (Table 1.6).

Table 1.6. Combined analysis mean marketable and total root yield (t/ha) of early maturing sweet potato variety trial of 1997-98 and 2000

Treatments	Marketable root yield ($t\ ha^{-1}$)	Total root yield ($t\ ha^{-1}$)
192040 I	13.3	18.4
Kudade (standard check)	12.3	18.9
192054 V	12.2	16.3
192009 VIII	12.1	17.4
192054 VII	11.4	15.8
192054 VIII	9.5	13.3
192054 IX	8.7	12.5
192001 I	8.5	15.1
192009 V	7.8	10.6
192008 III	7.4	13.1
Local check	7.1	10.5
192054 VIII	6.9	10.2
192001 II	6.8	10.7
LSD (5%)	5.373	6.097
CV (%)	40.5	21.17

Another set of medium maturing clones were evaluated in 1997-2000 at three locations (Wonago, Awassa and Areka) with the objective of selecting adaptable, medium maturing and high yielding varieties (Table 1.7). In addition to root yield, other economically important characters like stand at harvest, internodes diameter (for vigorous), vine length (in relation to number of planting material to be obtained and implication with soil conservation), and green top yield (feed purpose) were also evaluated

The overall mean results showed that most clones preformed better than the local check for total root yield in all locations. There was no significant difference among treatments when compared with standard check (Koka 7).

The clones were also evaluated for vine yield as this is a desirable trait next to root yield to use as planting material, livestock feed, weed suppression and retains soil moisture. Clones 192026-II and 192009-IX gave mean green top weight of 30.5 and 26.2 tones per ha, respectively which is higher than standard check (24.17 t/ha). But based on acceptable agronomic traits and quality, the clone 192026-II was released by the local name Beletech in the year 2004.

Western Ethiopia

Root and tuber crops has become the daily traditional food components in west Ethiopia. Its contribution for family level food security is growing vital. Therefore, efforts have been made to develop improved technologies such as varieties that are high yielding, resistance to diseases and pests, good flesh and post harvest qualities, high above ground biomass for livestock feed. The shape and size of the root are considered to be the most important horticultural qualities.

The other quality attributes like starch, sugar and fiber content as well as vitamins are also very important quality parameters though often are not under critical evaluation. In this part of the country specific preference of consumer is considered which includes white skin and white fleshed roots with good taste.

Oval shaped roots with weight of 200–500 g are most preferred in the market. In the region sweet potato has been perceived as a hardy crop, which performs well under relatively less fertile soil and poor management conditions. However, from several years of experience it is noted that continuous cultivation on the same field causes high infestation by beetles. The beetles damage the leaves while the larva feeds on the roots, which often causes serious yield loss.

Further selection of clones through field experiments were conduced in 1995 and 1996 at Bako to determine the extent of variability among twenty five sweet potato genotypes, 12 each for early and medium maturing types along with a standard check.

Yield ranges of 7.6-28.8 t/ha total root yield and 12.8-50.1 tons per ha fresh top part were recorded for medium maturity group. Similarly, yield ranges of 4.7-22.0 t/ha total root yield and 11.9-46.9 t/ha fresh top part were recorded in early maturity group. This shows the existence of variability for those traits in both maturity groups which provides useful ground for selecting the desirable genotype. High phenotypic and genotypic variances were also obtained for yields of total and marketable root and fresh top part (Table 1.8).

Table 1.7. Mean total root yield (t/ha) of sweet potato clones at Awassa, Wonago and Areka (1997-98 and 2000).

Cultivars	Awassa			Wonago			Areka		
	1997	1998	2000	1997	1998	2000	1997	1998	2000
192026-II	43.4	28.4	12.1	16.7	40.3	24.3	10.5	14.1	4.7
192026 V	29.0	29.0	8.2	23.5	22.2	20.0	22.7	3.1	1.7
192054-III	22.5	11.4	3.4	34.4	11.9	11.9	8.0	28.8	11.1
192009 IX	32.4	29.9	9.8	26.9	31.3	26.1	7.3	15.2	7.1
AJAC-I	33.5	33.5	10.0	23.5	32.9	20.6	15.8	24.9	8.1
Koka-6	28.7	41.1	11.6	35.2	34.5	10.3	20.0	22.6	5.6
Local check	22.2	16.0	9.6	10.5	17.4	14.6	22.7	6.9	5.5
Mean	29.5	27.1	9.2	24.4	27.2	18.3	13.1	16.5	6.2
LSD (%5)	9.67	9.28	9.33	14.06	11.69	8.67	6.92	7.9	4.86
CV (%)	22.1	23.1	68.0	38.8	28.9	32.0	35.6	32.3	52.5

Broad sense heritability estimates ranged between 44% and 79% in the medium maturity group and between 4.4% and 81.3% in the early one. Total root yield (76.8%), fresh top part yield (70.5%) and vine length (81.3%) in early group in medium group. Heritability (*H*) values ranged from moderately high to high, indicating that the genotypes contributed the largest shares of the phenotypes as compared to the environmental effects in these traits. Other characters showed lower to medium heritability values (Table 1.8).

Table 1.8. Estimates of variability, heritability in the broad sense and expected genetic advance for seven characters in sweet potato (early and medium maturity groups)

Character	Maturity	Range	Mean	+(-)SE	σ^2p	σ^2g	H (%)	GA
TRY	Early	47.08-220.2	133.50	15.36	8954.49	6873.05	76.75	149.62
	Medium	75.60-287.9	181.50	7.87	3264.60	2104.04	64.45	75.85
MRY	Early	41.43-163.0	140.47	10.50	20336.73	2239.86	11.01	32.35
	Medium	52.43-174.1	116.61	6.37	2227.65	1761.37	79.06	76.86
FTRY	Early	11.90-47.0	30.56	4.87	422.71	298.04	70.50	29.86
	Medium	12.83-50.1	30.09	1.29	90.26	50.95	56.44	11.04
VL	Early	0.29-1.31	0.98	0.75	0.16	0.13	81.29	0.65
	Medium	0.56-2.4	1.40	0.56	0.19	0.12	66.67	0.59
IL	Early	2.55-5.3	3.93	0.41	2.06	1.2	58.25	1.72
	Medium	3.10-12.2	6.27	0.34	5.66	4.43	78.26	7.90
NR/P	Early	4.25-9.9	6.44	1.92	20.94	0.91	4.35	0.41
	Medium	3.07-9.9	4.08	0.17	1.46	0.65	44.33	1.10
WR/P	Early	0.4-1.4	0.87	0.21	0.30	0.08	25.33	0.28
	Medium	0.37-1.9	0.78	0.04				

Key: TRY= total root yield; MRY = marketable root yield; FTRY = fresh top part yield; VL = vine length; IL = inter node length; NR/P = number of roots per plant and WR/P = weight of roots per plant.

Total root yield was negatively correlated with inter node length, vine length and fresh top part yield in the medium maturity group. The explanation is that excessive foliar growth could result in a compensated reduction of root yield. However, weight of roots per plant was positively correlated (r = 0.56) with total root yield (Table 1.9). The most desired economic character, i.e. marketable root yield was positively and significantly correlated with total root yield, with weight and number of roots per plant in both groups.

Therefore, evaluation based on these characters should give valuable information if considered during variety selection. In contrary, marketable root yield was negatively correlated with inter node, vine length, number of roots per plant and fresh top part yield in the medium maturity group. This indicates the compensated reduction in marketable root yield for excessive vine growth.

Table 1.9. Correlation of seven quantitative traits in sweet potato

Characters	Maturity	IL	VL	NR/P	WR/P	FTPY	TRY	MRY
IL	Early	1	0.25*	0.24*	0.13	0.053	-0.08	0.13
	Medium	1	0.77**	0.05	0.36*	0.70**	-0.041**	-0.51**
VL	Early		1	0.12	0.21*	0.39**	0.11	0.04
	Medium		1	0.12	-0.36**	0.59**	-0.51*	-0.50
NR/P	Early			1	0.03	0.04	0.17	0.49**
	Medium			1	-0.24	0.20	-0.22	-0.33*
WR/P	Early				1	-0.1	0.33	0.06
	Medium				1	-0.35**	0.56**	0.70**
FTPY	Early					1	-0.03	0.11
	Medium					1	-0.39**	-0.47**
TRY	Early						1	0.29**
	Medium						1	0.87**
MRY	Early							1
	Medium							1

Key: ** = significant at ($p = 0.01$), * = significant at ($p = 0.05$)

Adapted from Girma (1997).

Evaluation of clones and release varieties under various environments (Bako, Loko and Nedjo) in western Ethiopia in 1998-2001, and south western (Jimma, Metu and Teppi) in 1996/97 cropping seasons for early and medium sweet potato varieties. Koka 18, an early maturing variety gave 29.51% higher marketable, and 22.70% total root yield over the standard variety in all locations. It was observed that on high acidity soils of Nedjo some varieties (for example, Dimtu, Koka 18 for early and 375 and AJAC-1 medium maturing) performed better (tables 1.10 and 1.11). Varietal differences were also recorded elsewhere in response to soil acidity (FAO, 1979).

Evaluation of sweet potato genotypes on acid soils seems to be an important area for future research. Moreover, it appeared that there was differential varietal reaction to sweet potato weevil and Cemsa roots were considerably affected. This might signal the emerging economic importance of the pest in the area. In the south west Koka-12 and Cemsa performed better (Table 1.12).

Table 1.10. Marketable and total root yield (t/ha) of early maturity varieties at three locations, 1998-2001

Variety	Bako		Loko		Nedjo		Overall mean	
	MRY*	Total	MRY	Total	MRY	Total	MRT	Total
Koka 18	28.7	32.59	19.01	22.29	3.85	4.57	17.2	19.8
Dimtu	24.32	28.49	8.82	10.64	4.58	5.04	12.6	14.7
Tis-1499	21.98	25.29	14.2	16.21	1.31	1.89	12.5	14.5
I-444	15.62	19.28	5.36	7.41	0.97	1.42	7.3	9.4
CN-1032-16	8.27	11.73	4.23	9.2	1.39	1.96	4.6	7.6
Local	11.29	14.43	2.79	4.98	1.51	2.05	5.2	7.2
Koka 9B	8.89	11.32	2.59	4.19	1.27	1.72	4.3	5.7
LSD (5%)	4.7	5.2	3.25	2.47	0.83	0.93		

*MRY= marketable root yield

Table 1.11. Marketable and total root yield (t/ha) of medium maturity varieties at three locations, 1998-2001

Variety	Bako		Loko		Nedjo		Overall mean	
	MRY*	Total	MRY	Total	MRY	Total	MRT	Total
375	25.0	30.5	5.8	6.3	2.5	2.9	11.1	13.2
AJAC-1	23.3	28.4	10.2	12.6	2.6	3.3	12.0	14.8
377	19.1	22.5	3.3	6.1	1.0	1.2	7.8	9.9
Koka 6	19.8	25.2	6.3	9.4	2.0	2.7	9.3	12.4
IS-35-2	14.7	17.6	2.0	3.1	1.3	1.7	6.0	7.5
White star	13.4	18.9	3.3	5.9	1.7	2.3	6.1	9.1
Cemsa	22.2	26.6	6.3	7.6	1.9	2.2	10.1	12.1
Local	17.4	20.2	3.5	5.7	1.3	1.8	7.4	9.3
LSD (0.05)	6.3	20.24	2.57	1.06	0.49	0.49		

*MRY= marketable root yield

Table 1.12. Mean marketable root yield t ha^{-1} of sweet potato varieties evaluated at different locations

Variety	Jimma	Metu	Teppi	Overall mean
Abosto	12.4	19.8	24.8	19.0
Melkassa-II	10.9	19.2	24.8	18.3
Cemsa	22.4	23.9	23.6	23.3
Koka-25	19.3	18.8	23.5	20.5
Koka-28	15.2	18.6	23.0	18.9
Koka-12	15.0	26.1	31.3	24.1
Koka-9B	15.5	19.7	27.8	21.0
Koka-6	8.8	19.8	18.9	15.8

Northern Ethiopia

Due to recent expansion of the crop in north Ethiopia, a regional variety evaluation was initiated to promote the production and improve productivity in this non traditional areas. As a result in 1998-99, a multi location evaluation of genotypes was conducted at Adet, Pikolo Abay and Finote Selam using 13 sweet potato genotypes of early to medium maturity groups.

Genotypes were found having differences for adaptability in the tested localities (Table 1.13). Stability of genotypes across varying environments, seasonal variation within a location and across differing locations, was seen on their mean total root yields. Stability measures on regression coefficients of genotypes mean yield on the environmental means using procedure of Eberhart and Russell (1996) ranged from 0.58 to 1.64. Some genotypes like 192040-I which also gave high root yield showed a tendency of specific adaptation to better environments. Some genotypes in this case 192054-IX was found reasonably stable it values of regression and high coefficient of determination (Table 1.13).

Table 1.13: Combined mean root yield and yield components of sweet potato variety trial or two years (1998-1999) and three locations

Genotypes	GTY* ($t\ ha^{-1}$)	MRY* ($t\ ha^{-1}$)	Total RY ($t\ ha^{-1}$)	*b*	S2d	R2
444-I	25.4	7.8	13.1	1.30	0.24	89.0
192001-I	42.4	4.3	9.1	0.87	0.14	90.0
TIS-3017	45.9	5.0	9.9	0.96	0.43	55.0
192040-I	50.0	10.5	16.3	1.64	0.36	84.0
192054- XIII	55.7	5.9	10.6	0.96	0.38	61.0
192054-IX	64.5	6.9	11.9	0.97	0.16	90.0
192008-II	44.9	4.1	9.1	0.58	0.32	45.0
192040-VII	61.9	4.5	8.6	1.01	0.31	73.0
192054-VII	43.5	4.8	10.2	0.85	0.20	82.0
192009-VIII	34.2	2.4	8.0	0.69	0.12	91.0
TIS-1499	48.6	5.5	11.4	0.65	0.49	30.0
192009-V	62.2	5.3	9.0	0.98	0.57	42.0
192054-V	42.7	7.3	11.8	1.47	0.29	87.0

*MRY= marketable root yield; *GTY= green top yield

Wide adaptability

Sweet potato is grown mostly in the south, Southeast and South-western part of Ethiopia under different soil, moisture and other environmental conditions. Considerable variation is experienced among temperature gradients, rainfall distribution, and soil types for different agro-ecological classification of Ethiopia. In order to identify varieties that can give good yield grown under such variable environment requires involving multi-location trials in the variety selection process. This test of varietal performance across different locations helps to assess the stability character of genotypes. The possibility for genotypes interacting with environment to reveal variable degree of gene expression for the unfolding environmental characters necessitates such studies. Micro-environmental variations and variable genotypes interact somehow differently that is well reflected on the performance of the crop in the field in terms of crop growth, yield, resistance to pests, and root quality. This interaction has been the fundamental reason for the selection program to undertake multi-location experiments in the improvement process in Ethiopia. Therefore, the Sweetpotato improvement research has been promoting varieties that have been suitable for growing in relatively diverse environment with wider adaptability.

Orange Fleshed Sweet Potatoes

Vitamin-A deficiency (VAD) is one of the most widespread micronutrient deficiencies in developing countries. More than 90 countries worldwide are categorized by the World Health Organization (WHO) as having a public health problem concerning clinical (very severe) and/or sub-clinical (severe) vitamin-A deficiency (WHO, 1995). Ethiopia is included in the clinical VAD category. The common diet of rural poor is cereal based which is lacking vitamin A (VA).

VAD increases children's risk of common illness impairs growth, development, vision and immune systems, and in severe cases results in blindness and death (Ruel, 2001).There are several approaches that are effective in combating VAD. These include, capsule supplementation, food fortification, diet diversification and public health measures.

The rural and urban poor can not afford expensive VA rich foods such as fish oils, liver, milk, eggs and butter, which do have VA in true form (retinol) that can be used directly by the body. Plant foods and vegetables contain precursors, or pro-vitamin-A (β-carotene) and other carotenoids that the human body converts to VA.

For long term and sustainable goal to combat VA deficiency, consumption of a variety of local foods that are rich in VA will provide adequate VA. Among the available options, orange fleshed sweet potato (OFSP) has a potential to provide adequate VA intake. Prior studies revealed that OFSP is the most promising plant source of β-carotene (Low *et al*, 1997, Hagenimana *et al*, 1999 and Sebuliba *et al*, 2001). Because of seasonal production and limited storage, life of the roots, the supply and regular consumption of OFSP for adequate intake of β-carotene is needed.

According to WHO lack of VA, Iron and Zinc are the three most important micronutrient deficiencies. Out of these, VAD is a leading cause of early childhood death, a major risk factor for pregnant and lactating women.

A recent impact assessment study conducted by international potato centre (CIP) and Michigan State University strongly suggests that 30 million African children under the age of 6 years benefit from the new orange-fleshed sweet potato varieties. A similar study conducted in Kenya by CIP and International Centre for Research on Woman (ICRW) indicated that OFSP based products are accepted by both producers and consumers in terms of appearance, taste and texture; and contributed to the alleviation of VAD. In the same way the study demonstrated that the daily addition of less than 100gm of OFSP to the diet could prevent VAD in children, pregnant women and lactating mothers.

Sweet potato is still the major food component in the highly populated areas of the country; β- carotene rich materials were tested around Awassa and found adapted to the area. Two OFSP varieties namely, Guntute (from Awassa Research Center) and Koka-12 (from Nazareth β-research Center) were released for root yield of 35.5 and 25t/ha, respectively (Table 1.14). These two varieties were also found superior in root yield and important agronomic parameters in the western parts of Ethiopia and thereby recommended for wider area production. These materials are well known for their rich content in β-carotene.

Therefore, these varieties are recommended against VAD. To have more orange fleshed sweet potato varieties with high dry matter and high beta-carotene content introduction and screening is strengthened since the year 2000. Out of various OFSP research and development activities, participatory evaluation of promising clones was carried out at Wonago, Chanomille and Awassa in 2202 and 2003. Combined analysis for vine length, green top, marketable root yield and total root yield revealed the presence of variation among clones.

Beta-carotene content and dry matter determination was worked out from last season root yield. Based on the laboratory analysis (Table 1.15), Guntute gave the highest beta-carotene content (744 μg/mg) followed by koka- 12 (310 ug/mg).

Table 1.14. Released orange-fleshed sweet potato varieties

Varieties	Year of release	Maturity group	Maturity Period (days)	Adaptation zone (Altitude)	Carotene (ug/mg)	Root yield (t/ha)
Guntute	1997	Intermediate	121-150	1200-2000	744	35.35
Koka-12	1987	Intermediate	121-150	1200-2000	310	25.00

Table 1.15. Mean beta-carotene content (μg/gm) of sweet potato clones on dry weight basis and dry Matter Content (%)

Clone	β-carotene (μg/mg)	Dry matter (%)
Zapallo	155.0	27.6
Kemb-10	0.0	20.2
Lo-323	172.0	29.8
TIS-8250	32.7	23.1
192054-IV	0.0	17.1
192040-I	3.2	16.5
Tainung No.15	18.9	18.2
Japon Tresmesino	202.0	15.9
Koka-12	310.0	17.3
Damota	63.4	18.3
Guntute	744.0	14.7
Local check	0.0	20.0

So far four early (3-4 months), three medium (4-5 months) and one late maturing (>5 months) white flesh sweet potato varieties are released. In addition, six orange/yellow flesh sweet potato varieties with high beta-carotene(precursor of Vitamin A) content have been also released.

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Chapter Two

Sweet Potato Agronomy

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Introduction

In sweet potato, like in all other crops, agronomic factors and indeed the management practices used are among the crucial factors that highly influence crop yield and quality. However, sweet potato farmers in Ethiopia usually use traditional management practices. In most cases, the farmers practices cannot effectively and efficiently address the different agronomic challenges and problems by growers. The production and productivity of the crop has thus remained low due to poor management, among other major reasons.

The sweet potato improvement research program undertakes different works that can help to alleviate the existing production and productivity barriers of the crop through the use of not only improved varieties but also appropriate management practices. Good management would enable farmers to exploit the potential of improved or local sweet potato varieties for higher yield and quality produce. The current chapter discusses the major agronomic factors affecting the production of the crop and reviews available research findings and field experiences.

Seed Bed Preparation

Different seed bed preparation methods are used in sweet potato production at different localities based on the soil type, moisture holding capacity, depth and workability. However, the most common methods are mounds, ridges and planting on the flat. Each method has its own merits or otherwise. In light of this, studies were undertaken to evaluate three seed bed preparation methods (flat, open ridge and tied ridge) for three consecutive years at Awassa and Areka. There was no remarkable variation in results in both locations among different methods of land preparation. Therefore, flat planting was considered beneficial and hence recommended for areas like Awassa where the amount of rainfall is sufficient and the soil is more of sand.

But, generally in moisture stress areas or during non-rainy season, tied ridge is the most universally recommended method of growing sweet potato. However, at Bako areas, flat planting yields lower than other methods like mound and ridge making. Planting on the flat is also unsuitable for soils with high water table and in places were soils are not easily workable. In addition, ridge making can be mechanized and it helps in ameliorating soil erosion. Hence it is progressively replacing mound making as the most common land preparation method for sweet potato production.

Spacing

Spacing may vary depending on soil condition and crop variety. In root and tuber crops, spacing directly affects the root size grades for domestic as well as for market. The effects of spacing on growth and root yield of sweet potato were evaluated at Areka and Awassa (representing the southern region) and at Bako, Jimma and Teppi (representing the sub-humid to humid western region) to determine the optimum plant and row spacing. Inter-row spacing of 20, 40, 60, and 80 cm and intra-raw spacing of 20, 30, 40, and 50 cm were evaluated for two consecutive years at Awassa and Areka. In addition, inter-row spacing of 60, 80, 100, 120 and 140 cm and intra-raw spacing of 25, 30, 35, 40 and 45 cm were evaluated at Jimma and Teppi for three years (1999-2002). Similarly, inter row spacing of 80, 100 and 120 cm and intra-row spacing of 30, 40 and 50 cm were evaluated at Bako. The results of the study at Awassa and Areka indicated that marketable root yield was not affected by inter-and intra-row spacing (Table 2.1). However, better marketable yield was obtained from the two areas at a spacing of 60 cm x 30 cm. The spacing was recommended for those areas and similar agro-ecologies.

Significant variation was recorded among row distances by plant spacing interactions during 1979 and 1980 cropping seasons on marketable root yield at Bako. The 100 x 30 cm spacing was found optimum for sweet potato production in benefiting the plants by providing optimum soil root coverage, ease of applying agronomic management practices and enabling large root yield to be produced (Table 2.2). At Jimma, 100 cm x 25 cm gave the highest (17.97 t/ha) mean total root yield. Whereas at Teppi, total root yield was affected by inter row and intra row spacing. As a result, the highest total root yield (18.35 t/ha) was recorded from the spacing combination of 60 x 35 cm.

Hence, the above spacing combinations were recommended for the respective test areas and other similar ecologies of the southwestern region (Table 2.3). The recommendations have considerable difference in spacing between rows varying form 60 up to 100 cm. This difference has an implication on quantity of planting material and cost of production. There might be a need to further look in to the problem and identify the reasons behind and see the possibility for cost effective recommendation.

Table 2.1. Effect of row and plant spacing on marketable root yield of sweet potato at Awassa (t/ha) in 1992-1993

Row spacing (cm)	Plant spacing (cm) 20	30	40	50	Mean
20	34.1	28.0	22.8	27.7	28.3
40	21.2	31.0	27.4	25.6	27.8
60	25.2	31.1	28.5	19.6	26.1
80	26.0	26.9	23.8	23.7	24.9
100	17.9	21.6	18.8	18.4	19.1
Mean	24.8	26.2	27.6	24.4	23.0
LSD (0.05)	Row spacing = 3.5; Plant spacing = 3.1				
	C.V. = 28.1%				

Source: Adapted from Geleta (1996)

Table 2.2. The effects of inter and intra row spacing on marketable root yield (t/ ha)

Spacing (cm)	Cropping season			Mean
	1979	1980	1981	
80x30	32.0	14.4	15.7	20.7
80x40	28.8	12.5	16.6	19.3
80x50	27.1	11.6	17.5	18.7
100x30	30.7	13.3	19.0	21.0
100x40	25.8	10.9	15.6	17.4
100x50	22.1	12.o	13.1	15.7
120x30	24.9	14.0	18.4	19.1
120x40	20.3	12.5	15.3	16.0
120x50	23.0	9.4	15.5	16.0
CV (%)	9.9	15.0	19.0	
LSD (5%)	2.1	4.5	NS	

Source: Girma (1998)

Table 2.3. Effect of row and plant spacing on total root yield (t ha^{-1}) of sweet potato at Jimma and Teppi, 1999-2002

Row spacing (cm)	Plant spacing (cm)					
	25	30	35	40	45	Mean
			Jimma			
60	15.5	15.3	16.4	15.8	16.1	15.8
80	14.2	17.7	16.2	16.7	15.8	16.1
100	18.0	17.9	15.6	15.4	15.6	16.5
120	15.6	16.7	15.9	14.4	14.3	15.4
140	17.5	16.3	16.8	14.7	16.6	16.4
Mean	16.1	16.8	16.2	15.4	15.7	
			Teppi			
60	17.8	15.8	18.4	14.0	18.1	16.8
80	13.5	13.4	11.2	15.4	16.3	14.0
100	11.7	12.3	14.0	12.9	14.6	13.1
120	13.9	15.9	12.2	12.7	12.5	13.5
140	12.4	10.7	11.6	12.4	10.0	11.4
Mean	13.9	13.6	13.5	13.5	14.3	

CV (%) = 23.05 (Jimma), 31.86 (Teppi)

Soil Fertility Management

Soil fertility decline is noted as the principal cause for crop yield reduction in Ethiopia. This has been happened due to continuous cultivation, removal of crop residue for livestock feed and fuel wood, insufficient fertilizer supply, erosion and poor soil management. This aspect may assume serious dimension in root and tuber crops production, particularly sweet potato as the crop is heavy feeder of nutrients, because it bulks high yield in a relatively short period. Therefore, it is essential to replenish soil fertility as the soils in most parts of the country are found depleted of the inherent nutrient content to sustain crop growth and good yield. Efforts that have been made to mitigate theses problems is discussed below.

In 1992-93 an on farm sweet potato variety Cemsa was verified along with White star (a standard variety and local check using two fertilizer levels 0/0 and 100/100 N/P2O5 at 13 farmer fields (Abdissa, 1997). Yield considerably varied between varieties and due to application of N and P. The economic analysis for applied fertilizer indicated that the highest net benefit was obtained due to applied fertilizer with net benefits of 33% (Cemsa), 59% (White star) and 50% (local) and MRR of 14% (Table 2.4). This high profitability remained robust even when cost of fertilizer was raised by 10 or 15%. Farmers preferred Cemsa to the other varieties for characteristics like ease for intercropping, palatability, resistance to diseases/pests, marketability, tuber size and color, and tolerance to tuber management.

Table 2.4. Partial budget, dominance and marginal rate of returns (MRR) analysis for on farm testing of sweet potato varieties at Bako

N/P (kg/ha)	0/0			100/100		
	Cemsa	White star	Local	Cemsa	White star	Local
Average yield (t/ha)	22.1	11.6	13.9	30.3	19.4	21.0
Adjusted yield ((t/ha)*	19.9	10.5	12.6	27.2	17.4	19.7
Gross benefit (Birr/ha)	29844	15681	18843	40864.5	26146.5	29538
Costs that vary (Birr/ha)						
Fertilizer	0	0	0	718	718	718
Opportunity cost of labor for fertilizer application	0	0	0	28	28	28
Total cost that vary (TCV)	0	0	0	746	746	746
Dominance analysis						
Net benefit	29874	15681	18843	40118.5	25400.5	28792
TCV	0	0	0	746	746	746
Status		D	D	ND	D	D

Source: Adapted from Abdissa (1997)

D = dominated treatments; ND=non-dominated treatments; * = yield adjustment coefficient of 10 % was taken appropriate.

In 1998-2001 fertilizer need studies have been conducted at different localities Awassa, Areka, Bako, Loko and Nedjo and it was indicated that N and P rates had no significant effect on total root yield, green top and stem length of sweet potato (Table 2.5). However, some rates like 46/44 and 92/22 kg per ha of N and P had higher root yields although inconsistent for statistical validation. The N increment beyond 46 kg showed root yield decline which could be caused by excessive vegetative growth (data not shown) instead of root bulking.

Table 2.5. Sweet potato root yield (t/ha) under different NP fertilizer rates at Awassa

N (kg/ha)	Phosphorous (kg/ha)				
	0	11	22	44	Mean
0	24.6	28.7	22.9	6.9	25.8
46	32.5	22.8	20.0	45.4	30.2
92	31.0	24.6	31.4	24.9	28.0
138	29.0	24.6	25.2	24.6	25.8
Mean	29.3	25.2	24.9	30.4	0.0

Table 2.6. Marketable and total root (t/ha) as influenced by N and P over four years (1998-2001) and three locations (Bako, Loko and Nedjo)

	Bako		Loko		Nedjo	
	MRT	Total	MRT	Total	MRT	Total
N (kg/ha)						
O	17.5	22.1	7.7	9.5	2.6	3
25	20.8	24.9	9.9	11.6	3.6	4.2
50	21.7	26.8	10.7	13.3	3.7	4.4
100	25.7	30.9	10.7	12.9	3.3	4.2
125	23.4	28.9	9.1	11.2	3.6	4
LSD 0.05	2.9	3.8	1.4	1.6	ns	0.73
P kg/ha						
0	20.9	25.5	8.9	10.9	2.5	3.1
20	22.5	26.9	9.5	11.7	3.3	3.7
40	22	26.5	10.2	12.5	3.4	4.3
60	21.9	28.1	9.7	11.5	4.2	4.8
LSD 0.05	ns	ns	ns	ns	0.7	0.7

Source: Girma et al (2003)

However, fertilizer trials conducted at Bako, Loko and Nedjo over three years (1998-2001) revealed the application of nitrogen as having significant impact on marketable and total root yield (Table 2.6). Maximum marketable root yield of 25.6 tons per ha was recorded at 100 kg per ha N at Bako. Extreme yield differences were observed over the locations probably due to the differences in the inherent soil macro and micro nutrients and other agro-ecological conditions which influence the nutrient release of the soils and its uptake by the crop. In contrast to N, applied P did not affect much marketable and total root yield both at Bako and Loko unlike at Nedjo.

The economic analysis showed that P application was at all rates was dominated by gains from N. Marginal rate of return recorded was high for most combination of N and P. Considering the high costs, the lower but affordable and profitable rate 50/20 N/P kg/ha was recommended as optimum for sweet potato production at Bako area (Table 2.7).

Table 2.7. Partial budget analysis (selected rates) of NP fertilizer on sweet potato at Bako in1998-2001

N/P (kg/ha)	AY(t /ha)	AY (t /ha)	GFB	NB	MRR (%)
0,0	19.8	17.8	5343	5343	
0,60	27.2	24.4	7332	6468	283.2
25,0	23.4	21.1	6318	6165	
25,20	27.5	24.7	7413	6931D	275.6
50,0	27.6	24.9	7461	7179	201.9
100,20	27.7	24.9	7467	6801	501.1
125,0	26.4	23.8	7128	6642	
125,60	33.9	30.5	9150	7825	760.9

Source: Girma et al. 2003. AY= gross average yield;

GFB= gross field benefit; NB=Net benefit;

MRR= Marginal rate of return. All costs are in Eth. Birr.

Vine Management

Planting material

Traditionally farmers use various size cuttings from different parts of sweet potato vine for production. This is because of vine cuttings have the ability to re-grow into full plant. Some use the tip delicate/young tissue; others use the basal vine, which might be old and difficult to root. The portion and size of cuttings however are found to vary in their rooting ability, establishment and overall vegetative growth performance and yield. To compare and evaluate the yield performance of different parts and length of vine cuttings of the sweet potato to be used as planting material (top, middle and basal parts), an experiment was conducted at Awassa, Areka and Bako. The result indicated that top vine part gave higher root yield compared to the middle and basal portion of the vine cuttings at Awassa and Areka (Table 2.8).

Table 2.8. Effect of different parts of sweet potato vine cuttings on stand and root yield

	Awassa		Areka	
Cutting parts	Stand (%) at harvest	Root yield (t ha^{-1})	Stand (%) at harvest	Root yield (t ha^{-1})
Top	88.3	33.8	83.9	15.1
Middle	65.8	19.7	78.1	11.7
Basal	63.9	18.2	75.2	10.6

Source: Terefe et al. (1994)

On the other hand, yield was also affected by vine length (study conducted at Bako in 1985-86). Vines 30-36 cm long from middle portion were found better quality planting material for sweet potato production (Table 2.9). Therefore, top cuttings and middle portion were recommended for better stand at harvest and root yield in respective location. Other parts of the vine may also be used if there is shortage of the recommended parts, respectively for each location. In general, the cuttings preferred with few leaves intact.

Table 2.9. Effects of variety and vine cutting length on marketable root yield of sweet potato mean of 1985-86

Vine length (cm)	Variety			
	White star	Koka-12	Koka-6	Overall mean
18	26.1	23.5	19.8	30.4
24	29.2	28.8	26.3	38.0
30	35.3	30.0	26.0	39.0
36	39.6	36.9	26.2	44.1
42	30.6	27.2	44.9	52.4
Mean	32.5	29.8	24.6	

Vine Clipping

Sweet potato roots and vine are good sources of food and feed, respectively. The young shoots are popular for many Africans and Asians. On the other hand clipping time and stage has an influence on the quality of a planting material. Therefore, it is legitimate to evaluate different clipping times and stages. Two cultivars (White star and local) and six clipping stages were evaluated for three years at Bako. High fresh top part yield was obtained when 50% of the top aerial mass was harvested between 3.5 and 4 months after planting without affecting the root yield (Table 2.10). In this study, the two varieties showed almost the same response and White Star was superior in total yield (data not shown). Therefore, some varieties like White Star would fit for human consumption and as animal feed. The improvement program needs to make purposeful selection taking this inherited character in to account. Moreover, plant growth stages affect the nutritional quality and digestibility of the green top, and further laboratory study might be worth considering to determine the best growth stage.

Table 2.10. The effect of clipping stages on mean root and fresh top part yield of sweet potato variety (White Star) at Bako, during 1989-1991

Clipping stage (months after planting)	TRY ($t\ ha^{-1}$)	MRY ($t\ ha^{-1}$)	Fresh top part ($t\ ha^{-1}$)
2.5	14.5	8.8	35.4
3.0	13.4	5.3	39.1
3.5	13.3	7.5	42.5
4.5	19.4	6.9	45.5
5.0	13.8	7.6	42.2
5.5	17.5	10.1	34.1
Mean	14.3	9.5	40.0

Source: Adapted from Girma and Lemma, 1997.

TRY= Total root yield; MRY= Marketable root yield

Vine Storage

Usually sweet potato plating materials are bulky and require large human labor and time for processing. Meanwhile, it may be left for some days unplanted. In addition, these planting materials may be brought from far distances and few days may elapse before they get planted. In such conditions, it is crucial to understand for how long these planting materials could stay with out losing their re-growth ability into full plant. Effect of duration of vine storage on the establishment and root yield of sweet potato was studied in 1991-1993 using varieties Koka-6 and Koka-12, were vine were stored for 0, 2, 4, 6, 8, and 10 days. Mean stand count at harvest and marketable root yield were affected by the duration of vine storage before planting. The highest average stand percentage (81.7) and marketable root yield (34.9 tons per ha) were obtained from vine stored for two days before planting (Table 2.11). This has been used as a recommended practice in Awassa area.

Table 2.11. Stand at harvest, marketable and total root yield of two sweet potato varieties as influenced by duration of vine storage

Duration of vine storage after harvest	Stand % at harvest	TRY ($t\ ha^{-1}$)	MRY ($t\ ha^{-1}$)
Immediately	52.2	27.6	22.9
Two days	81.7	37.7	34.2
Four days	77.8	34.6	31.3
Six days	67.8	27.6	24.6
Eight days	76.1	35.3	31.8
Ten days	75.6	33	29
Mean	71.9	32.6	29.0

Planting Date

Plating date can be site specific based on the set of rainfall, altitude variation and disease pressure. Planting dates were investigated at Bako for two consecutive years using white star variety of sweet potato and the whole month of June was found optimum the area and other similar agro-ecologies provided reliable rainfall exists during and after planting.

Post harvest handling of roots

Post harvest handling of sweet potatoes begins at the moment of harvest. It ranges in degree from simple lifting of roots, carrying them from field to house, and immediate consumption after cooking, to sophisticated method of curing and storage under controlled conditions followed by processing in to a variety of food products. Factors such as climatic and soil conditions before harvest as well as contamination or attack by microorganisms or insect pests while the crop is in the field may trigger or speed up subsequent deterioration of roots after harvest. Unwise root handling can lead to losses, both in quantity and quality, which may be extremely high in some areas and circumstances. So far research in the country has concentrated on the improvement of pre-harvest conditions to increase yield and there is very limited and scanty information on the high degree of loss associated with post-harvest handling of sweet potato.

Root storability

Sweet potato has a high moisture content, and relatively thin and delicate skin. In principle, like other tuber crops, sweet potato roots are perishable and demand high care during harvesting and thereafter. The root remains metabolically active after harvest and is easily damaged, highly perishable commodity, which makes its post harvest handling and storage more difficult than cereal crops. Because of this, storage avoidance is practiced in many parts of the tropics including Ethiopia. In other words, roots are harvested when and as they are needed (sometimes being left in the ground for several months after attaining adequate size), and used directly for consumption as soon as they are harvested.

In some cases, after harvest roots are left for a short period in the sun to dry. If they are to be sold they are usually transported to market almost immediately or soled by the side of roads. Nevertheless, storage is necessary to extend availability of fresh roots throughout the year where production is essentially seasonal and heavily dependent on rainfall. Lack of proper curing, packing and storage is the prevailing condition in almost all growing areas. This aggravates skinning, wounding and desiccation problems, as well as attack by pathogens, resulting in losses.

Various traditional storage methods are used in different countries depending local environmental conditions. Such include underground storage houses, Pit or cellar storages, on the floor of houses in shallow piles, piecemeal harvesting. In Ethiopia most farmers store on the floor of houses or leave in the ground harvesting a small portion when needed. There has not been systematic study to determine the loss which is known to be high and improve storage methods for the household use. Losses of roots piled in heaps in markets or being sold by the road side are likely to be much higher, but the extent of such losses has not bee explored. It is also to be noted that root weight loss, degree of shriveling, degree of decay and incidence of sprouting vary considerably depending on genotype (Jennefer, 1992).

Observations made on the storability of sweet potato roots in the soil as an alternative with and without vine after maturity shown that late harvesting resulted in reduction of marketable yield while unmarketable root yield increased due to insect damage, cracking and sprouting.

Physiological maturity of sweet potato depends on agro-ecologies and genotype. In lower altitude areas where there is hot weather conditions it mature earlier than the mid altitude areas. Therefore, harvesting time has significant effect root yield and quality. Early harvest resulted in immature, undersize, watery and less sweet and poor quality root. To the contrary, too late harvested roots become oversized, cracked and susceptible to weevil attack. Harvesting date studies at Bako shows that from 5th-11th month after planting harvesting can be done.

The optimum harvesting date was found to be 5th months after planting in order to harvest reasonably large root yield and good quality root (Table 2.12). It is apparent that rigorous screening of varieties into maturity groups is highly important and early varieties can give reasonably good yield earlier than the 5th month. Farmers need to be advised with more precise information on the maturity type of varieties and how harvesting and storage can be managed to meet their requirements and the quality needs of the market so that sweet potato is a more profitable enterprise for the household farmer.

Table2.12. The effect of harvesting date on root yield (t/ha) at Bako

Harvesting date (month after planting)	Marketable root yield	No. of roots plant	Weight of roots (kg/ plant
5th	16.9	7.3	1.8
6th	14.2	7.0	1.1
7th	15.8	6.5	1.9
8th	13.1	6.2	1.8
9th	10.9	6.8	1.9
10th	12.4	7.5	2.1
11th	8.7	6.3	1.5
Mean	13.1	6.8	1.7
CV	22.8	13.4	22.7

Intercropping

Different intercropping studies have been conducted at Awassa and Bako with maize where grain yield of maize was not much affected by time of intercropping with sweet potato. However, root yield of sweet potato was severely affected by intercropping with maize (Table 2.13). The yield of both crops was reduced compared to sole crop, which indicated competition (both) and shading effect (maize) and farmers have not been advised to intercrop sweet potato with maize at Awassa area.

Table 13 Root yield of sweet potato and grain yield of maize as influenced by intercropping (t/ha)

Cropping system	Maize	sweet potato
Sole crop	3 30	27.85
Intercropping at the time of maize planting	256	288
Intercropping at shelshalo	2.73	0.00
Intercropping 20 days after shelshalo	263	0.00
Intercropping at tasseling	2.45	0.53
Intercropping 20 days after tasseling	284	0.60
Intercropping at maturity	2.57	0.50
LSD 0.05	NS	4.3

Sours: AARC Progress Report, 1993.

In another study, maize (three varieties: Gutto, BH140 and BH660) and sorghum (Birmash and IS9302) were intercropped with sweet potato (Cemsa, Tis1499, 375 and White star) for two seasons (1996-97). Intercropping of BH140+375, Gutto+Cemsa, Gutto+Whitestar and BH660+Whitesatr gave relatively higher total grain and root yields. Gutto yield was superior under intercropping while BH140 and BH660 grain yields were reduced under intercropping as compared to mono-cropping (Table 2.14). These experiments, however, were done to see possibility of getting some harvestable sweet potato yield in maize or sorghum main crop.

Table 2.14 The effects of maize/sweet potato varieties intercropping on some agronomic parameters of the component crop varieties in 1997 cropping season

Treatment	GY ($t\ ha^{-1}$)	PH (m)	TRY ($t\ ha^{-1}$)	NR /plant	WR /plant	IL (cm)
BH140+375	5.2	2.4	2.5	0.6	0.1	8.63
Gutto+Cemsa	5.1	1.9	2.3	1.4	0.7	8.66
Gutto+Whitestar	4.1	1.6	2.1	2.3	0.78	2.9
BH660+Whitestar	5.8	2.4	1.7	2.5	0.44	3.26
Gutto+Tis1499	4.7	1.7	1.3	2.2	0.45	3.83
BH140+Whitestar	3.7	1.7	1.2	1.9	0.47	8.33
BH660+Tis1499	3.9	2.4	1.2	1.8	0.45	3.7
BH660+375	3.7	1.6	1.0	1.4	0.58	5.66
BH140+Cemsa	4.1	2.2	1.0	1.5	0.52	4.6
Gutto+375	5.4	1.9	1.0	1.4	0.22	2.36
BH660+Cemsa	4.1	1.6	0.7	1.2	0.42	4.5
BH140+Tis1499	4.5	1.8	0.6	2.8	0.48	4.83
LSD (0.05)	13.3	0.28	ns	0.3	ns	ns
CV (%)	17.3	8.8	29	24	16.9	34.64

GY=grain yield, PH=plant height, TRY= total root yield.

NR=number of root, WR= weight of root and IL= inter node length.

The result revealed that maize variety Gutto was superior over others in suitability for intercropping cropping regardless of the sweet potato variety. Grain yield of sorghum varieties was not much affected by the associated varieties of sweet potato (Table 2.15).

Some root yield would be harvested from the associated crop sweet potato with out significantly affecting maize and sorghum yields. Total land equivalent ratio ranged from 0.84 to 2.00 for maize/sweet potato intercropping, while that ranged from 0.83 to 1.26 in sorghum/sweet potato intercropping. In the present study, LER indicated that higher biological yield record and efficient land use system under intercropping as compared to mono-cropping.

Table 2.15. Mean grain yield and other agronomic parameters of sorghum as influenced by intercropping with sweet potato

Treatment	Grain yield (t /ha)	Number of head/plot	Plant height (cm)
IS9302+Cesma	2.9	5.7	15.7
IS9302+ Tis1499	2.7	5.3	14.7
IS9302+375	3.3	6.3	15.9
Birmash+ Cemsa	3.2	5.8	17.3
Birmash+Tis1499	2.5	5.1	16.1
Birmash +375	3.1	6.0	16.9
LSD (0.05)	ns	ns	ns
CV (%)	24.4	17.8	5.7

Intercropping sweet potato with maize and sorghum varieties have shown yield advantage over the sole cropping of the maize variety Gutto and sorghum varieties, because of better use of environmental resources, smothering of weeds, better soil conservation by the prostrate crop, sweet potato, acting as barrier to some disease and insect pests. Nevertheless for sustainable and successful intercropping system, evaluation should focus on sweet potato as a principal crop. Further understanding of genotypic effects is required along with manipulation of the agronomic managements such as planting time, spacing and fertilizer use and economic evaluations.

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were recorded as minor insect pests. Armyworm (*Spodoptera exempta*) is considered as a sporadic pest of sweet potato.

Control of Sweet Potato Weevil

Resistant varieties

Varieties of sweet potato that could resist the pest damage and give good yield have not been developed. The latest effort to find resistance sources was made in 1996/97. A total of 56 early maturing varieties with 6 susceptible checks were used. Among these, 36 each for medium and late maturing varieties with 5 and 6 susceptible checks, respectively, were evaluated for their resistance level against the sweet potato weevil. Seven varieties were advanced, but repeated tests on the varieties did not yield true resistant or tolerant variety to the pest attack.

However, the development of insect-resistance is considered as a viable component of integrated pest management (IPM) approach. In other countries, considerable research was done on breeding and evaluating sweet potato germplasm for resistance against the sweet potato weevil. For instance, Allard et al. (1991) reported many resistance characters identified as under polygenic inheritance. These include fleshy root density, dry matter and starch content, root depth, vine thickness and tuber chemistry. In Ethiopia, therefore, there is a need for strengthening the variety development work using wider genetic material that may exhibit some of the above characters identified elsewhere for resistance to the pest.

Planting date

Planting tuber and root crops on very wet soil may lead to poor soil conditions, deeper compaction into the subsoil, poor root performance, and reduced leaf growth leading to reduced yield. Subsoil compaction can occur even on light sandy soils if planting is practiced when soils are too wet. In the Ethiopian context, early planting is done when the soil is dry or getting wet whereas late planting refers to the very wet soil conditions. In order to get higher yield of sweet potato, planting should be exercised at the earliest time possible when consequential soil compaction is minimum. Besides, manipulating planting dates may help to change the effect a certain insect pest may have on a target crop.

A study was made at Awassa and Areka to investigate the effect of planting date on the yield of sweet potato and infestation of sweet potato weevil. The study evaluated 6 planting dates fixed at a 15 days interval between late June and early September. The earliest planting date was found associated with the highest yield and lower sweet potato weevil infestation (Table 3.1). The relationships between the sweet potato weevil damage and the yields of sweet potato were highly but negatively correlated. The findings of the study indicated that early planting, besides increasing yield through plant growth vigor, is associated with significant reduction in sweet potato weevil infestation.

Table 3.1. Effect of varying planting dates on sweet potato weevil infestation and yield losses at Awassa and Areka

Planting date	Mean yield (t/ha)	Mean weevil infestation (%)
25 June 1995	11. 30	9.1
10 July 1995	8.4	52.3
24 July 1995	6.9	68.1
08 August 1995	6.7	68.0
22 August 1995	0.94	90.4
06 September1995	0.89	88.9

CV = 15.24%

R^2-value = 0.86, $F_{1,4}$ = 24, $P < 0.007$

Source AARC Progress Report, 1996, unpubl. data

Harvesting date and earthing-up

Sweet potato roots can be ready for harvesting in 3-8 months after planting. The exact time of harvest differs with variety and environmental conditions. In many traditional production practices, sweet potato is harvested when needed and there is no fixed harvest time. The fact that sweet potatoes can be left in the ground until needed is invaluable to subsistent farmers who use the crop only for home consumption and do not have storage facilities. In parts of the world where temperature and rainfall are favorable to crop production all year round, it is common to grow sweet potato as a perennial crop and harvest individual roots from the plant as necessary. In this case, vines are earthed up to encourage production of storage roots at the nodes. If lifting is carried out too early, yields are low.

On the other hand, if roots are left too long in the ground they are increasingly prone to attack by the sweet potato weevil and to rotting problem. The production of sweet potato in Ethiopia is predominantly traditional, and farmers widely practice staggered harvesting. The practice contributes significantly for the increase in sweet potato weevil infestation and thus makes the insect an economic pest. Therefore, appropriate time intervals for harvesting sweet potato should be identified for the Ethiopian context.

In view of the significance of earthing-up to enhance the production of more storage roots, a study was four harvesting times in combination with four earthing-up frequencies. Better yield was obtained as harvesting was delayed though that allowed higher weevil infestation to take place. The effect of earthing-up in managing sweet potato weevil infestation was minimal (Table 3.2). However, the weevil problem remains to challenge the production and productivity of the crop, and further investigation is needed to develop control measures.

Table 3.2. Root yield of sweet potato as affected by different harvesting dates and earthing-up frequencies

Yield (t/ha)					
Earthing-up frequency	Harvesting date (month after planting)				Mean
	5	5½	6	6½	
0	12.1	13.9	16.2	20.5	15.7
1	15.3	13.5	16.1	15.4	15.6
2	11.3	14.4	14.8	19.9	15.1
3	9.4	12.5	19.2	16.5	14.4
Mean	12.0	13.6	16.4	18.8	

SE = ± 8.36; CV = 28.62%

In addition, different alternative cultural control measures are reported to reduce damage caused by sweet potato weevil. Allard et al. (1991) reported many techniques that have been used in the management of *Cylas* spp. in sweet potato. These include: planting only in fields that have had no weevil infestation within the last one year and preferably are away from any infested field; planting resistant or tolerant cultivars; selecting deep-rooting cultivars, with long necks between the roots and the stems, which are less susceptible because the adult weevil cannot burrow downwards; planting early-maturing cultivars which can escape serious damage; earthing-up of plants; removal of all plant debris and volunteer plants after harvest; re-ridging approximately 30 days after planting as it places the roots deeper and out of reach of the weevils; planting non-infested material; and the use of intercropping.

Crop rotation appears to be the most effective method of preventing infestations, since the adults cannot move rapidly from one plantation to another. On the other hand, according to the review by Jansson (1992), there are no recorded releases of parasitoids or predators in Africa.

Integrated approach

Integrated pest management (IPM) practices were evaluated against sweet potato weevil. The practices include planting dates, chemical treatment and earthing up of the soil around the root. Planting date one (July 12 for Awassa, June 18 Goffa and June 14 Areka) varied at 15 days interval and continued up to third planting in all locations. The last planting was 15 days after farmers planting date. Dipping in chemicals was done before planting using either diazinon 60% E.C. or fenithrathion 40% E.C. Earthing up at interval of one month was practiced three times.

Early planting in combination with chemical application decreased sweet potato weevil incidence (Table 3.3). Earthing up in combination with early planting also reduced infestation and increased root yield. Chemical application with late planting did not show better performance. However, its interaction with second planting date, farmers practice, showed good performance. Interaction of chemicals with earthing up resulted in minimized infestation. Similar results were obtained at Areka and Goffa. Although yield advantage could not be recorded, in general the interaction of chemical by planting date and earthing up resulted in better quality tubers and sustainable yield.

Table 3.3. The interaction effect of chemical, planting date and earthing up on sweet potato weevil infestation and root yield at Awassa, 2003

	Planting date	Earthing up					
		% infestation			Yield (t/ha)		
		0	3x	Mean	0	3x	Mean
No chemical	12Jul	13.7	14.1	13.9	29.4	27.7	28.5
	27Jul	21.3	11.7	16.5	20.6	19.2	19.9
	12Aug	27.5	20.6	24.0	13.1	13.0	13.0
	Mean	**20.8**	**15.5**	**18.1**	**21.0**	**19.9**	**20.5**
Diazinon 60% E.C	12Jul	11.8	10.1	10.9	21.0	24.5	22.7
	27Jul	16.7	12.7	14.7	24.0	19.9	21.9
	12Aug	21.4	23.9	22.7	10.3	12.7	11.5
	Mean	**16.6**	**15.6**	**16.1**	**18.4**	**19.0**	**18.7**
Fenitrithion 40% E.C	12Jul	15.2	6.3	10.7	26.2	25.1	25.6
	27Jul	19.7	10.0	14.8	19.5	16.6	18.1
	12Aug	18.0	19.2	18.6	12.1	10.9	11.5
	Mean	**17.6**	**11.8**	**14.7**	**19.2**	**17.5**	**18.4**

Control of Sweet Potato Butterfly

The sweet potato butterfly larvae can produce complete defoliation of the crop during heavy infestations especially in the dry season (Smit et al. 1997). In the major sweet potato growing districts of Uganda, the sweet potato butterfly is considered by farmers as a moderate to serious constraint in sweet potato production (Bashaasha et al. 1995). Whereas in western Kenya, farmers consider the sweet potato butterfly as a constraint only in relatively dry agro-ecological zones (Smit and Matengo 1995). In Ethiopia, the pest is considered as economically less important by farmers.

Some works have been done to study and develop control measures against the pest using different insecticides at Areka in 1995/96. Five insecticides, Primiphos methyl (Artelllic®), carbryl (Sevin®); deltametrin (Decis®),endosulfan (Thiodan®), were compared. According to the results, weevil larval mortality of 98.8 and 97.9% was recorded using primiphos-methyl 50% EC and Endosulfan 35% EC, respectively while that of the control was only 44.80%. In similar study, insecticides such as Cypermethrin @100 ml/ha, Basudin @ 1500 ml/ha, cyhalothrin-L@320 ml/ha, Carbaryl @ 2000 g/ha, Malathion @ 2000 ml/ha, Endosulfan @1500 ml/ha and Deltamethrin@ 500ml/ha gave good control over the pest.

A study at Awassa evaluated different botanicals on sweet potato butterfly (*Aceraea acerata*) larvae. That the botanicals evaluated exhibited differential insecticidal activities with respect to larval mortality as measured by time. Among the botanicales, *M. ferruginia*, *T. vugilia* and *A. indica* gave the highest mortality of the butterfly larvae. *M. ferruginia* seed resulted in 80% mortality, while the leaf resulted in 66.7% larval mortality within 24 hours (Table 4).

Table 3:4. The effect of different botanicals on morality of sweet potato butterfly larvae, 2003

Treatment	Parts used	Local name	Days after treatment application			
			1	5	10	15
Tephrosia vuglia (seed)	seed		60	26.7	6.7	0
Tephrosia vuglia	Leaf		33.3	46.7	13.3	6.7
Datura strenium	Seed		6.67	6.7	0	0
Datura strenium	Leaf	Atse faris	13.3	0	0	6.7
Calusina abysinica	Leaf	Fyele feje	13.3	6.7	0	0
Azandrich indica	Seed	Neem tree	6.67	26.7	40	0
Mellia azadirachta	Leaf	Neem tree	0	20	6.7	0
Chenopodium spp.	Leaf	Amedmado	6.7	6.7	6.7	0
Millatia fergunie	Seed	Birbera	80	20	0	0
Milletia fergunlea	Leaf	Birbira	66.7	6.7	0	0
Endosulfan 35% E.C. (standard check)		Chemical	100	0	0	0
Control (untreated check)	-	-	0	0	0	0

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Chapter Four

Socioeconomic Studies on Sweet Potato

Million Taddesse

Introduction

Sweet potato is an important food security crop in Ethiopia. The crop is a staple or co-staple food for the majority of the population especially in the South region. It is the second important root crop in area coverage and production next to enset. The southern region alone accounts for 65% of total production in the country followed by Oromiya region that accounts for 34%. The national average yield of sweet potato is estimated to be 7.0 t/ha which is very low when compared to that of East African countries. The low productivity of sweet potato can be enhanced through the use of improved technologies. Therefore, analysis of agricultural marketing systems is important to identify production constraints for research and development interventions. That would help to improve the crop to wards achieving more food and marketable products.

Sweet potato is used for home consumption as well as for sale to generate cash. Similar to other root and tuber crops, sweet potato is a perishable crop and thus challenged by many marketing problems. The marketing challenges need to be addressed well to ensure the sustainable production of the crop and improve its productivity. Hence, the current chapter discusses some of the salient issues regarding the marketing situation of sweet potato. These include: marketing efficiency, channels, opportunities, and constraints in the different sweet potato producing agro-ecologies.

Sweet Potato Marketing

A survey study was made to investigate into the sweet potato marketing situation in some areas. According to the results of the study, the sweet potato marketing system was relatively not well developed because of various reasons. Although the sweet potato marketing channel was very long, the volume of transaction and the incremental profit margin that traders obtained was very low. From the total number of sample traders interviewed, 86% were retailers and 6% wholesalers, while the remaining 8% were assemblers. Except the wholesalers, almost all retailers and assemblers were operating with in production areas.

The demand for sweet potato in urban towns was very low mainly because the crop was considered as a poor man's crop. In some urban areas, people also considered the crop as a snack food. In addition, there was no processed product prepared from sweet potato in the country that could attract urban consumers and consequently help in improving the marketing condition of the crop. Therefore, the potential consumers of the crop were people who live both in urban and rural areas of the zone and neighboring zones.

However, the demand for sweet potato in the study area was influenced many factors. These, in order of importance, were: the price of other cereal crops such as maize and teff, season or time of sweet potato supply, the yield of sweet potato itself, and quality or taste of sweet potato varieties supplied to the market. Because of these factors, the price of sweet potato was also fluctuating from time to time.

he results of the study also indicated that sweet potato consumption increased during May and June mainly because during these months, household grain reserves were usually finished and the price of cereals mostly tended to rise. Hence, people consumed more sweet potatoes. Due to increased demand during this period, farmers who had irrigation facilities were encouraged to produce sweet potato and get a better price. Nevertheless, the major supply of sweet potato remained to be influenced mainly by price of other crops and its price, availability of moisture or rainfall, and occurrence of insect pests. Lack of high yielding varieties was also one of the important factors influencing the market supply of sweet potato.

According to the results of the survey, 67% of the traders in the study area (petty rural traders, retailers and wholesalers) reported that the sweet potato marketing system was not improved in the last five years. The reasons for that trend were: lack of market outlet, storage and processing techniques, asymmetry of market information, financial constraint, increasing number of unlicensed traders, and high transportation costs and marketing risks.

There was also considerable price variability across seasons. The price of sweet potato declined especially in October and the average retail price reached upto 13.00 while the average producer price was 9.60 Birr/100 kg. On the other hand, the price increased in May and June during which the average producers and retailers prices were 28.00 and 32.00 Birr/100 kg, respectively. Variability was also considerable for costs and margins. The marketing margins for producers and retailers during the low (October) and high (May) price seasons were computed. That was done using the assumptions for transport costs for a farmer at 2 Birr/100 kg over 32 km distance and for a trader at 1.50 Birr/100 kg over 15 km distance.

The marketing margin for producers is presented in Table 4.1 and for retailers in Table 4.2. According to the results, the producer's marketing margin was very high in May (21.50 Birr/100 kg) as compared to October (4.93 Birr/100 kg). But the majority of producers did not have transport service to sale their products in urban markets, and usually they did not get such margins. The results also indicated that the variability of marketing margin during the high and low price seasons was not as considerable as that of producers' marketing margin.

Table 4.1. Sweet potato producers marketing margin during low (October) and (May) low price seasons

Items	Value (Birr/100 kg)	
	October (Low price season)	May (High price season)
Average producer price	9.60	28.00
Average transport cost over 32 km	2.00	2.00
Loading and unloading costs	0.50	0.50
Average storage loss per 100 kg	1.50	2.50
Average production costs	0.67	1.75
Net marketing margin*	4.93	21.5

*calculated by subtracting marketing and production costs.

Table 4.2. Marketing margin for sweet potato retailers during high (May) and low (October) price seasons

Items	October	May
Retailers gross margin	3.40	4.00
Average transport cost over 15 km	1.50	1.70
Loading and unloading costs	0.50	0.50
Net marketing margin	1.40	1.80

Marketing problems and recommendations

The survey results indicated that the trend in the marketing of sweet potato did not show improvement over the last several years. According to the respondants of the survey, the major marketing problems were lack of market outlet, storage and processing problems, lack of market information and high transportation cost and market risk.

Lack of market outlet: The most important markets for sweet potato producers in the study areas were rural and urban markets near the production areas. Sweet potato has low demand in large cities like Addis Ababa mainly because it is usually considered as a snack food because people are less accustomed to the use of the crop in their diet. Hence, lack of adequate demand and outlets for sweet potato marketing was the most important problem that affected the price of sweet potato to decline and production not to expand despite the existing huge deficit for food energy.

Storage and processing problems: Both farmers and traders used traditional underground storage systems. Due to such type of storage, a considerable quantity of sweet potato could usually be lost. In addition, sweet potato could lose its quality and taste if stored underground for a long time. According to the farmers' responses, an average estimated loss of 25% per hectare was observed within six months due to underground storage systems. Farmers, traders and consumers lacked knowledge on the utilization of sweet potato including processing the produce into different products. As a result, less attempt was being done at all levels in the production-to-consumption chain to add a value to the product.

Lack of market information: Most of the sweet potato producers in the study areas had little or no access to market information. Producers and wholesalers did not get up-to-date information on the supply and demand at terminal markets. Since sweet potato is perishable, even if the price might below in terminal markets traders were forced to sale the product below the purchase price to avoid total loses. Because once the sweet potato was transported to the market areas, there could be no option for the traders other than selling the product at any price offered. Thus, the transaction in sweet potato market was very traditional and did not encourage the farmer and other partners to thrive for higher production.

High transportation cost and market risk: Rural petty traders paid on average 2.00 Birr/100 kg of sweet potato over an average distance of about 15 km. However, the price of sweet potato for 100 kg was sometimes not greater than the transport cost. Since the fresh produce is perishable, the chance of committing market risk was very high.

In general, it is important to promote the demand for sweet potato in large cities like Addis Ababa and regional capitals and towns. The primary step can be through creating awarness so that traders could diversify market outlets rather than confining only within the production areas. This may be created by introducing improved post harvest techniques such as better storage, processing and utilization techniques, and by increasing awareness and educating the community. In addition, strengthening the partnership in the sweet potato value chain in order to encourage establishment of cottage sweet potato processing industries need to be considered. Moreover, utilization options of the different recipes have to be demonstrated to promote the demand for sweet potato in urban and rural areas. Lack of access to market information is also one of the major constraints. The problem becomes more serious in a situation where storage, processing and transport facilities are underdeveloped, which is the case in most growing areas. Therefore, to avoid asymmetry of price information and minimize transaction costs, it is very important to create mechanism of market information linkages to help producers attain better bargaining capacity.

Availability of working capital is an important condition for business activity. Traders who have relatively better capital can easily run their business and obtain relatively better profit. However, many traders lack working capitals and, because of this, the quantity of supply they could purchase is limited. Hence, informal and formal financial institutions should be encouraged to provide credit both for urban and rural petty traders and strengthen their purchasing capacity. Following the market liberalization policy of the country, the number of unlicensed traders in sweet potato marketing is increasing from time to time. Since these traders do not pay taxes, they are in a better position as compared to the licensed ones. As a result, some licensed traders were forced to return their license and start to run their business illegally. Therefore, government intervention to control illegal marketing activities is essential for ensuring lawful and appropriate conducts in sweet potato marketing systems.

Consumption Patterns of Sweet Potato

Sweet potato roots are consumed mainly at home in Ethiopia, although it may be eaten on the streets as a snack. The basic method of cooking the roots in all areas is boiling. The consumption declines when there is good harvest of other cereal crops. However, due to rapidly increasing population and deceasing of landholdings from time to time, unreliability of rainfall, farmers are increasingly forced to grow crops of high productivity to avoid food shortage. This is becoming no more an option to the poor farmers to feed the family. Hence the far consider sweet potato as a food security crop.

On-farm Variety Verification

An on-farm sweet potato variety verification trial was conducted in the mid-altitude farming systems of Bako area during 1992 and 1993 cropping seasons in five and eight locations, respectively.Two fertilizer levels 0/0 and 100/100 N/P_2O_5 and three varieties Cemsa, White star (standard check) and a local cultivar, were used.

The results showed that Cemsa out-yielded White star and the local cultivars by 69% and 46%, respectively. The variety also responded better at lower fertilizer levels (Table 4.3). Nevertheless, fertilizer application tremendously increased root yield compared to unfertilized plots. Fertilization increased the lengths of both vine and roots of the sweet potatoes by 19.15 and 2.98 cm, respectively. Comparatively the increase was lower in Cemsa. Fertilizer application increased the net benefits from Cemsa, White star and the local cultivars by 33, 59 and 50%, respectively, and the marginal rate of return (MRR) was higher (13.73%) (Table 4.4). Farmers prefer sweet potato variety based on some characteristics like ease for intercropping, palatability, resistance to diseases/pests, and marketable tuber size and color. Cemsa was ranked best Based on these criteria

Table 4.3. Root yield of sweet potato varieties under recommended and farmers' fertilizer levels on farm, Bako 1992

Factor	Level	Yield (t/ha)	P < 0.01
Fertilizer	0/0 kg/ha N/P_2O_5	15.9	
	100/100 kg/ha N/P_2O_5	23.8	**
Variety	Cemsa	26.2	
	White star	15.5	**
	Local	17.9	
Mean		19.9	
LSD (1%)		4.8	
Interaction			**
CV (%)		33	

Source: Adapted from Abdissa (1997)

Table 4.4. Partial budget, dominance and marginal rate of returns (MRR) analysis for on

By variety						
N/P_2O_5 (kg/ha)	0/0	0/0	0/0	100/100	100/100	100/100
Item	Cemsa	White star	Local	Cemsa	White star	Local
Average yield (t/ha)	22.1	11.6	14.0	30.3	19.4	21.0
Adjusted yield (t/ha)*	19.9	10.5	12.6	27.2	17.4	19.7
Gross benefit (Birr/ha)	29844.0	15681.0	18843.0	40864.5	26146.5	29538.0
Costs that vary (Birr/ha)						
Fertilizer	0.0	0.0	0.0	718.0	718.0	718.0
Opportunity cost of labor for fertilizer application	0.0	0.0	0.0	28.0	28.0	28.0
Total cost that vary (TCV)	0.0	0.0	0.0	746.0	746.0	746.0
Dominance analysis						
Net benefit	29874.0	15681.0	18843.0	40118.5	25400.5	28792.0
TCV	0.0	0.0	0.0	746.0	746.0	746.0
Status		D	D	ND	D	D

Source: Adapted from Abdissa (1997)

*yield adjustment coefficient of 10% was taken appropriate.

Part IV

Other Root and Tuber Crops

Part IV

Other Root and Tuber Crops

Introduction

Amsalu Nebiyu

Integration of horticultural crops in the food system of the Ethiopian people is an indispensable approach to achieve food self-sufficiency and food security. In addition, with improved production and productivity, the sector can deliver high potential impact on the improvement of the livelihood of farmers. The high productivity per unit time and area for most root and tuber crops and their uses as food, feed and industrial raw material sources are great promises for continued effort in research and development. The diversity of the crops, ability to tolerate adverse environments, biotic and abiotic stresses such as diseases and pests, ability to thrive on poor soils and moisture stress conditions, among others, are important features of the crops to combat the challenges of population growth and natural resource degradations. Besides, the crops are important sources of rural employment and, in many areas, sources of income for poor farmers.

In Ethiopia, root and tuber crops are parts of the traditional food systems of the people especially in the southern, southwestern and western parts of the country. Nevertheless, among the root and tuber crops, the potential of crops like cassava, anchote, taro, yam, and Ethiopian Dinich is the most untapped resource. There is an enormous possibility for millions of poor farmers to boost production and improve their livelihood using these perhaps highly neglected but strategic crops for the country's economy. Unlike other crops, the leaves of cassava, taro, tania, and anchote can be consumed as vegetables. The crops are highly responsive to improved management.

In many cereal based farming systems of the country, root and tuber crops are grown as security crops against crop failure and as hunger reliever at some part of the year. In the past three to four decades, the research on these crops has been extremely limited to some occasional activities like collection and introduction, maintenance, and screening of varieties.

In recent years, several efforts were made in the area of variety improvement and crop management in order to solve important production constraints of other root and tuber crops. These are mainly taro, cassava, yam and to some extent the indigenous crops anchote and coleus which is also called Ethiopian potato. The important production problems as well as achievements made so far are discussed in the chapters of the current part of the book which covers together these other root and tuber crops.

Chapter One

Variety Development

Amsalu Nebiyu, Weyessa Garedew, Assefa Tofu, Wubishet Abebe, Asfaw Kifle and Edossa Etisa

Taro (*Colocasia esculanta*)

Taro (*Colocasia esculenta.*) and tania (*Xanthosoma sagitiffolium*) locally referred to as *godare* are tuberous tropical food crops that supply high-energy food. They are commercial crops for many countries. Taro and tania are grown mostly as staple or subsistence crops throughout the hot and humid areas of southwestern Ethiopia. There are some cultivars that are adapted to varied conditions such as swamps, marshy areas, flooded lands, bottomlands, and dry uplands. These crops extensively cover the wet valleys and streamside in areas inhabited by the Bench and Majangar people. According to the CSA (2002) report, some 23,590 ha of land with a productivity of 8.0 t/ha was covered by taro, and a large proportion of the acreage was in the southwestern part of Ethiopia. In general, taros are more adapted to wet conditions although they can be cultivated in uplands where there is ample amount of moisture. In southwestern Ethiopia, tania is a recent introduction and now it is under cultivation comparable with taro. The cultivation of tania is wider especially in drier seasons. All corms, cormels and young leaves of the plant can be eaten. Taro has the capacity to supply cheap and high quality food within a short time and in a wider environment, from 900 m at Bebeka to 2600 m at Dedo (Edossa 1996).

Taros are propagated vegetatively using suckers. However, the best planting materials are small corms, cormels, cut corms or setts. Taros are usually planted under coffee tree shade or with citrus crops. Sometimes taros are also intercropped with pepper and cassava. The crop usually matures in 7–9 months in valley bottoms, but it may take 12–24 in highlands. The importance of taro cultivation in the humid regions is attributed to its high yield per unit of land, 50–70 t/ha on research station and 20–30 t/ha on farmers plots (Edossa 1996). Taro is also highly resistant to pest and diseases, while other horticultural crops are seriously attacked in humid regions. Other important features of taro include high productivity with minimum management and storability for a relatively longer time.

Since 1978, lots of taro germplasm accessions of diverse origin were collected in the country and introduced mainly from Cuba. More than 120 taro and 87 tannia collections and introductions are currently maintained and conserved at Jimma Research Center. The collections are under characterization and evaluation studies. Through evaluation and screening at Jimma, Metu and Teppi, some high yielding varieties with good quality characteristics for production and use have been promoted to growers. Superior cultivars such as Rosadu Habain and Jullena Japonica and the local collection Goderie Adi which were found to be superior in their yield potential (40–60 t/ha), tuber quality and post harvest characters were recommended (Table 1.1).

Table 1.1. Mean yield and other agronomic data of recommended taro varieties*

Variety	Plant height (cm)	No. of suckers	No. of tubers/hole	Wt. of tubers/hole (kg)	Length of tubers (cm)	Diameter of tubers (cm)	Mean yield (q/ha)	Tuber dry matter (%)
Rosadu Habain	79.94	4.94	6.83	1.0	10.06	6.42	31.3	32.44
Jullena Japonica	104.37	4.52	6.49	1.5	11.47	6.64	49.1	35.41
Goderie Adi	108.15	2.43	4.5	0.95	11.3	10.85	25.7	31.12

* Mean of three years and locations

Another collection was made from different areas in the south: North Omo, Alaba Tenbaro, Hadiya, Derash, Keficho, Benchi-Maji and Sheka. A total of 87 accessions were collected and screened at Areka. Ten promising accessions were promoted to regional variety trial across three locations: Areka, Donga Tunto and Yirga Chefe. Among the accessions, ARC/064/96 which gave a higher yield of 21.9 t/ha was released (Table 1.2).

Table 1.2. Mean root yield (t/ha) of taro accessions tested in regional variety trial at three locations

Accession	Areka	Donga Tunto	Yirga Chefe	Mean
ARC/004/95	13.8	7.8	16.0	12.5
ARC/026/96	9.1	6.9	9.8	8.6
ARC/039/96	9.1	5.4	10.3	8.3
ARC/042/96	10.5	7.7	16.3	11.5
ARC/044/96	15.2	10.8	14.0	13.3
ARC/047/96	20.0	12.2	27.0	19.7
ARC/064/96	18.5	17.3	30.0	21.9
ARC/065/96	9.2	9.5	12.5	10.4
ARC/074/96	18.7	8.2	8.2	11.7
ARC/080/96	15.5	8.5	14.7	12.9
Local check	11.7	6.6	7.2	8.5

Source: Areka Research Center, Progress Report 2001, unpubl.

Cassava

Cassava (Manihot esculenta Crantz) is one of the most important food crops in Africa. The starchy, tuberous roots of the crop are a valuable source of cheap calories, especially in developing countries where calorie deficiency and malnutrition are widespread. In many parts of Africa, the leaves and tender shoots of cassava are also consumed as vegetables (IITA 1990). Cassava is a hardy plant locally known in Ethiopia as yefurno duket zaf. The consumption of cassava in Ethiopia rose during and after the 1984 famine (Edossa 1996). It is mostly cultivated and grown around fences and homestead in Ethiopia.

Humans consume over two-thirds of the total production of cassava in various forms. Its usage as a source of ethanol for fuel, energy in animal feed, and starch for industry is increasing (IITA 1990 and Scott et al. 2000). The crop is amenable to agronomic as well as genetic improvement. It has a high yield potential under good conditions and performs better than other crops under sub-optimal conditions (Otim-Nape 1994).

Cassava is an important food crop in the tropical areas of Africa, Asia and Latin America. The crop provides about 40% of all calories consumed in Africa (Scott et al. 2000). Cassava is considered an ideal food crop in the tropics because it is resistant to drought, grows in relatively poor soils, and requires minimum human labor (Negeve 1999). Cassava is particularly important in terms of food security since many tropical areas often experience unfavourable weather conditions (Horton 1988).

In general, cassava has the ability to grow under conditions considered sub-optimal for the majority of other food crops and in ecosystems where food supply is constantly threatened by environmental constraints such as drought, pest and disease outbreaks. As a low cost source of carbohydrate, cassava is an important food security crop and plays a prominent role in animal feed, bakery and other industrial applications (Negeve 1999).

One of cassava's principal characteristics is its ability to produce economic yields under relatively marginal rainfall and soil condition. In addition, the crop is efficient in water use and is able to withstand dry periods of up to 5 months (Horton 1988). Cassava is also adapted to low pH and high aluminum content, which are common in tropical soils. The major characteristics of cassava in the farming system, which makes it preferred by farmers in the tropics, are summarized below.

1. Ease of propagation by stem cuttings
2. High carbohydrate yield per unit of land (high yield potential)
3. Adaptation to poor soils and water stress
4. High drought tolerance
5. Compatibility with a variety of crops in association
6. Inexpensive production (minimum management)

In Ethiopia, therefore, cassava can be well suited to areas like the rift valleys and to the drought-prone areas. Hence, the improvement, distribution, and popularization of the crop in different parts of the country will have a significant contribution towards the achievement of food security.

A survey conducted in different parts of southern and southwestern Ethiopia showed that cassava grows in areas that are 480–1800 m high and with annual temperature of 15–30^{0}C and annual precipitation of 692–1470 mm (Mulugeta 1994). The crop is grown and used almost as a staple food particularly in Amaro Kelo, Gedio and Gamo Gofa zones.

Variety improvement work in cassava was started in 1975 through introduction of germplasm of different accessions (IAR 1980). After several years of rigorous selection and evaluation at Jimma, three outstanding genotypes (NR 44/72, NW 45/72 and OY 45/72) were recommended based on root yield (Table 1.3). The recommended genotypes also responded very well to Awassa conditions, indicating wider adaptability. Moreover, awareness created about the potential importance of the crop towards achieving food security at household level and about the various dishes and recipes of cassava in southwestern Ethiopia triggered high demand for improved varieties and seed.

Table 1.3. Yield of the recommended cassava varieties at Jimma Research Center

Variety	Yield (t/ha)
NR 44/72	300–450
NW 45/72	300–500
OY 45/72	400

Source: Edossa (1996)

In further germplasm evaluations at Jimma in 2002–2003, 36 accessions of cassava were tested for different qualitative and quantitative characters. The performance of the accessions for 13 quantitative characters is presented in Table 1.4. In addition, detailed characterizations of the accessions were made using different qualitative descriptors. The results for morphological and root characters are presented in Table 1.5 and results for flowering and fruit set characters in Table 1.6. Ac cording to the results of the study, there was significant variability among the tested accessions. The results indicated, therefore, the possibilities of improvement through selection and hybridization in the future.

Table 1.4. Mean performance values for 13 quantitative characters of 36 cassava germplasm accessions at Jima

Acc. No.	PH (cm)	CW(cm)	NB	NN	NMS	SG (cm)	NR	LR	DMR	WTR	ABM	RDM	HI (%)
26/84	252.5	166.3	6.7	46.8	2.5	3.1	9.0	43.8	4.6	2.3	4.8	30.4	46.0
25/84	269.4	156.9	6.1	51.5	2.6	3.0	10.8	45.9	4.4	2.4	5.2	31.9	47.1
50254-12	241.3	150.0	3.4	30.0	2.8	2.5	7.5	40.3	3.7	1.5	4.0	35.6	37.4
5028/73	242.5	141.4	3.0	25.8	2.0	2.8	8.9	53.4	4.1	2.3	3.5	34.8	65.8
46106/73	241.3	163.8	6.3	23.3	2.8	2.9	12.1	39.4	3.4	1.2	5.8	35.1	21.3
53115-40	240.0	133.1	4.6	25.3	2.8	2.3	10.6	35.6	3.5	1.1	5.8	37.6	18.4
F-100	153.8	130.6	5.0	20.5	1.5	2.2	6.3	35.2	3.1	0.8	2.1	36.2	39.3
3025-30	235.0	165.0	5.0	26.0	2.7	2.4	10.9	42.5	3.4	1.2	4.7	38.9	25.4
5648-50	239.4	156.3	4.9	27.0	2.6	2.3	11.4	42.6	3.5	1.6	4.5	36.1	34.2
5538-19	235.0	189.4	3.0	26.8	2.9	2.3	13.5	39.9	4.7	2.6	4.9	32.1	53.9
5632-8	251.9	191.9	3.0	28.8	2.4	2.2	6.6	51.3	4.3	1.5	2.7	31.5	62.2
46330-22	168.1	126.3	3.6	40.5	2.6	2.5	9.9	49.8	3.5	1.6	4.6	31.9	34.9
50583-14	220.6	182.9	3.6	20.3	2.3	2.3	6.8	43.6	3.6	1.2	3.7	39.2	32.2
104/72W	253.1	183.1	3.4	24.8	2.5	2.6	11.8	46.5	4.3	2.3	5.4	36.4	45.2
5532-4	240.0	140.6	3.1	31.5	3.3	2.4	10.5	41.0	3.9	1.7	4.2	35.0	40.0
5048-33	226.9	156.3	4.0	26.3	3.3	2.3	16.0	40.5	3.5	1.7	3.8	37.8	45.6
50298-21	263.1	193.1	2.9	31.8	2.8	2.6	7.6	42.9	4.3	2.6	5.0	35.4	49.5
Wolamo	257.5	150.6	2.9	28.0	2.3	2.5	7.0	42.4	4.0	1.3	3.2	38.5	50.0
AAGT-028	198.8	138.1	3.6	41.3	1.9	2.5	12.8	59.8	4.3	2.9	3.6	39.1	84.7
AAGT-009	275.0	140.0	3.5	43.0	2.2	2.3	12.6	48.9	4.3	2.0	2.7	43.0	72.5
AAGT-062	233.1	130.6	3.4	44.8	2.8	2.4	15.0	51.8	3.9	2.7	4.0	44.4	66.6
AAGT-194	226.9	127.5	3.1	44.0	2.5	2.2	12.9	52.8	4.4	2.7	3.6	39.1	77.1
AAGT-108	203.1	132.5	3.4	38.3	2.3	2.2	12.0	50.0	4.2	3.0	3.4	38.7	86.6
AAGT-189	231.3	155.0	3.0	28.3	3.2	2.2	9.3	50.1	4.0	3.2	3.2	37.9	1.1

AAGT-150	207.5	130.6	3.6	36.3	3.1	2.3	9.9	45.1	4.0	1.9	3.1	37.4	65.6
AAGT-134	236.9	132.5	3.5	39.5	2.7	2.3	13.3	49.4	4.0	2.5	3.8	37.6	67.5
AAGT-191	235.0	141.3	3.9	38.0	2.7	2.4	14.3	55.7	4.4	2.9	4.6	37.7	67.9
AAGT-160	228.8	145.0	3.3	33.5	2.7	2.3	15.3	51.7	4.3	2.5	3.7	38.3	67.2
AAGT-156	214.4	131.9	3.3	36.8	2.9	2.3	13.4	57.6	3.8	2.4	3.2	37.2	81.7
AAGT-201	230.0	125.6	3.6	43.3	2.8	2.6	13.5	51.5	4.1	2.4	3.0	39.6	80.0
AAGT-200	242.5	143.8	3.5	39.8	2.9	2.6	14.5	49.3	4.0	2.9	4.8	39.9	59.3
AAGT-101	230.0	124.4	3.4	31.0	3.7	2.3	10.3	44.7	3.6	1.8	3.2	41.4	70.3
AAGT-104	227.9	127.5	4.5	39.8	2.5	2.5	9.6	44.9	4.7	2.5	4.0	31.9	62.5
AAGT-049	229.4	138.8	3.4	38.3	2.6	2.4	11.1	53.6	4.7	2.3	3.2	38.3	86.4
AAGT-192	243.1	136.3	3.5	37.8	2.6	2.2	11.6	52.1	4.1	2.7	3.2	39.3	84.4
AAGT-095	229.4	146.9	4.6	39.5	2.8	2.3	10.5	45.3	4.2	2.5	4.5	35.0	57.9
SE	18.2	13.21	0.52	2.85	0.37	0.21	1.67	4.72	0.23	0.46	0.67	1.88	0.15
CV(%)	11.09	11.79	19.09	11.83	20.3	12	21.35	13.85	30.86	11.21	23.96	7.11	37.15
$LSD_{0.05}$	NS	37.92	1.49	8.19	NS	NS	4.79	NS	0.65	1.33	1.93	5.39	0.44

PH = Plant Height; SG = Stem Girth; CW = Canopy Width; NMS = Number of Main Stems; NB = Number of Branches; NN = Number of Nodes; NR = Number of Roots per plant; RL = Root Length; RW = Weight of roots per plant; DR = Diameter of Roots; RDM = Root Dry Matter content; ABM = Above ground Biomass and HI = Harvest Index

Source: Amsalu (2003)

Table 1.5. Detailed characterization of 36 cassava germplasm accessions based on qualitative descriptors of morphological and root characters

Acc. No.	Emerging leaf color	Color of 1st fully opened leaf	Petiole color	Petiole length	Shape of the central leaf lobe	Stem epidermis color	Stem periderm color	Branching habit	Root surface color	Root cortex color	Root flesh color
26/84	Purple	Light purple	Light green	Very long	Elliptical	Silver grey	Green	Irregular	Light brown	White	White
25/84	Purple	Light purple	Pink	Very long	Elliptical	Grey	Dark green	Tetrachotomous	Light brown	White	White
50254-12	Light purple	Light purple	Green with purple streaks	Very long	Lanceolate	Grey	Dark green	Trichotomous	Brown	Pink	White
5028/73	Purple	Purple	Green with purple streaks	Very long	Lanceolate	Grey	Dark green	Trichotomous	Light brown	Pink	White
46106/73	Purple	Purple	Green with purple streaks	Very long	Lanceolate	Silver grey	Light green	Irregular	Light brown	Pink	White
53115-40	Purple	Purple	Green with purple streaks	Long	Lanceolate	Silver grey	Light green	Irregular	Light brown	Pink	White
F-100	Purple	Purple	Light green	Long	Elliptical	Light brown	Green	Trichotomous	Brown	White	White
3025-30	Purple	Purple	Green with purple streaks	Very long	Elliptical	Silver grey	Light green	Trichotomous	Light brown	Pink	White
5648-50	Purple	Light purple	Green with purple streaks	Long	Lanceolate	Silver grey	Light green	Trichotomous	Creamy	Pink	White
5538-19	Purple	Light purple	Light green	Long	Lanceolate	Grey	Light green	Trichotomous	Light brown	White	White
5632-8	Light purple	Light purple	Green with purple streaks	Very long	Lanceolate	Grey	Dark green	Trichotomous	Brown	Pink	White
46330-22	Light	Light	Dark pink	Long	Elliptical	Silver	Green	Tetracotomous	Light	White	White

	green	green				grey			brown		
50583-14	Purple	Purple	Dark pink	Very long	Elliptical	Grey	Green	Trichotomous	Light brown	White	White
104/72W	Purple	Light purple	Pink	Long	Elliptical	Grey	Light green	Trichotomous	Brown	White	White
5532-4	Light purple	Light green	Green with purple streaks	Very long	Lanceolate	Silver grey	Dark green	Trichotomous	Light brown	Pink	White
5048-33	Purple	Light purple	Dark pink	Very Long	Lanceolate	Silver grey	Light green	Trichotomous	Creamy	Pink	White
50298-21	Light purple	Light green	Light green	Long	Lanceolate	Grey	Green	Trichotomous	Light brown	White	White
Wolamo	Light purple	Light purple	Dark pink	Long	Lanceolate	Silver grey	Green	Trichotomous	Brown	Pink	White
AAGT-028	Light purple	Light purple	Light green	Long	Lanceolate	Silver grey	Dark green	Irregular	Creamy	Light pink	White
AAGT-009	Light purple	Light purple	Light green	Very long	Lanceolate	Silver grey	Green	Trichotomous	Creamy	Light pink	White
AAGT-062	Light purple	Light purple	Light green	Long	Lanceolate	Grey	Green	Trichotomous	Creamy	White	White
AAGT-194	Purple	Light purple	Pink	Long	Lanceolate	Grey	Green	Trichoto mous	Creamy	White	White
AAGT-108	Purple	Light purple	Pink	Long	Lanceolate	Grey	Green	Trichoto mous	Creamy	Light pink	White
AAGT-189	Light purple	Light purple	Dark pink	Very long	Elliptical	Silver grey	Dark green	Trichoto mous	Brown	Pink	White
AAGT-150	Purple	Light purple	Pink	Long	Lanceolate	Grey	Green	Trichoto mous	Creamy	Light pink	White
AAGT-134	Light purple	Light purple	Pink	Long	Lanceolate	Silver grey	Green	Trichoto mous	Creamy	Light pink	White
AAGT-191	Purple	Light purple	Light brown	Long	Lanceolate	Silver grey	Green	Trichoto mous	Creamy	Pink	White
AAGT-160	Light purple	Light purple	Light green	Long	Elliptical	Grey	Dark green	Trichoto mous	Creamy	Light pink	White
AAGT-156	Light purple	Light purple	Pink	Long	Elliptical	Grey	Green	Trichoto mous	Creamy	Light pink	White
AAGT-201	Purple	Light purple	Light green	Long	Elliptical	Grey	Green	Trichoto mous	Creamy	Light pink	White
AAGT-200	Purple	Light purple	Pink	Long	Lanceolate	Grey	Green	Trichoto mous	Creamy	Light pink	White
AAGT-101	Purple	Light purple	Pink	Long	Lanceolate	Silver grey	Dark green	Trichoto mous	Light brown	White	White
AAGT-104	Purple	Light purple	Green streaked with purple	Very long	Elliptical	Silver grey	Green	Trichoto mous	Light brown	White	White
AAGT-049	Purple	Light purple	Light green	Very long	Elliptical	Silver grey	Dark green	Trichoto mous	Creamy	Light pink	White
AAGT-192	Light purple	Light purple	Pink	Very long	Lanceolate	Silver grey	Dark green	Trichoto mous	Creamy	Light pink	White
AAGT-095	Light purple	Light purple	Green streaked with purple	Very long	Elliptical	Silver grey	Dark green	Trichoto mous	Light brown	White	White

Source: Amsalu (2003)

Table 1.6. Detailed characterization of cassava germplasm accessions based on qualitative descriptors of flowering and fruit set characters* in 2002–2003 at Jimma

Acc. No.	Color of sepals	Color of disc	Color of ovary
26/84	White	Orange	Green
25/84	White	Orange	Green
50254-12	Purple	Red	Purple
5028/73	Purple	Red	Purple
46106/73	White	Red	Green
53115-40	Purple	Red	Purple
F-100	White	Orange	Purple
3025-30	Purple	Red	Green
5648-50	Purple	Red	Purple
5538-19	White	Red	Green
5632-8	Purple	Orange	Green
46330-22	White	Red	Purple
50583-14	White	Orange	Purple
104/72W	White	Orange	Green
5532-4	Purple	Orange	Purple
5048-33	Purple	Red	Purple
50298-21	White	Orange	Green
Wolamo	Purple	Red	Purple
AAGT-028	Purple	Orange	Purple
AAGT-009	Purple	Orange	Purple
AAGT-062	Purple	Orange	Purple
AAGT-194	Purple	Orange	Purple
AAGT-108	Purple	Orange	Purple
AAGT-189	Purple	Red	Purple
AAGT-150	Purple	Orange	Purple
AAGT-134	Purple	Orange	Purple
AAGT-191	Purple	Orange	Purple
AAGT-160	Purple	Orange	Purple
AAGT-156	Purple	Orange	Purple
AAGT-201	Purple	Orange	Purple
AAGT-200	Purple	Orange	Purple
AAGT-101	Purple	Orange	Purple
AAGT-104	White	Orange	Green
AAGT-049	Purple	Orange	Purple
AAGT-192	Purple	Orange	Purple
AAGT-095	White	Orange	Green

*Flowering present in all accessions with white stigma and all set fruit

Source: Amsalu (2003)

Yam

Yams (*Dioscorea spp.*) are among the most important tuber crops in Ethiopia, especially in humid areas where there is heavy year-round precipitation. The tubers are storage organs and often grown to a considerable size; they produce short, fibrous root and annual shoots. Many species produce bulbils in the axils of their leaves which have the appearance of condensed stem and relatively large and tuberous (Kay 1987).

Onwueme and Sinha (1991) reported that Ethiopia is the seventh largest yam producing country in Africa with about 62,000 ha of land. The subsistence farmers in Ethiopia particularly in many areas in south, southwest, and western regions such as Konso, Keficho, Shekicho, Bench-Maji, Welaita, Sidama, Amaro, North Omo, South Omo, Benishangule, Jimma, West and East Wollega, and Illubabor, cultivate yams (Edossa 1998).

Yams are staple carbohydrate foods with relatively high protein and ascorbic acid content. Yams are commonly eaten as boiled, baked, tried, or can be made into flour. Westphal (1975) reported that yam is the most valuable tuber crop and many mixed yam species grow wild in the above-mentioned areas and in the forests of lowland zones. Yams in Ethiopia are known among many nations and nationalities by different vernacular names: Boye, by Kulo people; Kocho or Wocheno, Oromo; Bohe, Welayita; Kuso, Yem; and Boina, Sidama (Edossa 1996).

Of the cultivated species of yam, *D. bulbifera* (aerial yam), *D. abyssinica*, and *D. schimeriana* are native to Ethiopia (Westpal 1975). Many other important yam species worldwide such as *D. alata* and *D. esculenta* are also widely cultivated mixed with other crop species. About nine types of yam have been reported to grow in Ethiopia indicating the diversity of the species in the country (Westpal 1975). They are grown in a wide range of soils. Most varieties require long rainy season. They can grow at elevations up to 1800 m.

Considerable variability exists in yams with respect to leaf type, nature of stems, roots and tubers. There is also great variation in the number, size and form of the tubers. The flesh tubers of some species are dark purple, owing to the presence of anthocyanins. Other species have white flesh tuber. There are still unidentified yam species grown wild which shows the existence of diverse flora of yams in Ethiopia (Edossa 1998).

A total of 105 collections of yams was done from different parts of the country. The southwestern collections are maintained at Jimma, while the south collections from Gedeo, Sidama, Kembata-Tembaro, Wolayita, Dawro, Gamu Gofa and Amaro areas are maintained at Areka).

Although much has not been done, some remarkable collection/introduction missions were successfully accomplished for further improvement programs. Accordingly, more than 50 accessions of yams including aerial yam are under characterization and evaluation at Jimma.

Moreover, yield and some other assessments were made on the first yam entries for five years at Jimma. According to the study, there was high variability among the accessions both in yield and other characters (tables 1.7 and 1.8). Accessions Badi 2/81, Melko 56/76 and 7/83 gave tuber yield of 60.7, 44.8 and 39.8 q/ha, respectively (Edossa, 1998). These three varieties were recommended by the center in 1998.

Table 1.7. Yield performance of some yam accessions in a variety trial at Jimma

Accession	Mean yield (t/ha)
27395	39.2
30498	34.8
29618	46.7
57/76	37.7
60	45.4
30468	41.0
28	43.1
37	33.0
39	39.2
63	34.8
32	46.7
16	37.7
29646	45.4
56/76	41.0
46	43.1
34	33.0
CV(%)	19.99
LSD (5%)	11.915

Sourc Edossa (1998).

Table 1.8. Mean yield performance and tuber properties of the top yam accessions at Jimma tested for 5 years

Accession	Yield (t/ha)	Tuber shape	Tuber skin texture	Cortex color	Mucilage	Browning of flesh	Spine	Taste
56/76	44.8	Vary, spine root all over the tuber	Rough	White	Yes (medium)	No	No	Excellent
7/83	39.8	Cylinder	Smooth	Purple	Yes (medium)	No	Yes	Good (slightly bitter)
3/81	37.9	Amoeba shape (deformed)	Rough	White	High	Little	No	Good (slightly bitter)
6/83	33.2	Cylinder	Slight rough	White	No	No	No	Excellent (dry type)
57/76	38.0	Cylinder	Slightly rough	Purplish	No	Yes	No	Good
2/81	60.7	Cylinder but not uniform	Rough	-	No	Yes	Yes	Very good
1/75	32.7	Cylinder	Smooth	-	No	No	No	Poor (pumpkin-like)

Source: Edossa 1998

Indigenous Root and Tuber Crops

The most important indigenous root and tuber crops to Ethiopia are anchote *(Coccinia abyssyncia)*, yams (*Dioscorea bulbifera, D. abyssinica, D. Schimperiana*) and coleus (*Coleus edulis*). They are cultivated as a source of food and cash in the south, southwest and western Ethiopia. They have different vernacular names among the different ethnic groups. Although these crops can considerably contribute to alleviate food insecurity problems, little attention was given to their improvement in the past. The limited information available on these crops is discussed in the current section.

Anchote (Coccinia abyssyncia)

Anchote, which belongs to the *Cucurbitaceae* family, is an indigenous as well as endemic root crop to Ethiopia that widely grows throughout the south, southwest and western parts of Ethiopia. Anchote can be found both cultivated and wild. It is known by different vernacular names like anchote in Afan Ormo and Amharic; ushushe Walayita; shushe, Dawaro and ajo, Keffa.

However, its cultivation as a root crop is common in Wellega, Illubabor, Jimma, Kefa, and Sidamo (Amare 1973 and PGRC/E 1988). It is grown principally for its edible tuberous roots. Its newly growing leaves along with the tendrils also make a good vegetable and are served cooked. It is a good source of vitamins, minerals, and proteins compared to other root crops (Table 1.9). The crop is also grown for its high content of protein and calcium

(Amare 1973). Therefore, it can be used as a strategic crop to alleviate protein deficiency in areas and nutrition with low protein source.

Tubers of anchote are boiled and prepared with local butter. Finely prepared local anchote dish can be prepared during special ceremonies like wedding, betrothals, circumcision, birthdays, the Finding of the True Cross (Meskel) and new years holiday. The newly emerging flush of leaves and shoots are plucked, cooked and served with other foods. A local dish made of anchote is highly recommended for individuals suffering from bone fracture and displaced joints. Its use in repair is possibly due to its high protein and calcium content (Abera 1995 and Abdissa 2000). The crop is also an important source of income. Women are exclusively involved in marketing of both the tubers and the seeds.

Survey result by Dawit and Estifanos (1991) showed that juice prepared from roots of anchote are used in Ethiopian traditional medicine. The authirs indicated that the juice has saponin as an active substance and is used to treat gonorrhoea, tuberulosis and cancer. As a result, it fetches higher price in the market. Indeed, the demand for all tuber crops always surpasses the supply. In 1998/99, the price of anchote in the two zones ranged between 1.25 and 2.25 Birr/kg.

In this crop, there are two extreme tuber colors, 'red' and 'white', which are used by farmers as criteria to distinguish one from the other (Abera 1995). In anchote, the pollination behavior is not well known and further study is needed to determine the extent of self or cross pollination to generate information for its improvement.

Table 1.9. Composition of anchote tuber compared with honey dew, sweet potato and Irish potato

Crop type	Gm/100 gm fresh weight of edible portion						
	Water	Protein	Fat	Crude fiber	CHO	Ca	Fe
Anchote	74.47	4.19	0.12	1.73	21.11	11.9	1.8
Honey dew	87.0	0.9	0.0	-	10.30	5.0	0.02
Irish potato	78.0	2.0	0.0	-	19.0	11.0	1.0
Sweet potato	69.0	2.0	1.0	-	28.0	30.0	1.0

Source: Edossa (1996)

Coleus (Coleus edulis)

Coleus, also called Ethiopian potato, is in the family *Labiateae*. The crop is known locally by different vernacular names. The crop is widespread and often found growing in homesteads. It is an aggressive plant that can over-run an area once established (Abera 1995).

The crop is cultivated for its edible tubers in different parts of the country at altitudes of between 1300-2600 m. The edible tubers have a fine starchy grain and are good for instance, for people with asthma. The leaves are also used for treating bloat (Abera 1995).

It is propagated commonly by stem cuttings or by its tubers. The use of stem cuttings is advantageous because tubers can be used for consumption. Once planted and established, it grows with minimum management. The crop is planted in June and harvested after 3–4 months.

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Chapter Two

Crop Management

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Taro

Plant spacing

To determine the spacing requirement of the taro (*Colocasia esculanta*) crop, trials were conducted at Jimma research center for five consecutive years (1989-1994) using an improved variety, Rosadu Habain. Corms and cormels were used as planting materials. A combination of five row spacings (50, 60, 70, 80 and 90 cm) and five plant or intra-row spacings (30, 40, 50, 60 and 70 cm) were used. Diamonium phosphate was broadcasted at the rate of 280 kg/ha at planting, and urea at the same rate was side-dressed a month after planting.

Tuber yield

Both plant and row spacings highly affected total tuber yield. However, there was no interaction effect due to plant and row spacing (Table 2.1). The best combination for the highest yield (78.9 t/ha) was obtained from the plant spacing of 70 cm and row spacing of 30 cm. The spacing combination was adopted in Jimma area and other areas with similar agro-ecologies.

Table 2.1. Mean yield of taro tuber as affected by row and plant spacing in a trial of four replications conducted for five years at Jimma.

Plant spacing (cm)	Tuber yield (t/ha)					
	Row spacing (cm)					
	50	**60**	**70**	**80**	**90**	Mean
30	75.6	76.4	78.9	72.3	75.1	75.7
40	77.4	76.7	75.8	70.9	74.0	74.9
50	76.4	76.1	76.4	72.3	72.7	74.8
60	74.0	69.5	69.6	62.6	67,2	68.6
70	72.0	72.9	68.3	62.4	63.5	67.8
mean	75.1	74.7	73.8	0.0	70.7	72.4

CV (%) = 16.22; LSD 0.05

Row spacing means = 14.45 q/ha; Plant spacing means = 7.918 q/ha

Source Edossa et al. *(1996)*

Number of tubers

The effects of spacing were also revealed through tuber numbers per unit area. The highest total tuber number yield was obtained from the widest plant spacing of 70 cm and row spacing of 90 cm (Table 2.2). The results were in agreement to those reported for other tuber crops like potato. The results can be useful information for determining appropriate spacing for maximizing seed yield.

The effect of spacing on tuber length and diameter was not pronounced. Nevertheless, tuber length tended to increase with increase in plant spacing. The highest tuber length was recorded from the widest plant spacing, i.e. 70 cm.

Table 2.2. Effect of spacing on tuber number/m^2 at Jimma

	Row spacing (cm)					
Plant spacing	50	60	70	80	90	Mean
30	38.7	36.4	35.2	32.7	38.7	36.3
40	34.0	28.5	33.0	27.7	29.3	30.5
50	27.2	31.8	27.1	4.5	25.4	23.2
60	23.6	25.1	23.5	26.0	24.6	24.6
70	19.2	22.7	21.5	21.5	22.7	21.5
Mean	28.9	28.1	22.5	28.2	28.9	

Source: Adapted from Edossa et al. (1996).

Planting material

Taro is propagated vegetatively using tubers, corms and suckers. Planting in garden as well as in the field is very common in areas where root crops are staple or secondary staple foods. Shortage of planting material is reported to be one of the production constraints. To manage this problem, farmers use cut corms, cormels and whole corms as planting materials regardless of their yielding ability (Edossa et al. 1995). A trial was conducted at Jimma between 1987 and 1992 to select the best yielding taro-planting materials. Three types of planting materials were evaluated: whole corms, cut corms and suckers.

Results showed that mother corms (whole corms) gave the highest mean tuber yield (66.3 t/ha), while suckers gave the lowest yield (49.9 t/ha). Cut corms or setts gave the second highest yield (61.9 t/ha) (Table 2.3). On the other hand, length, diameter and number of tubers per plant were not affected by the type of planting material. In general, using either whole or cut-corms (setts) as planting materials is ideal. However, in case of shortage of planting materials, farmers can also use suckers and even cormels along with the corms with the expectation for some yield reduction while not using the best yielding planting material.

Table 2.3. Mean tuber yield of different taro planting materials evaluated at Jimma 1998–1992

	Mean tuber yield (t/ha)					
Planting material	1988	1989	1990	1991	1992	Mean
Sucker	72.9	35.6	58.6	49.1	33.3	49.9
Whole corms	83.4	65.1	57.6	58.9	48.1	66.3
Cut corms	72.4	58.6	70.2	53.6	55.0	62.0
$LSD_{0.05}$	7.3	21.2	9.1	12.9	12.5	
CV (%)	5.49	20.68	7.15	13.83	15.83	

Source: Edossa et al. (1996)

Planting time and method

Since taros are plants of the lowland, wet culture and uplands, the planting time also varies accordingly. For the wetlands, field preparation for taro crop resembles like that of rice producing a well puddle soil. The planting materials are pushed by hand into the mud to a depth of 20–30 cm. Most of the farmers in southwestern Ethiopia plant during March–April. In dry culture (uplands) where rainfall is sufficient, planting is done at the beginning of the rainy season. Intercropping of taros with maize, beans, enset, coffee, yams and banana is a common practice.

The maturity period of taros varies according to cultivar and growing conditions of an area. Its maturity period at Jimma and the surrounding areas is 8–9 months. However, taros can be ready for harvesting when the leaves begin to turn yellow and start to wither. Usually, harvesting commences in October–November. Harvesting can be delayed for some weeks in dry weather without significant loss due to deterioration.

Yam

Plant spacing

A wide range of planting distances are used for yam crop depending on the yam variety used and the soil type of the crop field. Another important factor for spacing is whether intercropping is practiced or not in yam production. Therefore, a trial was conducted at Jimma for three years to determine the optimum spacing. The results of the study showed that 90 cm x 45 cm between rows and plants, respectively, gave the highest meal tuber yield consistently over the three years (Table 2.4).

Propagation methods

The propagation of yams is entirely carried out by vegetative means. The normal practice is to use tuber cuttings or bulbils in case of *D. bulbifera.* Three types of planting systems are usually practiced in yams production. These are: setts planted on the flat bed, setts planted in trenches or holes, and setts planted on mounds, ridges or raised beds. The third type of planting system is very common almost throughout southwestern Ethiopia. The time of planting is between February and March.

Table 2.4. Mean tuber yield of yam as affected by different spacing combinations evaluated for three years at Jimma

Row spacing (cm)	Yield (t/ha)				
	Plant spacing (cm)				
	45	60	75	90	Mean
90	54.59	49.39	45.46	41.65	47.77
105	51.85	51.88	47.92	42.83	48.62
120	44.80	46.98	40.33	38.98	42.77
Mean	50.41	49.41	44.57	41.15	

Staking

Yams are strongly climbing vines, with more or less smooth stand, and they are therefore climbing plants. Staking is therefore very important to enable them expose a large leaf area to the sun. Hence, staking is the most usual cultural practice in yams. Farmers usually provide one stake for each plant. Usually 2, 3 or 4 vines growing on a single stake can give satisfactory results. Yams can also be intercropped with taro, cassava, fruit trees, and maize. Inter-cropping yams especially with maize is important; because the maize stalks left after harvest can serve as stakes for yams. However, further investigations in to the type and number of stakes for yams are required for different growing environments.

Harvesting

Harvesting of yam tubers commences between September and November when vegetative growth is over for the year. In the case of aerial yam, bulbils may be harvested 3–4 months after planting in July–August. That indicates the importance of the crop during the food shortage periods.

Anchote

Propagation

Anchote can be propagated vegetatively and from seeds. However, seed propagation is common method for achote. Vegetative propagation involves planting of either the whole tuber or slicing into two or more pieces provided that each piece has a root let and external covering. This is usually done to establish mother plants to serve as seed source for further planting.

In the case of seed propagation seeds are extracted from fully mature fruits, red ripe harvested before they start to rot. The fruits are macerated or split just to separate the seeds from the fleshy and juicy part. The seeds are then mixed with some amount of wood ash and dried in the sun. Maintaining the moisture content of the seeds for storage is done usually based on a subjective assessment by women. The seeds are then kept in either clay or wooden pots or wrapped in a sheet of clothe until the coming growing season. Seed preparation and maintenance is entirely the responsibility of women.

Method of sowing

Broadcasting is a common practice. Seeds are covered either by plowing with oxen or more commonly using a digging hoe or with any available material that canl cover the seeds with the soil.

Sowing date

Anchote seeds can be sown during the onset of the main rainy season. At Bako, early sowing (June) was found to give better results (Sirak 1985).

Staking

The anchote plant has a weak stemmed vine and thus it grows up on supports. It can also grow by trailing on the ground in the absence of supports. Staking, therefore, is optional because a reasonable amount of tuber yield, leaves and shoots can be produced without staking. However, staking or some sorts of supports will be critical for seed production. Because, without support, the plan will produce very few fruits which may even rot before ripening.

Weeding

The anchote crop is usually grown in the backyards and near homesteads where the soil is fertile and high inorganic matter and humus content. Such a soil is conducive for abundant growth of different weeds. Hence, early weeding is necessary. Weed management in anchote culture is also the responsibility of women in all the growing areas.

Harvesting

The tubers of anchote will be ready for harvest some 4–5 months after planting. Harvesting is done by digging the soil and lifting up the tubers. Any equipment used for digging out other root and tuber crops can be used for the purpose.

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Chapter Three

Socioeconomics and Technology Transfer

Weyessa Garedew, Girma Abera, Amsalu Nebiyu, and Wubishet Abebe

Socioeconomics

Taro

Taro is the most popular food security crop; nearly 80% of the farmers produce it on small fields (0.25 ha) in areas like Asendabo and Omonada. The crop helps farmers escape the severe food shortage when harvest from other crops is insufficient. Taro cultivation declined significantly after the 1984 drought because farmers lost their planting materials during the drought. The taro types grown by farmers yield about 15t/ha as compared to improved varieties, which give about 50t/ha (Kassahun and Hailu 1990).

Taro is planted in rows in March after three to four plowings. Hoeing with the aim to aerate the soil follows each cultivation.

On-farm variety evaluation showed that farmers have their own criteria of selecting taro varieties. The criteria include: tuber size, palatability, tolerance to weed, storability, and cooking time. The larger the tuber size, the more the variety is preferred. Farmers, however, evaluate tuber size before harvest by observing the thickness of the lower stake above the ground while the plant is growing. Palatability refers to the variety's fiber content and the mucilage it produces upon cooking. Varieties with low fiber content are considered as palatable. In addition, traditionally farmers do not weed taro fields unlike for other crops when there is labor shortage. Taro, unlike cereal crops, is left in the soils for storage purpose. It is picked when the need arises. The storage practice extends harvesting until the main rain starts. Farmers also prefer taro varieties with shorter cooking time.

According to the on-farm evaluation results, improved varieties 34/79 (Rodadu Habain) and 33/79 (Julena Japonica) were found superior to the local ones for most of the evaluation criteria, (Table 3.1). Rodadu Habain followed by Julena Japonica, performed better than the local variety in terms of tuber size and palatability. The local variety was found more weed tolerant and better in storability and cooking time (Kassahun and Hailu 1990).

The on-farm yield results showed differences among the varieties (Table 3.2). Highest yield (41.4t/ha) was obtained from Rosadu Habain. All the varieties performed consistently across sites followed by Julena Japonica (38.7t/ha). The local variety yielded a little over Godare Adi.

Table 3.1. Percentage of farmers responses in assessment of taro varieties using some selected non-yield criteria*

Variety	Tuber size			Palatability			Tolerance to weed			Cooking time			Storability		
	Large	Medium	Small	Better	Good	Average	Better	Good	Poor	Similar	Shorter	Longer	Better	Good	Unknown
Rosadu Habain	29	71	0	100	0	0	9	34	57	34	66	0	0	6 0	40
Julena Japonica	0	100	0	0	17	66	0	34	66	25	75	0	0	25	75
Local Variety	0	0	100	0	0	100	100	0	0	0	100	0	0	10 0	0

*Percentages do not add up to 100 since farmers responded more than once.

Source: Kassahun and Hailu (1990)

Table 3.2. On-farm yield performance of taro varieties at three locations, 1988/89

Variety	Yield (t/ha)			
	Asendabo 1	Asendabo 2	Omonada	Mean
Rosadu Habein	33.6	45.8	44.8	41.4
Julena Japonica	34.3	44.1	37.7	38.7
Godare Adi	17.8	24.8	18.6	20.4
Local check	19.0	29.7	16.0	21.6
Mean	26.2	36.1	29.3	0.0

CV % = 11.06 ; $LSD_{0.05}$ = 6.738

Source: Kassahun and Hailu (1990)

Technology Transfer

On-farm demonstrations were made to popularize the improved variety Rosadu Habain. The comparative yield performance of the variety under improved and traditional management was tested during 1991-1995, at different locations. The variety was introduced with the recommended fertilizer rate, 120 kg/ha P_2O_5 during planting and 130 kg/ha N after emergence, in comparison with the traditional management of farmers. The results showed up to 220% yield increase of the improved management over the local (Table 3.3).

Table 3.3. Yield increase of improved variety Rosadu Habain with improved management over the local in on-farm demonstrations at different locations, 1991–1995

Year	Locations	Yield (t/ha)		
		Improved Management*	Local practice	% yield increase over the local
1991	Mana, Kersa, Mettu	21.2	12.3	73
1992	Metu, Mizan, Kettie, Gimbo, Kersa/Dedo	24.5	14.3	70
1993	Mizan 1, Mizan 2, Metu, Dedo	27.9	11.7	138
1994	Sekoru, Seka, Gimbo, Shishinda, Dedo, Asendabo, Bedele, Metu	30.1	12.2	147
1995	Seka, Gimb	34.2	10.7	220
Mean		27.6	12.2	125

* Fertilizer application at 120 kg/ha P_2O_5 at planting and 130 kg/ha N after emergence.

Source: IAR (1997)

A survey was made to assess the acreage, production and yield of anchote, dinda oromo, taro and yam in East and West Wellega zonew in 1998/99. The survey results showed that the average tuber yield of the four crops varied from location to location. For instance an overall yield advantage of upto 7 t/ha could be found in East than West Wellega (Table 3.4).

Table 3.4. Some production aspects of some root and tuber crops grown in East and West Wellega zones of Oromiya. Region,1998/99.

Crop	Variable	East Wellega	West Wellega	Variable total	Variability (range)
Anchote	Area (ha)	440.75	440.00	880.75	0.75
	Production (t)	8815.00	4400.00	13215.00	4415.00
	Yield (t/ha)	20.00	10.00	30.00	10.00
Dincha Oromo	Area (ha)	217.13	62.00	279.13	155.13
	Production (t)	3799.78	279.00	4078.78	3520.78
	Yield (t/ha)	17.50	4.50	22.00	13.00
Taro	Area (ha)	50.00	1504.00	1554.00	1454.00
	Production (t)	1000.00	15040.00	16040.00	14040.00
	Yield (t/ha)	20.00	10.00	30.00	10.00
Yam	Area (ha)	152.00	2200.00	2352.00	2048.00
	Production (t)	3420.00	33000.00	3642.00	29580.00
	Yield (t/ha)	22.50	15.00	37.50	7.50
Total	Area (ha)	859.89	4206.00	5056.88	3346.12
	Prodution (t)	17034.78	52719.00	69753.78	35684.22
	Yield t/ha	19.81	12.53	32.34	7.28

The most productive tuber crop in West Wollega was yam. The differences were attributable to some environmental factors such as moisture stress and pest problem like termite damage in West Welega. In the two zones, a total of 5066 ha was planted with root and tuber crops and 69,754 t/year of tuber was produced. With a complete assessment of farming systems, the estimate of both the area and production of these crops is expected to increase by 20% (Abdissa 2000).

Root and tuber crops are largely overtaking farming areas around homesteads. The acreage of the crops is increasing because of their tolerance to termite damage and high yield per unit area.

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