CACTUSNET
NEWSLETTER

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Improved utilization of cactus pear for food, feed, soil and water conservation and other products in Africa

Proceedings of International Workshop held in Mekelle, Ethiopia, 19- 21 October 2009

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Ali Nefzaoui,
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Tesfay Belay

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FOREWORD

This Workshop was jointly organized by the Tigray Agricultural Research Institute (Mekele, Ethiopia), The Tigray Bureau of Agriculture and Rural Development, Ethiopian Institute of Agricultural Research, Food and Agriculture Organization (FAO), FAO- ICARDA CACTUSNET, International Center for Agricultural research in the Dry Areas (ICARDA), Swiss Association for International Development (Helvetas-Ethiopia), and International Society for Horticultural Science (ISHS).

The choice of East Africa and Ethiopia to host this workshop was not incidental. Indeed, (i) East Africa is facing food security and poverty issues challenges; (ii) FAO has been and still implementing fruitful projects in Tigray to promote cactus crop as food, feed and income diversification option; (iii) Tigray region and its research institutes and centers are obviously the most advanced in East Africa in the field of cactus pear crop development and uses (iv) the interest and support of the FAO Sub-Regional Office for Eastern Africa was a guarantee for the success of the workshop. The workshop coincides with the first shipment of cochineal to abroad to be processed to produce red carmin; this new initiative is most welcomed to diversify and increase poor farmers' income.

The impact of FAO projects was highly visible. Indeed, the rich contribution of Ethiopian scientists in the workshop and the field visit witness how both research and development are increasingly mastering techniques of cactus pear cropping and uses. During the entire workshop, lunches offered to participants were basically prepared using cactus cladode, and all of us appreciated the hospitality of farmers offering simple cactus-based dishes. All these good examples that need to by outscaled to other regions in Ethiopia and Africa.

Moreover, the reader can easily acknowledge the quality of the research presented in this volume, mostly produced in Africa. Many problems are addressed and many questions are still open, but the road is paved and the experience and the vision of the local scientists and farmers will be able to launch the cactus pear as one of the primary crops in East Africa Countries, particularly if the political and technical support of local Institutions will continue.

The FAO-ICARDA International technical Cooperation Network (FAO-ICARDA Cactusnet) will continue as by the past to support promoting this crop in other Countries in the region. Participants from other East African Countries expressed strongly this need and we are engaged as usual to be there to bring necessary support.

We express our thanks and recognition to all institutional partners and single collegues who supported financially and worked hard to make this event a successful one.

Special recognition goes to Dr Enrique Arias, FAO officer who struggled during many years to promote cactus crop for the benefit of the rural poor.

*Besides its well known uses as food, feed, red dye, medicinal, and natural resources conservation, cactus pear as a CAM plant will play an increasing role in the future. Prof. Park S. Nobel in his recent book **"Desert Wisdom Agaves and Cacti CO2, Water, Climate Change"** stated that agaves and cacti with their substancial biomass productivities and their high water use efficiency should be considered for the terrestrial sequestration of atmospheric CO2 in underexploited arid and semi-arid regions. Such regions, which occupy 30 % of the Earth's land area, are poorly suited to C3 and C4 crops without irrigation. Indeed, Opuntia ficus indica, for example, can generate a carbon sequestration of 20 tonnes of dry matter (equivalent to 30 tonnes of CO2) per ha and per year under sub-optimal growing conditions as those prevalent in many African arid regions.*

The editors

STATEMENT OF THE CONVENER

The workshop on improved cactus pear utilization for food, feed, soil and water conservation and other products in Africa was held in Mekelle, Ethiopia from 19-21 October 2009. The event was organized by the Tigray Bureau of Agriculture and Rural development (BoARD), Tigray Agricultural Research Institute (TARI), Food and Agriculture organization of the United Nations (FAO), FAO-ICARDA International Technical Cooperation Network on Cactus (CACTUSNET), International Center for Agricultural Research in Dry Areas (ICARDA), Helvetas Ethiopia, Ethiopian Institute of Agricultural Research (EIAR), and the International Society for Horticultural Sciences (ISHS).

H.E. Abay Woldu, Vice president of the Tgray Regional Government and Head of the Bureau of Agriculture and Rural Development of the Tigray region opened the workshop.

H.E. Mr. Mafa Chipeta, SRC for Eastern Africa and FAO Representative in Ethiopia to AU and ECA sent his keynote address through his delegate that attended the opening ceremony.

H.E. Mr. Hector Valezzi, Ambassador of Mexico to Ethiopia also attended the opening ceremony and gave a keynote speech on the status of cactus development and commercialization in Ethiopia. He stressed the start of cochineal exports from Ethiopia to Mexico.

The event was attended by 130 participants from 10 countries: Chile, Italy, Kenya, Mexico, Morocco, South Africa, Switzerland, Tunisia, Zimbabwe, and Ethiopia.

This international workshop focused on the utilization aspects of cactus pear for food, feed, soil and water conservation and other products. Cactus pear or more generally cactus is found in many parts of Africa and can be considered as least or not utilized at all despite its wider area coverage. Typical example is Northern Ethiopia where cactus is covers around 30000 hectares growing wild with no management. The only notable case of its utilization in Ethiopia is the use of fresh fruit as human food and also cladodes at times drought. Recently, carmine cochineal has been introduced. In other countries like Kenya, Zimbabwe and Tanzania, much is not known and practiced by way of cactus utilization. Cactus do have an ecological role in combating desertification and therefore need to be integrated into soil and water conservation practices as well as for numerous other products like beverages, vegetarian dishes, drugs, cosmetics, etc. Cactus also provides shelter for wildlife species in arid environments.

The workshop program covered different topics including socio-economics, institutional arrangements, genetic resources, fruit production and post harvest, livestock feed, soil and water conservation, carmine cochineal production and agro processing.

The workshop was a great success in terms of participation, scientific contribution and sharing of knowledge and experiences. The importance of cactus in the development of dry land areas was once again stressed. I believe the result of this workshop is technically sound and I also wish a great future for the growing scientific community that is working hard to promote improved utilization of cactus pear for sustainable use of marginal lands in the dry lands of Africa.

Tesfay Belay

Convener
Crop Research Coordinator, Tigray Agricultural Research Institute (TARI), Mekelle, Ethiopia

KEYNOTE ADDRESS

By Mafa Chipeta

H.E. Ato Abay Woldu, Vice President of the Tigray Region and Head of the Bureau of Agriculture and Rural Development,
H.E. Mr. Hector Valezzi, Ambassador of Mexico to Ethiopia,
Distinguished Guests,
Workshop participants,
Ladies and gentlemen,

I have the honor and privilege to be here with you today to deliver the message of Mr. Mafa Chipeta, SRC for Eastern Africa and FAO Representative in Ethiopia to AU and ECA, on this important regional cactus pear workshop entitled "Improved Cactus Pear Utilization for Food, Feed, Soil and Water Conservation and Other products in Africa". Mr. Chipeta wanted to be with you but could not do it due to urgent work he had. He asked me to extend his apology for not being with us.

This workshop is a value for FAO because of the cactus potential in the sub region and as we all will learn more about the cactus pear values, its management and utilization from the world's known professional and researchers in the area of this important plant. By doing so the FAO mandate of knowledge sharing to national and international professionals is being met. Even though I am not expert in the field of cactus pear, I can confirm that cactus grows in poor and highly degraded areas where other crop can not survive. The plant is considered as one of a few reliable insurance type plants that can grow in a difficult environment. It is an insurance plant because if we plant wheat or maize or any other crop the production is likely to fail due to moisture stress while cactus can survive the time of moisture stress or any major climate problems, so that the farmer can benefit from this plant.

Cactus plant has high potential as commercial crop that it can be processed so easily and it has potential international market to be source of foreign currency for the country. The experience of Latin America countries including Mexico shows that cactus could be used as a major economic crop for foreign currency earnings. Most of the cactus process technologies are within reach to small holders and does not include complicated procedures. The processed products include fruit, juice, jams and even wine. The leaves are used as vegetable and salad for human consumption but also as fodder for livestock and soil conservation. It is also important for the growth of cochineal for production of dye.

The involvement of FAO in improved cactus development and support to the government of Ethiopia in this regard started in 2002 through the technical cooperation (TCP) which was successfully implemented in this region. The success of the TCP project resulted in the implementation of "strengthening of fruit crop and cactus production in Tigray and Amhara regions" supported by the Italian government. The project is now in its second phase and focuses on the introduction and improvement of the management of fruit and cactus plants.

I am confident that to achieve the workshop objectives, you will deliberate on the management and utilization which is core problem of cactus production. Your discussion will also focus on the identification of which work needs a follow up, address issues to do with marketing and this forum can be used as exchange of knowledge and experience.

Distinguished guests,

Ladies and gentle men,

I would like to assure you that the FAO Sub Regional Office in Ethiopia will continue to technically support the government of Ethiopia in its effort in the production, management, commercialization and value addition of the cactus plant.

I would like to extend my thank and gratitude to the government of Ethiopia and regional government for agreeing to host this regional workshop, I also recognize and thank the organizing institutions: Tigray Bureau of Agriculture and Rural Development, Tigray Agricultural Research Institute, Helvetas-Ethiopia, Ethiopian Institute of Agricultural Research, International Center for Agricultural Research in the Dry areas (ICARDA), FAO-ICARDA CACTUS NET and International Society for Horticultural Sciences. I would like also to thank the organizing committee (at National and International Level) without whom this workshop would not be possible. My thanks also extended to all institutions and professionals whom I cannot all mention, who are involved in the organization of this workshop.

I wish you the best in your deliberation during the next three days to come up with agreements for the way forward of this plant.

HIGHLIGHT ON FAO TCP PROJECT TCP/ETH/2901 " CACTUS PEAR (OPUNTIA SPP) PRODUCTION AND UTILIZATION IN ETHIOPIA" (FOLLOWED BY A PHASE II – TCP/ETH/3002)

The cactus plant (Beles) grows profusely in Ethiopia and has adapted perfectly to the arid zones of the country characterised by droughty conditions, erratic rainfall, and poor soils subject to erosion. It thus contributes in times of drought, serving as a life-saving crop to both humans and animals. Beles has become the major income and food source for about four months of the year (May - August) and it is very much part of the culture and livelihood of the people in spite of the limited uses. Today it is fully integrated into the landscape of the highlands. Cactus pear has become the dominant plant in many areas. Despite being an alien plant that is able to spread aggressively without the presence of any natural enemies, it is accepted now as an integral part of people's environment and food security.

It is the most readily available source of fresh fruit during summer, providing valuable minerals and vitamins to rural families as well as city dwellers. Being collected from the wild stocks it reaches the market at prices affordable to all population. As the harvest season coincides with the school holidays, children find selling the fruit a means of obtaining income for school needs. Fruit is produced and consumed in fresh form in large quantities, but the surplus is wasted due to lack of knowledge of its full utilization and processing potential. Over the last few years the economic interest in the cactus plant has remarkably increased. The country faced the problems of lack of improved varieties, production techniques and processing technologies. The lack of control had also bred a negative response to the crop generally given its potential to threaten some of the local plant genetic resources

Considering beles' primitive cultivation, the absence of local experience on full utilization, careful selection of species, suitable farm management and defined cropping systems, the government requested FAO's technical support to improve cactus cultivation and utilization. FAO responded positively and through the Technical Cooperation Programme (TCP) one project was implemented. The national implementing institution was the University of Mekelle.

The objective of the project was to strengthen and develop the capabilities of the Government for cactus pear domestication, improvement and full utilization, as a means to increase food security, through the provision of selected technologies, expert advice, training, and acquisition of planting materials and the insects for natural dye production.

Cochineal production for export established in two areas, namely within existing cultivations and in areas where the plant is invading and has naturalized, selection of local clones, introduction of foreign high-quality varieties, establishment of pilot orchards for fruit, vegetable and forage production, establishment of variety collection and provision of in-country (farmers and technicians) and abroad training were the main outputs of the project. General and technical information was delivered to technical staff, farmers, academics and students in different formats: seminars open to all audiences, technical conferences, workshops and field demonstrations. The project was executed between 2001 and 2004.

Cochineal production was introduced with the double aim to help to control cactus where it has become an invader and to present an economic activity in wild cactus populations taking into consideration the total absence of pests and diseases. The establishment of cochineal production in the remote and under-utilized thickets can provide valuable income to the poorest of the poor, who are unable to sell their fruit and other produce to the main markets because of accessibility problems.

The activities of the project met successfully the unforeseen short-term technical assistance needs and in pragmatic and flexible manner by strengthening of the beneficiary country's capacities to utilize cactus as crop that can contribute to the country's food production.

Up to then, little did the authorities and the rural populations in the arid and semi-arid Regions of Ethiopia believe that the thorny dwarf cactus plant could have been transformed into a food crop item that would assist vulnerable families to cope with cyclical incidences of malnutrition caused by crop failures due to drought.

The breakthrough in the utilization of the technology of developing the cactus as a food source came when a rural women's association (NGO) called "Mum for Mums" was drafted into the project implementation and assigned the task of carrying out the training on cactus utilization for human consumption.

The "Mum for Mums" recognized the potential offered by the development of cactus as a food crop and immediately internalized it into their activities. They started to promote it vigorously given that because of its adaptability to low rainfall and poor soils, it that does not enter into competition with grain production as it thrives in areas that would not normally be used for grain production.

The moment the cactus was accepted as a food crop, it offered vulnerable populations an additional coping mechanism of stabilizing household food security and thereby assisting them in absorbing the consequences of the cyclical shocks they face, which are all too common in Ethiopia.

The project was particularly successful in introducing the alternative use of young pads for human consumption. Farmers (mainly female) were trained in the basic elements of simple processing techniques of fruits and pads; this represented an opportunity to add one more source of vitamins and minerals to the diet of the country's population.

The utilization of the aerial part as forage represents and immediate link to other crop value chains such as milk, milk derivatives, meat and hides production. All these possibilities do not compete for land or water with the existing crops, because beles can be cultivated in lands with low productive potential for other crops.

The work is far to be accomplished, cactus pear is not yet fully exploited, therefore a follow-up project proposal was formulated with the aim to achieve full utilization of cactus and its gradual long-term integration into sustainable agricultural systems.

The Italian Cooperation is currently financing an FAO executed project in Tigray and Amhara Regions, therefore the activities initiated by the TCP project have continued.

Thank you.

RECOMMENDATIONS OF THE WORKSHOP

General assessment

We recognize the efforts implemented in Ethiopia in the field of cactus with various stakeholders like Bureau of Agricultural and rural development, TARI, FAO, Helvetas, EIAR, ISHS, and CACTUSNET etc.

There are many stakeholders, FAO, TARI, Helvetas, MU, and CPPI that are working on cactus development and therefore require harmonizing their interventions.

Recommendations

There is a need to spread the knowledge of the current and potential uses of cactus pear, stressing their function as a biological barrier to reduce the impact of desertification and their adaptive responses to the expected global increase of CO_2 through programs of integrated development, extension and technical assistance as an essential adaptation tool to combat desertification.

For countries participating in this meeting for the first time like Kenya, Zimbabwe they should seek cultivate support from their respective government and international organizations so that they work in close collaboration with countries with extensive experience in cactus development.

Ethiopia needs a clear strategy (midterm and long-term) for cactus development. There was one under development that was not completed and there is an urgent need to finalize the strategy.

Cactus has a great potential to contribute to the development of the Tigray people. There are various development options like fodder, fruit production, value addition and cochineal production and soil and water conservation.

There is a need to assess the existing cactus pear genetic resources, describe and identify species and ecotypes in the country in a coordinated manner

We also need to be sure about the taxonomy of the existing cactus genetic resources: exact species and ecotypes need to be defined following the internationally accepted procedures. Introduction of new varieties of cactus pear also need to follow the proper and the internationally accepted procedures.

There is a need to develop integrated cropping system without forgetting the indigenous biodiversity

There is a need to develop sustainable production system including cactus crop especially in agroforestry system aimed at the conservation of soil and water.

Up-scaling good experiences in water shed management including cactus pear.

As regards cochineal:

- Need for economic and environmental assessment of cochineal production.

- Carmine Cochineal should not be regarded as a pest but a resource that have to be utilized.
- There is a need to embark on a publicity campaign about cochineal to the public, experts and the policy makers to bring the real fact about carmine cochineal.
- Determine optimal production method for cochineal in different areas as it is practically impossible to limit cochineal to certain localities.
- Harmonize the benefits of cochineal with other uses of cactus
- We must ensure there is optimal harvesting of cochineal at all times and must remove all barriers to this goal.

Define regulatory and contextual policy aspects to release homestead cactus to promote.

Human capacity development in all fields of cactus pear.

STRENGTHENING CACTUS PEAR PRODUCTION IN TIGRAY AND NORTH WOLLO

Giuseppe De Bac
FAO Project Coordinator
Mekelle- Ethiopia
gdebac@gmail.com

ABSTRACT

A review of the current state of FAO projects concerning cactus pear (Beles) is given, with specific emphasis to its use as a fruit crop and its role in the small scale horticultural system of northern Ethiopia.

INTRODUCTION

North Wollo and specifically Tigray region are largely covered by cactus (*Opuntia ficus-indi*ca). The plant is traditionally grown in the rural areas of Tigray and the fruit, locally known as "Beles"-, is the only source of food for many farmers during the raining season (June-September), just before the harvesting of staple crops (cereals).

The Region of Tigray and North Wollo Zone of Amhara Region (which lays south-east of Tigray) are characterized by highlands and plateaus intermingled with flat lands and low hills. Due to this unique landscape, great variation in altitude (1500-3000 meters above sea level) can be found, together with a climate which exposes plants to irregular temperatures ranging between 5°C to 40°C. Moreover, rainfall varies from 400-800 ml and hence making the region usually moisture deficit and leading to recurrent droughts.

In regard to Tigray, about 83 % of the region's population of estimated 3.4 million lives in rural areas whilst their main source of livelihood is based on agriculture. For that reason, regular income and food security is highly dependent on the annual rainfall, making Tigray and Amhara (North Wollo) the regions with the highest harvest failures (Middlebrook, 2005) and lowest per capita income/ expenditure (Bevan, 2000).

These facts explain the special role played by Cactus *(Opuntia ficus-indica)*, to food security for both, humans and livestock. Moreover, as being the most readily available source of fresh fruit during Ethiopian "winter" time (May-August), it provides at affordable prices valuable vitamins and minerals to the rural and urban population.

Although it is not clear how Beles arrived in Ethiopia (most probably brought by Italian missionaries at the beginning of last century), nowadays it plays an enormous cultural, economical and food ensuring role. The crop is also mentioned in traditional songs (Brutsch, 1997) as well as repeated in local sayings, such as: "A farmer without Beles is like a stream without water".

Moreover, Beles serves as a highly important economic source to farmers, collectors from wild plantation and vendors (mostly children on school vacation), whilst the economic interest has remarkably increased in the past few years. However, a lack of improved varieties, production techniques and processing technologies contributes to challenges in exploiting the market to the fullest (Mondragon, 2005).

ACHIEVEMENTS

FAO has successfully tackled the above mentioned challenges through the implementation of project GCP/ETH/073/ITA and cooperation in various areas of intervention from public to private and non-governmental sector. In this respect, the improvements in the selection of suitable varieties as well as the increase of availability of fruits in near by markets are part of the project objectives. In regard to the poor crop management, FAO carry out trainings on management and distribute ad-hoc designed harvesting tools throughout the two regions in cooperation with the local bureaus of agriculture.

In collaboration with locally contracted NGOs, more than 3000 women received training on cactus preparation and processing techniques while the use of mobile kitchen reached almost 20,000 persons with the promotion of cactus recipes (FAO, 2009).

Nevertheless, the market is not fully explored yet, as marketing of cactus fruit in Ethiopia is seasonal and covers only about three months of the year despite its large diffusion (Inglese, 2009). Despite it, the link of farmers with external markets could help to increase the economic output of the fruit during the production season. Therefore, Beles could be a way for farmers in Tigray and North Wollo to make use of their unique selling proposition to generate higher incomes and improve livelihoods.

Having this in mind, FAO also carried out several promotion activities not only for economic purposes but also to change the perception and to call attention for this exotic and relatively unknown fruit in the capital city of Addis Ababa.

This paper includes an overview of the efforts made and results achieved by Food and Agriculture Organization and Bureau of Agriculture in improving the cultivation of Beles during the implementation of the project GCP/ETH/073/ITA, which initiated in August 2007.

The paper also covers the activities carried out in the last two years for the promotion of Beles in drought prone areas of North Ethiopia and the attempts made so far for the improvement of the quality of the fruit during harvest and the aspects related to post-harvest management and marketing. The promotion of different cactus produces obtained from fruits and cladodes and the importance of the crop as fodder together with the utilization of the plant to control soil erosion is also highlighted.

The introduction of valuable genetic material is also being carried out, through the selection and transport of cladodes from Central and North Tigray (Wukro and Adigrat) which is the main center of diversity and where promising land-races have been so far identified.

The landraces have been selected based on different names and characters and in several areas of six Woredas.

During collection the following phenotypical distinctiveness have been considered for the characterization of the plant: cladode shape, cladode color, fruit shape, fruit pulp color, time of harvest, presence or absence of spines. In this respect, two main blocks have been established, with the collection of more than forty landraces.

The other most important activities conducted so far in the two project areas are hereunder listed:

Training of farmers

It has played an important role during the project implementation.

Specific sections carried out at school level have been conducted by the appointed NGO MUMS for MUMS (LoA) from February to June 2008 in Tigray and from September to November 2008 in North Wollo, with the involvement of 27 schools and a total of fifty teachers and 3000 students.

Specifically in North Wollo and Wag-Hamra zones a three day's training has been conducted on cactus production and management as well as on preparation of silage from cactus for eight animal forage experts with the participation of: thirty-two (32) development workers, eight (8) horticulturists, two (2) investors and four (4) farmers.

Hands-on training was given to a group of 25 farmers per session (four). The type of food produced included juice extracted from the young leaves. A variety of soups mixed with "nopalitos" and incorporated with different vegetables and legumes was prepared and tested. Following the workshop, cactus cladodes have been distributed to selected farmers and planted accordingly.

Traders have also been trained on post-harvest cactus fruits management and appointed by the project in order to facilitate transport to Addis Ababa fruit markets.

In this respect, 150 wooden crates locally made were provided to selected trader companies for better "preserving" cactus fruits during transportation.

Introduction of improved varieties of cactus and harvesting practices, particularly ones aimed at extending the harvesting season with the selection and introduction of promising varieties

The introduction of valuable genetic material has been made, with the selection and transport of propagation material (cladodes/leaves) of cactus from Central and North Tigray (Wukro and Adigrat) where promising varieties have been identified. In this respect, two plots have been established in Tigray (Wukro and Dereka) and one in North Wollo and Sekota. The plots display a collection of more than fifty landraces, the characteristic of which will be evaluated in the next two years. The collection is based on the following features: plant habit/cladode, fruit pulp color, % of seeds, fruit quality, harvesting time.

Promotion of the utilization of cactus recipes though the mean of a mobile kitchen and introduction of recipes in the restaurants

The appointed local NGO "Mums for Mums", which is specialized in Beles promotion, carried out a hands-on training through the use of mobile kitchens. More than 3000 women were trained in Enderta Woreda (Tigray). Five hundreds (500) women have also been trained in Sekota and North Wollo. Both trainings were addressed to *Opuntia ficus-indica* utilization and preparation of cactus based recipes.

Beles (cactus pear) marmalades and related recipes have also been tested and recommended to women communities and cooperatives in order to facilitate access to markets.

Demonstration of silage, animal feed, and soil conservation practices

Community plots for silage demonstration have also been selected and prepared; training has been carried out in Tigray and North Wollo in August 2008 for a total of 130 farmers.

In North Wollo, in order to exploit the potential of cactus pear spineless species, a total of 21,000 cactus planting materials (cladodes) were purchased and distributed among project Woredas; cladodes were planted in the nurseries in different sites like surrounding homesteads, communally owned cactus covered areas, around farmers training centers, and waste farmlands. The purpose of planting cladode was multiple to treat gullies, for its forage value, to have nopalitos for human consumption.

Soil conservation practices are part of the yearly intervention of the bureau of Agriculture of Tigray, and in this respect, cactus is largely used to control erosion and reinforce terraces in the hill slopes. FAO supported the on going program with the transport of cladodes to Amba Alaje in June 2009, and planted by the local community in the surrounded degraded slopes of the mountain, in order to contain the soil erosion which is depleting the top soil and is jeopardizing the security of the near by road.

Also in North Wollo, and especially in Kobbo woreda, soil erosion is becoming more marked; as a result of FAO intervention many gullies have been planted with cactus and other species.

Strengthening of post-harvest management and marketing of "Beles" fruits

Selected farmers have been trained in post-harvest management through hands-on session conducted in the field in order to improve the quality of fruits to be marketed in Addis Ababa. In this respect, the Project Management contracted selected potential traders and assisted them in providing properly designed wooden crates (by NGO Helvetas) to facilitate fruit transportation.

A research study at hand, strives to assess the local Beles market and thus evaluate the challenges and opportunities of Beles trade for the future. The study has been conducted for a period of three months (May-August) by a UN Volunteer, appointed by FAO to assist the project. The study aimed at evaluating the situation of Beles and the challenges and opportunities of its trade between farmers in the northern region of Ethiopia and selected retailers and hotels in Addis Ababa.

One part of the study at hand was designed as a cross-sectional study to allow surveying the status quo of Beles market in selected areas in the Tigray and North Wollo region. To reach this goal, a quantitative approach in form of a questionnaire seemed suitable as it allowed the collection of metric data and information directly from farmers.

The study sights in Tigray have been chosen with the support of the cactus focus person in the Bureau of Agriculture in Mekelle as well as through advices given by regional agricultural experts. These sights are seen to offer a high potential of Beles production and have already experienced special attention by FAO and the Bureau of Agriculture.

Through these questions the following areas of interest were surveyed:

- Economic and special importance of cactus fruits (6 questions)
- Market activities on cactus fruits (10 questions)
- Knowledge, handling and management of cactus fruits (5 questions)
- Major challenges in cactus production (1 question)

During the inquiry time it was possible to survey a total of 109 farmers from Tigray and North Wollo (76 % in Tigray).

The results have shown that cactus fruits are of great economic importance for farmers in Tigray as about 25 % of their annual income is generated through cactus activities. At the same time, cactus plants are highly utilized in the region for personal consumption, promotion and animal forage. Moreover the analysis showed that cactus fruits are mostly sold in caretas whilst their average cost per piece during the rainy season reaches 0.18 Birr. In general the market situation seems well organized and offers a stable amount of fruits during the main harvesting season.

Also, it became clear that knowledge, handling and management are quite low whilst it has been found out that harvesting tools that were designed by FAO and distributed through the Bureau of Agriculture did only reach about 17% of the farmers. This also underlines poor post harvesting management and a lack of quality control. Still, farmers mainly use traditional harvesting methods and consequently physically harm the fruit.

Most importantly, farmers face health problems during harvesting because of spines on the fruits but also cactus leaves. Another major challenge they see in transporting the fruit to the nearest market as they face a donkey shortage.

In North Wollo the results made clear that Beles has almost no economic importance for farmers. Moreover, the survey showed that the cactus plant is generally underutilized. Even the many farmers have noticed and personally addressed this matter when participating in a local FAO training on the management and processing of cactus plants. As a result they have promised to pay more attention to and to promote the fruit within the community. Still, it became obvious that cactus plays a different role and should be used for food security purposes.

FAO project activities will continue to focus on post-harvest management and focus on the training aspects in order to improve the quality of the fruits from production to markets.

Figure 1. Field day training on cactus planting and uses, Tigray

Figure 2. A farmer practicing "deflowering" or flower removal to postpone production season.

Figure 3. Appropriate and simple tools to harvest beles (cactus fruit)

Figure 4. Beles selection and proper packaging are needed for better marketing

CACTUS - BASED DEVELOPMENT IN TIGRAY AND EXPERIENCE FROM MEXICO

Fesseha Yaye Dulume
Tigray Bureau of Agriculture and Rural Development
Cactus development coordinator
E mail: fiseha.yaye@yahoo.com

ABSTRACT

Opuntia ficus- indica is originated from central and southern Mexico. It was introduced to Ethiopia at the end of 19th Century and widely distributed in the northern arid and semi arid regions of the country. According to some sources cactus was introduced to Tigray and broadly distributed in eastern and southern zones of the region about 160 years ago. Cactus pear production in Mexico has a history and they started to produce the crop using modern technologies 60 years back. Currently there are many universities and research organizations working on cactus based development in Mexico. The "Chapingo" and "San Luis Potosi" universities and "INIFAP" research stations are among the organizations working strong on cactus pear development. Nowadays cactus pear is not only life saving but also among the leading agricultural products which brought a significant hard currency to the Mexicans. It is the 6th fruit crop, after orange, avocado, banana, mango and apple and it is more important than peach, guava or grapes. Every year around 428,763 tones of fresh fruit are harvested from 53,876 ha of commercial plantations. During the market fluctuation the Mexican government is heavily committed to subsidize the growers. While in Tigray where cactus was considered as wild it is estimated that only 128,660 tones could be harvested from 30,520 ha. Cactus fruit production in Tigray was done traditionally due to lack of knowledge on the planting method and management practices despite that fact cactus in the region is very abundantly grown. They are often dense, above height and with mixed variety. The establishment of Cactus Production and Processing Initiative (CPPI) did not contribute more to improvements in management and utilization. To overcome this problem the Regional Government of Tigray devised poverty alleviation strategies including cactus promotion and utilization and has started for their realization. In the last three years alone the Bureau of Agriculture and Rural Development (BOARD) tried to expand millions of planting material to the non cactus growing areas in 2007 and 2008 cropping seasons more than 1,425,426 cladodes were distributed and planted in around 1419ha. Form this 9723 house holds are expected to be benefit. In 2009 over 18 million cladodes were planted in different watersheds for soil conservation purposes. BoARD in collaboration with FAO established one collection center in Agulae around 30 km north to Mekelle and trained for more than 118 farmers and wereda experts in cactus management.

The overall impression is that we have not gone far as far as cactus development is concerned in our region. There is also this problem of lack of integration and collaboration among the stakeholders so as to impact development. Collaborative and organized efforts are therefore required to bring about significant changes on cactus development.

INTRODUCTION

Cactus pear *(Opuntia ficus- indica)* is originated from central and southern Mexico (Griffith 2004). This miraculous plant was introduced to Ethiopia at the end of 19th Century and widely distributed in the northern arid and semi arid regions of the country. It is also believed that about 160 years ago cactus was introduced to Tigray and broadly distributed in eastern and southern zones of the region. Agriculture in Tigray like in other parts of the country is the main sector on which more than 85% of the population is directly dependent on it for a livelihood but with long periods of drought and unreliable rainfall, compounded by excessive human and livestock pressures on the land resulting in high food insecurity. It is in this context that the cactus pear plays an increasingly vital role as a source of food and feed. It is also used as a fuel, as a live fence or hedge, for soil conservation and its fresh fruit as a limited source of household income. In this regard cactus might be an integral and impressive part of the culture and economy of Tigray. However due to low attention, this ample resource of the region is still under utilized.

In Mexico even though cactus pear production has a history of long decades, they started to work intensively on it nearly 60 years ago (Mondragon, 2002). Cactus pear is the 6th fruit crop in Mexico, after orange, avocado, banana, mango and apple, it is more important than peach, guava or grapes (SIAP, 2005).

CACTUS DEVELOPMENT INITIATIVE IN TIGRAY

Cactus is thought to be introduced 160 years ago by the catholic missionaries through *Irob wereda* (*Alitena* town), since its introduction until the establishment of CPPI (Cactus Production and Processing Initiative) the attention given for the crop was very low. It was the farmers who practiced a lot in the expansion of cactus to many parts of the region. The importance of cactus was limited only for life fencing and the fruits as poor men foods during the rainy seasons. However, through time when environmental degradation got worst farmers start to use the cladodes as feed (mainly during dry season). In the recent time particularly after the intervention made by Bureau of Agriculture and Rural Development (BOARD) in collaboration with other CPPI members, tremendous promotional works and training have been given to all level of the community with in the region. In the past three years the Bureau of Agriculture and Rural Development tried to distribute millions of planting materials to the non cactus growing areas. In 2007 and 2008 more than 1,425,426 cladodes were distributed and planted in around

1419ha. From this nearly 9723 house holds were expected to be benefited. In 2009 over 18 million cladodes were planted in different watersheds mainly for soil conservation purposes. In the year 2008, B0ARD in collaboration with Helvetas 1090 jobless youths, 79 wereda experts and 243 development agents and 300 family headed house holds and 150 primary school students were trained in cactus based food processing.

Moreover BOARD in collaboration with FAO established cactus varieties collection center in *Agulae* around 30 km north to Mekelle. So far around 42 types of cactus cultivars were collected here in the collection center. Besides more than 118 farmers and wereda experts were trained in modern cactus orchard management (Fig. 1).

Nevertheless, comparing with potential and economic importance of cactus for the region the efforts made to promote the plant is still limited.

As cactus pear is a native to Mexico, the ancient Mexicans develop cactus from a wild plant, a source of fruit and tender cladodes, in to a semi domesticated resource for the family gardens to secure home consumption. Then urbanization pushed farmers to develop cactus pear in to a formal crop in less than six decades, adaptable to different environments and production system. Nowadays, cactus pear is firmly established as the best productive option for semi arid lands (Flore et al., 1999), more profitable than corn or dry beans the stable crop in Mexico.

CACTUS FRUIT PRODUCTION IN TIGRAY

Cactus fruit production in Tigray was done traditionally and due to lack of skill on the modern cactus orchard management practices; most cactus plantation in the region is found grown very densely, above height in very steepy places where there is no enough pathways (Fig. 2).

Because of the aforementioned farm problems utilization of the potential resource is very low, that is the percentage of fruit harvest is estimated to be not more than 28%. That is only 128,660 tones could be estimated to be harvested from 30,520ha (SAERT, 1994). The majority of the produce is lost in the field. This also has impact on the quality of the harvest, that is, there is no proper pruning and harvesting equipments to reduce lose.

Therefore, to alleviate these problems Bureau of Agriculture and Rural Development in collaboration with Helvetas Cactus Development Project (HCDP) established 15 model cactus orchard sites in seven priority *weredas*. In addition to this BOADR together with FAO introduced and distributed around 2500 cactus fruit harvesting tools to the model farmers from eastern and southern zones of the region.

In Mexico it is believed that more than two million ha was covered by cacti. How ever every year around 428,763 tones of fresh fruit were harvested from 53,876ha of commercial plantations (SIAP, 2005).

Moreover during the market fluctuation the Mexican government is heavily committed to subsidize the growers. Despite the large number of registered varieties in the country national cactus production is based on a few cultivars mainly white flesh (*O. albicarpa*), yellow pulp under cultivation (*O. megecantha*), and red cultivars (*O. ficus-india*).

All these varieties are cultivated under rainfed using modern technologies and proper agronomic practices (Fig. 3 & 4). All the commercial fruits are harvested by hand and cleaned in cactus prickling machine (Fig. 5).

Unlike in Tigray the limiting factor in cactus pear production in Mexico is the presence of frosts during winter and early spring.

LINKAGE BETWEEN RESEARCH ORGANIZATIONS, EXTENSION SERVICES AND FARMERS

In Mexico there are many universities and research organizations working on cactus pear promotion. Among these the *"Chapingo"* and *"San Luis Potosi"* universities and "INIFAP" research station (Fig. 6) are the organizations working on cactus development strongly. Here a lot of researchers are involved in cactus development programs and the results disseminated to the cactus growers directly or through governmental agencies. Almost all cactus growers in the country are organized in cactus growing and processing organizations and involved in cactus researches by funding to the research. For research and educational purposes five *ex-situ* cactus germplasm banks and other seven collection centers (Fig. 7) are established by the government through out the country.

In Tigray regional state even though few years ago different governmental and non governmental organizations came to involve in cactus development programs, their involvement did not bring break through in changing the existing problem of cactus production. Of course regarding the collection center, BOARD in collaboration with FAO established one collection center in *Agulae* (Fig. 8) around 30 km north to Mekelle.

By now more than 45 cultivars of cactus were collected and planted in this collection center. But in the future the objectives and the ownership of this collection center should be revised. The involvement of research organizations on cactus based development is at infant level. It is clear that cactus for the Tigray farmers is not an optional. It is strongly linked with their life. However, the research institutions and universities gave more emphasis to other crops/plants which has less social and economic value comparing with cactus pear. On the other hand the linkage between different organizations working on the area of cactus is very weak. Even after the establishment of CPPI in 2004, every member of the initiative is not actively involved under the umbrella of CPPI for the cactus based development in the region.

CONCLUSION

For good or bad reasons cactus pear and the people of Tigray are strongly interlinked for more than 16 decades. However owning this ample and huge resource our people remained victim of famine for several years. To overcome this chronic problem the Regional Government of Tigray designed poverty alleviation strategies including cactus based development program and has started work for its realization. Although there are some promising achievements in promoting this miraculous crop, the over all interventions made by different stakeholders are not sufficient. This is due to lack of integrity among the stakeholders, lack of attention to the plant and others. In Tigray condition the immediate solution to bring food security especially in those drought prone areas is working on cactus. Nowadays, cactus pear in Mexico is not only life saving but also among the leading agricultural products which brought hard currency to the Mexicans. This is what we can learn from Mexico.

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Figure 1. Training on modern cactus orchard management

Figure 2. Cactus pear plants on the hillsides of Erob

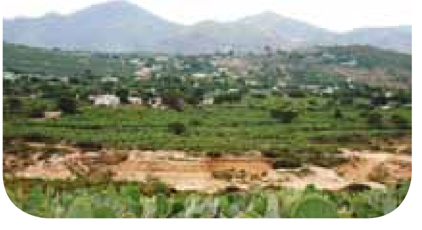

Figure 3. Backyard cactus orchard in Mexico

Figure 4. Modern cactus plantation in Mexico

Figure 5. Cactus fruit cleaning machine in Mexico

Figure 6. INIFAP research center

Figure 7. The Chapingo cactus collection center

Figure 8. Agulae cactus pear collection center in Tigray

CURRENT STATUS ON THE OCCURRENCE, UTILIZATION AND MANAGEMENT OF CACTUS PEAR (*OPUNTIA* SPP.) IN KENYA

Eunice W. Githae* and Moses M. Nyangito
Department of Land Resource Management and Agricultural Technology, University of Nairobi, P. O. Box 29053-00625, Nairobi, Kenya
** Correspondence (e-mail: egithaeh@gmail.com; tel.: +254 725 286 095)*

ABSTRACT

Kenya has a wide range of biological diversity with a rich flora of about 7,000 native plant species. Several of these species were introduced in Kenya among them the common pear cactus (Opuntia spp.), which is a succulent shrub growing up to a height of 2.5 m with flattened, jointed stems with edible fruits. The species has now been naturalized in several parts of Kenya especially along the Coast, Rift Valley and Nyanza provinces, and along the eastern shore of Lake Victoria. The plant is commonly found in agro-climatic zones VI to VII (semi arid to very arid, with average annual rainfall ranging from < 350 mm to 600 mm). These are areas which are also characterized by soils of low inherent fertility and where potential for plant growth is medium to very low. Except under extreme drought conditions the plant is hardly used as a source of food but is commonly used as a protection fence for homesteads and agricultural fields where it is known as a cactus fence. This hedge however becomes difficult to be controlled once established, and thus become progressively thicker and develops into a dense thicket, which neutralizes large areas of farms and pastureland. Despite this ideal purpose, the plant is often found growing alone in the wild, where it interferes and competes with indigenous plant populations especially in the drylands. In other areas, the plant is commonly used as a potted plant, houseplant or in ornamental gardens. The main constrain of utilizing this species, among others factors, are the cultural factors, with a complexity to adjust the eating habits. Children are the main consumers of these fruits, while the adults consume particular species with a negative attitude, as the fruit is associated with drought and hunger. Research is therefore required in order to address the environmental, biophysical and particularly socioeconomic importance of this species in Kenya.

INTRODUCTION

Kenya has a high biological diversity due to its variation in climate and topography, which result in a great range of habitats. This in turn has provided a wide variety of ecological niches and a rich flora of about 7000 native plant species (Maundu and Tengnas, 2005). Three quarters of Kenya land comprises arid and semi-arid ecosystem and most of the introduced plant species come from America and Europe (Stadler, 2000). Among them are the cacti, which thrive in areas of low rainfall where production of more succulent food plants is severely limited, and this adaptation to arid and semiarid climates allow them to be an interesting agricultural resource (Kossori *et al.,* 1998). The genus *Opuntia* is distributed in Europe, Mediterranean countries, Africa, southwestern United States, Mexico and other areas. Many resources have been available for research for traditional dryland crops such as sorghum, millet etc., but the resources devoted to cacti research and development is infinitesimally small (Felker and Inglese, 2003). A growing number of scientists now argue that cactus pears can make important contribution to economic development in arid and semi-arid lands while others highlight instances of its invasiveness (Middleton, 2002).

Several studies have been done on the economic importance of this species such as the nutritive value and composition (Kossori *et al.,* 1998; Sawaya *et al.,* 1983), salt tolerance (Nerd *et al.,* 1991) and a source of human and animal food in the arid and semi arid regions (Russell and Felker, 1987; Felker and Inglese, 2002). These studies are yet to be addressed in Kenya despite its wide distribution in many parts of the country such as along the Coast, Rift Valley and Nyanza provinces, and along the eastern shore of Lake Victoria (Agnew and Agnew, 1994; Ivens, 1967) with small patches occurring in many other districts.

There is need to educate the local communities on the socio-economic and environmental values of this most useful and widely found plant, for the purpose of sustainable utilization and improvement of dryland livelihoods. This paper therefore highlights the status and current management practices of cactus pear in Kenya with a view of formulating future policy recommendations through research on its potential to the Kenyan communities.

DESCRIPTION OF KENYA

Kenya has a wide range of altitudinal gradients ranging from the hot and humid coast adjacent to the Indian Ocean and adjoining arid lowlands of the east and northeastern of the country to the cool highlands and mountains at the center of the country. This range has a great influence of temperatures and precipitation resulting in the formation of seven agroclimatic zones (ACZ) (Fig. 1). This in turn has provided a wide variety of ecological niches with a rich flora of about 7,000 native plant species.

Kenya has rich biological resources, which are diverse. Around 25,000 species of animal and 7,000 plants have so far been recorded, along with at least 2,000 fungi and bacteria. These resources form the basic source of livelihood for the country's population especially in view of the fact that about 80% of the country's population directly or indirectly relies on biodiversity for survival (MENR, 2001). One of the major challenges of biodiversity conservation and management in

Kenya is the society's inability to make informed decisions regarding biodiversity management as they lack adequate information on the non-consumptive values of these resources.

SPECIES INTRODUCTION IN KENYA

Three quarters of Kenya land comprises arid and semi-arid ecosystem and most of the introduced plant species come from America and Europe (Stadler, 2000). They have been introduced for several purposes (Dharani, 2002). There are several invasions of alien species in Kenya that have had negative impacts on biodiversity, agriculture and human development. Studies show that Kenya has been invaded by nine plant species, among them showed in Table 1, which was modified from Kedera and Kuria, (2005).

Some species have been introduced with good intentions but have become invasive. If not properly managed, most of them can eradicate the indigenous species, for example, *Prosopis* spp. in the northern Kenya, which has blocked rivers, made large areas useless and interfered with plant diversity (Maundu and Tengnäs, 2005). Other species like *Eucalyptus*, which were introduced from Australia for firewood and timber, are now being uprooting due to diminishing the ground water tables. These shortcomings of introduced species contribute to the fear of their adoption and various efforts are towards their eradication, containment and control.

DESCRIPTION OF CACTI SPECIES IN KENYA

The cacti (Cactaceae) are among the most extremely drought-resistant plants, and consequently they thrive in very arid regions. The group is characterized by a fleshy habit, presence of spines and bristles, and large, brightly colored, solitary flowers. Many of the species are grown as ornamentals or oddities. Two genus of Cactaceae are found on Kenya; *Rhipsalis* and *Opuntia*. *Opuntia* (cactus pear) is the largest with jointed-stemmed species and recognizable by the fleshy stems made up of either cylindrical or flattened joints called pads. Two species of *Opuntia* are recognized in Kenya; *Opuntia vulgaris* L., (Fruits without spines) and *Opuntia ficus-indica* (L.) Mill (fruits having up to 15 mm long spines on the bristle tufts). They survive in altitudes below 1800 m ASL and are now naturalized in several parts of Kenya.

ECONOMIC IMPORTANCE OF *OPUNTIA* SPP. IN KENYA

Several documents have been written on the use of cactus pear (e.g. Russell and Felker, 1987; Felker and Inglese, 2002; Middleton, 2002). In Kenya, it was introduced in the 1940s - 50s for use as a hedge plant in dry areas and continues to serve the same purpose. The plant is commonly used as a protection fence for homesteads and agricultural fields where it is known as a cactus fence. This happens especially where there is a lack of either natural resources or financial means to construct a permanent fence. This is often seen in arid and warm climates, such as the Masai Mara in Kenya. Once the pear hedge is established, it is difficult to be controlled since cut or broken fragments of stem readily take root when they fall to the ground. This hedge thus become progressively thicker and develops into a dense thicket, which neutralizes large areas of farms and pastureland. Despite this ideal purpose of being a hedge plant, the plant is often found growing alone in the wild, where it interferes and competes with indigenous plant populations. In other areas, the plant is commonly used as a potted plant, houseplant or in ornamental gardens. In Laikipia District, the plant is consumed together with seasonal wild fruit jams and jellies from "Lamuria" berries (*Carissa edulis*) and wild kei apple (Wren and Powys, 2008). The fruits are also sun dried and stored for several months by pastoralists. In Baringo District, the fleshy leaves are cut, then partially exposed to fire to remove the thorns and then fed to livestock during the prolonged dry period. Though this harvesting requires a lot of expertise and patience to avoid being pricked by its thorns, it is the only solution left to reduce hunger and this should be further addressed as a measure to drought adaptation. The Kenya Government and other research organizations in Kenya should therefore educate Kenyans on how to manage, collect, prepare and cook the fruits and pads, and to exploit any medicinal uses of this most useful and widely found plant (DenaCrain, 2009).

MAJOR CONSTRAINS OF CACTUS PEAR UTILIZATION IN KENYA

Majority of wild fruits are known to be poisonous and reportedly have caused health problems that sometimes lead to fatality (Simitu *et al.,* 2009). The potential uses of the pear cactus in Kenya have not yet been well documented and exploited. The main constrain of utilizing this species is the cultural factors, with a complexity to adjust the eating habits. Children are the main consumers of these fruits, while the adults consume particular species with a negative attitude on the use of indigenous fruits trees. That is, these are only consumed during the time of food shortage and famine. This has been the case identified with the consumption of many dryland indigenous fruit trees (Simitu *et al.,* 1009). The species is also regarded as poisonous with dangerous spines (Kedera and Kuria, 2005). The method of removing these spines from the fruit is tedious and once they penetrate the human skin they normally become invisible leading to itching and pain. The species is also regarded as invasive and with its nasty thorns, it is often found growing alone in the wild, and interferes and competes with indigenous plant populations.

CURRENT CONSERVATION STATUS OF *OPUNTIA* SPP. IN KENYA

Kenya possesses a wide diversity of indigenous knowledge, innovations and practices that can be harnessed for sustainable utilization and conservation of biological resources. Newton (1995) documents 364 succulent taxa in 22 families in Kenya, with 23 taxa having unknown conservation status. *Opuntia* spp. is not included in the list and therefore research of its inventory is required to document its current status in Kenya. The Kenya Succulent Species Conservation Project, which was initiated in 1996 under the auspices of Plant Conservation Program (PCP) of the East African Herbarium, has the mandate to facilitate conservation of Kenya's succulent plant taxa (Oldfield, 1997). The major succulent species being addressed are the indigenous species, which unfortunately do not include the cacti.

CONCLUSIONS AND RECOMMENDATIONS

There is hardly any information on the occurrence, distribution, use and management of prickly pear plant in Kenya. Both basic and applied research is lacking that would address the biophysical and socio economic importance of this species. It is important that local communities should be educated on its socio-economic and environmental value for the purpose of sustainable utilization and improvement of dryland livelihoods. Attempts should also be made to address the issues of value chain addition associated with this species, as this would greatly improve the rural livelihoods of the local communities.

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Table 1. Several introduced species in Kenya with their pros and cons

Species	Source	Year of arrival	Cause for introduction	Impact on native vegetation
Lantana (*Lantana camara*)	Tropical America	1950s	Ornamental	Invasive
Mesquite (*Prosopis juliflora*)	Central America, Mexico	1983	Soil stabilization	Invasive
Morning glory (*Ipomoea spp.*)	South America	1960s	Ornamental	Out-competes vegetation
Water hyacinth (*Eichhornia crassipes*)	South America	1989	Ornamental	Colonization of water bodies
Mexican marigold (*Tagetes minuta*)	South America	Unknown	Medicinal	Invasive, weed
Opuntia spp. (*Cactaceae*)	Central America, Bolivia	1940s-50s	Hedge plant	Invasive
Eucalyptus (*Eucalyptus spp.*)	Australia	1939-45	Firewood and timber	Diminish the ground water table, affect crop yield

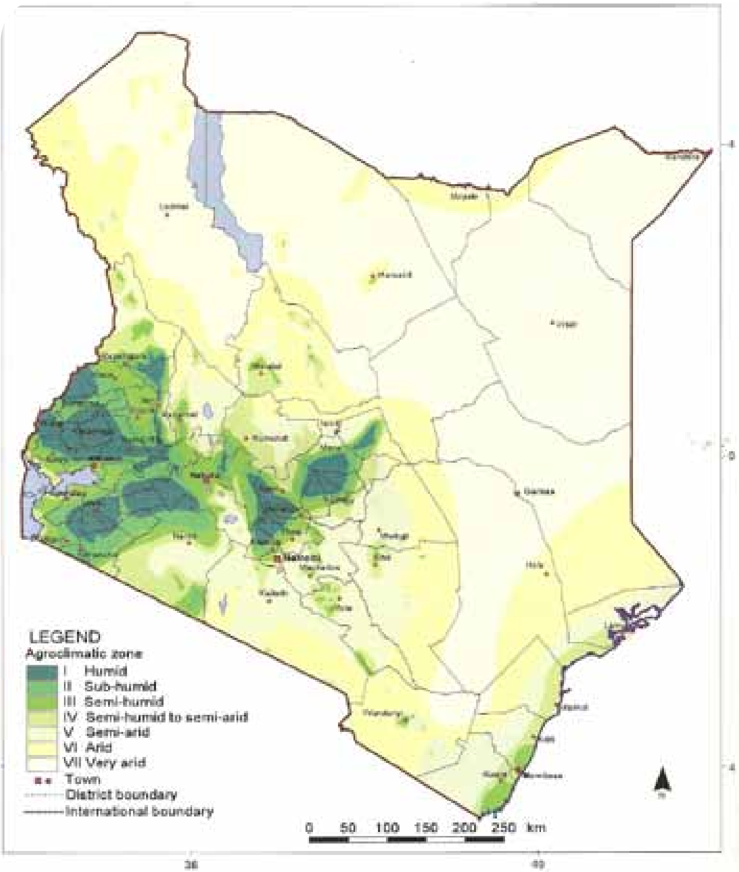

Figure 1. Agro-climatic zones of Kenya (Source: Maundu and Tengnäs, 2005)

A REVIEW OF THE DISTRIBUTION, USE AND POTENTIAL OF CACTUS PEAR (*OPUNTIA FICUS-INDICA (L.) MILL.)* AS RUMINANT FEED IN ZIMBABWE

Milton T. Makumbe
Ministry of Agriculture, Mechanization and Irrigation Development (AMID), Department of Research and Specialist Services (DR&SS), Henderson Research Institute, P. Bag 2004, Mazowe, Zimbabwe
E-mail: mtmakumbe@yahoo.com
Mobile: +263-912 357 765

ABSTRACT

The utilization of cactus pear (Opuntia ficus-indica (L.) Mill.) in Zimbabwe has not been given due attention. Varieties of cactus pear occurring throughout Zimbabwe are little known. However, both spiny and spineless varieties of cactus pear occur on rangeland. New spineless cactus pear varieties were recently imported from the Republic of South Africa for research and use as ruminant feed. Varieties of spineless cactus pear imported into Zimbabwe are Skinners Scot, Drikteur, Mixed Variety, Malta and Algiers. Some varieties of spineless cactus pear have been characterized from the rangeland in Zimbabwe. These are Makoholi, Somabula and Zvishavane. They are named based on their place of origin in Zimbabwe. There is however still great potential to characterize new cactus pear germplasm from rangeland in Zimbabwe.

The use of cactus pear in ruminant feed in Zimbabwe has been minimal. The poor adoption of cactus pear in ruminant feed in Zimbabwe can be attributed to the ability of country's rangelands to support livestock mainly with feed supplement during dry and drought periods characterized by nutritional stress. Cactus pear's aggressive growth habit can be a threat to indigenous plant biodiversity with a potential to reduce accessibility of rangelands and their forage. Varieties of spiny cactus pear on rangeland in Zimbabwe are a danger to ruminants with their large spines and groups of small spicules with minute barbs, further contributing to the poor adoption rate of the plant by livestock farmers in the country.

Cactus pear is little but rarely utilized by ruminant livestock farmers. There is limited knowledge on cactus pear use in Zimbabwe. There is thus need to further expand on current research programs on cactus pear in the country with the assistance of experienced researchers from countries with experience on cactus pear utilization.

The utilization of cactus pear in ruminant feed is likely to play a significant role in the sustenance of livestock based agricultural production systems in semi

arid zones in Zimbabwe in future as an alternative and reliable energy and water source. Cactus pear has the potential to provide feed for ruminants and thus reduce competition for grain between ruminants and humans. Cactus pear has potential to reduce water stress and minimize water requirements of ruminants in Zimbabwe's drier regions and predicted drier future. The objective of this paper is to briefly review the distribution, use, on-going and conducted research work, and potential of cactus pear as ruminant feed in Zimbabwe.

INTRODUCTION

Cactus pear (*Opuntia ficus-indica (L.) Mill.)* was introduced for food, ruminant livestock feed and for use as protective hedges in Zimbabwe. Most of the cactus pear was introduced from the Republic of South Africa. Records dated as early as 1959 in the National Herbarium of Zimbabwe indicate that cactus pear was cultivated at Harare Experiment Station with the intention of propagating for research and dissemination in Zimbabwe. Despite this, there has been little research work done on cactus pear to date, with little documentation on varieties of cactus pear growing on rangeland and their distribution in Zimbabwe.

VARIETIES AND DISTRIBUTION OF CACTUS PEAR IN ZIMBABWE

Cactus pear has become naturalized on rangelands in Zimbabwe. The species' ability to survive adverse conditions has led to its establishment and distribution countrywide in the country. The plant species is found in a wide range of climates that vary from the extremely cooler and wetter Eastern Highlands to the extremely hotter and drier Southern parts of Zimbabwe.

Both spiny and spineless varieties of cactus pear can be found growing in Zimbabwe. Very little effort has been made to characterize varieties of cactus pear growing on rangeland in Zimbabwe. To date, three distinct varieties have been characterized from the rangeland in Zimbabwe namely Makoholi, Somabula and Zvishavane. These varieties derive their names from their places of origin in Zimbabwe.

New varieties of spineless cactus pear were recently imported by livestock research institutes into Zimbabwe from the Republic of South Africa. These varieties include Skinners Scot, Drikteur, Malta, Mixed Variety and Algiers. The cultivation of these new varieties is still in its infancy stages and localized to government research institutes.

UTILISATION OF CACTUS PEAR IN RUMINANT FEED IN ZIMBABWE

Ruminant livestock farmers in Zimbabwe's semi arid regions rarely utilize cactus pear as feed for ruminants. Most livestock farmers in Zimbabwe are unaware that the plant can be fed to livestock. Cactus pear's potential in ruminant diets in Zimbabwe as an emergency feedstock in dry and drought periods was clearly defined when some livestock farmers in the semi arid areas of Zimbabwe made use of cactus pear on the rangeland during the 1991-1992 drought. Cactus pear replaced forage consumed and reduced requirements of scarce water by ruminants on the rangeland in Zimbabwe. The use of cactus pear in ruminant feed became minimal after the 1991-1992 droughts when good rains were received with a subsequent growth of new forage on the rangeland and good crop harvests.

Reasons for poor adoption of cactus pear in ruminant feed in Zimbabwe

Favorable climatic conditions for ruminant livestock production from rangeland and production of legume and cereal crops for livestock supplement.

Zimbabwe is a characteristic sub-humid to semi-arid country. It receives mean annual rainfall ranging between 400 mm to 2000 mm depending on region during five summer months spanning from November to March. Rainfall, being the major determining factor in crop production, has been influential in Zimbabwe's relatively high food security and strong agricultural economy. Maize, pearl millet and sorghum have been grown traditionally by most Zimbabwean commercial and smallholder farmers. These crops were allocated large cropped areas in Zimbabwe, with relatively high cereal grain production. These cereal crops provided grain, silage, and crop residues used as livestock feed and/ or as supplementary feed particularly in times of nutritional stress. With a rangeland that was capable of supporting ruminant livestock, there was very little need for the use of cactus pear in ruminant feed in Zimbabwe.

Potential threat to biodiversity and invasive nature of cactus pear to graze land

Cactus pear is an aggressive invader that has great potential to eliminate indigenous vegetation once established on rangeland. Cactus pear can grow into dense thickets on rangelands rendering them inaccessible for grazing. Ruminant livestock farmers have thus viewed the plant as a noxious weed rather than a valuable feed resource.

Source of mortality for ruminants on rangeland

Spiny cactus pear varieties are a cause of high mortality in ruminants in areas where they grow on rangeland in Zimbabwe. Livestock farmers in Zimbabwe have recorded losses in goats, sheep, and cattle. Goats and sheep have been observed to be very fond of cactus pear fruit, particularly when new flowers appear. Goats and sheep nibble the young petals and their lips become covered with the minute spicules of the young fruits. This results in inflamed lips, reducing animal foraging and causing rapid loss in animal condition. Cattle and goats, in particular, eat ripe fruits when accessible. The minute spines that occur on the fruits can pierce and irritate the membranes of the digestive tract.

Minute spines can cause severe inflammation that interferes with digestion and results in loss of condition and death often follows. This has contributed to the reluctance by livestock farmers to use the plant in ruminant feed.

Factors contributing to increased potential of cactus pear use in Zimbabwe

Seasonal fluctuations in water, and total and nutritional composition of graze on rangeland

Ruminant livestock farmers in Zimbabwe depend on the rain-fed natural rangeland to raise their livestock. Feed and water resources for livestock on the rangeland vary with prevailing weather conditions (season). Water and feed qualities and quantities are low in the dry season (July to November) and lowest during drought period. The nutritive value of feed on the rangeland in the wet season in Zimbabwe is about 12% crude protein (CP) with a dry matter (DM) digestibility of 65%, rapidly declining in winter to between 2 - 4% CP with a DM digestibility of 45%. For the greater part of the year, natural rangeland barely meets the maintenance requirements of ruminants.

Shortages of water and feed are the major constraints to livestock productivity on rangeland in Zimbabwe. Ruminant production has to depend on feed supplement from inadequate quantities of crop residues during the dry period (Ndlovu and Sibanda, 1990). Water quantity dwindles in livestock watering points as a result of increased evaporation rates. Livestock use a considerable amount of energy for foraging on vast tracts of land to meet their dietary requirements, and to walk longer distances for water on rangelands. Livestock production declines with a possibility of livestock loss. The growing and use of succulent and nutritive forages like cactus pear (cladodes) is key source of water and supplement to rangeland graze and browse. Cladodes can provide mean moisture contents of 90.8 %, 89.1 % and 83.4 % for young, mature and older cladodes respectively (Flores, Murillo, Borrego, *et al.*, 1995). Cactus pear fresh weight yields are high, with a range from 106.9 to 205.0 tones per hectare per year (approximately 16 to 31 ton DM per hectare per year) depending geographical zone, soil type, fertilizer application, planting density and association with other crops (Santana, 1992). Cactus pear can provide a readily available, cheap, energy and water source for ruminants in Zimbabwe during dry and drought periods.

Harsh climatic conditions in semi arid areas suitable for the establishment of cactus pear over other fodder crops as ruminant livestock fodder banks.

Semi arid areas characteristically have low and erratic rainfall, sometimes with long dry spells within the rainy season. Droughts are common. Soils in these areas in Zimbabwe are loose, infertile, poor, and fragile granitic sands. The most suitable fodder crops for these areas are those that can withstand water shortages, high temperatures, poor soils, and require low energy inputs and easy management but still provide adequate, palatable and nutritious fodder for livestock. Cactus pear meets the criteria of fodder crop suitable for establishment in these areas as it establishes and grows better in comparison to other fodder crops. According to Nefzaoui, Chermiti and Ben Salem (1993), opuntias are advantageous over other fodder crops because they have high biomass yield, high palatability and good nutritive value, evergreen habit, drought resistance and soil adaptability. Opuntias are efficient converters of water to DM, and thus to digestible energy (Nobel, 1995), than C3 grasses and C4 broadleaves (Nobel, 1989).

Unavailability of surplus land in semi arid areas for use in establishing fodder banks

A considerable increase in the number of people in semi-arid areas in Zimbabwe has resulted in a significant proportion of the grazing land being used for crop production in the small holder sector. Consequently, there has been a general shortage of land in this sector for grazing. Most of the available '*suitable*' cropping land is reserved for food crop production, particularly drought tolerant small grains. Food crop yields are nonetheless low and inadequate for both humans and livestock consumption.

The introduction of fodder crops in this sector is an option to supplement the dwindling grazing land. Establishment of fodder crops is mostly limited by the availability and suitability of land to grow them as they compete with food crops. Potentially, fodder banks in these areas may be established on fallow lands, contour ridges, water ways and the natural veld (Mache and Mupangwa, 1993). Of the range of crops that are most suitable for establishment on these lands, cactus pear has an advantage over other fodder crops.

Decline in crop production

Crop production has been declining in Zimbabwe as commercial farmers diversify into better paying enterprises such as horticulture (Zimbabwe Country Report, 1997). There has thus been a reduction in the amount of cereal grain, silage and crop residues for use as livestock feed.

The adverse effects of climate change will have adverse consequences to future livelihoods in Zimbabwe due to severe and frequent droughts and increased temperature. A 2°C increase in temperature will potentially decrease the agricultural zone in Zimbabwe by a third (Downing, 1992), and reduce quantity and quality of water sources. There is potential for increased risk to crop production.

Food shortfalls will increase in Zimbabwe due to reduced crop harvests versus an increasing population. Priority for crop production is for human consumption rather than for livestock feed. This will severely impact on livestock production in Zimbabwe. In response to future moisture limited farming in Zimbabwe, cactus pear may be grown and used as a substitute for grain and crop residues in supplementing ruminants in Zimbabwe as a strategy to adapt to climate change.

CACTUS PEAR RESEARCH IN ZIMBABWE

Cactus pear research as ruminant feed in Zimbabwe is still in its infancy. It is being conducted by livestock research institutes within the Department of Research and Specialist Services (DR&SS) in the Ministry of Agriculture, Mechanization and Irrigation Development in Zimbabwe. The research focus at the Livestock Institutes particularly in semi arid areas in Zimbabwe is to improve utilization of rangelands and other feedstuffs and promote the use of adapted and appropriate additional livestock feed resources.

Current cactus pear research in Zimbabwe is on the *'Screening of cactus ascensions for adaptability and high yield for feed availability improvement during the winter period'*. This research is focusing on several imported spineless cactus pear varieties with the intention of identifying high yielding and most adaptable varieties within semi arid areas in Zimbabwe. This work is still an on-station trial. Another livestock research institute is working on *'The evaluation of Cactus Pear as feed for livestock in semi-arid areas of Zimbabwe'.* This research work is assessing different ways in which different cactus pear feeds can be made with conventional high protein feed sources coupled with their potential to reduce drinking water requirements of ruminants in semi arid areas. One research was conducted involves the comparison of crop stover with ensiled cactus pear, wilted cactus pear, and fresh cactus pear as sheep feeds. Clean water was made available *ad libitum*. The results obtained showed the potential of the cactus pear diets as a potential substitute feed to traditional crop stover for sheep and in reducing water consumption by sheep.

A second research trial was conducted on dairy cow feed formulated on a conventional cactus based diet that had acacia leaves as a protein source and some maize silage. This cactus pear based diet was compared to a dairy concentrate based diet. Results showed that the conventional cactus pear based diet was suitable for feeding dairy cows, with results showing comparative and high milk yield with reduced water consumption by the dairy cows fed on this diet. There is potential for higher profit margins in dairy production using the conventional cactus pear based diets than bought-in dairy concentrate based diets.

RECOMMENDATIONS

There is need for a detailed survey to be conducted on cactus pear to generate information on the existing cactus pear germplasm and its distribution in Zimbabwe. Cactus pear varieties need to be described and suitably prepared for record purposes in the National Herbarium in Zimbabwe. This will aid future research work on cactus pear in the country.

More research needs to be conducted on the inclusion of the cactus pear in ruminant diets in Zimbabwe. There is need for Zimbabwean researchers working on cactus pear to network through forums, workshops and the internet with researchers in countries that have experience in utilizing cactus pear as a strategy for feed (and food security).

Establishment of cactus pear fields should be promoted at household level and on rangelands as fodder banks to provide feed in the dry season and during droughts in Zimbabwe. There is need to sell the idea of cactus pear use in ruminant livestock feed to ruminant livestock farmers in Zimbabwe. Farmers should be trained on the establishment and control of (spineless) cactus pear fields. Farmers should be informed of the proper utilization of the cactus pear to avoid unnecessary losses of ruminant livestock during dry and drought periods.

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CACTUS PEAR GENETIC RESOURCES CONSERVATION, EVALUATION AND USES

Innocenza Chessa
Dipartimento di Economia e Sistemi Arborei, Università degli Studi di Sassari, Sassari, Italy
Via De Nicola, 9, 07100 Sassari; email: chessa_i@uniss.it

ABSTRACT

Cactus pear has been evaluated as one of the potential important species for crop production, due to its role in promoting sustainable cultivation systems and landscape conservation, as well as safeguard of both natural and cultural heritage. With the objective to collect, characterize, evaluate and preserve the genetic resources of Opuntia spp. developed in the Mediterranean environment since the plant introduction, as well as to enlarge the genetic base diversity, the result of the conservation activities carried out in Italy are reported. A crop-oriented in field ex situ collection was established at the DESA (Department of economics and woody plant ecosystems), University of Sassari to promote the conservation and utilization of cactus pear diversity. The objective of the Opuntia germplasm conservation and management initiatives undertaken in the Mediterranean area, as well as the main key factors affecting the conservation status of the species are discussed. General biodiversity related implications are reported concerning the collection, description and evaluation of cultivated and wild genotypes of the platyopuntias in the region. The recent knowledge deriving by the application of the molecular markers technique has been applied to evaluate the level of genetic diversity. The effective use of the collected germplasm in designing a crop improvement program has been one of the main uses of the collection and some of the results up to now obtained are highlighted. Recent activities aimed at introducing in other countries and promoting the cactus pear utilization as a multipurpose crop are finally indicated.

INTRODUCTION

An unparalleled rate of crop varietal diversity erosion within the short span of the last few decades has been documented in various part of the world. Environmental changes, together with abrupt population growth and intensive market globalization have been indicated as main causes of agrobiodiversity decline. The biological diversity of the species of domesticated plants and animals, resulted from the millennia of selection, provide a huge potential for the adaptation of farming systems to new priorities and new constraints. In the today's very unstable climate situation and in view of the expected more warming, genetic resources undervalued so far may become crucial to cope with increasing disruption to agriculture and unforeseen threats to agricultural production. The utilization of crop varieties or species better suited to new growing conditions may be critical to food security, since these may contain genes for traits that could be used to improve crop species and varieties (Burke et al., 2009). Among crops best suited to difficult environments, cactus pear has become one of the most well-known examples of exotic and sometimes invasive plant species, spread in several world regions from the native highlands of Mexico.

In the Mediterranean basin, some *Opuntia* species and mainly the *Opuntia ficus-indica* has been widely distributed, but generally the invasion trend has been kept under control by the local vegetation. Besides the succulents were found to be particularly invasive, the Mediterranean basin has neither recruited nor evolved many naturally-occurring succulent species (Blondel and Aronson, 1999). Many exotic plants have been introduced since millenia in the area both intentionally, because of their utilitarian value, and unintentionally in association with trade and travel. In these areas, *Opuntia* species have found optimal environmental conditions fitting to their functional traits. Where *Opuntia* has become invasive, its spread has been controlled by various means or, in some cases; the invasiveness has been managed improving resource utilization and value-adding initiatives. In the new areas of diffusion the *Opuntiae* are also extraordinarily important as part of the landscape, as well as for forage and fodder utilization, in the subsistence agriculture, and for the market-oriented fruit industry. A continuous process of naturalization may have led to the rise of a new phenotypic and genetic diversity in the new areas of diffusion, and the resulting populations have undergone a selection process mainly related to the plant agricultural uses.

OPUNTIA GERMPLASM CONSERVATION AND MANAGEMENT

The large diffusion of *Opuntiae* outside their native area has allowed the conservation of their original large genetic variability and the development of new variability, as a result of adaptation to new environments. To preserve this diversity a conservation approach has been chosen, both in the origin area (Mondragon et al., 2009) and in countries where *Opuntiae* have developed into a crop and have been spread for agricultural uses (Potgeiter and Mashope, 2009; Snoussi Trifa et al., 2009).

The *Opuntia* spp. genetic resources have been collected and a main collection has been established in Italy, starting from 1990. The conservation effort has been planned to maintain *Opuntia* germplasm as a living *ex situ* collection, useful for characterization, evaluation of collected genotypes and makes their use easy.

The followed approach is supported by the high value of the *Opuntia* genetic resources. This multiple use plant is a biological resource for adaptation to current anthropogenic environmental changes, and valuable agricultural resources intrinsically resistant to drylands conditions (Nefzaoui and Salem, 2001). Moreover, since the crop may be cultivated with low input, as in southern Italy due to the absence of main pathogens and pests, evident benefits to the environment and to the conservation of biodiversity are assured. Concurrently the crop is also endowed with the conservation of traditional farming systems and their natural values, the maintenance of rural landscape, and at the same time is a potential source of innovation for sustainable agriculture as a new crop option.

In developing an *ex situ* collection each sample obtained and maintained should be representative of extant *in situ* diversity and makes the most efficient use of available resources. Criteria used in selecting material for a collection include taxonomic diversity, ecological diversity, geographical diversity, genetic diversity and morphological diversity. In the case of *Opuntia*, the main working goal has been to conserve the genetic diversity evaluated as a source of new variability and diversity linked to the plant uses, with the potential for future exploitation. More specific objectives were also defined, such as: 1) to preserve the diversity of cultivated local accessions; 2) increase the value of their productions and of the traditional knowledge associated to their use; 3) understand the diversity collected, to support traditional uses and promote alternative uses; and 4) enhance genetic variability by hybridization and selection to develop new selections and variety lines for multiple utilization. In order to optimize the collection management and address the conservation to the direct utilization of the genetic resources maintained a strategy has been applied, providing that all the steps are connected, as summarized in figure 1.

Following the collecting activities, and the genetic improvement program developed, the *Opuntia* spp. collection hosted by the University of Sassari includes more than 2200 accessions and is located in Sardinia (Oristano, 39° 53′ N; 08° 37′ E). The current composition encompass different species of *Opuntia* and the *Nopalea cochenillifera*, wild genotypes and ecotypes, international and local varieties (Photo 1), selected variety lines, as well as a number of seedlings obtained from free pollination, and by inter- and intra-specific crosses and embryoculture. The samples provenance is mainly from Italy, Sardinia and Sicily, but also from other countries such as: Argentina, Canada, Chile, France, Mexico, Morocco, South Africa and Texas (USA).

ACCESSIONS ACQUISITION, COLLECTION AND CONSERVATION

The type of diversity, the sample origin, and main use were assumed as basic criteria to acquire genotypes to be entered into the collection. Depending on these criteria collection was carried out by different means. To represent the variability at species level *Opuntia* and *Nopalea* species have been mainly acquired from botanical gardens or existing collection. Samples from wild population and ecotypes have been identified and collected in Sardinia.

The crop intra-specific variability has been represented by accessions collected from commercial plantations and traditional orchards, where the main cultivars or the local cultivated genotypes are grown. The lack of a well defined standard for varieties has led to local heterogeneous populations being developed in producing countries. A few varieties, mostly distinguished on the basis of some morphological features of the fruit and cladodes, sustain the *Opuntia* commercial production. While the widest biological diversity is found in the origin area and in few naturalization zones where *Opuntia* spp. become invasive, in Southern Italy a narrow base of genetic variation was originated by the prevailing vegetative propagation behavior of *Opuntia* species (Nieddu et al., 1998).

The improvement of cultivated plant species and varieties mostly rely on intra-specific diversity, originated both from cultivated and related wild population. Consequently, the importance of conserving this diversity has been highlighted to ensure productivity and stability of plant species. Furthermore, it has been demonstrated that the potential exists for the future exploitation of the diversity within species natural population, even if its economic value is currently unrecognized (Jump et al., 2008). Concerning sample origin, accessions were acquired from other than Sardinia Italian regions, mainly Sicily where the cultivation is mostly concentrated. More samples were also collected from various countries, mainly by means of contributions from others Institutions.

The availability of information on the geographic origin of accessions entries in a collection is a vital prerequisite for both the conservation and effective utilization of plant genetic resources (Khoury et al., 2010). The species-environment relationships have been studied on *Opuntia* using a methodology based on statistical tools and GIS applications, applied on the Mediterranean island of Sardinia (Fig. 2) and validated on Corsica island, and the expected probability surface have been calculated (Fig. 3). The environmental factors limiting the species spatial distribution were determined, together with those favoring its adaptability to the Mediterranean region (Erre et al., 2009).

In order to strengthen the link between conservation and utilization, the *ex situ* collection has been established following international methods (Jaramillo and Baena, 2002), with specific reference to perennial and woody plants vegetatively propagated. The selected site hosting the collection fields has been prepared to favour plant growth. Optimal cultivation conditions are provided to sustain the potential productivity of accessions and maintain the plant in health conditions, as well as their original genetic characteristics preserved. All the conservation and management activities have been conducted thanks to the availability of suited land and facilities, provided by the experimental station of the University of Sassari.

CHARACTERIZATION AND EVALUATION

The knowledge of genetic diversity is a useful tool in gene-bank management and breeding experiments, identification and/or elimination of duplicates in the collection and establishment of core collections. Adequate characterization for agronomic and morphological traits is necessary to facilitate utilization of germplasm by farmers, researchers and breeders. To achieve this, germplasm accessions are characterized for morphological traits and evaluated for agronomic behaviour over the years. Monitoring includes also continuous screening against biotic and abiotic stresses (Photo 2), and the estimations of traits linked to the quality of the production addressed to different uses. The characterization of genotypes for distinctive genetic traits inherent the fruit production industry (caduceous glochides, small seeds, high number of abortive seeds, early and late ripening time) has been one of the aims.

More precisely, major objectives of characterization work on the *Opuntia* collection are: 1) describe accessions and identify duplicates; 2) classify groups of accessions on the base of their current and potential uses; 3) identify accessions with desired agronomic traits and select accessions for more precise evaluation; 4) identify interrelationships between geographic groups of cultivars; and 5) estimate the extent of variation in the collection.

An European inventory and a database on germplasm collections of Mediterranean underutilized fruit tree species have been developed by the RESGEN project: *Conservation, evaluation, exploitation and collection of minor fruit tree species*, founded by the European Union in 1996. Information collected on 16 underutilized fruit tree species, including cactus pear, are comprehensive of both first and advanced characterization, and descriptors also linked to the agronomic evaluation of collected material. In the framework of this project 130 accessions of *Opuntia* spp. collected in Italy, Greece and Spain have been characterized and evaluated by means of a minimal descriptor lists.

As one of the result of the activities conducted within the FAO–ICARDA International Technical Cooperation Network on Cactus (Cactusnet), a more comprehensive in scope Descriptor List has been published in 1997 (Chessa and Nieddu, 1997). This publication is the standard accepted descriptor currently used, and has been applied to optimize the management of other *Opuntia* collections, as that established by the University of Santiago del Estero in Argentina (Ochoa, 2003). More recently, other descriptors have been proposed, with a minimum number of characters of highest priority, also drawn to provide greater standardization between collections, as well as improved utilization of accessions (Reyes-Agüero et al., 2005; Potgieter and Mashope, 2009).

Although the existing descriptors may be evaluated as more or less adequate, there is the need to recognize the importance of adoption and standardization of use of a common descriptor across all collections. With standardization and adequate training, accessions may be more easily compared across collections, facilitating greater utilization and rationalization of collections management. The helpfulness of standardized descriptors has been stressed by Felker and Inglese

(2003) in identifying the many forms, varieties and cultivars within the commercial fruit types on the basis of external morphological characters.

MOLECULAR MARKERS FINGERPRINTING

Characterization of germplasm using molecular fingerprinting has attained special attention due to its increased use in crop improvement and the selection of desirable genotypes for breeding crops. The application of genetic markers is also successfully used to resolve the taxonomic and evolutionary problems of several crop plants, to assess the structure and genetic variability of the accessions, to show the genetic relationships among them, and locate genes that express potentially useful traits in agricultural production or crop improvement.

DNA fingerprinting proved to be useful to classify *Opuntia* different species (Gordon and Kubisiak, 1998; Wang *et al.*, 1998, Labra *et al.*, 2003; Zoghlami et al., 2007; Snoussi Trifa et al., 2009; Souto Alves et al., 2009), by different molecular methods. In a first report on the molecular phylogeny of Galapagos'*Opuntia* cacti applying multiple DNA sequences, the need to use both molecular and morphological data in conservation planning has been demonstrated by Helsen et al., (2009).

Among the activities aimed at managing the *Opuntia* germplasm collection the genetic relationships within the accessions were investigated. In order to complement the observations on phenotype with more direct information on the genotype, an isozyme analysis has been undertaken (Chessa et al., 1997), and unique proteins patterns were identified to genotypes that are nearly identical morphologically. With the availability of more reliable molecular markers, *Opuntia* species and genotypes selected from traditional varieties cultivated in Italy have been analyzed by means of two different molecular markers, RAPD (Random Amplified Polimorphic DNA) and cpSSR (Chloroplast simple sequence repeats).

As a case study, the results obtained investigating the genetic relationships within a group of the *Opuntia* accessions (table 1) selected from the collection are reported. The usefulness of RAPD in describing genotypes tested for germplasm conservation purposes has been evidenced. All genotypes were uniquely identified by their banding patterns associated to six primers. The *O. robusta* accessions and the unclassified genotype were distinguished by 27 and 24 primers, respectively. Six primers produced the same profiles for the two selections of *O. amyclaea* (fig. 4). Moreover, the two clusters grouping the *O. amyclaea* and *O. ficus-indica* selections showed a high Similarity Index (0.87 and 0.86), thus indicating a very close genetic relationship between the accessions that were classified as belonging to the two species. However, this high similarity could also indicate the existence of two variants of the same species differing only for the presence of spines, as a result of the species development in the Mediterranean area.

The genetic differences between closely related species were evidenced applying the cpSSR marker on diverse *Opuntia* species. The results have shown the same cpSSR profile for *O. ficus-indica, O. amyclaea, O. robusta, O. stricta* and the unclassified genotype. On the contrary *O. dillenii, O. soherensis* and *Nopalea* were distinguished from the other *Opuntiae* by only one polymorphic locus out of the eight selected, showing two different allele size variants (fig. 5). The results obtained evidenced that the use of different molecular tools is useful to analyze cactus pear genetic diversity for different purposes, such as variety selection, genotypes identification and certification.

As a development of researches aimed at analyzing the molecular diversity and the population genetic structure of *Opuntia* species we developed a set of 10 microsatellite markers. The preliminary investigations conducted on a panel of genotypes from the germplasm collection were aimed to test transferability of the developed primers. The level of polymorphism and the relatively high number of alleles detected ranging from six to 22 suggest that these markers can be used for both inter and intra-specific studies, as well as to determine the presence of polyploidy within the *Opuntia* genus. The work currently in progress will contribute to the assessment of genetic diversity of the cactus pear.

To facilitate the evaluation work and the utilization of *Opuntia* genetic resources a core collection development task has been recently undertaken. The genotype selection is based on all characterization and evaluation data collected, and the availability of more reliable molecular markers such as the microsatellites will offers an opportunity for adjusting the size, the representativeness and the general quality of ‘core’ samples.

PLANT GENETIC RESOURCES UTILIZATION

As one of the multi-purpose plant species, cactus pear has a very considerable value in terms of horticultural production, as key component for the productivity and sustainability of arid and semi arid areas and as option crop to face the threats linked to environmental changes. To meet the demand of more suitable genotypes to support commercial cultivation, mainly in the areas of introduction, as well as contribute to sustainable development of marginalized rural areas the approach is to make available sound and health genetic materials for the various productions the *Opuntiae* offer. Combining conservation and use, the established *ex situ* in fields collection for long term conservation act as a working collection, aimed at identifying valuable accessions that express potentially useful traits in agricultural production or crop improvement.

Therefore, in terms of utilization the collection has been designed to be a source of characteristics for germplasm enhancement and breeding, or directly as varieties for those accessions that have already been evaluated and selected for specific production purposes. This is the case of the selection work conducted on fourteen genotypes identified within the Italian germplasm for their direct utilization in the cactus pear fruit industry (Photo 3). A preliminary general description on six varieties under selection has been previously presented (Nieddu *et al.*, 2002) and a more comprehensive description of twelve selected varieties has been lately reported (Chessa et al., 2005). For each selection the main descriptive traits specifically linked to the fruit production are given (Photo 5). Other main uses the collection may offer are materials for basic research (e.g., biology, taxonomy, pharmacology, etc.) and adding diversity to narrow genetic base.

The lack of selected varieties and the limited knowledge of growers on the levels of productivity and on the different uses provided by the plant are the main restraining factors for cactus pear cultivation in most of the southern areas of Italy. To add diversity within the Mediterranean *Opuntia* spp. naturalized population, a hybridization program has been developed, with the main objective of identifying new genotypes characterized by specific traits inherent the fruit quality such as: high yield, fruit size, balanced acidity, sugar and flavour content, small seeds and high number of abortive seeds, early and late ripening time. Suitable techniques to improve seed germinability were studied and applied to establish a large seedling group obtained by free-pollination (Photo 4) (Nieddu and Chessa, 1997; Nieddu et al., 2006).

Tests were conducted to identify appropriate hybridization techniques able to overcome the constraints related to the reproductive biology of *Opuntia*, mainly linked to cleistogamy and polyembryony, also applying the embryo culture technique of the zygotic embryo. The effectiveness of the crossing and of embryo culture techniques applied have been also described and the main observations on *Opuntia* species compatibility to hybridization and the hybrids fertility have been more recently reported (Nieddu and Chessa, 2005). More than 1000 hybrids were obtained, and about 400 were developed through in vitro embryo culture. Among the F1 progeny obtained, twenty hybrids have been selected by means of preliminary screening based on agronomic and pomological traits (Photo 5).

Since many economically desirable traits are controlled by polygenes, screening of accessions from a large collection must be subjected to refined testing procedures at different locations, and their different behaviour in diverse environments monitored (Damania, 2008). With this objective in mind, the Italian DESA collection has promoted the release of several of its germplasm accessions directly as superior varieties or promising hybrids as candidate varieties in different countries. Testing of the released genotypes were conducted in the Capo Verde island, as part of a cooperation project founded the Piedmont region, and in various countries (Libia, India, Morocco and Tunisia) within an ICARDA project.

CONCLUSION

The growing recognition that the diversity of cultivated crop species has vastly diminished in the last decades, affecting the livelihoods of resource-poor farmers and threatening the future of agricultural development, has intensified global efforts to conserve plant genetic resources for food and agriculture. In addition, the preservation and utilisation of crop genetic diversity is of particular importance to the more marginal, diverse agricultural environments where the agroecosystems stability is strictly linked to the biodiversity level.

The collection, conservation and management of *Opuntia* spp. genetic resources work conducted will contribute to diversity of cactus pear for food safety, sustainable productivity, and value-added profitability. The extensive cooperation between researchers in diverse disciplines and in many countries working within the FAO-ICARDA technical cooperation network on cactus (FAO-ICARDA CactusNet) for improving the cactus cultivation and utilization, may contribute to prevent genetic erosion and consequent loss of the crop diversity.

The establishment and maintenance of a crop oriented collection have been conducted in Italy with this objective in mind. Characterization and evaluation data may provide useful information to define the level of genetic variability within a population. The new investigative tools provided by biochemical and molecular technologies have been also applied to the genus *Opuntia*, used to approach a number of problems in breeding and other applied areas, as well as in more basic studies of genetics and developmental biology. The identification of accessions having particular traits valuable for specific utilization is the requirement for their inclusion in improvement programs.

The importance of combining conservation and utilisation, especially when dealing with commercial species, has been evidenced through the improvement program conducted. Promising candidate clones and hybrids will be further tested in order to verify the real yielding behaviour and the expected increase of this parameter at commercial level, when standard techniques of cultivation will be applied. Moreover, the availability of improved genotypes, in terms of quality and adaptation to various environments, will benefit biodiversity conservation and the environment protection by the adoption of farming system based on low energy input for the selected genotype cultivation.

To overcome major constraints in the *ex situ* conservation effort more collaborative plans are needed to find synergies between biodiversity and development of the agricultural system, as well as to strengthen the link between protection of biodiversity and its usefulness. To achieve these goals the acquired results provide a good foundation to improve on farm conservation methods. An increased awareness should arise on the long-term social benefits of diversity, as compared to the short-term private benefits of uniformity of the intensive agriculture. Moreover, understanding the critical role of agrobiodiversity and its close relationship with global changes (climate change, desertification) and food security is a prerequisite to move forward toward a more efficient and useful system of conservation and use of these invaluable resources.

Future collaborative projects should be aimed at 1) more extensive collecting actions, including also wild relatives; 2) gathering and exchanging information on the existing collections; (2) filling taxonomic gaps and standardizing the taxonomic content of the collections; 3) improving germplasm collection information systems for management purposes and for adding value to accessions for efficient utilization; (3) providing criteria to rationalize the collections and developing a conservation-priority core collection; 4) planning on farm conservation strategies where considerable crop diversity can be maintained on small farms in the form of traditional crop varieties.

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Table 1. List of analyzed Opuntia species and variety selections by means of RAPD and cpS

Species	Accession designation	Fruit pulp color	Cladode spines	Origin area
O. ficus-indica	Gialla Sarroch	dark yellow	none	Sicily
	Bianca Macomer	green	none	Sardinia
	Bianca San Cono	white	none	Sicily
	Rossa Macomer	purple	none	Sardinia
	Rossa San Cono	purple	none	Sicily
O. amyclaea	Gialla Bonarcado	dark yellow	high	Sardinia
	Bianca Bronte	white	high	Sicily
O. spp	Senorbì	yellow	none	Sardinia
O. robusta	-	purple	high	Sicily
O. dillenii	-	deep red	high	Private collection
O. soherensii	-	deep red	high	Private collection
O. stricta	-	red	high	Private collection
Nopalea	-	red	none	Argentina

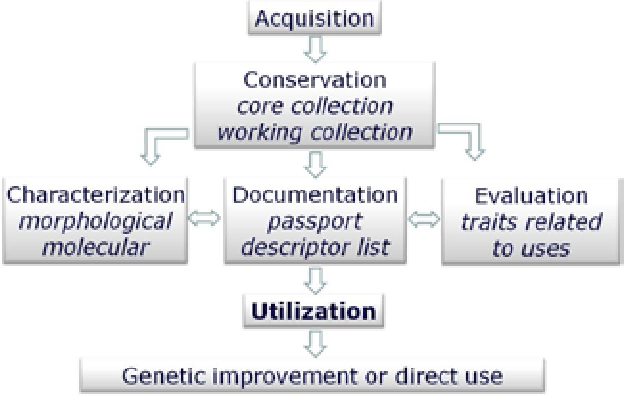

Figure 1. Scheme adopted for the establishment and management of the *Opuntia* spp. *ex situ* Italian collection.

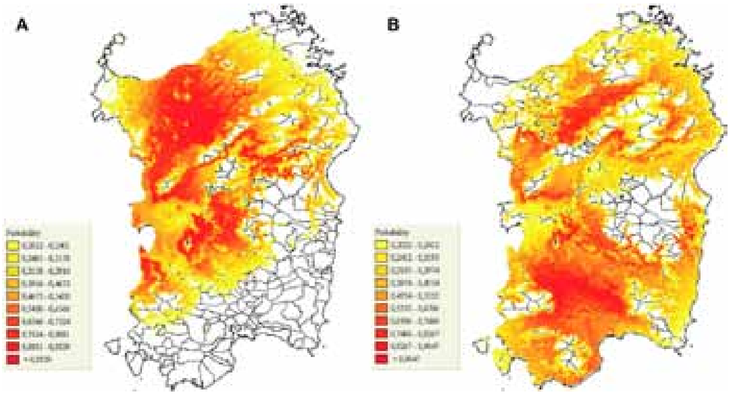

Fig. 2. Distribution map of accession points related to (a) *Opuntia ficus-indica* (L.) Mill. and (b) *O. amyclaea* Tenore (Source: Erre et al., 2009).

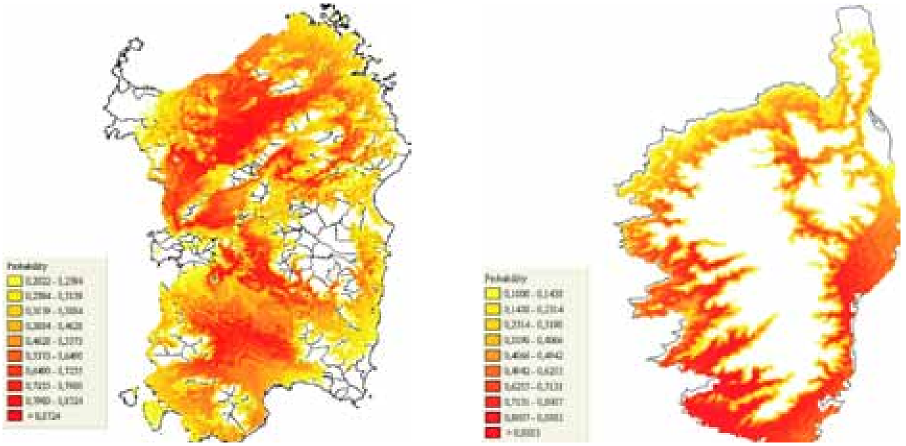

Fig. 3. Probability surface of *Opuntia* species on the islands of Sardinia (left) and Corsica (right) (Source: Erre et al., 2009).

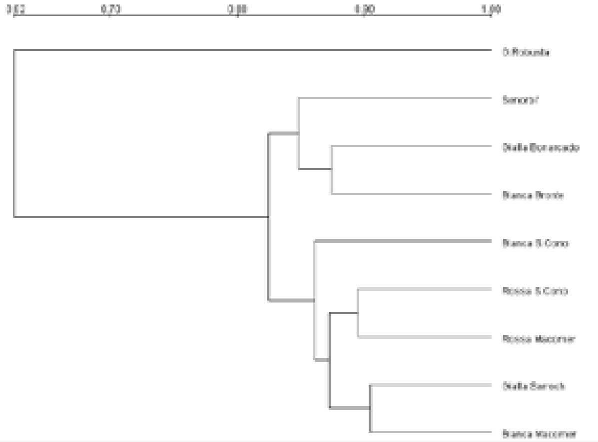

Fig. 4a. UPGMA dendrogram on Dice similarity coefficient computed on RAPD data from species and local Italian varieties of *Opuntia* spp.

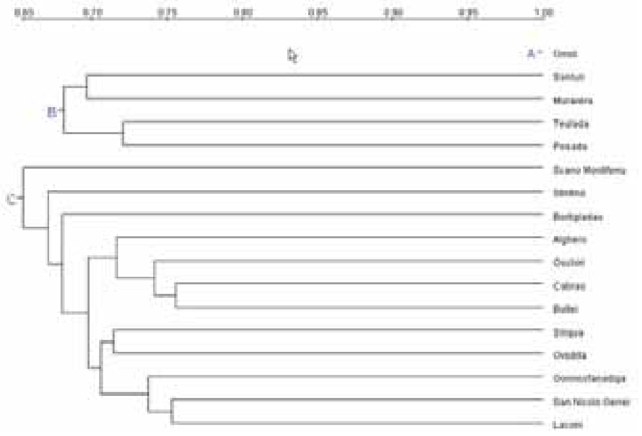

Fig. 4b. UPGMA dendrogram on Dice similarity coefficient computed on RAPD data from wild genotypes collected in Sardinia.

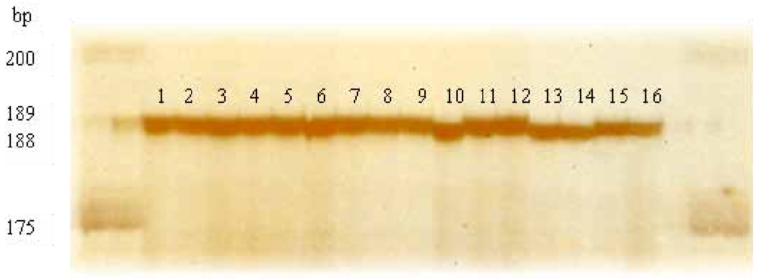

Fig. 5. cpSSR length variation detected using ccssr9 primer combination. Gialla di Sarroch, 2. Bianca di Macomer, 3. Bianca San Cono, 4. Rossa di Macomer, 5. Rossa San Cono, 6. Gialla di Bonarcado, 7. Senorbì, 8. Bianca Bronte, 9. *O. robusta,* 10. *O. dillenii,* 11. Senorbì, 12. Bianca Bronte, 13. *O. soherensii,* 14. *Nopalea,* 15. *O. robusta, 16. O. striata*.).

Photo 1. Collection of Italian cultivars, local varieties and ecotypes

Photo 2. Monitoring of accessions for age of first fruit set (above) and for biotic and abiotic stresses resistance (below).

Photo 3. The genotype M2 selected from the Sardinian local genetic resources for the fruit high quality.

Photo 4. Collection of seedlings from Gialla cultivar free pollination

Photo 5. Hybrids obtained by crossing Rossa and Bianca cultivars and embryoculture.

DIVERSITY OF CACTUS PEAR (*OPUNTIA FICUS-INDICA* (L.) MILL.) IN TIGRAY, ETHIOPIA, THE CASE OF EROBE

Mulugeta Gebresilassie[1], kebede Weldetsadik[2], Tesfay Belay[3]
[1]Tigray bureau of agriculture and rural development, .P.O.Box 10 Mekelle, Tigray, Ethiopia.
[2]Haramaya University Faculty of agriculture, department of plant science
[3]Tigray Agricultural research institute, P O Box 492, Mekelle, Tigray Ethiopia

ABSTRACT

Cactus Pear (Opuntia fícus-indica (L.) Mill) is a horticultural crop which is extensively used as food for humans and feed for animals in many countries of the world. The plant has widely adapted to different parts of Ethiopia and is an integral part of the culture and economy of some part of Tigray, North Ethiopia. Due to its drought tolerance and higher productivity new interests has aroused for its development and utilization particularly in Tigray region. This research was conducted in Eastern zone of Tigray, Erob Wereda, during the crop season of 2006 with the objectives to determine the variability in fruit quality and to identify cactus pear cultivars with superior fruiting potential using the descriptors for cactus pear prepared by FAO and CACTUSNET.

The identified cultivars were studied with respect to different qualitative and quantitative characters that determine cactus pear fruit quality. Thirteen commonly growing local cultivars were taken as treatments with three plants as replicate from each cultivar. Taking five fruits from each plant randomly, the morphological and chemical quality parameters were measured and analyzed for quality attribute and variability among the cultivars.

Analysis of variance for quantitative characters indicated highly significant variations for the majority of the characters while significant difference was observed in total soluble solids of the cultivars tested. Correlation tests between the parameters showed highly significant associations among characters. Fruit weight was highly significant and positively associated with fruit length, fruit width, fruit volume and, juice volume peel weight seed number per fruit and TSS were also highly significant and positively associated with pH. Flesh percent was highly significant and negatively associated with recepticular scar depth, peel weight and peel thickness. Principal component analysis showed about 86.4% of the variation in cactus pear fruit could be explained by four principal components. Out of this, 46.9% was explained by PC1 which was determined by fruit weight, fruit length, fruit width, fruit volume, juice volume, juice weight, & seed number per fruit.

The second component was highly determined by flesh percent of the fruit, peel thickness, TSS and recepticular scar depth. The third component (PC3) was highly determined by pH and TA and the fourth (PC4) by EC of the fruit. The cluster analysis of the 18 quantitative characters studied showed five groups of clusters. The first two clusters 1 and 2 were characterized predominately by large fruits, high TSS, high flesh percent and thick peel. Cluster 3 comprised one cultivar alone and the local cultivars clustered in cluster 4 and 5 were comparatively characterized by poor quality characters and high EC values.

Hence, cultivars Gerao, Suluhna and Orgufa, grouped in cluster 1, were found to meet most of the fruit quality requirements of fresh fruit market of cactus pear. However, as there are other values of this plant besides the fresh market fruits, the diverse fruit and plant characters observed in this study would enable to find cultivars that could meet various types of consumer requirements and preferences.

INTRODUCTION

Cactus pear is an introduction to Ethiopia. There are different views about the way cactus pear was introduced to Northern Ethiopia. Neumann (1997) who based his information on a Swiss geographer that carried out an extensive research in the Erob area during 1970s described that French missionaries introduced cactus pear to Ethiopia in the north east of Tigray as early as 1848. However, recently Habtu (2005) reported that Muslim pilgrimages from Mecca (Saudi Arabia) introduced cactus pear to the lowlands of Southern Tigray in 1920. Now, cactus pear is widely spread through out the Tigray region and is believed to cover more than 300,000 hectares of land (SAERT, 1994). It has, of course, become source of nourishment for several people during the summer months when there is shortage of cereals and other food crops.

Cactus pear is also found in Eastern and Southern Parts of Ethiopia. However, its popularity as human food and animal feed is relatively low compared to that of Tigray. Northern Ethiopia, particularly Tigray, is known for its crop failures due to shortage and poorly distributed rain. So, identifying crops with high water use efficient that produce acceptable yield is a priority for the area (Fetien, 1997). Many of the tropical and subtropical fruits that are very popular in other parts of Ethiopia, such as orange, banana, mango, and avocado are not well developed in Tigray due to their high water requirement. Cactus pear thus remains the primary source of fruit and income for the people particularly starting from late June to September. Occasionally, the cactus pear fruit is a substitute for grain food during the summer seasons when grain food are scarce in some areas of Eastern Tigray and the farmers are used to eating fruits. In other parts of Tigray, not only the fruits are eaten but also the cladodes are source of feed for their animals especially at times of drought. Farmers have also acquired the knowledge of discriminating the cactus cultivars on the basis of taste or some other features of the plant (Melaku, 1997).

In spite of its diverse uses in northern Ethiopia, cactus pear received little attention by horticultural researchers nationally and region wise. Under Ethiopian condition, many aspects of cactus pear have not yet been investigated. And its full potential has not been utilized. Hence, this study was initiated to study the variation among fruits of locally available cactus pear cultivars that could provide information for management of this crop and also assist in further development of best cultivars. Therefore this study was conducted with the objectives to determine the variability in fruit quality of commonly grown cactus pear and to identify cactus pear cultivars with superior fruiting potential.

MATERIALS AND METHODS

Description of the Study Area

The study was conducted from July to December 2006 in *Erob* W*ereda* of the eastern zone of Tigray in Northern Ethiopia. Erob has seven *Tabias* (lower administrative unit of the region), that consist 28 *kushets* (villages) with a population of 31031. It is located at 14^0 10′-14^0 25′N and 39^0 40′-39^0 50′E and an altitude ranging between 1200 and 3000 m. According to *Erob Woreda* bureau of Agriculture and Rural Development sources (2005), it covers an area of about 93345 ha. The topography is undulating with hardly any flat land for cultivation. The average arable land in the *Wereda* is extremely low, i.e. 0.19 ha. The area has agro-pastoral farming system. Temperature of the area ranges between 15 and 30^0C and rainfall ranges between 140 and 400 mm. Besides, the rainfall pattern is erratic and drought is a recurrent phenomenon. The study area predominately has sandy soil.

Site identification

The potential cactus pear growing *Kebele*, *Weratle,* was identified in collaboration with Erob *Wereda* Bureau of Agriculture and Rural Development. Site selection for sampling was done on watershed basis (starting from the high altitude to the lowest altitude in the watershed) and according to the settlement of the people in the watershed. The site was known for having the first cactus pear genotypes to have been introduced to Tigray (Kibra, 1992).

Sampling

From the *kebele*, five key informants were selected to identify and collect samples of cactus pears types commonly found in the locality to determine their fruit and plant characters. Accordingly, 13 commonly growing and used cultivars were identified by the key informants. Non-random, purposive sampling techniques were employed in the identification and collection of the fruits. For the purpose of fruit characterization, three plants from each cultivar were considered as replicates and the cultivars as treatments.

Experimental procedure and data collection

Data collected

Using five ripe fruits collected from each plant or cultivar, the following parameters (morphological and quality characters) were measured: weight, length, width, recepticular scar position, recepticular scar depth, areoles per fruit, fruit volume, pulp weight, peel weight, peel thickness, juice volume, seed weight, seed number per fruit, % aborted seed, pH, total soluble solids (TSS), titratable acidity (TA). Most of these traits were described using the FAO manual developed by Chessa and Nieddu (1997).

Chemical analysis

Total soluble solids

The total soluble solids were determined following the procedures described by Waskar *et al*. (1999). An aliquot of juice was extracted using a juice mixer and the slurry was filtered through cheese cloth. An Atago N hand refractometer with a range of 0 to 32 ^{0}Brix was used to determine TSS. The refractometer was standardized against distilled water (0 percent). The TSS was measured by placing 2 drops of clear juice on the prism of the refractometer. In between the readings, the prism of the refractometer was washed with distilled water and dried with tissue paper before use.

pH titratable acidity and EC

Cactus pear juice was extracted with juice mixer and the fruit slurry was filtered through cheese cloth and clear juice was used for analysis. The pH value of the juice was measured using HI 8521 pH meter. The titratable acidity expressed as percent citric acid, was obtained by titrating cactus pear juice with 0.1N NaOH. The EC was measured using HI8820 pH meter calibrated by 0.01N KCL at 25^{o} c because solubility of salts is affected by temperature. The reading was taken by immersing the EC meter in to the sample.

Estimate of Productivity of the cultivars

Productivity of the cultivars was estimated according to the descriptor by Chessa and Nieddu (1997). Estimation of productivity was made by counting fruits on the sample plants and taking mean fruit weight per plant for that cultivar and by multiplying with the recommended plant densities per ha.

Data analysis

The data generated were analyzed using SPSS statistical software version 12.0 for windows (SPSS, 2003). Duncan's Multiple Range Test (Duncan, 1995) was used for mean comparison. Cluster analysis (CA) was made in order to group the cultivars based on the fruit characteristics. Finally calculation of linear correlation matrix between the fruit characteristics was done.

RESULTS AND DISSCUSSION

Cultivars Described

Characterization of cactus pear cultivars growing in Erobe, eastern Tigray was carried out on 13 commonly known cultivars. The cultivars with their vernacular names are presented in Table 1. The names have got meanings and these names are associated to their taste, location or color.

Fruit Characteristics

Recepticular scar position and shape of the Fruit

The cultivars showed little variability in terms of recepticular scar position and fruit shape as presented in Table 3. Nearly 70 % of the cultivars have sunken scar position while the remaining cultivars were identified as having flattened scar position. Similarly, fruits of most of the cultivars have ovoid shape while *Naharissa* had oblong shaped fruits. *Neitsi* and *Asakurkura* had round shaped fruits and *Ameudegaado Belesa* had mixture of round elliptic and oblong shaped fruits. Although the shape of the fruit bears no direct relationships to fruit quality, it could determine the method of packing and pack layout (Wessels, 1988). In this study too, it has been observed that fruit shape can affect fruit quality by decreasing the flesh percent obtained from the fruit as seen in cultivar *Naharisa*. This cultivar had the largest fruit, averaging 146.6 g, but due to its oblong shape, the cutting edge goes up to the middle of the fruit which consistently decreased the amount of flesh obtained from the fruit, the lowest flesh (51.33 %) compared to other cultivars.

Peel and pulp color

Peel and pulp color are among the parameters dominantly used to distinguish cactus pear types. As reported by Inglese *et al.* (2002), cultivars can be distinguished by the color of the fruit peel and ripe flesh, which can be red-purple, yellow-orange, white cream or greenish. In this study the cultivars showed great variability in terms of pulp and peel color (Table 3). In the study area the community differentiates the cultivars traditionally in to two major categories viz. by color, a “red” and “white” and by spineless as “spiny” and “smooth”.

Four cultivars have yellow-orange color while two cultivars each are represented by red, white and white-green peel. The remaining three cultivars are found to have distinct peel color. The pulp color of fruits was also found to be different ranging from white pulped to red pulped types. In general, pulp and peel color in the materials studied appear to be associated. *Gerao* and *Suluhna* were identified as having fruits with yellow- orange peel and pulp color. Cultivars with white and greenish white peel were also observed to have pulp color similar to their peels. The remaining cultivars were found to have pulp colors slightly different from their respective peel colors. *Gerao* and *Suluhna* cultivars in this study have yellow-orange peel and pulp color which could be seen as potential cultivars for international markets.

Pulp firmness

Eventhough the measurement was subjective, fruit firmness of the fruits of the thirteen cultivars were evaluated according to the descriptors manual (Chessa and Nieddu, 1997) into firm, medium, and soft by pressing with hand (Table 3). *Gerao, Naharisa, Suluhna, Orgufa,* and *Ameudegaado Belesa* were found to be relatively firm cultivars *Geleweiti* and *Hawawisa* appeared to be medium and the rest six cultivars were found to be less firm compared with other cultivars. In this study the firmness was not associated with the peel thickness because some of the cultivars with thick peel such as *Kalamile* (4.8 mm) appeared to be soft and, to the contrary, *Orgufa* with thin peel (2.5 mm) was found to be firm.

Fruit weight and fruit volume

In this study mean fruit weight among the cultivars were found to be highly significantly ($p<0.01$) different (Table 4). The largest fruits were recorded in *Naharisa* and *Gerao* cultivars averaging 146.6 and 144.4 g, respectively. Cultivar *Suluhna* ranked third averaging 142.4 g; however, differences in mean fruit weight among these top three cultivars were not statistically different. On the basis of some export market standards these cultivars meet the first class fruit size which is in the range of 120-160 g (Inglese *et al*., 1995). Seven cultivars out of the remaining ten with a fruit size ranging from 84.5 g (*Kalamile)* to 119.9 g *(Hawawisa)* were not statistically different, and also fall in the second class fruit market described by the same author. According to Wessels (1988), fruit with a mass of less than 80 g should not be offered for fresh marketing. Inglese *et al.* (1995) also reported that, in Italy, fruits are considered as third class type if their weight is less than 80 g on the basis of these groupings, only three cultivars could be considered as unmarketable or substandard in this study. On the other hand, average fruit size of commercial cultivars in Mexico is indicated to range from 67 to 216 g (Mondragon, 2001). This range could further increase the list of commercially acceptable cultivars in this study to eleven on the basis of fruit size excluding *Geleweiti* (60.02g) and *Asakurkura* (54.02g) cultivars.

Fruit weight can be increased by different management practices such as irrigation, fruit thinning and pruning. According to Felker and Inglese (2003) commercial production of cactus pears was indicated to involve irrigation if no rainfall occurs during the fruit development period or when the annual rainfall is < 300 mm. Reduction of fruit size in rain fed orchards has been reported to occur far before any visible symptom of water stress appears and that fruit thinning alone did not result in any significant increment of fruit size unless irrigation was applied (Lamanita *et al*., 1998 as cited in Felker and Inglese, 2002).

In the study area, no rainfall was recorded from August 2005 to June 2006 period that coincided with fruit development. Therefore this could be the main reason for some of the cultivars to have low fruit weight. Had there been sufficient amount of rainfall, especially at time of flowering and fruit development, the real mean fruit weight could have been different. Farmers in the study area also perceived that when cactus pear gets rainfall in October and November, it flowers better and that rainfall in February is very crucial for better fruiting. Size of cactus pear fruit may be affected by environmental factors such as soil moisture. In Sicily irrigation at early and late stage of fruit development was found to be very effective in increasing fruit size of the late cultivars (Barbera, 1984) cited in Nerd and Mizrahi (1995).

Fruit weight showed highly significant and positive association with fruit width (r = 0.95**) fruit length (r = 0.94**), and seed number (r = 0.74**) (Appendix 4). Chapman *et al.* (2002) also indicated that fruit size correlated with these fruit characters. Fruit volume also varied extensively between the local cultivars (Table 3). *Gerao* had significantly highest (P<0.01) fruit volume than all other cultivars except *Naharisa, Suluhna*, and *Orgufa*. *Geleweiti* and *Asakurkura* had a significantly lower fruit volume. In general, the order of fruit volume followed cultivar's fruit weight.

Fruit length and width

Fruit length showed highly significant difference among the cultivars (P<0.01). Cultivars *Gerao*, *Orgufa, Naharisa, Suluhna* and *Hawawisa* ranked 1 to 5 in their fruit length with mean fruit length range of 7.8 cm to 8.22 cm; however, the differences in mean fruit length of among cultivars were not significantly different. Five cultivars have fruit length ranging from 7.2 to 6.5 cm but did not differ significantly in their mean fruit length. Cultivars *Geleweiti* and *Asakurkura,* which were the least in their mean fruit weight, were also found to have the shortest fruit that were 6.17 cm and 4.98 cm, respectively, although the difference in their mean fruit length was statistically different.

Similarly, mean fruit width showed highly significant difference among the cultivars (Table 4). Mean fruit width ranged from 5.61 in *Gerao* to 4.0 cm in *Gerwanlyele*. The top seven cultivars with fruit size range of 5.18 (*Gelewiti*) to 5.61cm (*Gerao*), however, did not differ in their fruit width. The correlation coefficient between fruit length and width showed highly significantly (r= 0.92**) correlated some of the cultivars that had long fruits were also found to have fruits with large width (e.g. *Gerao*, *Naharisa* and *Suluhna*). In some cultivars, however, fruit width and length were found to be inversely related (*Asakurkura*, *Gerwanlayele* and *Neitsi*).

The fruit length and width in this study were found to be almost similar with those of the Mexican cultivars reported by Mondragon and Perez (1996). As discussed earlier fruit length and width determine the shape of the fruit, parameter that may not have direct effect on quality but can determine packaging options to be used.

Recepticular scar depth

The cultivars considered in this study showed highly significant difference ($P \leq 0.01$) in their recepticular scar depth, a character that could be used to distinguish a given cultivar (Table 8). *Naharisa, Kalamile* and *Hawawisa* cultivars had the highest recepticular scar depth averaging 7.93, 7.66 and 7.46 mm, respectively.

Wessels (1988) pointed out that the flower end depth (recepticular scar depth) is characteristic for each cultivar. This characteristic is related to fruit quality as a deep flower-end means there is less edible portion of the fruit. In this study, too, cultivars that exhibit deep recepticular scar depth, *Naharisa* and *Kalamile* were also observed to have the lowest flesh percent compared to other cultivars. *Neitsi* with the lowest recepticular scar depth (0.66) was found to be almost flat at maturity. Other cultivars such as *Gerao, Ameudegaado Belesa* and *Asakurkura* were also can be considered as flat (3.66, 2.6 and 3.2 mm scar depth, respectively) at maturity. Also this character is associated to ripeness.

Areole number per fruit

The cactus pear cultivars in this study also showed significant difference ($P<0.01$) in mean areole number per fruit (Table 5). *Neitsi* has ranked first in mean areole number per fruit, averaging 82.86, followed by *Gerwanlayele,* with average of 76.35, and *Suluhna*, *Hawawisa* and *Ameudegaado Belesa* with areole number of 72.46, 71.13 and 70.73 per fruit, respectively. Although only number of areoles was considered in this study, the areole of *Suluhna* was found to be free of glochides (small hair like spines) which have the potential to damage the fruit and also be of problem during handling. The areole of *Suluhna* cultivar could be touched with out brushing, a character that makes this cultivar preferred by the local community to the others. On the other hand, cultivars *Gerwanlayele* and *Naharisa* were found to have many glochides on the areoles which can be dangerous at and after harvest unless precaution is made.

Peel thickness and peel weight

Peel thickness of the fruits of the local cultivars under evaluation also showed great variability (Table 5) with highly significant difference ($P<0.01$). *Naharisa* had the thickest peel averaging 6 mm followed by *Kalamile* and *Suluhna,* averaging 4.83 and 4.8mm peel thickness, respectively. Peel thickness is one of the parameters which can determine the handling and storability of the fruit. Wessels (1988) described that rind thickness is an important quality characteristics and that the thinner the rind the more likely the fruit is to be damaged during handling. In contrast to this the report of Mondragon and Perez (1996) showed that thin peel (<0.5 cm) is considered to be quality trait despite the fact that thin peel is inconvenient for handling. In relation to this trait, cultivars considered in this study, except *Naharisa,* had acceptable peel thickness. However, perceptions of the farmers in the study area was different where local cultivar *Orgufa* which had the thinnest peel was indicated to stay for several days even if the fruit drops to the ground.

Peel thickness showed significant and positive relationship with recepticular scar depth (r = 53**) seed number per fruit (r = 0.36*), and peel thickness showed highly significant and negative relationship with flesh percent (r = -0.49**) although cultivar may have fruits with large mean fruit weight, high percentage of the peel could substantially reduce the edible pulp portion, as in the case of cultivar's *Naharisa* in this study. The local cultivars evaluated in this study also showed highly significant difference (p<0.01) in peel weight. *Naharisa* had highest peel weight, averaging 71.02 g which is related to the thick peel and the shape of fruit it has. The fruit is oblong shaped and some of the rind around the fruit end is peeled. This character could considerably reduce the edible portion of the fruit and negatively affect acceptability of the fruit. *Hiraydaglayele* had the lowest peel weight averaging 19.23 g.

Pulp weight, pulp percentage and juice volume

Mean pulp weight and pulp percentage showed highly significant difference among the cultivars studied (Table 6). Cultivar *Gerao* that ranked second in mean fruit weight was found to have the highest mean weight of pulp per fruit while *Naharis*a, cultivar with the highest mean fruit weight stood third in its fruit juice weight. The percent pulp (juice percent) in *Naharisa, Gerao, Suluhna,* that ranked first, second and third in mean fruit weight was 51.3 %, 64.33 %, and 61.6 % respectively. The highest percentage of pulp contents were observed in *Hiraydaglyele* (75.06 %), *Neitsi* (71.10 %). Unfortunately, however, *Hiraydaglayele* was a cultivar with a fruit weight in unmarketable or low class category (77.41g) while *Neitsi* could be considered as potentially acceptable with mean fruit weight of 114.62 g and high percentage of pulp. Although cultivar *Naharisa* ranked first in its mean fruit weight and third in mean juice yield per fruit, the percentage of fruit pulp was found to be the least (51.3 %). *Kalamile* with its fruit pulp percent of 52.7 % coupled with its small mean fruit weight (84.52 g) was found to be inferior compared to other cultivars. Cultivars that could meet the first class fruit on the basis of mean fruit weight as indicated by Inglese *et al.* (1995) and also have relatively higher percentage of pulp are *Gerao* (64.33 %), *Suluhna* (61.6 %) and *Hawawisa* (65 %).

Generally, the pulp percent variation of the cultivars in the study (51.33 to 75.06) appeared to be wider and also comparable or higher compared to cultivars from other cactus pear growing countries. In Italy, for instance, the pulp percent of the best cultivars *Gialla, Rossa* and *Blanca* Was reported to be 55 to 60 % both in summer and late crop (Barbera *et al*., 1992 as cited in Inglese *et al.,* 1995).

Ofer, the Israeli cultivar, has pulp percentage of 42 % (winter crop) to 55% (summer crop) while a wider range (30 to 60 %) has been found in South African cultivars, most probably because of different management and environmental conditions (Wessels, 1988). In Mexico a comparison between nine cultivars revealed a 40 to 60 % range in pulp content of cactus pear (Pimienta-Barrios and Munoz-urias, 1995). The percentage of pulp is an important parameter that should not be lower than 55 to 60 % for export fruit (Inglese *et al*., 1995).

The cultivars considered in the study also showed significant variation (P< 0.01) in their pulp (juice) volume (Table 6). *Gerao* had the highest juice volume followed by S*uluhna*. Cultivar *Naharisa* which ranked second in fruit volume exhibited low pulp volume which could be attributed to its thick peel and its oblong shape as well as due to its deep recepticular scar. Cultivars *Geleweiti* and *Asakurkura* also had significantly (P<0.01) lower juice volume compared to other cultivars and they were among the cultivars with deep recepticular scar.

Pulp percent was negatively correlated with recepticular scar depth. This was in harmony with the report of Rachel *et al.* (2006) that showed a shallower recepticular scar depth to have higher relative pulp mass.

Seed number and seed weight per fruit and percent aborted seed

Mean seed number of the cultivars per fruit showed high variability that ranged from very low (97.67) in *Geleweiti* to many (353) in *Gerao* (Table 6). Cultivar *Gerao and Suluhna* had the highest seed number per fruit averaging 353 and 343, respectively, which is similar to the number in the Chilean clone 1320 (Parish and Felker, 1997). Karababa *et al*. (2004) also showed that total seed number of fruit varied from 227 to 270 in wild cactus pear found in eastern Mediterranean region of Turkey.

The cultivars also varied in their seed weight per fruit which ranged from 1.52 to 5.36 g, and this showed that all cultivars have low seed weight. The report of Mondragon and Perez (1996) indicate total seed weight of <6 g per fruit as acceptable for fresh fruit. The range of seed weight in this study also found to be wider compared to those reported by Karababa *et al.* (2004). *Orgufa* had significantly higher seed weight than all cultivars (p<0.01) However, the seed weight of most of the cultivars appeared to be lower than the cultivar in central Mexico which was 5.2 g per fruit. *Gerwanlyele* and *Asakurkura* had significantly lower seed weight per fruit from all local cultivars considered in this study. Seed weight per fruit is highly associated with fruit weight. Local cultivars having large fruits have also higher seed weight which could be also negative quality traits for fresh fruit market. This needs future breeding efforts to develop cultivars with low seed number and weight. However, such cultivars could be of great interest for emerging seed processing industry in the region.

The ratio between empty and normal seeds is one of the most important parameters which define fruit quality (Inglese *et al*., 1995). In this study, the total seed were separated in to aborted and viable seeds. Cultivars *Naharisa* and *Geleweit*i exhibited the highest percentage of aborted seeds (66%) while *Hiraydaglayele*, *Suluhna* and *Orgufa* had the lowest percentage aborted seed averaging 38, 41 and 41%, respectively. In general, the aborted seed percent in all the cultivars ranged from 38 to 66%. Some of the cultivars like *Naharisa* and *Geleweit*i have higher aborted seeds which are good quality attribute and are comparable or better than the Italian best cultivars, with 44 % aborted seeds (Inglese, *et al.,* 1995). Similar results were also reported by Karababa *et al.* (2004) that showed Turkish cactus pear cultivars contained fewer viable seeds than aborted seeds.

There are controversial arguments regarding the abortive seed ratio as quality trait. According to the report of Mondragon (2001), low seed content is regarded as a good quality trait because a high percentage of aborted seeds make the fruit more palatable. Pimienta and Engelman, (1985) as cited in Felker and Inglese, 2003, however, stated that true seedless varieties are not possible because the pulp of the fruit develops from the funiculus of the seeds. To this end, Israeli workers reported that a parthenocarpic clone (BSI) produced 100 % aborted seeds but variety was not commercially acceptable. The present observation also showed that cultivar *Naharisa* which had the highest percentage of aborted seed was the least in the flesh content of its fruits. Therefore, as Chapman *et al*. (2002) stated special care must be taken when selecting and developing cultivars or varieties on the basis of elevated number of abortive seeds as it might negatively affect the percentage of the edible portion of the fruit.

Seed weight per fruit showed highly significant and negative correlation with abortive seed number. This result was expected because abortive seed have not comparable weight with viable seeds. It was also observed that aborted seed has negative and significant relationship with fruit weigh ($r = -0.10$), fruit length ($r = -0.15$), fruit width ($r = -0.23$), pulp volume ($r = -0.13$), and weight ($r = -0.28$). Juice weight showed significant and positive relationships with seed number ($r = 0.71^{**}$) and seed weight ($r = 0.75^{**}$). This result agrees with the report of Felker and Inglese (2003) which indicated that the pulp of cactus pear fruit is produced from the funiculus of the seeds and reduction in fruit size of seeds may affect the actual fruit size..

Total soluble solids

The mean total soluble solids (TSS) of the cultivars showed significant difference ($P<0.05$) with TSS range of 13.5 to 16.5 ^{0}Brix (Table 7). The white colored cultivar *Ameudegaado Belessa* had the highest mean TSS content (16.5 ^{0}Brix) followed by *Orgufa*. In this study all the cultivars showed high TSS content which is in the acceptable range of 13-17 ^{0}Brix described for commercial cultivars (Mondragon, 2001). Kader (2006) also quoted the quality indices for

TSS to be from 12 to 17%. The highest TSS recorded in this study appear to be greater than TSS content of cultivars from Mexico (14-15 ^{0}Brix), Italy (13-15 ^{0}Brix), Argentina (12-15 ^{0}Brix), Israel (14 ^{0}Brix) and South Africa (11-14 ^{0}Brix) described by Pimienta-Barrios and Munoz-urias (1995). The result is also higher than the TSS value reported by Parish and Felker (1997) in the USA which was 10.7 to 14.6 %. Wang *et al.* (1997) also reported TSS values of 10.3 to 16.8 % for 24 cactus pear accessions tested in Texas, USA. This characteristic makes the cultivars in this research area to be unique partly due to low moisture in the area that might have increased the TSS of the fruit pulp.

pH and titratable acidity

The pH of the fruit pulp of the cultivars shown in Table 7 ranged from 5.04 to 6.37 and showed highly significant difference (P<0.01). *Hawawisa* had the highest pH. *Gerwanlayele, Kalamile* and *Neitsi* had low pH averaging 5.7, 5.65 and 5.53, respectively, while *Adomuluhta* had the lowest pH. As its name indicates, *Adomuluhata* in Erob language means "white salty" and farmers gave this name after its taste. However, this study indicated that the "salty" taste of the fruit described by the farmers was not due to saltiness of the fruit as it had the least value for EC. Instead, the low pH and acidic nature could be the reason for farmers' perception for the cultivar as salty type.

The pH value showed significant and positive correlation with the TSS (r = 0.51**) and seed number per fruit(r =0.50**), Seed weight per fruit (r =0.38$^{**)}$ while it showed significant and negative correlation with TA Generally, as the fruit of cactus pear becomes more mature, the pH increases with sugar content. The pH of the cultivars in this study is in the range of those reported by Parish and Felker (1997) for Mexican and Chilean varieties.

The titratable acidity of the fruits of the different cultivars was found to be significantly different and ranged from 0.056 to 0.130 % (Table 7). The highest acid content measured in this study was from Cultivar *Adomuluhta* which could be the reason for its "salty" taste perceived by the local people. The lowest TA value was measured in cultivar *Geleweiti*. The TA values in this study are generally similar with those of South African cultivars described by Wessels (1998), with ranges from 0.06 to 0.2 %. All cultivars except *Admuluhta* were within the range of TA quality indices 0.03 to 0.12 % for cactus pear fruit described by Kader (2006) and Cantwell (1995). According to Wessels (1988), TA is of little importance in prickly pears as the acid content is very low and contributes little to the flavor of the fruit.

The EC of the fruit pulp of the local cultivars was measured to prove the farmers' description for some cultivars like *Adomuluhta* was associated their name to saltiness. The observed EC value had no direct relationship with the description given by the farmers. However the EC value of the local cultivars pulp was showed highly significant (P<0.01) variation and *Orgufa* had highest EC value

(3.05 mS/cm) while *Hawawisa* had the least EC value among other cultivars averaging (1.49 mS/cm).

Cluster analyses

The thirteen cultivars in this study were grouped in to five clusters. The clustering pattern of the local cultivars in respect of 18 quantitative characters measured is presented in figure 1. Cultivars *Gerao, Suluhna*, and *Orgufa* were grouped together (cluster 1). And cultivars *Neits*i, *Ameudegaado Belesa* and *Hawawisa* are grouped under cluster 2. Cultivar *Naharisa* clustered alone as cluster 3. Cultivars *Kalamile* d *Adomuluhta Gerwanlayele* are grouped as cluster 4 and lastly cultivars *Geleweiti*, *Asakurkura* and *Hiraydaglayele* are grouped as cluster 5.

It is observed from the figure that cultivars in cluster 1 and 2 are characterized predominately by large fruits, high TSS, long fruit, high flesh percent, and thick peel.

Naharisa cultivar which is clustered alone is characterized by both good traits such as high aborted seeds, heavy fruit , long and wide fruit diameter and poor characters like low juice volume, low flesh percent, and low TSS as compared to cluster 1 and 2. Cluster 4 and 5 are characterized by small fruit, low fruit length, low flesh percent, low TSS and low juice volume compared to the cultivars grouped in cluster 1 and 2. Generally all cultivars are grouped in to clusters in equal number that are three cultivars in each group except *Naharisa* which is grouped alone and considered as having unique character. This preliminary observation showed possibility of getting useful traits in the different cultivars that could be used in hybridization to exploit good traits, like thin skin and good storability of fruits observed in *Orgufa*; high percent abortive seeds of *Naharisa* and *Geleweiti*, and other useful traits that can be crossed to high yielding large fruited cultivars.

Productivity estimate of the cultivars

Based on the estimation made from sample plants, *Neitsi, Gerao, Naharisa, Orgufa* and *Suluhna* cultivars were among the high yielding cultivars which produced 423, 322, 317, 278, 224 fruits per plant (Table 2). Cultivars *Adomulhta, Hiraydaglayele, Gerwanlayele, Ameudegaado Belesa* and *Kalamile* were medium yielding with mean fruit number range of 155 to 197 per plant; *Asakurkura, Hawawisa and Geleweiti* were found to be low yielding cultivars with 140, 101 and 82 fruits per plant, respectively. Eventhough the above yield was obtained from traditional production system, the farmers indicated that majority of the cultivars have more yielding potential under improved management conditions as witnessed in the backyards of some households.

The productivity of *Opuntias* is extremely variable in different areas. As cited by Inglese (1995), in Israel Nerd and Mizrahi (1993) and Italy Inglese *et al.* (1995) reported cactus pear fruit yield of 15 to 25 tons ha^{-1} while yields in Chile were 6-9 tons ha^{-1} and in Mexico 3 to 15 tons ha^{-1} (Barbera, 1995). In South Africa Wessels

(1988) reported yields of 10 to 30 tons ha $^{-1}$ with peaks of 33 tons ha^{-1} obtained in experimental farms.

In this study cultivars *Neitsi, Gerao, Naharisa, Orgufa*, and S*uluhna* were estimated to produce higher (30.15, 28.44, 25.37, 22.2, 19.88) tons ha^{-1}, respectively, than the Mexican and Chilean cultivars. In general, the local cultivars in the study area were comparable in their estimated yield with the top South African commercial cultivars. Therefore, there is an opportunity to start commercial production with already adapted and high yielding cultivars.

CONCLUSIONS

A study was conducted to describe and evaluate most common cultivars of cactus pear grown in Erob, eastern Tigray from July to December, 2006. Non-random, purposive sampling method was adopted in identification and collection of sample plants and fruits. For characterization and assessment of cultivars, three sample plants were taken to serve as replicates. Field measurements, laboratory evaluation, discussion with farmers, panel test were used for the different parameters as deemed necessary.

The present study showed the presence of high diversity in morphological and fruit quality characters of cactus pear growing in Erob, eastern Tgray. Some of the cultivars were found to have unique and good quality traits such as large fruit size, high total soluble solids, high ratio of aborted seed, high flesh percent and low peel and various pulp colors. In terms of major fruit quality parameters, eleven out of the 13 cultivars meet the minimum export size of 80 g used in many cactus producing countries. Of these, four cultivars, *Naharisa, Gerao, Suluhna,* and *Hawawisa,* could qualify for fruit size with prime quality (120-140 g). Regarding the weight of the edible portion of fruit, *Gerao, Suluhna, Neitsi, Hawawisa* and *Naharisa* stood in the leading position in their order of presentation. Some of the cultivars that had large fruit size (weight) were found to have less percentage of the pulp because of their peel thickness. However, except *Naharisa* and *Kalamile*, all cultivars were found to have the minimum of 55 % pulp recovery expected for export market.

The presence of low number of seeds with more percentage of aborted seed is one of the good qualities wanted in cactus pear. These values were found to fall in the range of many cultivars known elsewhere. In general there existed a positive and highly significant correlation between seed number and fruit weight as well as percent fruit pulp. Most of the cultivars that had higher fruit and pulp weight were also found to have high number of seeds per fruit. Except *Naharisa*, most of these cultivars were also found to have less percentage of abortive seeds.

Percentage of TSS and pH of fruit pulp as a measure of fruit quality was also found to be in the acceptable range The highest and significantly different TSS content was recorded in cultivar *Ameudegaado Belesa* (16.5 ^{0}Brix) while cultivar

Adomulhta had the least TSS content (13.5 ^{0}Brix). The leading cultivars in fruit weight had narrow TSS range (14.36 to 15.33 ^{0}Brix) and statistically non significant difference was observed in their fruit pulp TSS content. Similarly, the TA of the leading cultivars were found to be in the medium sweet to sweet category which also related with organoleptic test values. Generally, their morphological and chemical properties are diversified in which one can find cultivars that could satisfy diverse consumer preferences.

Considering the differences among the cultivars, characters such as fruit weight, recepticular scar depth, peel thickness, seed number per fruit, juice weight, plant height, plant width, and areole per cladode all showed high range of variations.

The cultivars have been naturalized and adapted very well in the area. The people in the area are highly dependent for food and animal feed on this plant. The climatic pattern of the area has shown great changes over the past few years. The amount of rainfall has reduced from the ranges of 300-400 mm to 200-300 mm within the past five years. The presence of this plant in the area has been an opportunity for the community who lived in such harsh area mainly for two reasons. In the first place this plant has ability to grow in arid environment and can withstand drought. Secondly, farmers in the area have not enough farmland to grow other agronomic crops. Therefore, Cactus pear plant can play major role in household food security in the area by maximizing its way of utilization.

The various uses of cactus pear is still limited to only fruit consumption and fodder which has to go far beyond. The efforts that have been started in the region should be encouraged and supported by concerned NGO's and governmental bodies to establish commercial cactus pear fruit production, value added products and consistent market flows. The existing higher production of cactus pear was obtained without application of modern management practice which showed the possibility for producing more than the existing production.

Transformation of the existing traditional cultivation practice in to modern production and marketing system is an urgent issue for the study area. Extension services to promote the production and utilization of cactus pear have to be given special attention. Modern management practices such as row planting, pruning, fruit thinning, irrigation (water harvesting technologies) have to be introduced for areas with low rainfall areas and cactus pear plantations for better yield and quality fruits. There is a need to renew the old plantation without loosing existing diversity. Establishing nurseries and multiplication centers are required to test and multiply the best cultivars which are found in the wild as well as in homestead cultivations.

All cultivars investigated in this research could be utilized for different purposes. However, cultivars such as *Suluhna, Gerao, Orgufa, Neitsi, and Ameudegaado Belesa* are promising cultivars both in their fruit quality and potential yield. Other cultivars may be utilized for forage and value added utilization such as medicinal uses, jams, marmalades, cosmetics, candies, and flower and seed production.

New expansions for cactus pear cultivations have to be undertaken with special care and specific objectives. The spineless cultivar *Suluhna* could be the best cultivar for commercial fruit production which can reduce the cost of brushing and post harvest handling and its easiness for cultivation practices and fodder production.

The best cultivars from the spiny types like *Gerao* and *Neitsi* could be also planted at house hold level for fruit production. Other spiny cultivars could be also recommended for environmental rehabilitation since they are not easily browsed by domestic and wild animals. *Naharisa* a cultivar which is clustered alone have unique characteristics with large fruits and high percentage abortive seeds, which could be an important character for future breeding purposes. NGO's and Government institutions are required to provide improved production and post harvest inputs to the producers as well as support and strengthen supplier cooperatives in order to be able to establish and penetrate the national market. Capacity building for different stakeholders (farmers' extension agents and merchants) on how to produce, harvest, package and transport would be of paramount importance to improve the existing quality of the produce. The community who live in such area needs to set sound land use systems to isolate cactus pear production and grazing area.

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Table 1. Cactus pear cultivars identified for description in Erob, eastern Tigray (give data on spiny or spineless fruits)

No	Vernacular name (in Erob)	Name associated to fruit character	Meaning
1	Gerao	taste	sweet
2	Naharisa	response after eating	causes vomiting
3	Kalamile	color	colorful after ripening
4	Adomuluhta	color and taste	white and salty
5	Geleweiti	color	a fruit with mixed color of skin
6	Gerwanlyele	location and taste	Gerwan is location in the village and layele is its watery taste
7	Suluhna	spiny ness	smooth (spineless)
8	Hiraydaglayele	Location and taste	Hiraydag is location in the village and layele means watery
9	Neitsi	color	white
10	Orgufa	staying ability of the fruit on the tree	falls down early
11	Ameudegaado Belesa	location and color	Ameudega is location in the village and adoBelesa means white colored fruit
12	Hawawisa	color	looks ripen but not yet
13	Asakurkura	color and shape	red and ball shaped

Table 3. Fruit morphological characters of some cactus pear cultivars growing in Erob, eastern Tigray

cultivar	Recepticular scar position	Fruit shape	Peel color	Pulp color	Pulp firmness
Gerao	flatten	ovoid	yellow-orange	Yellow-orange	firm
Naharissa	sunken	oblong	yellow-orange	pale yellow	firm
Kalamile	sunken	ovoid	red	pink	soft
Adomuluhta	sunken	ovoid	white	white	soft
Geleweiti	sunken	ovoid	green white+ pink	White- green	medium
Gerwanlayele	sunken	ovoid	yellow-pale	yellow	soft
Suluhna	sunken	ovoid	yellow-orange	yellow-orange	firm
Hiraydaglayele	sunken	ovoid	yellow-red	yellow	soft
Neitsi	flatten	round	green-white	white	soft
Orgufa	sunken	ovoid	yellow-orange	yellow-red	firm
A/adoBelesa	flatten	elliptic	white	white	firm
Hawawisa	sunken	ovoid	deep red	yellow red	medium
Asakurkura	flatten	round	red	red	soft

Table 4. Weight, volume, length and width of fruit of some local cultivars growing in Erob, eastern Tigray

Cultivars	Fruit weight (g)	Fruit volume (cc)	Fruit length (cm)	Fruit width (cm)
Gerao	144.41[a]	149.00[a]	8.22[a]	5.61[a]
Naharisa	146.59[a]	140.66[ab]	8.22[a]	5.30[abc]
Kalamile	84.52[ef]	79.66[efg]	6.50[cde]	5.32[abc]
Adomuluhta	90.31[def]	87.66[def]	6.62[cde]	4.92[cde]
Geleweiti	60.02[g]	58.00[fg]	6.17[e]	5.18[abcd]
Gerwanlayele	109.38[cde]	105.33[cde]	7.21[bc]	4.00[f]
Sulhuna	142.36[ab]	124.00[abc]	8.18[a]	5.61[a]
Hiraydaglayele	77.41[fg]	83.33[def]	6.22[de]	5.46[ab]
Neitsi	114.62[cd]	110.53[bcde]	7.09[bcd]	4.58[e]
Orgufa	110.99[cd]	117.00[abcd]	7.84[ab]	4.84[de]
A.adoBelesa	97.17[def]	98.66[cde]	6.97[bcde]	4.06[f]
Hawawisa	119.92[bc]	113.66[bcde]	7.80[ab]	5.11[bcd]
Asakurkura	54.06[g]	49.66[g]	4.98[f]	5.56[a]
SD	32.11	32.64	1.04	0.55
CV%	13.19	17.56	6.67	4.72

Means with in a column followed by the same letter are not significantly different at the 0.05 Probability level

Table 5. Recepticular scar depth, number of areoles, peel weight and peel thickness of fruit of some local cactus pear cultivars growing in Erob, Eastern Tigray.

Cultivars	Receptacular depth (mm)	Areoles per fruit (no)	Peel weight (g)	Peel thickness (mm)
Gerao	3.66[cde]	69.13[cd]	51.43[bc]	3.83[c]
Naharisa	7.66[a]	62.73[de]	71.02[a]	6.00[a]
Kalamile	7.46[a]	68.53[cd]	40.00[cd]	4.83[b]
Adomuluhta	6.46[ab]	67.06[cd]	35.29[def]	3.63[cde]
Geleweiti	6.33[ab]	49.06[g]	24.86[fg]	3.16[cdef]
Gerwanlayele	5.06[bc]	76.35[ab]	37.31[de]	3.60[cde]
Suluhna	4.53[cd]	72.46[bc]	54.84[b]	4.80[b]
Hiraydaglayele	3.80[cde]	54.13[fg]	19.23[g]	2.60[ef]
Neitsi	0.66[f]	82.86[a]	33.28[def]	2.50[f]
Orgufa	4.20[cde]	63.26[de]	37.04[de]	2.50[f]
Ameudegado belesa	2.60[e]	70.73[bc]	39.85[cd]	3.66[cd]
Hawawisa	7.93[a]	71.13[bc]	40.38[cd]	3.83[c]
Asakurkura	3.20[de]	59.53[ef]	22.44[fg]	2.76[def]
SD	2.28	9.61	15.14	1.09

Means with in a column followed by the same letter are not significantly different at the 0.05 Probability level.

Table 6. Pulp and seed characters of fruit of some cactus pear cultivars growing in Erob, eastern Tigray

Cultivars	Pulp wt. (g)	Pulp vol. (ml)	Pulp (%)	Total Seed/ fruit (No)	Total seed weight /fruit (g)	Aborted seed (%)
Gerao	92.97^{a}	85.67^{a}	64.33^{bcd}	353.00^{a}	4.88^{ab}	46.8^{de}
Naharisa	75.90^{abc}	68.33^{bc}	51.33^{f}	270.00^{bc}	3.20^{ef}	66.66^{a}
Kalamile	44.52^{ef}	37.33^{ef}	52.70^{ef}	234.67^{c}	2.56^{fg}	51.33^{cd}
Adomuluhta	55.02^{de}	50.00^{de}	61.00^{cd}	158.00^{d}	2.69^{f}	53.33^{bcd}
Geleweiti	35.16^{f}	31.00^{f}	58.53^{de}	144.00^{d}	1.95^{gh}	66.33^{a}
Gerwanlayele	69.73^{bcd}	58.67^{cd}	65.00^{bcd}	97.67^{e}	1.58^{h}	58.96^{abc}
Suluhna	87.52^{ab}	81.00^{ab}	61.60^{cd}	343.33^{a}	4.67^{abc}	41.66^{e}
Hiraydaglayele	58.17^{cde}	46.33^{de}	75.06^{a}	173.67^{d}	2.56^{fg}	38.33^{e}
Neitsi	81.33^{ab}	75.00^{ab}	71.10^{ab}	244.33^{c}	4.10^{cd}	59.00^{abc}
Orgufa	73.95^{bc}	79.33^{ab}	65.00^{bcd}	271.67^{bc}	5.36^{a}	41.00^{e}
A.adoBelesa	57.62^{cde}	50.33^{de}	59.12^{cde}	233.67^{c}	3.68^{de}	52.33^{bcd}
Hawawisa	76.00^{abc}	70.67^{abc}	65.00^{bcd}	316.67^{ab}	4.27^{bcd}	60.00^{abc}
Asakurkura	31.62^{f}	27.67^{f}	58.26^{de}	123.33^{de}	1.52^{h}	61.00^{ab}
SD	20.70	20.47	7.18	85.24	1.29	10.07

Means with in a column followed by the same letter are not significantly different at the 0.05 probability levels.

Table 7. The pH, total soluble solids, titratble acidity and EC of fruits of thirteen local cultivars of cactus pear in eastern Tigray

Cultivars	PH	TSS (^{0}Brix)	TA (%)	EC (mS/cm)
Gerao	6.15^{b}	15.33^{abcd}	0.083^{bc}	2.52^{bc}
Naharisa	5.97^{bc}	14.36^{cde}	0.100^{b}	2.62^{ab}
Kalamile	5.65^{d}	14.06^{de}	0.090^{bc}	1.87^{def}
Adomuluhta	5.04^{e}	13.50^{e}	0.130^{a}	1.9^{def}
Geleweiti	6.05^{bc}	14.66^{bcde}	0.056^{c}	1.6^{ef}
Gerwanlayele	5.70^{d}	14.66^{bcde}	0.090^{bc}	2.7^{ab}
Suluhna	6.13^{b}	14.66^{bcde}	0.090^{bc}	2.13^{cd}
Hiraydaglayele	6.05^{bc}	14.50^{ab}	0.086^{bc}	2.51^{bc}
Neitsi	5.53^{d}	15.00^{bcd}	0.070^{bc}	2.2^{bcde}
Orgufa	6.08^{bc}	15.66^{abc}	0.100^{b}	3.05^{a}
Ameudegado belesa	6.06^{bc}	16.50^{a}	0.090^{bc}	1.96^{de}
Hawawisa	6.37^{a}	15.33^{abcd}	0.073^{bc}	1.49^{f}
Asakurkura	5.89^{c}	15.4^{abcd}	0.100^{b}	2.32^{bcd}
SD	0.35	1.02	0.03	0.48

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

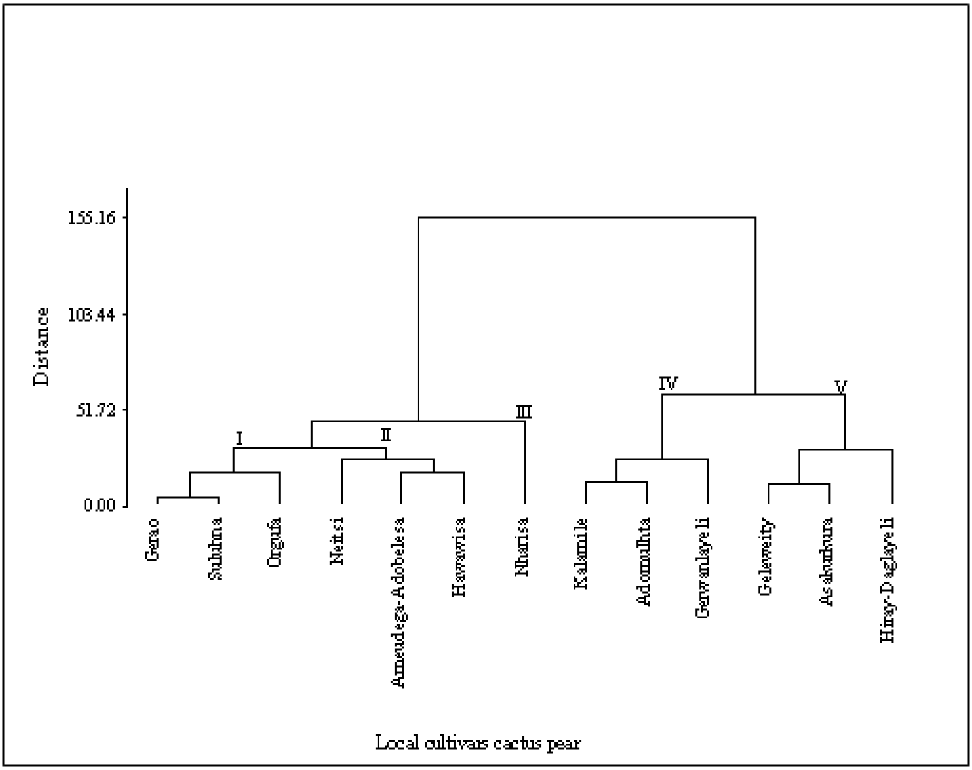

Figure 1. Dendrogram showing similarity of thirteen local cultivars of cactus pear growing in Erob, eastern Tigray. Cluster analysis based on 18 quantitative characters of the fruit.

CACTUS PEAR, *OPUNTIA FICUS-INDICA L.* (MILL.) FOR FRUIT PRODUCTION: AN OVERVIEW

Paolo Inglese
Università degli Studi di Palermo
90128 Palermo, Italy
pinglese@unipa.it

ABSTRACT

An overview of the cactus pear industry in Italy is given, with particular regard to fruit production, which is discussed in term of fruit quality parameters.

INTRODUCTION

The cactus pear (Opuntia ficus-indica L. (Mill.)), Cactaceae, is a species originating on the plateau of central Mexico. Together with maize, gourd, agaves and some legumes, for centuries it has constituted the alimentary base of the local populations (Turkon, 2004). In the 16th century, it was brought to Europe by the Spaniards. At first the cactus pear was grown in the gardens of the nobles and subsequently in cultivation, naturalizing itself quickly and becoming, in the whole Mediterranean basin, an essential element of the natural and agrarian landscape. Widespread in both hemispheres and on all the continents, it is a constant presence in the livestock and human diets of the aboriginal populations of North Africa, the Middle East and southern Europe, in particular Sicily, Greece and southern Spain. Opuntia is cultivated, according to the more reliable estimates, on a total area of about 100,000 ha for fruit production and more than a million hectares of land devoted to pasture or to the production of forage for cattle, sheep and goat fodder in Mexico, South America (in Brazil more than 300,000 ha of Opuntia are cultivated for forage production), the USA (Texas in particular), North Africa and Western Asia (the so-called WANA Region), the Horn of Africa and South Africa. In each of these regions, byproducts are created from the processing of both the fruit and the cladodes, and they are destined for human consumption or for non-alimentary uses (Barbera et al., 1995). The Opuntias have a strategically important role in the diet and therefore in subsistence agriculture of the semi-arid regions, where their cultivation is widespread. Only recently, from the 19th century in Italy and the 20th century in the rest of the world, have they been cultivated on a large scale for commercial purposes. These are two very different cultivation and cultural models, both of equal importance.

- For fruit production, the *Opuntia ficus-indica* is cultivated, in specialized plantations, on more than 70,000 ha in Mexico, in the northern central region (Zacatecas, Saltillo, Durango, Saint Luis Potosí, Aguascalientes and Guanajuato) and in the southern central region (Puebla, Mexico, Tlaxcala and Hidalgo). In Chile it is found in the Metropolitana region on a little more than 1,000 ha; in Argentina there are specialized plantations in the regions of Santiago del Estero, Tucuman and Catamarca, covering a little less than 1,000 ha; in Israel, there are approximately 250 ha of specialized plantations in the area of the Negev; in South Africa another 1,000 ha is planted with cactus pear in the Western Cape, the Northern Province and the region of the Ciskei. In the United States, *Opuntia ficus-indica* is cultivated in California in the Salinas plain on more than 300 ha of specialized cultivation. Data are lacking on its diffusion in the North African countries, where it is estimated that not less than 50,000 ha are under specialized cultivation (25,000 in Tunisia alone) (Fig. 21.1).

- In Italy, cactus pear is cultivated on a little more than 3,000 ha distributed in the areas of Santa Margherita Belice (AG) and San Cono (CT), as well as on the south-western slopes of Mount Etna (Biancavilla, Belpasso and Paternò).
- Considering an average production of 10 t/ha world-wide, it can be estimated that there is an annual production of 1 million t from specialized plantations, while that from spontaneous plants and non-intensive cropping, common in many of the regions of subsistence agriculture where the species is present, must be enormously greater (Pimienta Barrios, 1990; Barbera and Inglese, 1993; Nobel, 1988, 2002).

FLOWERING AND FERTILITY

Opuntia ficus-indica, family *Cactaceae*, is the most widely cultivated cacti for fruit and forage production, though other species or hybrids are grown in Mexico and South America. The flowers generally develop from the areolae disposed along the crown of the cladode, but the production of flowers from the areolae on the planar surface exposed to the sun is also not infrequent. A cladode can produce 35-40 flowers; each one can lose, during the abundant flowering in conditions of high potential evapotranspiration, up to 3 g of water per day, equivalent to 15% of its weight at the time of anthesis (De La Barrera and Nobel, 2004).

The species shoots in spring and blooms in May. If all the flowers and the young cladodes put out in the spring are removed before and during (but not after) the flowering, the species re-flowers and the resulting fruit will not ripen in summer (July-August), but in autumn (October-November), giving rise to the so-called "scozzolati" or "bastardoni" hybrid crops. This production constitutes 95% of the Sicilian crop. The species tolerates dryness and is very resistant to high temperatures, but its photosynthetic productivity can diminish enormously if the temperature exceeds 30°C, even when the water supply is sufficient. Crassulacean acid metabolism allows for considerable water saving because of the nightly opening of stomata. The increased efficiency in the use of water equals 3-4 mg of dry substance per gram of transpired water. The growth period for the fruit is 70-120 d, beginning from the flowering, while the commercial lifetime of an orchard is about 25 years. Ninety per cent of the fruit appears on the one-year-old cladodes, whose average number of flowers is 6-9, with peaks of 30-35. Over 90% of one-year-old cladodes are fertile, while cladodes of 2-3 years are responsible for vegetative renewal. Considering that the commercial value of the fruit decreases sharply from fruit smaller than 120 g, it is assumed that no more than 6 fruits can be retained in each fruiting cladode, to avoid size reduction. This means, in turn, that the only way to increase productivity, without reducing fruit value, is to increase the number of fertile cladodes on plant and/or hectare basis. Fruit thinning has to be done no more than two weeks after fruit set.

CULTIVARS

In Mexico, in addition to *O. ficus-indica*, various species such as *O. megacantha* are grown. In the case of *O. ficus-indica* the fruits differ depending on the color of the pulp on ripening, which can be yellow, red or creamy white. Distinctions can be based on the size of the fruit, on the seed content or soluble sugars of the pulp, on the time the fruit ripens or on the vegetative habits and/or habitus. The greater variability is in Mexico, where the more imposing germplasm exists with more than 50 varieties and clones, of which 14-15 are the most widespread (*Reyna, Cristalina, Burrona, Chapeada, Fafayuco, Naranjona, Roja Lisa, Rojo Pelon, Amarilla Montesa, Blanca de San José, Copena, Cascaron, Liria, San Martin, Esmeralda, Pico Chulo*). In Mexico, many of the varieties cultivated have thorns on both the fruit and the cladodes, while in Italy the varieties cultivated are defenseless and the glochids appear only on the fruit. In Italy, the *Gialla* (yellow flesh) variety covers 90% of the invested surface and the *Rossa (*red flesh*)* covers 8%. *Gialla* is widespread thanks to an elevated re-flowering capacity and to the optimal general characteristics of the fruit. *Rossa* ripens later, while *Bianca* (white flesh) is more sensitive to post-collection damage and to fruit fly. Among the varieties diffused internationally we note *Ofer*, a cultivar with a yellow pulp grown in Israel; the cultivars *Algerian*, *Blue Motto* and *Director* prevail in South Africa, where there exists a wide variability in terms of the plant's habits and low temperature requirements; *Andy Boy*, a cultivar with a red pulp, is found in California.

NURSERY TECHNIQUE AND IMPLANTATION MATERIAL

Propagation and implantation take place in the field, exclusively by means of cuttings, even if g it is possible to resort to micropropagation for the purpose of genetic improvement or conservation of the germplasm or for the production of plants in containers and their successive transfer to the field. The cuttings are made up of single cladodes of 1-2 years or of multiple cladodes constituted from a 2-year-old cladode that carries two cladodes, "ears", of one year. After being taken from the mother plant, the cuttings are dried in the shade in order to "heal" the surface of the cut. The ideal is a period that allows dehydration of not more than 20% of the fresh weight; in practice that means 10-12 d at 20-25°C. The cuttings are implanted with the base part in the soil (not more than 50% of the cladode in the case of single cladodes, up to 70% in the case of multiple cladodes) and placed in a perfectly vertical position, with the planar surface normally forming the row. In order to obtain the fastest and most intensive root development, it is advisable to take the cuttings at the end of the rainy season to plant them, if there is irrigation, before the dry season begins.

PREPARATION OF THE SOIL

It is advisable not to plough the soil extensively, but to reduce the impact by placing the cladodes in single holes or in single rows. Only in case of soil conservation, preparation of hedges is required.

PLANTING AND PRUNING

Planting distances vary according to the nursery methods used (in rows or in groups) and the habitus of the variety. In Italy, plants are mainly planted in sixes in 4 x 6 m rectangles (416 plants/ha) or 5 x 7 m rectangles (290 plants/ha), or six to a 6 x 6 m square. If the plants are raised in hedges, the distances come down to 2.5–3 m along the row, and 5-6 m between the rows. The height of the plant should not exceed 3 m. Pruning consists in the elimination of those cladodes not opportunely situated or growing on shadier parts of the plant and in reducing to two the number of new cladodes carried on each “mother cladode”. These procedures apply equally for ordinary pruning.

SCOZZOLATURA, THINNING AND FRUIT HARVEST

Thinning the fruit is necessary in order to obtain a uniform and maximum size (above 120 g). Regardless of the initial number of flowers on the cladodes, it is necessary to leave not more than 6 fruits on each cladode, eliminating all those growing on the planar surface. The fruit is thinned manually, not beyond the second week of flowering. The *scozzolatura* is carried out by removing all the flowers and the new cladodes put out in the spring effusion, during anthesis, but not later. The plant sprouts anew 2-3 weeks after this operation. It sprouts more intensely and quickly according to how early the *scozzolatura* is undertaken. The *scozzolatura* allows the production of extra-seasonal fruits (autumnal). By removing the first spring flowering, and then also the shoots that come after the first *scozzolatura,* it is possible to obtain a third flowering in August that, with opportune measures (tunnel protection of the plants to facilitate fruit ripening and prevent damage from cold), produces a crop in mid-winter (from December to February). The *scozzolatura* is normally carried out by hand with the aid of rudimentary tools.

The fruit is collected the moment the coloring appears at the bottom of the epicarp. At this stage, the color of the *pulp* is already formed and the solid soluble content is close to the maximum, but the fruit is still firm enough to allow for post-collection handling and conservation. The fruit is collected early in the day in order to avoid the excessive annoyance of the glochids that come away from the epicarp. Also, if fruit is collected when the pulp temperature is high, the post-collection life of the fruit is reduced and its sensitivity to damage from cold is increased. Maturation is generally gradual and therefore collection occurs in two or three stages and can be fairly differentiated, depending on the implantation level at the time of the *scozzolatura*. The ripening rate is a function of the thermal conditions, which, if characterized by high temperatures, induce a very rapid and early maturation. If, on the contrary, temperatures are lower than the necessary 18-25°C, maturation will be delayed and substantial modifications to the shape and characteristics of the fruit will be induced (smaller pulp yield, less sugar content and less coloration of the epicarp).

FRUIT COLLECTION AND CONSERVATION

Fruit growth follows a double sigmoid pattern in terms of fresh weight, and a pronounced gain in dry weight occurs for the peel during Stage I, for the seeds during Stage II and for the core during Stage III of the fruit development period (FDP). Cladodes are strong sinks during the sigmoidal growth period that occurs during the earlier 4-5 weeks of their development. At this stage they switch to a linear growth in terms of dry weight accumulation and from being sinks for carbohydrate they become sources (Luo and Nobel, 1993).

The growth of the fruit and the daughter cladode implies a substantial translocation of stored carbohydrates from basal cladodes. In fact, when more than five fruits develop on a one-year-old fruiting cladode, an extensive import of assimilates occurs, particularly during Stage III of fruit growth.

Being a not climacteric (with no raise in respiration during ripening and after harvest), the fruit of the cactus pear has a low respiration rate and is sensitive to damage by cold and suffers from fungi (*Penicillum*, mainly). Yields of the cactus pear vary in relation to the planting pattern and the intensity of the cultivation. A high-density planting (24 plants/m^2), which ensured almost full interception of incident solar radiation, led to an extremely high shoot dry-weight productivity (50 Mg/ha/y) in the second year and maximal fruit productivity (6 Mg/ha/y) in the third year (Nobel, 1992). Cladode dry weight tended to increase with cladode surface area (Nobel, 1992).

Italy has the highest yields in the world, equal to 20-25 t/ha (Mohamed-Yasseen et al., 1996); the average is 10-12 ton/ha. Wastage is high (10-20%) and has little commercial value. The fruit should be collected at the peel color breakage. At this stage, the color of the pulp is already formed and the solid soluble content is close to the maximum (13%-17%), but the firmness is still sufficient (6 kg cm^{-2}) to allow for post-harvest handling and conservation. Collecting the fruit is carried out early in the day in order to avoid the excessive annoyance of the glochids that come away from a the epicarp and to avoid collecting at a moment when the pulp temperature is high, thus limiting the post-harvest life of the fruit and increasing its sensibility to damage from cold. Fruits must be removed manually, using a sharp knife and removing a very small piece of the mother cladode, in order to avoid a rapid rot of the fruits. Fruit ripening is generally gradual and therefore 2-3 or more “takes” can be necessary to collect one single tree, depending on:

- the number of fruits per cladodes (the higher the more gradual the ripening);
- the manipulation of flowering time achieved by SFR (the later the SFR, the later the crop);
- orchard altitude (later crop at higher altitudes);
- the prevailing temperature at fruit harvest time (the higher the temperatures, the more advanced and concentrated the fruit ripening time). If, on the contrary, it is inferior to the necessary 18-25°C, maturation will be delayed and substantial modifications to the shape and characteristics of the fruit will be induced (smaller pulp yield, less sugar content and less coloration of the epicarp).

Fruit size varies with trees according to factors such as plant architecture and crop yield per plant and per cladode. Fruit that do not attain the prime quality in term of size have 50% to 70% less market value than the top quality ones and their relative occurrence is often higher than 50%. Understanding the sources of this variability that depends on plant (genotype) x environment interaction, would greatly enhance orchard profitability, without necessarily increasing yields. The marketable fruit must weigh at least 120 g, with 13° Brix and a firmness equal to 8 kg/cm^2 on a penetrometer (8 mm tip). In regard to some qualitative aspects, the fruit must have a pulp content of at least 55%; the prevalent reducing sugars are glucose (6-8% of the fresh weight) and fructose (5-6% of the fresh weight), with very low acidity (0.03-0.12%, expressed in malic acid). The pH varies from 5.0 to 7.0 and the nutritional value is equal to 15 kJ/kg of fresh digestible fraction.

The number of seeds in a fruit varies from 120 to 350 with a particularly high percentage of aborted seeds (50-60%) in Italian varieties (Gorini et al., 1993).

Not climacteric, the fruit of the cactus pear has a low respiration rate and is sensitive to damage by cold and suffers from fungi (*Penicillum*, mainly). For the purpose of conservation, the best results are obtained by conditioning the fruit for 24 to 48 h at 37-38°C or by dipping them in water at 50-55°C for 3-5 min. and then conserving them at 6°C at a relative humidity of 95% for 6 wk after gathering.

The cactus pear fruit is sensitive to fruit fly (*Capitata ceratitis*), which is the only problem in Italy. A more serious parasite, one that is increasing greatly, is the *Cactoblastis cactorum*, which very effectively attacks the cladodes to the point that it is employed, in fact, in the biological control of invasive Cactaceae (Hoffmann et al., 1998; Knight, 2001). A specific entomoparasite is the *Dactilopius opuntiae*.

Among the cryptogams that cause root decay or *Armillaria* cancers are *Alternaria*, *Cercospora*, and *Phytophthora cactorum*; among the important bacteria are *Erwinia carotovora* (which causes soft rot on the fruit) and *Agrobacterium tumefaciens* (which causes root tumors).

SECONDARY PRODUCTS

Cladodes are rich in mucilages, complex carbohydrates with a large capacity to absorb water that can be considered a potential source of industrial hydrocolloid. The mucilages contain L-arabinoside, D-galactose, L-rhamnose and D-xylose and also galacturonic acid in proportions that vary according to the management of the cultivation, temperature and humidity. In some environments, the mucilages are used in wastewater treatment systems on a commercial and domestic level and recently they have been tried as a means of improving the hydraulic permeability of soils (Sáenz et al., 2004).

Opuntia ficus-indica is also used, exclusively in Mexico, for production of cladodes destined for human consumption (nopalitos or nopals), as well as for the breeding of a cochineal that is specific to the *platyopuntia*, the *Dactylopius coccus*. When this insect is dried and ground, it yields carmine, a natural red colorant (grain cochineal or dacty dye) that, for centuries, has constituted one of the main sources of export wealth from the New to the Old World, and that even today has a significant economic and commercial role as a food colorant and dye in the textile industry of Central and South America (Mexico, Peru and Chile) and on the island of Lanzarote (Canary Islands).

CULTIVATION REQUIREMENTS

Climate

Opuntia colonizes environments characterized by:

- mild winters (mean annual temperature > 10°C);
- a prolonged dry season that coincides with short days; and
- summer rainfall.

These are the conditions of the environments in which the species is autochthonous, while in the Mediterranean basin, the dry season coincides with long days and fruit growth.

CAM metabolism enables the plant to reach maximum photosynthetic productivity with day temperatures of 25°C and nocturnal temperatures of 15°C; temperatures higher than 30°C cause reductions of up to 70% of photosynthetic activity. Temperatures lower than 0°C, even for 4 h, produce irreversible damage to the cladode tissue and the fruit. During the development of the fruit, temperatures lower than 18°C slow down growth, delaying maturation, and diminish the reducing sugars content of the pulp.

Soils

The species grows in all types of soil. It frequently adapts even to soils that are limited by continuous hard rock in the first 25 cm, or that rest on materials with a calcium carbonate content greater than 40% or that contain less than 10% by weight of fine soil (Nobel, 2002).

It does not tolerate salt and a concentration of the soil solution of 50 mM NaCl is considered the threshold for commercial production of the species (Nobel, 2002).

Water Requirements

In spite of the *Opuntiaceae* being typically drought-resistant and able to accumulate in their tissue more than 1500 t/ha of water (Han and Felker, 1997; North and Nobel, 1997), and although Flores-Hernández et al. (2004) showed that drip irrigation (~ 30%) does not increase cactus pear crop production, *Opuntia ficus-indica* cultivated in the Mediterranean basin is irrigated, although the growth of the fruit comes during the dry period. The seasonal volumes vary from 60-80 mm in Italy to 500 mm in Israel using drip irrigation or fine low-level spray.

Nutrients

In Italy, typical fertilizations include 80-100 kg/ha of nitrogen, with the phosphate and potassium fertilization varying widely. The optimal content of N in the one-year-old cladodes is 0.8-0.9%. In winter, 50 kg N per hectare, 80 kg K and 100 kg P are advisable, and the nitrogen is distributed also in spring-summer in at least two applications (60 kg/ha, using urea). Significant correlations have been verified between the calcium available and the quantity of fruit produced as well as between the potassium present and the quality of the fruit (Galizzi et al., 2004).

In Italy, there is no literature on the effect of fertilization on the out-of-season winter crop. In Israel, Nerd et al. (1991) demonstrated that under continuous NPK fertigation the number of floral buds per plant was much lower in the winter than in the summer crop. Fertilization increased production of floral buds in both crops, but to a greater extent in the winter crop. The increase in floral bud production in fertilized plants was associated with an increase in NO_3^--N content in the cladodes. The fruits of the winter crop ripened in early spring, following the pattern of floral bud emergence the previous autumn. Mean fresh weight and peel to pulp ratio (w/w) were higher in fruits that ripened in the spring (winter crop) than in fruits that ripened in the summer.

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Figure 1 Cactus pear spiny variety with white-flesh fruits, grown in Zacatecas (Mexico)

Figure 2. Three-year-old cactus pear orchard growing in Mexico, with drip irrigation and close spacing within the row

Figure 3. Eight-year-old cactus pear orchard grown at Roccapalumba (Sicily-Italy).

Figure 4. Fruits of the "Gialla" cultivar, grown in Sicily, at harvest time.

Figure 5. Cactus pear fruit processing, including glochids removal done in Sicily (Italy)

Figure 6. Fruits of the "Gialla" cultivar, grown in Sicily, ready to eat. Note the high percent flesh.

Figure 7. Fruits of "Rossa" and "Gialla" cultivars, soon after harvest. Note the small piece of the mother cladode at the fruit's edge

USE OF CACTUS AS FEED: REVIEW OF THE INTERNATIONAL EXPERIENCE

Ali Nefzaoui
Livestock and rangeland scientist, ICARDA North Africa Program
a.nefzaoui@cgiar.org

ABSTRACT

Cactus cladodes and waste fruits are cost-effective feed for ruminant animals. Benefits of using cactus as feed are well documented. Opuntia spp. used for animal feeding are abundant, easy and cheap to grow, palatable, and able to withstand prolonged droughts. Large areas of cactus are available year-round in Algeria, Mexico, Ethiopia, and especially Brazil and Tunisia and serve as an emergency feedstock in case of drought. In many arid areas, farmers make extensive use of cacti as emergency forage to prevent the unfortunate consequences of frequent and severe droughts. The cladodes constitute the majority of the biomass of an Opuntia and can be fed to livestock as fresh forage or stored as silage for later feeding. Cactus cladodes are low in crude protein, fiber, phosphorus, and sodium. The water content on a fresh weight basis averages nearly 90%. The ash content of cladodes is high, mainly because of the high calcium (Ca) content. Cladodes also have high levels of oxalates (about 13 % of the dry weight and 40 % of it in soluble form). The crude protein is often below 5% but can be up to 10% of the dry weight. Animals can consume large amounts of cladodes. For instance, cattle may consume 50 to 70 kg fresh cladodes per day, and sheep 6 to 8 kg per day. The energy content of cladodes is 3,500 to 4,000 kcal/kg dry matter, just over half of which is digestible and comes mainly from carbohydrates. In arid and semiarid regions of North Africa, cereal crop residues and natural pastures generally do not meet the nutrient requirements of small ruminants for meat production. Cladodes can provide a cost-effective supplementation, such as for raising sheep and goats on rangelands. Cactus improves rumen fermentation. Sheep rumen fluid pH is not affected by up to 600 g dry matter of cladodes per day, remaining at 6.9. Adding cladodes to the diet can increase the volatile fatty acids (such as propionic acid) by up to 30%, reflecting the increased intake of soluble carbohydrates. High water content of cladodes is beneficial in dry areas. Animals given abundant supplies of cladodes require little or no additional water. The consumption of cactus cladodes increases the amount of omega 3 (CLA) in lambs and kids meat. This encouraging result is of high importance and meets the ultimate goal, which is human health concern. Although grazing of cladodes in situ is the simplest method, it is not the most recommended and care should be taken so that the animals do not overgraze the plants. The most common method is to cut and feed indoors.

CACTUS WELCOMED FEED FOR ARID ZONES

Opuntia spp. used for animal feeding are abundant, easy and cheap to grow, palatable, and able to withstand prolonged droughts (Shoop et al., 1977). Such characteristics make them a potentially important feed supplement for livestock, particularly during periods of drought and seasons of low feed availability. The cladodes constitute the majority of the biomass of an Opuntia and can be fed to livestock as fresh forage or stored as silage for later feeding (Castra et al., 1977). In any case, the idea of using cactus to feed livestock is not recent and goes back to the 18th century (Griffith, 1905; Curtis, 1979; Le Houérou, 1992; Russell and Felker, 1987; Clovis de Andrade, 1990; Flores Valdez and Aguirre Rivera, 1992).

Cactus cladodes and waste fruits are cost-effective feed for ruminant animals. Benefits of using cactus as feed are well documented. *Opuntia* spp. used for animal feeding are abundant, easy and cheap to grow, palatable, and able to withstand prolonged droughts. Large areas of cactus are available year-round in Algeria, Mexico, and especially Brazil and Tunisia and serve as an emergency feedstock in case of drought. In many arid, farmers make extensive use of cacti as emergency forage to prevent the disastrous consequences of frequent and severe droughts. The cladodes constitute the majority of the biomass of an Opuntia and can be fed to livestock as fresh forage or stored as silage for later feeding.

FEEDING VALUE

Nutrient contents

The nutritive quality of *Opuntia* cladodes depends on plant type (species, varieties), cladode age, season, and agronomic conditions (e.g., soil type, climate, and growing conditions). Cacti cladodes are an unbalanced feed nutrient wise but a cost-effective source of energy and water. Cladodes are low in crude protein, fiber, phosphorus, and sodium. Therefore, diets containing cactus should be balanced for these nutrients by appropriate supplements. The water content on a fresh weight basis averages nearly 90%. The ash content of cladodes is high, mainly because of the high calcium (Ca) content. Cladodes also have high levels of oxalates (about 13 % of the dry weight and 40 % of it in soluble form). The crude protein is often below 5% but can be up to 10% of the dry weight. The fiber content is also relatively low, about 10% of the dry weight. The nitrogen-free extract, which includes monomeric and polymeric sugars, is about 60% of the dry weight (Nefzaoui and Ben Salem, 2002; Gonzalez, 1989; Teles, 1978; Gregory and Felker, 1992; Ben Salem et al., 2002-2004-2005; Azocar and Rojo, 1991; Azocar et al., 1996). Cladodes' low content of phosphorous (about 0.3% of the dry weight) and sodium (about 0.01%) requires supplementation when they are fed to animals (table 1).

High intake

Animals can consume large amounts of cladodes. For instance, cattle may consume 50 to 70 kg fresh cladodes per day, and sheep 6 to 8 kg per day. Cladode consumption can have a laxative effect, leading to a more rapid passage of the food through the animal's digestive tract. This leads to poorer digestion, especially when the cladodes constitute more than 60% of the dry matter intake; supplementing with fibrous feed (e.g., straw or hay) can alleviate such laxative effects (Terblanche et al., 1971). The dry matter intake of straw steadily increases as the amount of cladodes supplied increases. Because of the low gut fill of cladodes, an increase of cactus in the diet does not necessarily reduce the intake of other components of the ration (Ben Salem et al., 1996). This is of great importance for arid zones where livestock is fed mainly with straw or cereal stubble, which are low quality coarse feeds that have poor intakes, resulting in low animal daily weight gains.

Cactus cladodes: rich in energy, poor in proteins

The energy content of cladodes is 3,500 to 4,000 kcal/kg dry matter, just over half of which is digestible and comes mainly from carbohydrates (tables 2 and 3). In arid and semiarid regions of North Africa, cereal crop residues and natural pastures generally do not meet the nutrient requirements of small ruminants for meat production. Cladodes can provide a cost-effective supplementation, such as for raising sheep and goats on rangelands. For instance, when diets of grazing sheep are supplemented with cladode cakes, the daily weight gain increases nearly 50 % (145 g average daily gain) (Ben Salem et al., 2002-2004-2005). When cladodes are supplied to grazing goats that have access to alfalfa hay, the milk yield is increased by 45% (to 436 g/day). When cladodes are associated with a protein-rich feedstuff, they may replace barley grains or maize silage without affecting sheep and cattle daily weight gains. For instance, milk yield for lactating goats supplied with 2.2 kg alfalfa hay day-l is actually slightly higher (1.080 g/day) when 0.7 kg cladodes replaces an equal mass of alfalfa (figure 1).

Feeding cactus improves rumen fermentation

The cactus improves rumen fermentation. Sheep rumen fluid pH is not affected by up to 600 g dry matter of cladodes per day, remaining at 6.9. The cladodes are rich in easily fermentable carbohydrates, and their consumption probably enhances salivation. Compared with a cactus-free diet, the highest supply of cladodes doubles the concentration of ammonia nitrogen in the rumen of sheep fed diets based on straw or acacia. This leads to ammonia concentrations near optimal for microbial growth and fiber digestion in the rumen. Adding cladodes to the diet can increase the volatile fatty acids (such as propionic acid) by up to 30%, reflecting the increased intake of soluble carbohydrates (Ben Salem et al., 1996).

No need to water animals fed on cactus

Water scarcity can depress feed intake, digestion, and therefore weight gains of sheep and goats. Thus, supplying livestock with water during the summer and during drought periods is crucial in hot arid regions. Animals consume considerable energy to reach water points. Therefore, the high water content of cladodes is beneficial in dry areas. Animals given abundant supplies of cladodes require little or no additional water (Ben Salem et al., 1996).

FEEDING CACTUS IMPROVES MEAT QUALITY

Investigation jointly conducted by INRA Tunisia and the University of Catania (Italy) showed that the consumption of cactus cladodes increases the amount of omega 3 (CLA) in lambs and kids meat. This encouraging result is of high importance and meets the ultimate goal, which is human health concern. Indeed, it is established now that "CLA is the only fatty acid shown unequivocally to inhibit carcinogenesis in experimental animals" (Abidi et al., 2009). Other positive effects of CLA are the (i) reduction of cancer risk, (ii) reduction of diabetes, and reduction of arteriosclerosis (figure 2).

PRACTICAL CONSIDERATION

The method of utilization of cladodes for livestock will differ according to circumstances, such as available labor, facilities, and quantity of cactus available. Although grazing of cladodes *in situ* is the simplest method, it is not the most recommended and care should be taken so that the animals do not overgraze the plants. The most common method is to cut and feed indoors. Cactus cladodes may be ensiled and used when needed. It is cheapest to store cladodes as parts of living plants instead of ensiling or drying (figure 3).

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Table 1. Mean chemical composition of Opuntia cladodes used as forage or fodder (reported by Nefzaoui and Ben Salem, 2002)

Species	Water (% of fresh weight)	Ash	Crude protein	Crude fiber	N-free extract	Ca	P	K	Na
		% of dry weight							
O. englemannii, O. lindhymeri	85		2.9			8.3	0.04	3.0	
O. ficus indica									
Various	89	17	4.8	10.9	65				
California	90		10.4		64	6.3	0.03	1.2	0.003
Chile	89		8.9			3.9	0.01	2.0	0.003
Tunisia	87	27	3.8	8.6	58	8.7	0.04	1.1	0.05

Table 2. Energy content of Opuntia cladodes compared to other forages in total digestible nutrients (TDN)

Forage	TDN1 (% DM)	TDN2 (% DM)	Author
Opuntia	64.33	65.91	Mendes Neto et al., 2003
Opuntia	-	63.73	Melo et al., 2003
Opuntia	-	61.13	Magalhães, 2002
Bermuda grass	59.94	53.11	Mendes Neto et al.,2003
Sorghum silage	-	52.07	Melo et al., 2003
Corn silage	59.56	-	Rocha Jr. et al.,2003
Elephant grass	49.59	-	Rocha Jr. et al., 2003
Sugar cane	60.57	-	Rocha Jr. et al., 2003

1 – Digestibility trial; 2 – NRC. 2001

Table 3. Effect of supply of spineless cactus (O. ficus indica var. inermis) on intake and digestibilities by sheep fed straw-based diets in Tunisia (Nefzaoui and Ben Salem, 2002)

	Amounts of cladodes (g dry matter)				
	0	150	300	450	600
Dry matter intake, g/day					
Straw	550	574	523	643	761
Cactus + straw	550	724	823	1093	1278
Total digestibility					
Organic matter	45	50	54	58	59
Crude protein	50	55	54	59	64
Crude fiber	53	51	53	52	47
Digestible intake (% of maintenance requirements)					
Organic matter	93	123	158	193	212
Crude protein	52	52	64	93	111
Protozoa (104 per ml)	3.5	9.3	13.0	17.7	13.1
Degradability of cellulose, %	85	72	57	55	56

Table 4. Intake, digestibility, nitrogen balance, and growth for lambs on straw-based diets supplemented with conventional feeds (barley and soybean meal) and alternative feeds (spineless cactus and Atriplex nummularia) (Nefzaoui and Ben Salem, 2002)

Quantity	**Supplements**			
	Soybean meal		Atriplex	
	Barley	Opuntia	Barley	Opuntia
Organic matter intake (g per kg metabolic weight ($Kg^{0.75}$)	68	85	81	94
Digestibility, %				
Organic matter	70	71	68	75
Protein	73	71	71	73
Fiber	68	69	68	74
Retained nitrogen (g/day)	9.4	9.5	7.5	12.2
Average daily weight gain (g/day)	108	119	59	81

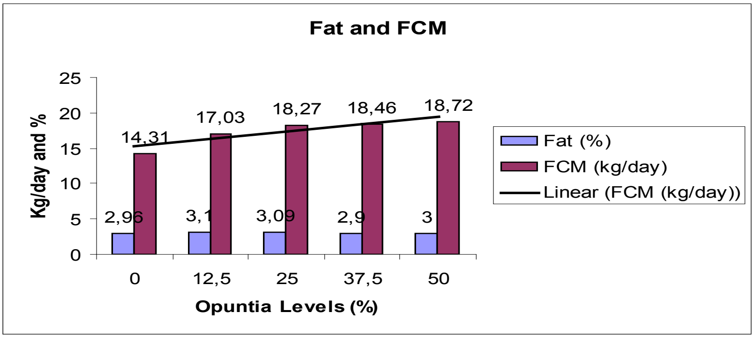

Figure 1 . Opuntia cladodes in replacement of Bermuda grass (Tifton hay) (Cavalanti, 2005) for dairy cattle in North East Brazil

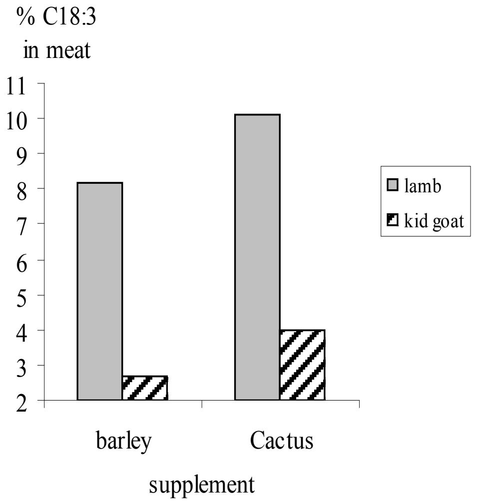

Figure 2. Effect of feeding cactus on CLA contents (omega 3) in lambs and goats meat (Abidi et al., 2009)

Figure 3. Cactus pads being shopped at farm level before feeding using simple tools and household labor (left) or simple-designed choppers (right)

FARMERS PRACTICE IN USE OF CACTUS AS ANIMAL FEED-IN TIGRAY

Tadesse Yohalashet Desta
Tigray Bureau of Agriculture and Rural Development
Regional forage development Team
Mekelle, Ethiopia

ABSTRACT

Ethiopia is well known for its huge livestock resource with defined critical feed shortage. Tigray is designated as dryland arid region, and its agricultural potentials seldom grow from time to time. Livestock production in such environment is terrible due to feed shortage. On average, livestock owners, sufficiently, supply feed for only 3 months, in a year. Otherwise, weeds and cactus cladodes supplement the feed demand of animals.

The camel of plant world is the name given to cactus (Opuntia ficus-indica) as it suits to the arid and semi arid regions of the globe. Cactus is extensively grown in eastern and southern zones of the Tigray region. The total area of land covered by cactus is estimated to be 360,000 hectares which covers about 6.74 % of the total land of the region. 82 % of farmers in the cactus growing areas plant cactus for different purposes. Cladode harvesting methods range from direct animal consumption in the field to cut and carry system. Farmers have traditionally been supplying 55 to 65 cladodes to their cattle daily by cutting, burning and slicing freely, and 5 to 10 cladodes mixed with straw. The average weight of fresh cladode was measured as 780 grams in dry period and 1.5 kg in wet season. Thorny dominates over spineless in rangelands by 73 % to 27 %, respectively. Farmers use spiny and spineless cactus to feed their animals. The proportion of spiny and spineless cacti actually used as feed, was similarly 78.7% and 21.3%, respectively. Farmers used to burn the spiny plant to avoid its thorns with fire. An average of 109 grams of fire wood is required to burn a single cactus pad. And nearly 4468 kg of fire wood materials were demanded daily for about 90 days in a year. This usually affects the time, energy, and resource efficiency of the farmers. The use of about 3,681,088 cladodes weighing 2.9 tons (only in three woredas) indicated huge biomass contribution of cactus to animal feed. Cactus contributes as much as 4.11 % to 21.22 % of the feed resource in the region. Cactus in the area of livestock production is not only the source of feed but also prominent source of water to animals. Palatability of LQR was also increased by proper ensiling technique of cactus with 4-6 % urea. Now days, farmers are adopting the techniques of silage making from cactus. This system (ensiling) is useful for areas like Tigray, where feed shortage extends over a certain period of time. Recently, 97 farmers and 23 DAs were trained at wukro on

the theoretical and practical aspects of silage making from cactus. Ensiling cactus is not only the method of preservation, but also a good system of making the resource more palatable by animals. Cactus feeding has saved the lives of some 3526 cattle and 181 camels in Erob and Hintallo-wojerat. Most farmers in cactus growing areas appreciated the plant for its multiple uses. The future therefore looks bright in using cactus for animal feed in various utilization methods.

INTRODUCTION

Ethiopia is a well-known in Africa as well as in the world for its high livestock population. The region holds around: 3,415,333 cattle, 2,439,121 shoats, 2,416,348 poultry, 400,274 equines, 14,889 camels, and 206,000 bee colonies in different zones. However, the contribution of this huge resource, to the GDP of the country is only 15-20%, which is significantly low (TLDP, 1997). Major problems that contribute to low productivity of the sub-sector are poor nutrition in terms of quality and quantity, prevalence of diseases and parasites with undeveloped veterinary service, low genetic potential and poor breeding schemes of the animals and poor management practices and the like.

Of the aforementioned problems poor nutrition, in terms of both quality and quantity is considered to be crucial (Hailey, 2001). A large area of the region is located in semi-arid category with low and erratic rainfall and extended drought periods. Most of the areas in southern, southeastern and eastern zones of the region lie under arid environment. The major feed sources for animals in the region are; natural grazing and crop residues supplemented by hay and weeds. The production and productivity of natural pastures and other feed resources of this region depend up on the rainfall distribution and intensity. The production of forage and food crops is significantly reduced due to shortage of rainfall. Other factors that contribute to feed shortage are small land holdings of the farmers that lead to encroachment of the grazing lands and the production of less amount of crop residue from that limited land.

In arid and semi-arid environments, not only feed but also drinking water is a real problem for animal production. To assuage this problem, farmers in drought prone areas, have developed a system of infrequent watering, by supplying water every two or three days. Although, such practice seems to benefit farmers to save water, time and labor spent in search of water, it significantly affects the productivity of the animals. Cactus, in this regard, has been playing a great role in solving water problem. Some farmers also practiced cactus feeding intentionally when they want to de-worm their animals.

Cactus grows in a wide range of environmental conditions and remains green throughout the dry season. Cactus was introduced to the region through Erob, (a district in the northern most part of the Tigray region) as early as 1848s probably by French missionaries (Neumann, 1997). Cactus plantation has been given little attention for many years, while poor households gave due attention, as means of subsistence to their animals and also themselves. The objectives of this study were therefore to assess problems of using cactus as animal feed in the field, and address it unto researchers for solution, comprehend the level of acceptance of scientific research findings of cactus at field level, show the actual danger of thorny cactus feeding and suggest possible alternative solutions, indicate practical problems of cactus when using as feed and compile data on farmers' indigenous practices useful to researchers and students who want to study the field.

MATERIALS AND METHODS

Three weredas namely; Raya Azebo, Hintallo-wejerat and Irob were selected for data collection. Fifteen farmers (from each wereda) were chosen for the purpose of collecting the relevant data as regards cactus feeding practice. Focus group discussions that involved 15 to 25 respondents in three Tabias at each wereda were also conducted. Secondary data from the woreda and regional offices of agriculture and rural development were also collected to augment the realities obtained from the field. Questionnaires were distributed to some other cactus growing areas for triangulation purpose and collect some more relevant data to the study.

RESULTS

Historical background of cactus

Although it is the oldest cultivated plant in countries like Mexico, cactus pear was introduced to this country in the last 160 years (Neumann, 1997). Cactus pear locally known by the name *Beles* was considered as poor man fruit for many decades in the region (Mulgeta, 2004). It was even considered as fruit of dark days as it matures during the times of the year when the stored cereals are almost exhausted. Cactus pear is also a livestock feed. Prolonged drought, over grazing, deterioration of rangelands and poor crop residue yields forced animals to graze on cactus pears directly from 1960s on-ward (Zamra, 2001).

Many people consider cactus as poor in nutrients. Curek (2001) however considered cactus as comparable to mid quality grass hay in terms of its digestible energy. These days animal forage experts have appreciated the multiple use of cactus and started to develop interest in this plant as a suitable fodder. The plant now is coming to backyards as feed security resource. A large number of people are convinced on cactus as dry period animal feed, with some reservations on its nutritional quality. Cactus is an alternative feed supplied to animals at times of drought and is supplied to cattle in different forms.

Farmers have utilized both thorny and spineless cactus as forage. Spineless cactus, in the region is considered as strategic fodder encouraged by government policy to be planted with caution. Spiny cactus is however used for live fence and biological conservation purposes in the region. Thorny cactus, on the other hand, is not recommended for feed as it causes physical and mechanical damages.

Cactus as forage

Contribution of cactus as feed source for animals

Farmers practice in using different feed resources varies considerably. But they usually offer different feed resources to animals at different proportions, cactus being one resource utilized in only 16 weredas (about 47%) of the region. The contribution of various feed resources in non-cactus growing areas (high lands) is completely different from cactus growing areas i.e. dry arid and semi arid areas. In areas where cactus has adapted to grow, an average of 2.8 % feed was contributed by cactus (Fisha et al., 2007). However, it is realized during the survey that the contribution of cactus within similar agro-ecologies was found to vary (and for Raya-azebo (6.8 %), Hintallo-Wojerat (4.11%), and Irob (21.22 %).

The data in table 1 clearly shows the higher the feed resource available in an area, the lesser is the cactus utilization and vice versa. Cactus feeding practice is a more familiar activity in Irob than Hintallo-wojerat and Raya-Azebo. This could be mainly due to the fragmentation of the land leading to low crop residue yield and decreased volume of pasture from rangelands. Moreover, farmers in *Irob* have long history of adaptation to cactus than others. Low production and productivity of crop and the resulting poor crop residue yield urged the shift of feeding habits of animals to cactus. Besides cactus pear is the only drought tolerant plant available to animals at times of feed shortage.

Farmers in *Irob* are not worried at all about feed shortage at times of drought because they are used to feeding their animals with cactus that is available around their homesteads.

Farmers practice with respect to cactus feeding

Feeding cactus by mixing it with low quality roughages (LQR)

Farmers have exercised cactus feeding some 40-50 years back following the increased frequency of drought happening in the region. Cactus plantation covered only 6.74 % of the total land in the region. Farmers have been using cactus pear cladodes to satisfy their animals feed and water demands all over the cactus growing areas of the region. Many believe cactus to substitute some common grasses by observing physical or performance change of their animals. This is in agreement with Nefzaoui and Ben Salem (1996).

Farmers supply 55 to 65 cladodes to their cattle daily. Cladodes are cut, burned and sliced before being fed to cattle. They also feed 5 to 10 cladodes when mixed with straw. The average weight of fresh cladode was measured as 780 grams in dry period and 1.5 kg in wet season. Nefzaoui and Ben Salem (1996) reported an average intake of cattle as 50-80 kg of cactus pear cladodes per day. According to Fekede (2002), cattle take around 40 cladodes daily during critical times of feed shortage.

Increasing palatability of cactus pear cladodes

Barley and wheat straws mixed with cactus pear cladodes are often feed to cattle. 53.3 % of the farmers in this study agreed palatability increase of cactus by mixing with crop residues while 31.1 % agreed with the idea that palatability of crop residue itself is increased by cactus (Table 2). Others (15.6%) do not have clear cut observation. A farmer slices 4 to 6 fresh cladodes (weighing 6-9 kg) and mixes it with 8-12 kg of barley or wheat straws and is supplied to an ox daily.

Ensiling cactus with 4-6 % urea was reported to improve the palatability of LQR as seen at St Merry collage at Wukro. Intake of these resources was increased after wilted cacti have been ensiled with 5% urea. The amount of urea to be recommended needs to be worked out by researchers. Equally important for research is also the determination of the contributions of the cactus and also the low quality roughages towards the improvements of low quality feed resources.

Mixing proportions of cactus with LQR

Mixing cactus cladodes with different feeds at various levels of mixing practically enabled farmers to save the lives of their animals in all the study areas. The proportion of cactus with LQR varies from place to place and from farmer to farmer but had no remarkable difference in the condition of their animals (Table 3).

Utilization of Spiny and Spineless cactus

Thorny dominates over spineless in rangelands by 73 % to 27 %, respectively (Fekede, 2004). Both spiny and spineless cacti are used as animal feed at time of critical feed shortage. Farmers burn the spiny cactus plant to remove the spines. This usually consumes the time, energy, and also affects the resource efficiency of the farmers. Moreover, all participants of the focal group discussion indicated that feeding newly roasted cactus kills animals This is especially common among small ruminant animals and research is required on the timing of feeding exercise.

Table 4 indicated about 3,681,088 cladodes weighing 2.9 tons was used annually. This is an indication of the huge biomass contribution of cactus to recurrent feed shortage.

Composition of spiny and spine less cactus

The proportions of spiny and spineless cacti used for feed, in the study areas, are on average 78.7% and 21.3%. Spiny cacti are grazed freely at field but causes mechanical damages to the eyes, nostrils and alimentary canals of animals. In cut and carry management practice, farmers usually burn the plant and give it to animals later just after 3 - 4 hours. The percent of cactus utilization in free grazing management is not yet known.

Using thorny cactus for animal feed costs a lot of energy. On average 109 grams of fire wood is required to burn a single cactus pad (Tadesse, 2008). In the study areas, about 6682, 4468 and 3001.2 Kg of fire wood were burned daily for about 90 days a year in at Raya Azebo, Hintallo-wejerat and Irob woredas, respectively. The cost of fire wood or energy cost spent to burn remove spines of cactus cladode was not considered by farmers but the cost of fire wood may exceeds the cost of cactus itself..

The higher the volume of spiny cactus utilized the greater fire wood was consumed. There is significant difference among study areas in utilizing different types of cacti. Moreover, all weredas show the trend of using more spineless cacti from time to time. All respondents in focus group discussion and farmers under study have agreed on the easiness of working with spineless cactus and its acceptance by livestock. There is therefore an increase in the amount of spineless cactus planted on the backyards of farmers.

Practical advantages of cactus during drought periods

Farmers plant huge numbers of cactus every year. Farmers in the study area planted cactus for different purposes. The data in table 6 show that 82 % of the farmers planted cactus for different objectives and none planted cactus for no reason. 57 % of the farmers in this study plant cactus for multiple purposes like feed, food, fence, fuel wood etc. 35% of them however planted cactus for fruit production purpose. Farmers from Irob (5.5% of them) plant cactus for soil and water conservation purposes.

Practice and acceptance of ensiling cactus

Silage is a method of preserving feed materials in an aerobic environment. Ensiling cactus is not only the method of preservation, but also a good system of making the resource more palatable by animals. Ensiling is becoming a possible practice that can be implemented on cactus by farmers. The drawback of the technology lies on its requirement for good silo and proper techniques in choosing the time, material and energy. The response of farmers on silage making out of cactus is presented in table 7. 76% of the farmers suggested silage making as a good practice because it can preserve and increase the palatability of pioneer resource. 16 % of the practitioners involved in ensiling cactus suggested not to ensile cactus because some farmers did not used plastic containers for keeping the cactus and used a mad silo instead. This is a technical problem and not related to silage. These studies make us believe that it is really possible to make silage out of cactus. As the impacts of silage feeding on milk or meat yield were not evaluated in this study, further research is therefore crucial.

Developments so far

The regional government has taken important steps to develop and encourage production. Cactus is becoming a strategic crop that can strengthen the economic development of the region. As to the role for livestock production, cactus is meant to be planted in caution, for harmonized development with other agricultural activities. BoARD is collaborating with GOs like MU and TARI as well as with NGOs like HELVETAS-ETHIOPIA, FAO and REST.

Activities undertaken:

- Training of Experts, development agents and farmers
- awareness creation on new technologies in cactus production and utilization (offering hand tools, and simple machines to community)
- Undertake exposure visit programs to places where model farmers are doing better.
- Practical training program at field level in silage making.
- Expansion of spineless cactus to new places where cactus had never been planted.
- Silage making practice of farmers and its impact on production and body condition of cattle at wukro
- A lot of works have been done by government and non government organizations to introduce silage technology from cactus at household level, HELVETAS-ETHIOPIA, FAO, institutions like Mekelle University, and TARI have exerted remarkable efforts to demonstrate how cactus could be ensiled.
- Data from project areas of HELVETAS-ETHIOPIA and FAO was collected to analyze the value of ensiled cactus.

Opportunities and challenges

Opportunities

- Awareness created is good opportunity
- The presence of committed leadership & organized structure with the working environment in the community, all together are opportunities that we can use.
- The availability of jointly working development institutions (NGOs, like FAO and HELVETAS-ETHIOPIA) create additional opportunities
- Availability of Educational and research institutions around creates conducive environment to extend the effort.

Challenges

- There is still a challenge in the human mind not to fully embrace the plant that arises invasive nature which in turn demands systematic approach.
- There is a need of additional effort to be exerted in convincing community at all level, to intensify it. This requires some more resource (Skilled labor, material and logistical support).

CONCLUSIONS

It can be summarized from the respondent's consensus; during discussion, that cactus saves lives of nearly 4500 cattle and 250 camels at time of drought all over the arid zones of the region.

- Average daily cactus utilization has determined to arrive at yearly average for animal feed.
- Average weight of a cladode at times of feeding has determined to be 780 gm.
- The volume of fire wood required to burn the thorns is estimated to be 4468 kg daily for 90 days in a year.
- The proportion of spiny and spineless cacti used for animal feed is determined to be 79 and 21 respectively.
- It can be concluded that ensiling cactus is possible practice at household level but requires special technical care.

Recommendations

- Research must be empowered to undertake studies on cactus development and utilization.
- Research must be conducted to scientifically evaluate the technical and economical advantages of cactus feeding.
- Two questions remained unanswered needs further study. The resource which adds intake of feed and why small ruminants die when fed on newly roasted spiny cactus and others are sick for a while.
- Cactus expansion strategy must come to existence and applied**.**

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Table 1. Feed types and proportion of their utilization (Source: Respective *Woreda* offices of Agriculture and Rural Development - 2007)

Feed type	*Woredas* **Under study**		
	Raya-Azebo (%)	Hintallo-wejerat (%)	Irob (%)
Crop Residue	39.3	34.0	14
Crop aftermath	11	9.0	3
Grazing	28	31.14	35
Hay	14	20	26.63
Industrial by-product	0.64	1.15	0
Improved forage	0.26	0.60	0.15
Cactus	6.8	4.11	21.22

Table 2. Palatability increments of crop residues and cactus in the study areas

Study Areas	**Palatability is increased by**		
	Crop residue(*)	Cactus (**)	I don't know
Raya Azebo	10	3	2
H/wojerat	8	4	3
Irob	6	7	2
Total	24	14	7

*, *Intake of cactus is increased by crop residue;*
**, *Intake of crop residue is increased by cactus*

Table 3. Mixing proportion of cactus with crop residue

Study Areas	**Mixing proportion %**	
	Crop residue	Cactus
Raya-Azebo	55	45
Hintallo-wojerat	65	35
Irob	40	60

Table 4. Mean daily cactus (Cladode) utilization in the region

Weredas	**Amount of cactus**	**Daily Average**	**Spiny**	**%**	**Spineless**	**%**
Raya Azebo	194380 - 352000	253190	230403	91	22787	9
H/Wojerat	136500 - 208900	172700	154068	84	27632	16
Irob	178624 - 250000	264312	161230	61	103082	39
Mean		690202 / 3 = 230068		78.7%		21.3 %

Table 5. Fire wood demanded for burning spines of cactus pear

Weredas	Cactus pear cladodes in tons (Spiny)	Cactus pear cladodes in tons (Spineless)	Fire wood used in tons
Raya Azebo	163.6	16.1	22.2
Hintallo-wojerat	113.1	21.6	16.8
Irob	125.8	80.4	12.6

Table 6. Purposes of planting cactus in their backyards and farm fields in the study woredas of Tigray

Weredas	No of farmers	Purpose of planting					
		forage only	fruit only	fence only	All purpose	Soil conservation purpose	don't know
Raya Azebo	14	0	8	1	5	0	0
Hintallo-wejerat	13	0	3	0	10	0	0
Irob	10	0	2	0	6	2	0
Total	37	0	13	1	21	2	0

Table 7. The response of farmers on silage efficiency

Survey area		No of respondents		
	No of farmers	Good	Bad	No difference
Kilete-awlaelo	25	20	4	1
Hintallo-wejerat	12	8	2	2
Enderta	18	13	3	2
Ganta-Afeshum	20	16	3	1
Total	75	57	12	6

DEVELOPMENT OF HAND OPERATED CACTUS CLADODES CHOPPING MACHINE APPLICABLE FOR SMALL-FARMS

Mehari Woldu

Associate researcher Tigray agricultural Research Institute Ethiopia,
P.O.Box 492, Phone +251344402801, Fax +251344408030 Mekelle, Ethiopia

ABSTRACT

Cactus pear (Opuntia ficus-indica (L.), though extensively grown in Ethiopia, has not been given due attention. Limited knowledge on the use of this very important plant has limited its use and means by which it can be converted into a usable or consumable product. The use of this product as forage is among the diversified uses of the plant and hence, it is of paramount importance to work on the development and design of implements that can effectively chop cactus cladodes and other forage materials.

The developed prototype was tested and evaluated as compared with the traditional method. The treatments were: two i.e. chopping using the developed prototype and hand chopping using a machete. The experimental design was completely randomized with fifteen repetitions. The results were evaluated and analyzed by a means of ANOVA software, and the following results have been achieved.

With regards to time required to chop 300 kg of cladodes using the prototype have significant difference $p<0.0030$ as compared to the conventional method. With regards to the cross sectional area of the chopped material, the prototype have significant difference $p<0.0001$ as compared to the conventional method.

In terms of chopped materials profile, the prototype was able to produce In the average 3 x 4cm rectangular shape pieces, while using the conventional method produce irregular shaped pieces with extremely variable sizes. In terms of average chopping capacity (kg/hr) the prototype was able to perform 103.45 kg/hr while using the traditional method is 90.91 kg/hr it was significantly and positively related to capacity per hour. With regards to the uniformity of the chopped materials the out puts of the prototype were all most interlay uniform; while using the conventional method are extremely deferent sizes. With regards to spine removing capacity the prototype was able remove only 70 % of spins from the surface of cladodes efficiently, while the using the conventional method can remove 98.2 %. In this case the found inferior by 28.71 %, also this method required 100 kg of trashes and fire wood to burn the spines from the surface of 300 kg of cladodes.

These results of the experiment showed that in terms of time required to chop the 300 kg of cactus cladodes, uniformity and profile, capacity in kg/hr and convenience of chopped materials.

INTRODUCTION

The major feed resource in Tigray Region is crop residue (Stable) and aftermath. Crop residues which include straws, stalks, sheaths and chaffers contribute almost 50% of the total livestock feed resource, especially ruminants feed resource [3]. Cactus cladodes also contribute significant proportion of livestock feed resources especially during drought period. Devising mechanism of improving the feed value of the major feed resources in the region (crop residues and cactus) must be of priority issue to be sought when one thinks of improving the productivity of livestock under extensive livestock rising. This can be achieved either by chemical or physical treatment methods. Among the physical methods, manual chopping is the major one applicable under small-scale farming. Chopping decreases the size of crop residues, increases the surface area of the feed exposed for digestion resulting in increased digestibility. Cactus, though extensively grown in the region, has not been given due attention. Limited knowledge on the use of this very important plant has limited its use and means by which it can be converted into a usable or consumable product. The use of this product as forage is among the diversified uses of the plant and hence, it is of paramount importance to work on the development and design of implements that can effectively chop cactus cladodes and other forage materials.

The developed prototype was tested on elephant grass and cactus cladodes and compared with the conventional methods. The main comparison parameters were:

- Profile of chopped material and removed thorns;
- Uniformity of the chopped material and quality of shaved surface;
- Chopping Capacity o of the tools;
- Convenience to operate, etc.

Performance of the machine as compared to hand chopping was: All most all chopped materials were uniform; all operators confirmed that the machine reduces drudgery and the time taken to chop the amount of test materials is significantly shorter

MATERIALS AND METHOD

Materials

The prototype has passed through a series of improvements and modifications to reach the possible satisfactory performance and design.

As a test material 300 kg of spiny cactus cladodes were made available for the conventional method and the same amount for the developed prototype. As a chopping tool, for conventional (traditional method) a pair of machetes, 20 cm diameter & 100cm long eucalyptuses log a pair of tongs, 100kg of trash (fuel for burning thorns) and burning platform made up of angle iron and reinforcement bar. For comparison purpose the developed prototype was made ready. Fifteen samples (test materials) 20 kg each from each test materials were also made ready.

Participants

Two work shop technicians have participated on the fabrication and modifications process of the developed prototype.

Three operators were selected among the technical assistants based on their experience in similar works. These three operators were allowed to exercise chopping both test materials using both methods (conventional and using the prototype) for three consecutive days before the actual test

Procedure

The traditional method of chopping cactus cladodes and removing spines was assessed and considered as a bench mark for developing the prototype. The first prototype was manufactured as per the design. Then a series of tests were conducted on the developed prototype to reach the best possible performance. The final design and prototype was developed and manufactured, and was compared with the conventional method.

The same weight /300 kg/ of testing materials was used for the conventional method and the developed prototype for comparison purpose.

The test / experiment were conducted in two steps. The test was conducted using conventional method and alternatively the developed prototype.

Conventional method

- Three hundred kilograms of test material was made ready;
- Fifteen samples having 20kgs of weight each were bundled separately;
- The three operators were selected and trained and allowed to exercise the chopping activities for three day before the actual experiment;
- Each cactus cladodes in the sample /20 kg / was exposed to a flame from burning trashes by laying dawn the cladodes on the burning platform to remove thorns during the test;
- After burning each sample was again bundled together allowed to get cool before chopping;
- The three operators were assigned to perform three different jobs
- Two of them were supplying cactus cladodes one by one and the third one was chopping using a machete on the wooden log.
- Staring time (T_o) and finishing time (T_f) and dawn time (T_d) were measured and recorded,
- All other activities and observation including operators' opinion were also recoded on the data record sheet.

Using the developed prototype

- Three hundred kilograms of test material was made ready;
- Fifteen samples having 20 kg of weight each were bundled separately;

- The three operators were selected and trained and allowed to exercise on how to operate the machine for three day before the actual experiment;
- Three of them were assigned to perform three different jobs during the actual test. i.e.:
- The first one weighs the test materials in 20 kg bundles, and puts the cladodes one by one using tongs on the feeding table of the machine;
- The second one feeds the machine in one by one and operates the roller using the crank;
- The third one chops the materials using the hand lever.
- Starting time (T_o) and finishing time (T_f) and dawn time (T_d) were measured and recorded,
- All other activities and observation including operators' opinion were also recoded on the data record sheet.

RESULTS

By comparing the conventional method chopping cactus cladodes with chopping using the developed prototype on the same amount of cladodes, the following results have been achieved.

While chopping cactus cladodes the prototype can save 21.85 mints as compared with the conventional method. In terms of chopped material profile and uniformity of chopped material; materials chopped using the machine have no significant difference between them and the average cross sectional area of chopped cladodes is smaller 2.01 times than those chopped using the conventional method.

To remove spins from the surface of cladodes using the conventional method 100kg of trashes was burned on the burning platform. Besides the inconvenience to search for trashes, the flame was creating discomfort to the operators and they were complaining of it.

All operators who have participated on the experiment confirmed that the machine reduces operator's drudgery and it is convenient to operate

With regards to time required to chop 300 kg of cladodes using the prototype have significant difference $p<0.0030$ as compared to the conventional method. With regards to the cross sectional area of the chopped material, the prototype have significant difference $p<0.0001$ as compared to the conventional method.

DISCUSSION

The experiment of chopping cactus cladodes using the conventional and using the developed prototype showed that spine removal process using the conventional method although effective, was very tedious and it requires additional hard work to look for trashes leaves, fire woods and similar materials that can be used as a fuel to remove thorn from the surface of the cladodes by burning. Besides the hardship to look for trashes, it has also impact on deforestation. On top of this the flames also create discomfort to the operators. In terms of capacity the conventional method took about 22 minutes longer than the developed prototype to chop the 300 kg of cladodes have significant difference p<0.0030 as compared to the conventional method. With regards to the average X-sectional area of chopped cladodes using conventional method was double of the chopped cladodes using the developed prototype having significant difference p<0.0001 as compared to the conventional method, besides the chopped materials were all most 100% uniform to the contrary of the conventional method. Besides, its current price i.e. 3200 ETB (equivalent to 248.25 USD) makes it affordable by average individual farmer of the region.

The strongest side of the conventional method is that spin removal capacity is superior by 28.71 % as compared to the developed prototype.

CONCLUSION

Based on the results of the experiment I recommend the prototype for small-scale farms as it is superior in many aspects when compared to the conventional method and is affordable by average farmers of the region and is to easy to operate. Secondary, since the conventional method is superior to the prototype in terms of spin removal capacity, the prototype requires farther improvement in this regard.

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Table 1. Main results of experiment

Parameters	Comparison		Remark
	Conventional method	Using the prototype	
Spine Removal Method	Burning	machine	Burning trashes and fire wood is unsafe for the operator
Trashes and fire wood require to remove spines from 300 kg cladodes	100kg	non	Using trashes/fire wood enhances deforestation Requires time for searching them
Spine Removal efficiency	98.2	70.0	The traditional method is by 28.72 % more efficient
Time taken to chop 300 kg [min]	197.60*	175.72	*time taken to burn spines and to collect trashes and fire wood not included
Average capacity [kg/hr]	90.91	103.45	Machine chopping is faster by 13.79 kg/hr
Max. x-sectional area of chopped material [Cm^2]	29.46	12.57	
Average x-sectional area of chopped material [Cm^2]	25.09	12.20	
Chopped material profile	Irregular	Entirely uniform	
Operators opinion	Tedious and Drudgery	More comfortable	

Table 2. Summary of results

Parameters	Treatments		SL	CV%
	1	2		
Time Taken to chop 300kg cladodes [seconds]	13.173333^a	11.714667^b	P< 0.0030	9.0
Cross sectional area of chopped materials [Cm^2]	25.069333^a	12.200667^b	p<.0001	4.4
Standard Error	0.28843	0.20811		

a=conventional method / b=using the developed prototype

Figure 1. The developed prototype

CACTUS PEAR FOR SOIL AND WATER CONSERVATION IN ARID AND SEMI-ARID LANDS

Ali Nefzaoui* and Mohammed El Mourid**

**Livestock and rangeland scientist, ICARDA North Africa Program (a.nefzaoui@cgiar.org)*

*** ICARDA North Africa regional coordinator (m.elmourid@cgiar.org)*

ABSTRACT

Land degradation occurs in all continents and affects the livelihoods of millions of people, including a large proportion of the poor in the drylands. Dry zones, with annual moisture deficits greater than 50 %, cover approximately 40 % of the earth's land surface. More than 70 % of all dry areas suffer from desertification, currently accounting for 36 million km².

Water and soil are the most precious renewable natural resources. Drought avoidance and coping strategies are imperative such as choosing drought-tolerant crops, low plant densities, water conservation and water harvesting. However, only a small fraction of rainfall becomes usable soil moisture: only 1 to 10 % of the rainfall that falls in the drylands ends up in the tissue of natural vegetation and crops of economic significance. The water erosion is accelerated by tillage on slopes and gully margins. Soil productivity is rapidly declining.

Several methods have been tested; water harvesting strips, contour ridges, gully check structures, biological control of rills and small gullies by planting cactus; and have given good results. The contour ridges consisting of parallel stone ridges are built 5 to 10 m apart to stop runoff water (and the soil it carries) from damaging downstream areas. Each ridge collects runoff water from the area immediately upstream/uphill, and the water is channeled to a small plantation of fodder shrubs or cactus. Indeed with a combination of well designed ridges and cactus, farmers are able to meet a large proportion of their fodder requirements.

In the countries of North Africa particularly Tunisia, cactus is successfully associated with water harvesting structures. Planted according to contour lines, cactus hedges play a major role in erosion control. Soil physical properties and organic matter content are considerably improved under these hedges and immediate adjacent areas, with an improvement in organic matter and nitrogen as compared to non treated fields. Rates of 40 to 200 % increase in organic matter and nitrogen have been reported. Top soil structural stability is enhanced, sensitivity to surface crusting, runoff and erosion are reduced, while permeability and water storage capability are increased. Marginal lands have been cheaply rehabilitated in Tunisia and Algeria by contour planting of cacti.

Comparing different cultivation systems, such as downhill planting, contour planting, reduced weeding, and Intercropping with contour hedges, it was found that soil losses (0.13 to 0.26 ton/ha/y) are the lowest with the last technique. Cactus planting in contour hedges may help retaining up to 100 tons of soil per ha per year. Experiments conducted in Brazil and Tunisia show clearly that planting cactus in agro forestry system is more efficient for soil and water conservation than conventional land use.

The eruption of massive dust storms in the Sahara can move 66 to 220 million tons of fine sediment each year. Wind erosion is a major cause of soil degradation on agricultural land in arid and semi-arid areas throughout the world. Wind damages soil by removing the lighter, more fertile, and less dense soil components, such as organic matter, clays, and silts. Reduced soil productivity is not the only agricultural impact of wind erosion. Also blowing sediment cuts and abrades plants, reduces seedling survival and growth, lowers crop yields, and can increase susceptibility to diseases and the spread plant pathogens.

In arid lands subject to wind erosion, cactus-planted alone as biological barrier or together with physical barriers (i.e. cement)- is an easy, cheap and efficient way to prevent and to control top-soil loss and facilitates the accumulation of wind-borne deposits.

The scattered results obtained so far witness the lack of research in this domain. Development actions have been mainly based on assumptions and observations gathered by practitioners. There is an urgent need to enhance the on-going research activities with a sound research initiative to investigate all the benefits to gain and the efficiency of the technologies associated with the use of cacti as a key-stone species to help controlling desertification and adapting to global warming.

INTRODUCTION

Poor farmers are the most dependent on agriculture in the drylands, so they are hit hardest by desertification and drought. They are frequently blamed as agents of land degradation through the phenomenon of 'soil mining'- growing crops and grazing livestock without replacing the nutrients and ground cover that are removed, due to their limited financial means. This blame may be misplaced. Poor farmers frequently initiate sustainable land management practices, especially when markets for higher-value crops emerge as long as the right technologies, infrastructure and policies are in place. Their ability to invest in the future is undermined, though by policies that subsidizes food imports, place taxes on the agricultural sector to support urban priorities, and neglect rural infrastructure and institutions (Winslow et al., 2004). Dryland environments are fragile. Their vegetative cover is sparse; when removed through overgrazing or excessive tillage, exposed soils quickly erode and lose fertility, and the surface sealed soils cause water to be lost as runoff. Sustainable solutions that preserve and enhance soil cover and organic matter such as mixed crop-tree-livestock systems, water harvesting and conservation, and the judicious use of manure and inorganic fertilizers at economically-optimal rates are showing success in many countries. Often these investments reduce rather than increase smallholder's risk (Winslow et al., 2004).

Cacti and *Opuntia* spp. in particular can prevent or reverses desertification through different ways: cacti are drought tolerant species, they are used in watershed management and in water harvesting and its efficient use, in wind and water erosion control, in rangeland and marginal land rehabilitation, in cropland management and crop diversification to contribute alleviating poverty and to reach better livelihood of the rural poor in dryland areas (Le Houérou, 1992; Nefzaoui and El Mourid, 2009) (Table 1)

The species of the *Opuntia* spp. subgenus have developed phenological, physiological and a structural adaptation favorable to their development in arid environments, in which water is the main factor limiting the development of most plant species. Among these adaptations stand out its asynchronous reproduction, and its CAM metabolism, which combined with structural adaptations such as succulence allow this plant to continue the assimilation of carbon dioxide during long periods of drought and in this way reach acceptable productivity levels even in years of severe drought (De Kock, 1980; Larcher, 1986; Nobel, 1994).

Soil and water conservation

Land degradation occurs in all continents and affects the livelihoods of millions of people, including a large proportion of the poor in the drylands. Dry zones, with annual moisture deficits greater than 50 %, cover approximately 40 % of the earth's land surface. More than 70 % of all dry areas suffer from desertification, currently accounting for 36 million km^2.

Water and soil are the most precious renewable natural resources. Drought avoidance and coping strategies are imperative such as choosing drought-tolerant crops, low plant densities, water conservation and water harvesting. However, only a small fraction of rainfall becomes usable soil moisture: only 1 to 10 % of the rainfall that falls in the drylands ends up in the tissue of natural vegetation and crops of economic significance.

Curiously, water is the major cause of desertification in the catchments! The water erosion is accelerated by tillage on slopes and gully margins. Soil productivity is rapidly declining.

Several methods have been tested; water harvesting strips, contour ridges, gully check structures, biological control of rills and small gullies by planting cactus; and have given good results. The contour ridges consisting of parallel stone ridges are built 5 to 10 m apart to stop runoff water (and the soil it carries) from damaging downstream areas. Each ridge collects runoff water from the area immediately upstream/uphill, and the water is channeled to a small plantation of fodder shrubs or cactus. Indeed with a combination of well designed ridges and cactus, farmers are able to meet a large proportion of their fodder requirements.

In the countries of North Africa particularly Tunisia, cactus is successfully associated with water harvesting structures. Planted according to contour lines, cactus hedges play a major role in erosion control (figure 2). Soil physical properties and organic matter content are considerably improved under these hedges and immediate adjacent areas, with an improvement in organic matter and nitrogen as compared to non treated fields. Rates of 40 to 200 % increase in organic matter and nitrogen have been reported. Top soil structural stability is enhanced, sensitivity to surface crusting, runoff and erosion are reduced, while permeability and water storage capability are increased. Marginal lands have been cheaply rehabilitated in Tunisia and Algeria by contour planting of cacti (Nefzaoui and El Mourid, 2009).

Comparing different cultivation systems, such as downhill planting, contour planting, reduced weeding, and Intercropping with contour hedges, it was found that soil losses (0.13 to 0.26 ton/ha/y) are the lowest with the last technique. Cactus planting in contour hedges may help retaining up to 100 tons of soil per ha per year (Margolis et al., 1985). Experiments conducted in Brazil and Tunisia show clearly that planting cactus in agro forestry system is more efficient for soil and water conservation than conventional land use (table 3).

The eruption of massive dust storms in the Sahara can move 66 to 220 million tons of fine sediment each year. Wind erosion is a major cause of soil degradation on agricultural land in arid and semi-arid areas throughout the world. Wind damages soil by removing the lighter, more fertile, and less dense soil components, such as organic matter, clays, and silts. Reduced soil productivity is not the only agricultural impact of wind erosion. Also blowing sediment cuts and abrades plants, reduces seedling survival and growth, lowers crop yields, and can increase susceptibility to diseases and the spread plant pathogens.

In arid lands subject to wind erosion, cactus-planted alone as biological barrier or together with physical barriers (i.e. cement)- is an easy, cheap and efficient way to prevent and to control top-soil loss and facilitates the accumulation of wind-borne deposits (Nefzaoui and El Mourid, 2009).

The scattered results obtained so far witness the lack of research in this domain. Development actions have been mainly based on assumptions and observations gathered by practitioners. There is an urgent need to enhance the on-going research activities with a sound research initiative to investigate all the benefits to gain and the efficiency of the technologies associated with the use of cacti as a key-stone species to help controlling desertification and adapting to global warming.

Rangeland and marginal land rehabilitation

Rangelands are facing several problems with regard to their institutional, social, economical and technical management. The total small ruminant number has been increasing in most of the arid areas. Several techniques were investigated to increase rangeland productivity. They include, deferment grazing, shrubs planting, reseeding, fertilizer application, scarification, etc. Some of these techniques show significant results under favorable conditions. Impressive results are obtained with fast growing shrubs (*Acacia cyanophylla*, *Atriplex nummularia*) or cactus (*Opuntia ficus indica*) planting in Central Tunisia (Elloumi et al., 2001) where average rainfall is 200-300 mm per year (table 4).

Rangelands can also be diversified, providing alternatives to the overgrazing of fragile native vegetation. Drought-tolerant fodder trees and shrubs and cactus accumulate biomass over the rainy season, serving as 'fodder banks' to help animals survive the dry season. Cacti (Opuntia), saltbushes (Atriplex), and wattles (Acacia) have been successfully introduced in West Asia/North Africa. Spineless cactus (Opuntia ficus-indica) is showing promise in large plantations in Algeria and Tunisia; the higher water content of cactus aids in feed intake and digestion (Nefzaoui and Salem, 2002). Agricultural wastes on-farm or from urban processing centers (straw, rice bran, date pulp, whey, brewer's grain, wheat bran, corn gluten etc.) can be compacted into nutritious 'feed blocks' and trucked to the drylands (where transportation is affordable), sparing the need to graze fragile vegetation. These approaches need to be accompanied by steps to avoid environmental damage potential from hazards such as overtillage for sowing range species, soil and water supply degradation around feed and watering stations, and the unwanted spread of alien species which could affect native biodiversity.

Cropland management and cactus-barley alley cropping

Expansion of cereal cropping into rangelands together with the replacement of fallow practice is one of the major reasons to declining soil fertility and wind erosion.

One way of combating degradation resulting from cereal mono-cropping is the introduction of adapted forage legumes, shrubs/fodder trees and cactus in the cropping system.

Alley cropping is an agroforestry practice where perennial crops are simultaneously grown with an arable crop. The practice is such that shrubs/trees or cactus are grown in wide rows with crop grown in the inter-space. Alley cropping is a form of hedgerow intercropping (Alary et al., 2007). Leguminous and fast growing tree/shrub species are preferred for this practice. These species are identified for use due to their soil improving attributes i.e. nutrient recycling, suppressing weeds, and controlling erosion on sloping land. This technology has the advantage of enabling the farmer to continue cultivating the land while the tree/shrub species planted in intermittent rows help to maintain the quality of the soil. Cactus may serve in this system as windbreak, resulting to improved grass/cereal yields. Wide alley may allow animals to graze biomass strata or cereal stubbles in summer time. In the latter case, cactus pads may be harvested shopped and given directly to grazing animals as energy supplement of low quality stubbles (Alary et al., 2007).

If Cacti are well known such as the best plants for the reforestation of arid and semi-arid areas because of their resistance to scarce and erratic rainfall and high temperatures, alley-cropping systems in Tunisia are largely new phenomena. Properly managed, alley cropping can provide income at different time intervals for different markets in a sustainable, conservation orientated manner. Alley designs can also make better use of the space available between trees and add protection and diversity to agricultural fields (table 5, figure 4).

Regional initiative Green wall for Sahara

Concerned with the precarious situation occasioned by the growing desertification process, the President of Nigeria and immediate past Chairman of the African Union, H.E. Olusegun Obasanjo, at the Sahel Saharan Summit held in Ouagadougou, Burkina Faso, proposed the Green Wall for Sahara Project from Mauritania in the West to Djibouti on the East Coast of Africa as a holistic approach to tackle the problems of environmental degradation, particularly desertification in order to save the African environment, conserve the eco-system and reverse the desertification process. The participating countries in the Green Wall for Sahara Project include: Liberia, Guinea Bissau, Central African Republic, Cote d'Ivoire, Togo, Nigeria, Benin, Gambia, Burkina Faso, Ethiopia, Senegal, Sudan, Chad, Mali, Eritrea, Mauritania, Morocco, Somalia, Tunisia, Niger, Djibouti, Libya and Egypt in the spirit of NEPAD and the Secretariat of the project is located at the African Union Commission.

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Table 1. Estimated land areas utilized for raising cacti, mainly *Opuntia ficus indica,* for forage and fodder (Data are from Le Houérou (1992), Nobel (1994), and various MOAs reports)

Region or country	Land area utilized, x 1000 ha
Brazil	600
Other South American countries	75
Mexico	230 + 3 million ha Wild
Other north American countries	16
South Africa	2
WANA region	
Italy	70
Tunisia	600
Algeria	150
Other WANA countries	300
Total	2 million ha cultivated + 3 million ha wild

Table 2. Water use efficiency (WUE) of CAM plants compared to C3 and C4 plants (adapted from Larcher, 1986)

Photosynthetic metabolism	Water use efficiency (kg of water/kg of DM)
C3	400-1000
C4	250-500
CAM	100

Table 3. Comparison of soil losses (tons per ha per year) under different crops in semi-arid NE Brazil (Margolis et al., 1985)

Crop type	Soil preparation phase	Cultivation phase	Harvest until next growing season	Total Soil losses	C factor
Bare soil	7.19	8.20	13.71	29.10	1.000
Cotton	2.42	1.77	6.72	10.91	0.392
Maize	1.51	0.68	3.75	5.94	0.199
Maize + beans	1.36	0.55	2.02	3.93	0.119
Opuntia ficus-indica	0.48	0.02	1.48	1.98	0.072
Perennial grass	0.00	0.02	0.01	0.03	0.001

Table 4. Productivity (forage units per hectare) of natural and improved rangelands in Tunisia (Elloumi et al., 2001)

Rangeland type	Productivity (forage unit per hectare)*
Natural rangeland in Dhahar Tataouine, Tunisia (100 mm rainfall)	35 -100
Private rangeland improved by cactus crop in Ouled Farhane (Sidi Bouzid, Tunisia)	800-1000
Cooperative rangeland improved by shrubs planting (Acacia cyanophylla), Guettis, Tunisia	400-500

(*) One forage unit is equivalent to energy content of one kg barley grain

Table 5. Total biomass changes and barley crop yields (t/ha) in Sidi Bouzid (Tunisia)* (Alary et al., 2007)

Treatment	Natural rangeland	Barley crop (alone)	Cactus crop (alone)	Alley cropping (cactus + barley)
Above ground biomass (t/ha)	0.51	0.53	1.87	7.11
Underground biomass (t/ha)	0.33	0.11	1.8	1.98
Barley grain yield, (t/ha)		0.82		2.32
Barley grain + straw + weeds (t/ha)		4.24		6.65

(*) Average rainfall in Sidi Bouzid is 250 mm/year. No fertilizers were applied to all treatments

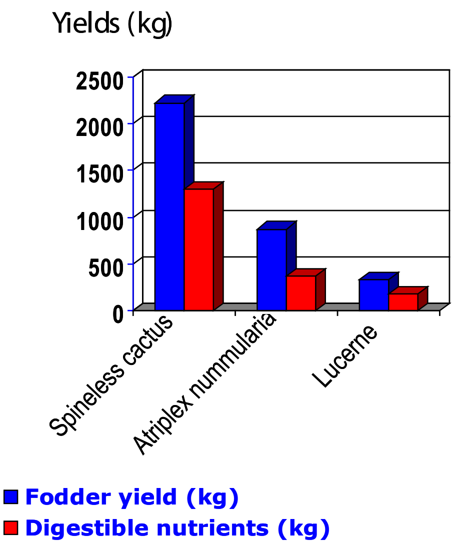

Figure 1. Compared WUE between cactus, atriplex & lucerne (yields per unit of 25 mm rainfall) (from de Kock, 1991)

Figure 2. Example of management used in Tunisia for the protection of watershed

Figure 3. Improved rangeland using Opuntia ficus indica in Central Tunisia (average rainfall: 300 mm) where biomass produced increased from 100 to 1000 forage units (Nefzaoui and Ben Salem, 2002).

Figure 4. Example of alley-cropping technique using Opuntia ficus indica and barley crop

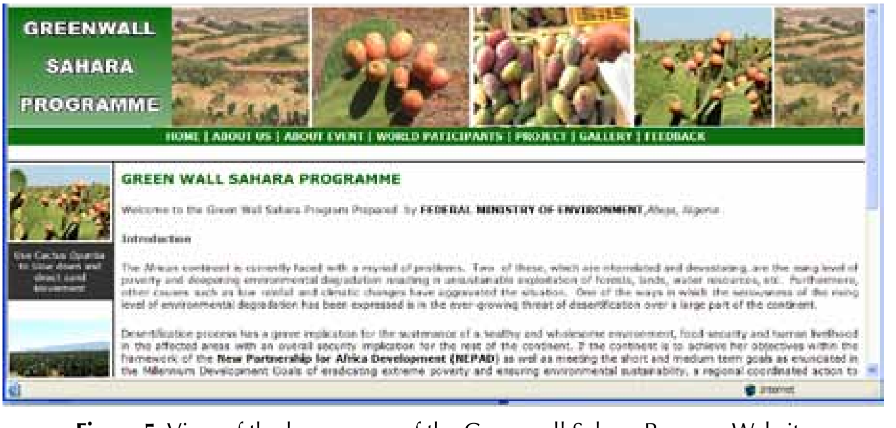

Figure 5. View of the home page of the Greenwall Sahara Program Website

INTRODUCING CACTUS-BASED AGRO-FORESTRY PRACTICES TO THE DRY LANDS OF NORTHERN ETHIOPIA

Tesfay Belay
Tigray Agricultural Research Institute
P.O Box 492, Mekelle, Tigray region, ETHIOPIA

ABSTRACT

The Tigray region of Ethiopia has poor vegetation cover, probably due to continuous cultivation of crops and free-grazing. Besides, the area has an annual rainfall not exceeding 500 mm. Cactus, Opuntia ficus-indica (L.) Mill), has adapted to many parts of Tigray. In the region alone, natural cactus covered about 32000 ha of land. Cactus fruits are eaten fresh in months of July to September. Cladodes are used as livestock feed and for soil and water conservation purposes. Recently other uses like nopalitos, jam and carmine are introduced. Currently, cactus is growing wild and must be cultivated if the benefits from plant are to be sustained. One likely option would be introduction of cactus into farm-lands as hedges or intercrops and of course with improved orchard management. This approach could help in climate change adaptation.

In this study an orchard of 11 cactus pear varieties was established and spaces in between plants were used for production of beans. Five cm deep trenches were dug in between the cactus plants to harvest water for use by component crops. Reduced tillage was employed when planting beans. The biomass of cactus cladodes, fruits and yield of haricot bean were then estimated.

Significant biomass of cactus pear cladodes (914.63 kg) and fruits (268.3 kg) were produced besides to a significantly higher bean yield (1333.3 kg) from a hectare. The biomass is going to increase every year. Bean plots with no cactus intercrops gave significantly lower yields (700 kg/ha). Intercrops had the additional benefits of trapping moisture in the trenches and this should have augmented the poor rains of the 2008 rainy season (375 mm). Cactus does have the potential for an alley and the combination helps increase biomass produced per hectare besides to increasing the vegetation cover. It can therefore be considered as one adaptation option to climate change in the dry lands.

INTRODUCTION

Drylands constitute about 60% of the Ethiopian landmass. Drylands, of Ethiopia at least, have poor vegetation cover probably due to continuous cultivation of crops and free-grazing. These areas have a high evapo-transpiration that exceeds precipitation. Livelihoods in such environments depend on resilience to cope with uncertainties in rainfall. Part of the resilience might be the ability to identify suitable plant species that can thrive and produce yields and farming practices. Inability to identify such sorts has often led to droughts or shortages of food.

On such plant species is cactus pear, *Opuntia ficus-indica* Mill. Cactus pear is a native of Mexico but is introduced to many parts of the drier world. It has tremendous potential of adaptation to drier areas and is often considered as an invasive species. They are often mentioned in classical biological control programs (in Australia, South Africa and Madagascar) that involved the introduction of insects to control cactus invasions. Insects introduced to control cactus pear invasions are now considered as pests because the have started farming cactus pear at least in South Africa. Thus we observed a change in the value of cactus plant over time. Similarly when the International Biodiversity Day was celebrated on the 22nd of May 2006, the theme was protecting biodiversity in drylands and the logo was a cactus flower symbolizing courage that triumphs over appalling obstacles as the writer and photographer Randall Henderson said. The year was also considered as the International year of deserts and desertification.

Cactus pear, *Opuntia ficus-indica* (L.), is an introduction to Ethiopia. There are diverse views as to the ways of cactus pear introduction to northern Ethiopia. According to Kibra, missionaries introduced cactus to Northern Ethiopia around 1847 (Kibra 1992) and recently Habtu (2005) reported that Muslim pilgrimage from the Middle East introduced cactus to Southern Tigray of Northern Ethiopia. It might be possible that multiple introductions to have happened.

Cactus pear has now adapted to many parts of Northern Ethiopia. In Northern Ethiopia alone, uncultivated cactus covered about 32000 ha of land. Cactus fruits are eaten fresh in months of July to September (Fig 1). Cladodes are used as livestock feed and for soil and water conservation purposes. Recently other uses like nopalitos, jam and carmine are introduced.

Cactus pear cultivars in Northern Ethiopia had total soluble solids (expressed as degree Brix) that reached 16.5 (Table 1) (Mulugeta et al., 2007). Cactus pear fruits also had sugar content greater than 50% (Nebbache Salim et al., 2009). The higher TSS and sugar content can make cactus pear fruits suitable for ethanol production especially in areas where fruits are not eaten fresh or are produced in excess.

Despite all these benefits there were no systematic studies or research programs that aim at improvement and development of varieties of cactus pear meant for different purposes like nopalitos, forage varieties, fruit varieties and other improved cultural practices. In some localities however farmers can discriminate so called varieties or cultivars. Limited scientific work done so far, however, which can supplement this information. No germplasm collection maintained for future breeding works too and no varieties identified for different uses. Therefore existing cactus pear germplasm need to be collected, maintained, described and useful traits identified, before thinking of specialized utilization and introduction.

Currently, cactus is growing wild and must be cultivated if the benefits from plant are to be sustained. One likely option would be introduction of cactus into farmlands as hedges or intercrops or alley crops and of course with improved orchard management. This approach could have the additional advantage in mitigating the impacts of climate change. There are however no known agro forestry practices that involve cactus pear in Africa except the long rows of cactus pears planted in vast areas of grasslands in Tunisia and Algeria. Similarly in Northern Ethiopia, cactus live fences are also common surrounding farm fields though they are not managed properly.

This study was therefore conducted with the objective to collect, maintain and describe cactus pear germplasm resources from Tigray (Northern Ethiopia), identify farmers' knowledge as regards uses and characteristics of cactus varieties in the area and test the potential of cactus pear for agro forestry in combination with annual crops like haricot bean.

MATERIALS AND METHODS

Cactus pear germplasm was collected from Mehoni locality in southern zone of Tigray. Varieties known by farmers were targeted for collection and description. From each cultivar 10 cactus cladodes and fruits were sampled and defined using a range of descriptors**.** Selected cactus pear varieties were described using plant, cladode, and fruit descriptors developed by FAO (Chessa and Nieddu, 1997). Collected germplasm were maintained at Mekelle Research center following the procedures for improved orchard management suggested by Inglese (1995). Two cladodes from each farmer variety were used for planting purposes and cut cladodes were kept in sun for 3 days for wound healing to avoid rotting of cladodes. A total of five plants were maintained from each farmer variety. Plants were then spaced 2.5 meters and rows were also spaced 3 meters apart. 5 cm deep trenches were also prepared in between the cactus plants within rows to harvest runoff.

Four haricot bean varieties namely *NSPT#2, Bayorata, Gofta* and *Ayenew* were planted in between the cactus rows i.e. the spaces in between cactus pear plants were used for production of beans. The land in between the cactus rows was not ploughed and instead rows were prepared for planting seeds of haricot bean. Reduced tillage was employed when planting beans (Fig 2a). Six rows of 8.20 meters long were employed for each variety. Rows were spaced 40 cm and plants were then spaced 20 cm apart. Five cm deep trenches were dug in between the cactus plants to harvest water for use by component crops. The biomass of cactus cladodes, fruits and yield of haricot bean were then estimated.

Descriptive analysis was conducted on the data collected using the SPSS statistical software.

RESULTS AND DISCUSSION

Variability among cactus pear genetic resources

Eleven varieties cactus pear was identified the farmers of the Mehoni area. (Table 2) Farmers have coined specific vernacular names for each variety identified. Cactus pear variety nomenclature by farmers depended on color, taste, names of farmers who promoted that specific variety, location, and spine or glochid abundance. On variety had however a name that is not associated with any category.

The cactus pear cultivars were also described using cladode and fruit descriptors. Cladodes characters employed in defining the cactus varieties identified by the farmers include length, width, thickness, spine length, number of spines per areole and number of areoles per cladode. *Mot Kolea* had the longest cladodes and the same variety had the biggest width. There seems to be a positive correlation between cladode length and width. Variety limo had the least thickness while *Meskel Gadaho* is the thickest. Limo again had the smallest spines and had few spines. The number of areoles (spine bearing spots on cladodes) per cladode ranged from 116 to 184 and the number of areoles per cladode had a direct relationship with cladode length and width. *Shenkor*, *Magal Hailu* and *Berbere Haileselassie* have fewer areoles/cladode. They show more variability in cladode & spine length than cladode width, shape and spine abundance. All are spiny except *Limo* with few and smaller spines. Except *Limo* all varieties have same cladode width. Cultivar Limo has less number of spines/areoles.

Of all the cladode characters number of areoles per cladodes, spines length and cladode length are much more variable as they have greater variance than cladode width, cladode thickness and spines per areole. This indicates the importance of those parameters in discriminating cactus pear varieties and the need to focus on the specific cladode characters in future germplasm characterization exercises.

Description of the cactus cultivars on the basis of some quantitative traits like fruit, pulp and peel weight, peel thickness, number of areoles per fruit, seed weight and number and pH are also presented in table 4. *Berbre Haileselassie*, *Tesemsama* and *Limo* have smaller number of areoles on the fruits. *Motkolla* has higher number areoles /fruit. *Meskel-Gadaho* and *Magal Hailu* were having higher number of seeds/fruit but Cheguar have less number of seeds. *Meskel Gadaho*, with higher seed number, has lighter seeds likely because of more number of abortive seeds. *Cheguar* compared to *Megal hailu* had the highest peel weight attributable to peel thickness.

Fruit characters like number of seeds per fruit, number of areoles per fruit, pulp weight and peel weight in a descending order of importance are more variable than peel thickness, fruit length and width, seed weight per fruit and pH. The much variable fruit characters need to be employed in future cauterization exercises.

Cactus based agro forestry practices

Significant biomass of cactus pear cladodes (914.63 kg) and edible fruits (268.3 kg) were produced besides to a significantly higher bean yield (1330.3 kg) from a hectare (Fig 2b) in a space of 8 months. The biomass is going to increase every year. Bean plots with no cactus alley cropped and planted with conventional tillage gave significantly lower yields (700 kg/ha). Cactus intercrops should have the additional benefits of trapping runoff in the shallow trenches and this should have augmented the poor rains of the 2008 rainy season (375mm) in the area. Besides cactus pear does have shallow but spreading root system and that should have helped the bean plants. Cactus does have the potential for hedge-row intercropping and the combination helps increase biomass produced per hectare besides to increasing the vegetation cover. This is relevant to drylands where the land is bare for more than 7 months of the year before the next annual crop. Cactus-based agro forestry practice with improved cactus orchard management can therefore be considered as one adaptation option to climate change in the dry lands. This experiment is the first of its kind to have involved cactus as alley crop. Excepting this farmers often plant cactus in their backyards using stone walls to protect the cactus from livestock with practically no care given to the plantation. Farmers then harvest cactus pear fruits once a year. With such improved management however t is even possible to harvest twice a year provided that we supply supplemental irrigation and fertilizers. Cactus therefore needs to be incorporated into the farming system as it has huge potential to contribute to food security in the face of an imminent threat from climate variability.

CONCLUSION AND RECOMMENDATION

Cactus pear is an exotic plant that seemed to have diversified in our area probably because of sexual reproduction. Variability in cactus pear germplasm can be verified and quantified using certain cladode and fruit characters like number of areoles per cladodes, number of spines per areole, cladode length, number of seeds per fruit, number of areoles per fruit, pulp weight and peel weight.

From this study it was clear that cactus pear will definitely have the potential to contribute to curbing the impacts of climate change if integrated into the farming system with improved orchard management to prevent its invasive behavior.

Cactus pear is often considered a nuisance than a beneficial plant. Emphasis is therefore needed on existing cactus pear genetic resources inventory, breeding and agronomy, improved utilization techniques including the inclusion of cactus pear into the farming system as cactus pear thrives on relatively smaller amount of rainfall than annuals.

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Table 1. The total soluble solids of fruits of 13 local cultivars of cactus from Northern Ethiopia

S.N	Cultivars	TSS (degree Brix)
1	Gerao	15.33
2	Naharisa	14.36
3	Kalamile	14.06
4	Adomuluhta	13.50
5	Geleweiti	14.66
6	Gerwanlayele	14.66
7	Suluhna	14.66
8	Hiraydaglayele	14.50
9	Neitsi	15.00
10	Orgufa	15.66
11	Ameudegado belesa	16.50
12	Hawawisa	15.33
13	Asakurkura	15.40

Table 2. Vernacular names of cactus pear varieties identified at Mehoni area and their meaning.

R.N	Vernacular name	description	Meaning
1	Magal hailu	After a person	Hailu's choice
2	Tsaeda aona	Color & location	White building
3	Shenkor	After taste	sweet
4	Berebere haileselassie	After a person	Haileselassie farm
5	Limmo	Spine abundance	Spine less
6	Meskal gadaho	After location	Place for camp fre
7	Chewchawe	After taste	salty
8	Tesemsema	After taste	oily
9	Mot Kolea	After location	Kids place
10	Aw Kulkual Bahri	unknown	unknown
11	Cheguar	Glochid abundance	hairy

Table 3. Cactus pear varieties described using cladode descriptors.

Vernacular name	Length (cm)	Width (cm)	Thickness (mm)	Spine length (cm)	Spines / areole	Areoles/ cladode
Magal hailu	31.5	16.5	11.9	21.5	3.8	126
Tsaeda aona	33.8	17.1	13.3	13.0	3.5	145
Shenkor	26.8	16.9	12.5	19.0	3.5	116
Berebere h/selassie	28.1	17.3	12.8	20.0	3.0	132
Limmo	27.9	14.4	9.5	0.4	0.8	148
Meskal gadaho	31.7	17.1	13.4	16.0	3.2	162
Chewchawe	28.3	16.1	13.3	20.0	3.3	146
Tesemsema	32.6	16.6	11.8	18.0	3.1	135
Mot Kolea	39.2	20.3	12.9	29.0	4.0	184
Aw Kulkual Bahri	32.3	17.3	13.7	19.0	3.5	146
Mean ± s.e	31.2±1.2	12.5±0.4	16.9±0.5	17.6±2.3	3.17±.0.3	144.0±0.0

Table 4. Cactus pear cultivars described for fruit characters like pulp weight (PLW) (PW), peel weight, peel thickness (PTH), seed weight per fruit (SWOF), seed number per fruit (SNPF), fruit length (FL) and width (FW).

Vernacular name of cultivar	PLW (gm)	PW (gm)	PTH (mm)	Areoles/ fruit	SDWPF (gm)	SNPF	FL (cm)	FW (cm)	pH
Magal hailu	55.0	34.5	0.5	66.6	2.8	275	8.03	6.0	6.7
Tsaeda aona	36.9	19.4	0.3	69.0	1.9	160	5.53	3.90	7.3
Shenkor	35.1	15.8	0.3	45.4	2.6	208.4	5.20	4.00	6.6
Berebere h/ selassie	41.4	20.7	0.3	58.0	2.2	165.6	6.05	4.80	6.7
Limmo	45.2	25.5	0.3	54.6	1.6	239.2	6.60	4.80	6.7
Meskal gadaho	37.2	24.2	0.4	66.4	1.8	332.8	7.70	4.50	6.9
Chewchawe	37.8	25.7	0.4	66.6	1.8	198.6	5.70	4.60	5.9
Tesemsema	47.6	23.3	0.3	53.2	2.5	178.8	7.20	4.40	6.7
Mot Kolea	39.8	21.3	0.3	76.4	2.1	225.8	6.90	4.50	6.6
Aw Kulkual Bahri	31.2	17.9	0.3	68.2	2.0	196.2	-	-	6.8
Cheguar	49.8	36.3	0.5	64.0	1.9	115.8	6.80	5.40	6.5
Mean±s.e	41.5 ±2.1	24 ±1.9	0.4 ±0.03	62.6 ±2.7	2.1 ±0.1	208.7 ±18	6.6 ±0.3	4.8 ±0.3	6.7 ±0.1

Table 5. Grain, fruit and cladode yields from the cactus alley cropping

S.N	Bean variety	Yield/ ha (Kg)	Cladode yield/ha (Kg)	Fruit yield/ha (Kg)
1	Bayo Rata + Cactus	1330.4	914.63	268.3
3	NSPT#2 + cactus	1053.2		
4	Gofta + Cactus	1219.5		
5	Ayenew + cactus	1219.5		
6	Bayo rata alone	700.0	0	0

Figure 1. Cactus pear hedge-row intercropped with haricot bean: a. at planting haricot bean, b. bean nearing maturity. (Note rows used for planting beans and shallow trenches made in between the cactus pear plants).

CACTUS IN SOUTHERN TIGRAY: CURRENT STATUS, POTENTIAL USE, UTILIZATION AND THREATS

Habtu Lemma[1], Mitiku Haile[2], Masresha Fetene[3], and Tesfay Belay[4]
[1]Tigray Food Security Coordination Office P.O.Box 1811, Mekelle, Ethiopia
[2]Mekelle University, P.O.Box, 231, Mekelle, Ethiopia.
[3]Addis Ababa University, department of biology, P.O.Box, 1176, Addis Ababa, Ethiopia
[4]Tigray Agricultural Research Institute, P.O.Box 492, Mekelle, Ethiopia

ABSTRACT

The cactus pear (Opuntia ficus indica) is expanding throughout Southern Tigray, Northern Ethiopia. Its current status, use, potentials and threats were investigated at Tabia Kara Adi-shabo of Raya Azebo Wereda, using socio-economic survey and environmental analysis. Knowledge and perception of farmers on the cactus pear was gathered through use of questionnaires and discussions with elders. Vegetation was sampled using quadrants from areas of differing cactus infestation. Soils sampled from different sites (dense cactus area, cactus cleared area, vegetated area, arable land and decayed cactus piles) were analyzed for percent organic matter, total nitrogen, available phosphorus, pH, electrical conductivity (EC), and bulk density at 0-15 and 15-30 cm soil depth. Despite heavy infestation of potential crop fields, about three quarters of the households who participated in the interview appreciated the economic value and presence of cactus in the area. Farmers indicated that the plant is utilized primarily as food for human consumption and as feed for livestock, especially during period of drought. The main constraint associated with cactus pear was indicated to be harboring of crop pests and invasion of cropland. The vegetation study indicated that average vegetation cover (other than cactus) declined. Average cover for ten dominant woody species declined as infestation of cactus increased. On the other hand, the number of woody juvenile individuals per hectare at three sites showed significant difference among cactus free, intermediate, and complete invasion sites. Regeneration and recruitment of juvenile woody species was found to be higher in the high cactus cover than cactus free area. High organic matter content was recorded from dense cactus areas, which was significantly different from the other sites at 0-15 cm soil depth. There was no significant variation for total nitrogen in both soil depths at different sites. Significant variation among sites was observed for available phosphorus at both soil depths. Soil samples from decayed cactus pile and dense cactus areas showed the highest mean available phosphorus values at 0-15 cm soil depth, which was significantly different from the other sites. Significant variation was also obtained

for EC and soil pH in soil samples of decayed cactus pile at both soil depths, where as bulk density was found to be higher in the cactus free area. The study showed that, although the fertile Raya plain get more and more infested with cactus, no coordinated controlling attempt has so far been made. It is concluded that the expansion of the cactus pear needs to be checked. Nevertheless, it should be noted, that in the absence of reliable irrigation schemes to use the area, and under prevailing condition of insufficient and unreliable rain and recurrent drought, the benefit of cactus pear as food for humans and feed for livestock are tied to survival.

INTRODUCTION

Traditional agriculture including the raising of livestock is the most characteristics form of economic activities in Tigray. Most of the inhabitants of the region support themselves through agriculture, which is largely of a subsistence nature. The level of subsistence has declined radically during the past decades, with almost everything produced being consumed. The Region faces serious threats to the survival of human and livestock population due to persistent drought, which greatly affects its agricultural production. Part of the causes of this phenomenon can be found in the environmental degradation in the region (Mitiku et al., 2002). Over-cultivation and indiscriminate vegetation removals have resulted in large-scale degradation and destruction of vegetation cover. The present status of the natural resource base in Tigray in general and South Tigray in particular is characterized by worsening climatic situation tending towards drier conditions. Landscapes are devoid of most of the original natural vegetation. Degradation of agricultural soils and a greatly reduced availability of water are a problem for rainfed agriculture.

According to SAERT (1994), about 12 % of Tigray's land is marginal, stony, rocky and bare steep slope. The fact that soils are degraded is forcing farmers to introduce multipurpose cactus pear around their fields and homesteads. Mitiku (1997) reported that cactus pears contribution to household food security and as livestock feed during period of drought in Tgray as enormous.

According to Neumann (1997), the main reason for the importance of cactus are: agronomically cactus as a perennial plant that does not underlie the usual cycle of annual crops that consists of germination, growth, fruit production and dying off. The growing period can be fully used and crucial phases of shortage of rainfalls during germination and fruit-formation do not matter so much due to water storage capacities. As a perennial and succulent plant cactus pear can profit from off season-rainfall by replenishing water storing tissue and continuing growth. Those parts of the plant that are not harvested are not lost; neither will die back and mineralize as it is with crop residues of other arable crops. Nutrient stays in the plant and might be used more efficiently. Cactus pear is an efficient water user as it produces the highest amount of dry matter per unit of water consumed (Russel and Felker, 1987). From economic point of view cactus is a multipurpose plant. According to Barbera (1995), the plant delivers human food as fruit and vegetable, fresh and processed, animal fodder including even water supply, medicine and cosmetic, erosion control, fencing as well as wind break, energy as biogas and fuel wood.

At present these two ideas are disconnected. Those advocating the utilization of cactus pear in arid and sub-arid regions make scant reference to the cases where they have become invasive. Conversely, environmentalists, who oppose the introduction of exotic plants on account of the threat they may pose to indigenous biodiversity, tend to down play the contribution cactus pear can make to vulnerable rural communities. While cactus can play an important role in local agro-production systems, it also appears to have become invasive and difficult for people with low input technologies and limited resource to control. Thus there is a need to evaluate the current use and potential utilization possibilities of the plant vis-à-vis the environmental consequences and threats it brings.

In this work we attempted to address the issue by investigating the benefits and consequences, which an introduced cactus pear has for social and environmental well being in southern Tigray, through a socio-economic and technical evaluation of its impact on land potential, soil properties and vegetation dynamics

MATERIAL AND METHODS

Description of the Study Area

The study was undertaken in the lowland plain of Raya Azebo wereda in southern Tigray, Northern Ethiopia. According to the traditional classification methods in Ethiopia the area is classified as *weyna dega*. The area lies between 1500 to 1800 meters altitude and is characterized by variable landforms with different altitudes. Altitude ranges from 1500m to 1800m in the top hills. Flatlands conducive for agricultural production dominate the area bounded by escarpments on both sides. Kara Adishabo (the specific study site) is 15 km from the wereda capital, Mohoni, in the southeast direction. The Tabia, or the peasant association in the study area, consists of four kushets (a subdivision of Tabia) of which two of them are with extensive naturalized cactus. The annual mean rainfall of Mohoni (the study area) is 488 mm and that of Cherecher is 620 mm. The area has a bimodal type of rainfall with poor and erratic distribution pattern.

According to hunting (1976), the valley floors are occupied by deep clay textured vertisols. The soils extend up the lower slopes and at higher elevations are replaced by medium textured and stony slope soils (regosols) derived from the weathering of basalt. Excavated profile indicates that the top 80 cm soils are alluvial deposit followed by black vertisol soils up to one meter and sixty centimeter. At a depth of about two meters the parent material was observed. Similarly previous studies by

RVDP (1996) reported that the soil type of the area is Eutric Vertisol. The topography is flat to almost flat and the slope is 1.8% with alluvium parent material. Further more, soils of the gentle slopes, alluvial plain and basin have favorable profile characteristics for agricultural development. They are very deep imperfectly to well drain, loam to clay texture and lies on undulating to flat topography.

The major land use types of the study area are cultivated land, grazing land, and open scrubland. Within the cultivated land use type one can find at least three components. These are intensive cultivated land where all the land is open for arable farming and no vegetation is visible (TFAP, 1994). Moderately cultivated land where trees in single stands or in patches of bushes are common and commercial farms where large areas of land are privately owned by individual investors. In the open scrubland land use type less woody species are dominating the area with extensive grazing stocks. This area is dominating the lowland plain of Mohoni where extensive wild cactus is prevalent. Patches of dense shrubs interspersing with scattered threes characterize the grazing land use type. Trees such as *Acacia tortilis*, *Acacia seyal*, *Zizipus spina-christ* and *Balanites aegypitica* dominate this land use type. Extensive livestock graze in this land use type where farmers cut branches of trees to feed their cattle with pods and twigs.

Sample Collection and Sampling Technique

To generate data pertaining to the knowledge and perception of farmers about the spread, establishment, and phenology of the plant sample survey was conducted. The survey was supported by Participatory Rural Appraisal (PRA) in which focus group and key informant discussion with elderly people and PA administration were held. The sample survey was restricted in two kushet (sub PA), which had abundant cactus plantations. After selection of the specific study site, registrations of households were made and a total of 1800 households were registered in two kushets. This was followed by wealth ranking of the households in to well off, medium, poor and very poor. Wealth ranking criteria are based on possession of properties. For example, a person is categorized as well off if he owns: more than ten camels, more than two pair of oxen, and ten cows and medium if he had more than four camels, one pair of ox and more than five cows. Similarly a person is considered as poor if he had one ox and two cows. One who is categorized as very poor is one who had nothing at all. This was done because the interview must accommodate all categories of people to avoid socio economic influence of the respondents. The chairperson of the kushet with two other people in each kushet set criteria for wealth ranking and ranked the whole households. Thereafter, random selection was made to select individuals for interview. A total of 110 households were interviewed in both kushets. The respondents were from all wealth categories and from both sexes.

In addition to the sample survey, to generate data about the impact of cactus on soil properties thirty soil samples were collected from Raya Azebo Woreda a Tabia called

Kara Adishabo. Soils samples were taken from plots of five sites namely dense cactus area, cactus clear area, vegetated area, arable land and decayed cactus piles. Within each site, samples were replicated at three sampling points that were approximately 50 m apart. Samples were collected from a depth of 0-15 cm to represent the general characteristics of topsoil and 15-30 cm to represent the general characteristics of sub-soils. Samples were collected by excavating a 20 x 20 cm square pit using spades and shovels to a total depth of 30 cm. Samples were collected in plastic bags, labeled, and then taken to Mekelle University for soil analysis

Vegetation Sampling

To investigate the ecological impact of cactus pear, vegetation was sampled from three transects. A total of 100 quadrants (20 m x 20 m) at interval of 20-meter distance were considered for vegetation sampling. The total sampled area was about four hectares and the altitude extends from 1500 to 1600 m ASL. The sampled area includes three locations, Adi Golo (cactus free area), Genda Chafe (intermediate cactus cover), and Gera Tesfay (complete cactus invasion). Percent cover of all woody species in each quadrant was recorded. In each quadrant the DBH/SBH of all species of tree/shrub >2.6 cm were recorded. The juvenile individual for each tree/shrub species were counted to assess the regeneration status of the woody species.

Soil Analysis

The soil samples collected from the study area were air-dried, ground, allowed to pass through a 2mm sieve and made ready for physical and chemical soil analysis. The analysis was done according to standard procedures with respect to each parameter. From each soil samples seven variables namely EC, pH, organic carbon, total Nitrogen, bulk density and available Phosphorus were determined. Particle size determination was made using hydrometer methods. Organic matter was removed by hydrogen peroxide and sodium hexametaphosphate was used as dispersing agent. Based on the percentage composition of sand, silt and clay, textural classes of the soils were determined.

Bulk density was determined by using a core sampler. Soil samples were collected for each site using core samples. The samples were dried in an oven for 24 hours after fresh weigh has been taken. Then dry weigh of soil samples were determined followed by calculating the bulk density of each sample taking the ratio of dry sample to volume of the core sampler.

Organic matter was determined following the Walkley-Black (1934) procedure. This method involves a wet oxidation of the organic carbon with a mixture of potassium dichromate, sulfuric acid, and titrated by ferrous sulphateheptahydrate. pH and electrical conductivity were determined from a soil suspension of solution prepared with 1:5 soil water ratios.

Total Nitrogen was determined following the Kjeldahl (1883) procedure for converting organic nitrogen to ammonium-nitrogen that can be readily estimated. Available phosphorus was also determined following the Olsen et al., (1954) method (for a soil pH > 7) by titrating using sodium bicarbonate and coloring it using mixture solutions and measured using spectrophotometers.

Data Analysis

The collected data was analyzed using SPSS ver 10(2002) software. Farmer's perception and knowledge about cactus were interpreted while soil samples were analyzed using one-way ANOVA and comparison of treatments with soil parameters at different soil depth was carried out.

For the vegetation analysis SPSS ver 10(2002) and Sigma plot ver 9 were used to measure the association between the degree of cactus cover and the juvenile count of the woody species at each locality. Chi-square test was carried out for analysis of the juvenile counts in each transect. DBH classes versus stem number per hectare were plotted following Lamprecht (1989) to analyze the population structure of the tree/shrub species.

RESULTS AND DISCUSSION

Survey result pertaining to knowledge and perception of local community about cactus pear

Composition of respondents

A total of 110 households, with an average family size of 4.92, were subjected to a sample survey of which 80.9 % were male and 19.1 % were female. The respondents had different wealth status: 12.7 % were well off, 27.3 % were medium, 24.5 % were poor and the remaining 35.5 % were categorized as very poor. Wealth ranking criteria was based on possessions of properties such as camels, cows and oxen. This was done to see whether socio-economic status influences perception and knowledge of households regarding cactus pear's use and utilization.

The average landholding of the respondents ranged from 0.5 to 2.25 ha in which the majority, 34.5 %, possessed 0.5 to 1.00 ha and 24.5 % owned 1 to 1.5 ha and 21.8 % of them had less than half a hectare and the remaining were landless. Almost all the households are farmers without additional occupation such as petty trade. Only 6 out of the 110 households exercised petty trade on top of their main occupation, farming. With regard to literacy, 18 household heads are literate the remaining 92 are illiterate.

Invasion Threat

Cactus' status as a weed or a valuable plant varies depending upon the use and management objective of the plant. Cactus in Southern Tigray is viewed as both a blessing and a curse. People increasingly rely on cactus to minimize risk and ensure crop and food security that arise from recurrent drought and famine. Cactus is playing a crucial economic role as food, feed, fuel wood, and a means of additional income, thereby increasing the efficiency and economic viability of small and low-income farmers. In all these cases cactus pear is viewed as a blessing and, therefore, a valuable plant.

On the other hand the economic and feed value of cactus is insignificant in times of good year. If there is adequate rain as it happens in some years, the people in southern Tigray especially the fertile plain are self-sufficient both in food and feed production. In such cases the contribution of cactus to household food and feed security is almost negligible. But since the climatic situation of the area is mainly erratic and unpredictable people are excessively dependent on cactus particularly for animal feed. This situation has forced rural households not only to cultivate cactus pear around their homestead and farm boundary but also encourage its spread and dissemination. This was proved in the interview made to understand the knowledge and perception of farmers about the expansion of cactus in their area. As depicted in table 4 rural communities have different opinions regarding the expansion of cactus in their area. About 74 % of the respondents perceive that expansion of cactus is useful and advantageous. They believe that cactus serves as a sole animal feed during severe drought seasons. This is in addition to the food value that the plant has.

On the other hand, 26 % of the respondents perceive that expansion of cactus is disadvantage. Their reason is based on the loss they encountered from wild animals that destroy crops and pray on domestic animals. Extensive naturalized cactus is home to a variety of wildlife such as baboons, wild pigs, and porcupines feeding on field crops and hyenas and leopards praying on domestic animals. Furthermore, the invasion of grazing land is of great concern and its magnitude of coverage is increasing. Similar opinions were also forwarded from the focus group discussions. Elderly people indicate that cactus reached its current coverage in70 years of time. If the plant is allowed to be free for additional 70 years; they fear it will invade almost all the land. Therefore, it is up to the society as well as the government to seek a solution. People were asked whether they are willing or not to control cactus by mechanical clearing. The majorities (44.5%) were not willing to control cactus mechanically while 27.3% indicate they would be willing. The remaining 28.2% were indifferent. Similarly, people were asked what constraints they have in controlling cactus invasion. Majority of the respondents responded that land security is the major problem followed by labor shortage and material scarcity.

The problem of cactus invasion is complicated not only because the people lack awareness but also they do not think they have much choice. The problem is further complicated due to land security issues. One elderly key informant explained that as cactus invades rangeland, they do not see the need to bother for its expansion. In ranking the problems associated with cactus, invasion threat was ranked second following harboring of pest and wild animals (Table 6).

This indicates that the threat of exponential invasion is increasing and this is likely to escalate in the future. At present there is not any means of control to arrest the spread of the plant. The problem is further enhanced by the fact that part of the inhabitants still propagate and encourage planting in as yet uninvaded areas. This may lead to a complete invasion that necessitates a huge resource to control. Perception of rural households about the mechanism of spread is similar. Most of the respondents believe that cactus spread by poor harvesting methods. Further more; browsing domestic and wild animals and birds also have a contribution in cactus spreading.

Perception of Farmers on Current Utilization of Cactus

Currently cactus is utilized for different purposes, as: animal feed, fruit for human consumption; live fence to protect farm plots and for soil and water conservation purposes. In their ranking of cactus use by priority, respondents put utilization for human consumption and for animal feed first and second followed by use of cactus for fuel wood, for live fence and as a source of additional income. Cactus fruits, despite their high nutritional value, have some negative effects such as problem of glochids and constipation. People also think the fruit may enhance malaria, This could happen as the pads could collect water for long time that create favorable condition for malaria breeding and it also causes malaria. Also the fruits when dropped and rotten may feed on the fruits.

The extensive utilization of cactus for animal feed has also some negative health effects. These may range from physical injury such as blindness from the thorns to death that arises when feeding roasted pads with high temperature. Such negative health effects are also manifested by delays in reproduction; death through worms associated with tender pads. When negative health effects to livestock were ranked according their severity, bloating, throat infection and mechanical injury were ranked first, second and third (table 8).

Bloating is a form of indigestions marked by an excessive accumulation of gas in the rumen. Immediately after cattle consume a feed, the digestive processes create gases in the rumen. Most of the gases are eliminated by eructation or belching.

With regard to cactus ownership, majority of the respondents who participated in the survey indicated that they have their own cactus plots. The purpose of planting is mainly for back yard live fence and for hedge around field boundary to protect from animal encroachment.

As indicated in the table 9 cactus is not planted for the purpose of fruit production. This is because the plant is abundantly available in the area. Fruit consumption does not have seasonal variation. Rural community consumes 26-50 % of the fruit produced in both good as well as bad year. Proportion of unharvested fruits that are leftover on the plant varies depending on the season. From 51-75 % of the fruit are left unharvested on the plant in time of good year while the left- over decreases to 26-50 % during bad year. Cactus fruit in the study area do not have commercial value except to schoolboys from the near by towns of Mohoni and Maichew. Furthermore some immigrants from the near by highland areas are also engaged in fruit selling. The income one earns from fruit selling during the rain season ranges from birr 100 to birr 1000 in good year and from 10 to 2000 birr in bad year with an average of 618 and 752 birr, respectively.

Perception of Farmers on the Effect of Cactus on other plants

Respondents who participated in the interview were cognizant of the impact of cactus on other vegetations (table10). Cactus suppresses growth of some herbaceous plants such as chat and field crops, While it inhibits growth of grasses at all. In other cases cactus displaces other vegetation by taking the space. Respondents indicate that different types of vegetation used to cover the area now under cactus. Apart from invasion by cactus the vegetation was destroyed for various reasons including land clearing for arable land and for fuel wood.

On the impact of cactus on other vegetation somewhat different opinion was forwarded by the focus group discussion. Despite the impact of cactus on herbaceous plants, they indicated that it also had a positive impact in protecting woodland clearing by restricting accessibility. Moreover some tree species like *Acacia tortilis; Balanites aegyptiaca* and *Acacia seyal* are strong competitors of cactus. These tree species grow in dense cactus area vertically to a maximum height and then expand horizontally to cover the cactus under it. The shading effects of these tree species suppress and finally destroys the cactus beneath it.

The impact of cactus is not limited to tree species but also to grass species and crop plants. The area now under cactus has been covered by different grass species such as *Highperenia hirta*, *Digitaria velutina*, and *Penstum*. These grasses are not available now. Cactus affects crops planted at an average distance of two meters. In the focus group discussion people expressed that cactus may affect crop plants up to a distance of seven meters, which may be acceptable as cactus roots can extend up to ten meters horizontally.

Perception of Farmers on the Impact of Cactus on Soil Fertility

Farmer's response to the impact of cactus on soil property was similar. They indicated that cactus pear has a positive impact on soil fertility. This may be because the pads, roots, and fruits of cactus decompose and mineralize easily and enrich the fertility of the soil by releasing plant nutrients and improve the soil structure by increasing the organic matter contents of the soil. Farmers' also indicated that cactus enriches soil fertility by controlling erosion thereby conserving moisture.

As shown in table 11, 56.36 % of the respondents responds that cactus enriches soil fertility through decomposition of the plant material. It is a common practice to clear cactus and utilize the land for crop production in the area. People were asked to compare the performance of crop growth on previously cactus covered and newly cleared area and arable land. Most of the respondents indicate that cactus cleared area would support vigorous crop growth. This is because cactus enriches soil fertility by decaying its roots and pads and mineralizing faster. Furthermore since land under cactus is not plowed for long time, it may accumulate plant nutrients and develop better soil structure.

Results of Soil Analysis

Soil Organic Matter

The influence of cactus on soil nutrients was evaluated by comparing dense cactus area; cactus cleared area, arable land, vegetated area, and decayed cactus pile. Analysis of variance for percent organic matter content at soil depth of 0-15 cm for the different sites showed significant variation. The mean percent organic matter content for the sites is shown in Table 13. The mean percent organic matter ranged from 3.19 to 9.00. The highest organic matter content was obtained for dense cactus area and was significantly ($p<0.05$) different from the other sites. All other sites did not show significant variation in organic matter content among them. The mean percent organic matter for the sites dense cactus area and decayed cactus pile were higher to most A horizon soils.

A number of reasons can be suggested for the high organic matter content of the top soil: (i) most plant root occurs in the upper part; this is especially true to cactus which has shallow and horizontally spreading root system. Troeh and Thompson (1993) reported that the upper soil zone contains most of the soil organic matter. (ii) More decomposition occurs in the upper layer because of its high organic matter content and is more aerated than the soil layer below.

On the other hand low organic matter content was recorded for cactus cleared area and arable land. The history of cleared area indicated that it was covered by dense cactus before 1998. In 1999, however, the area was given to an investor and the investor cleared the entire cactus together with other vegetation by using machinery and human labor. The cleared area was used for cereal cultivation for two consecutive years (1999-2001). Then the area was abandoned without cultivation for four years. Now, there is no any vegetation and it is totally bare. This must have contributed to its low organic matter content. Similarly the arable land had low organic matter content because it has been subjected to repeated cultivation for long time. Small grain production leads to a reduction of about 1% of their organic matter per year for the first 20 to 30 years of cultivation (Troeh and Thompson, 1993).

Similarly, one-way analysis of variance tests for percent organic matter content for the different sites at 15-30 cm soil depth did not show significant variation. The mean values are depicted in Table 12 and the highest organic matter content was observed for decayed cactus pile and dense cactus areas though not significantly different from the other sites. This could be due to the accumulation of decayed plant parts for a long time without soil manipulation.

Total Nitrogen

As indicated in Table 13 mean values for total nitrogen do not show any significant variation among the site at both soil depths. Soil samples from dense cactus area indicate relatively high mean value when compared with the others but still it does not show any significance difference. Similarly in the sub-soil 15 to 30 cm soil depth there was not significant different among different site means.

Soil samples from dense cactus area showed the highest mean value compared to the other sites mean but there were not significant variations. Unlike in the topsoil, soil samples form cactus pile show relatively higher mean value next to the dense cactus.

Available Phosphorus

Mean value for available phosphorus differed significantly among some of the sites at both soil depths. Cactus pile had the highest value while vegetated area had the smallest value (Table 14). Mean values for cactus pile and dense cactus area were significantly different from the others. There was also a difference among the remaining sites but it is not significant. Relatively high mean value was recorded at cactus cleared area followed by arable land and vegetated area.

Mean value for available phosphorus in the sub-soil of the cactus pile was significantly higher than in the other sites (Table 14). These are significantly different from the other treatment. There was also a variation among the different sites, which was, not significant. Relatively high mean value was observed at cactus cleared area followed by arable land and vegetated area.

Electrical Conductivity (Ec)

As shown in Table 15 the mean value of EC for all sites fell between 0.36 ds/m and 0.73 ds/m. This reveals that the soils under the study area were not in the category of saline soils (>4ds/m). From the table it can be seen that there was variation in EC level among the sites. The least EC value was recorded for vegetated area and arable land and the highest for decayed cactus pile in the 15-30 cm-soil depth.

Soil pH

Soil pH varied significantly between the sites for both soil depths (Table 16). The highest value was recorded from soil samples of cactus pile followed by samples from dense cactus. These values were significantly different from samples of other sites. Although there was slight difference among the sites these were not significant. The over all result indicate that soil samples from decayed cactus pile exhibits the highest pH value of 9.09 while soil samples from natural vegetated area showed lowest mean values of 8.29.

Unlike in the topsoil, for the subsoil the highest pH value was recorded in soil samples of arable land followed by soil samples of decayed cactus pile, vegetated area, and dense cactus. Variations among them were not significant but they were significantly different from soil samples of cactus-cleared area. The pH of soils at the study area as a whole was under the alkaline range. High alkalinity could be from the weathering process that occurred on the minerals found in the soils, which release exchangeable cations such as sodium. According to Brady (1984), conditions that permit the exchangeable bases to remain in the soil results in high pH values. Such conditions account for the relative high pH of soils of semi arid regions, which is also observed in the study site.

Soil Texture

Textural analysis of soil samples from different sites revealed different textural classes. About 66 % of soil samples from dense cactus and natural vegetation without cactus were classified as loam, while 66 % of the samples from cactus cleared area as silt loam. Similarly 66 % of soil samples from cactus pile and arable land were loam and silt loam. The result indicates that most of the soil samples were loam and silt loam.

A soil containing between 7 % and 27 % clay and equal amount of silt and sand has a loam texture. Soil texture has much to do with the passage of air, water, and roots through soils. Loam and silt loam soils are highly desirable for most uses. They have enough clay to store adequate amount of water and plant nutrient for optimum plant growth but not so much clay as to cause poor aeration (Throeh and Tompson, 1993). Thus the soils of the area could be said to have good texture for plant growth.

Bulk Density

The mean values for bulk density indicated that there was a significant variation among the sites with depth. The variation ranged from 0.95 g/cm^3 to 1.23 g/cm^3 in the topsoil and 0.99 g/cm^3 to 1.29 g/cm^3 in the sub-soil. The highest record was observed in cactus-cleared area and the lowest record was observed on dense cactus plantation. In addition to the topsoil, significant variations occur among different soil sample in the sub soil (15-30 cm depth).

Samples from cactus-cleared area showed the highest mean values of 1.29 g/cm^3, while soil samples from dense cactus areas had low mean value of 0.99 g/cm^3 (Table 17). This could be due to the variation in organic matter content. According to Troeh and Thompson (1993), organic matter decrease bulk density in two ways: (i) organic matter is much higher in weight than corresponding value of mineral matter, (ii) organic matter gives increased aggregate stability to a soil. Thus, this can be the prime reason for the higher bulk density reported in Table 17. Furthermore, most of the sites are utilized for grazing purposes as a result excessive trampling of livestock might contribute for compaction of the soil that results in high bulk density.

The interaction of cactus with other vegetation

The vegetation cover of three sites with different cactus cover was compared to see the effect of cactus on natural woody vegetation. The first site Adi Golo (AG) is free of cactus. This is because the spread of cactus has not yet reached the area. The area had cumulative vegetation cover (the average sum of the cover of woody species in one quadrant) of 40 %. The area was utilized for grazing purposes. The second site Genda Chafe (GC) had an intermediate degree of cactus cover (40-50 %). The third site Gera Tesfay (GT) was characterized by complete invasion and has cactus cover of 70-100 %. As can be seen from figure 15, the average cumulative woody vegetation cover declines as one moves from the cactus free area of Adi Golo (AG) to the complete invaded area of Gera Tesfay (GT).

The average cumulative woody vegetation cover in cactus free area of Adi Golo was 40 %. This has declined to 23 % in the intermediate cactus covered area of Genda Chafe and further declined to 13 % in the completely invaded area of GeraTesfay.

Generally it can be said that average cumulative cover of woody vegetation declined with increasing cactus cover. Cumulative cover of ten dominant woody species was compared at three sites. Cumulative percent cover of ten dominant woody species declined with increasing cactus cover. As can be seen in Figure 16, the cumulative cover of ten dominant woody species was relatively high in Adi Golo (AG), where there was no cactus cover. While it was very low in Gera Tesfay (GT) (Figure 16 c).

There was individual variation in cover among the ten dominant tree species. For instance *Balanites* aegyptiaca had the highest percentage cover followed by *Prosopis juliflora* (Figure 16 b).

The effect of cactus on regeneration and recruitment of woody species

There was a clear contrast between the effect of cactus on total cover and regeneration and recruitment of woody species. As can be seen in Figure 17 the highest number of juvenile woody species was recorded in the highly invaded area of Gera Tesfay (GT) while the lowest was found in the cactus free area of Adi Golo (AG).

A number of reasons can be enumerated for the high number of juveniles in the highly invaded area.

- Juveniles under heavy cactus cover were protected from utilization by people. This is due to the fact that dense cactus restricts mobility of people.

- Dense cactus cover area is secured from heavy grazing pressure and trampling of animals. As a result cactus creates a "safe site "for regeneration and recruitment of woody species.

To see the effect of cactus on regeneration and recruitment of different species further statistical analysis was carried out using chi-square test (see appendix 9). The result showed that there was a significant difference among the 19 species in number of juvenile individuals in the three sites [χ^2=2473 (df=36) $p < 0.01$] this clearly indicates the degree of cactus invasion plays a crucial role in germination and establishment.

To sum up cactus had a strong effect on woody vegetation. Generally it can be said that as cactus cover increases the average cover of woody vegetation declines. This could be due to the fact that cactus displaces woody vegetation by competition for space. It can also be said that people have utilized the vegetation before reaching adult stage. On the other hand cactus has a positive impact on regeneration and recruitment. This might be attributed to inaccessibility that heavy dense cactus create by restricting mobility of people and protecting heavy grazing pressure and trampling of animals. This indicates the importance of cactus in the vegetation dynamics of the area. However, this requires further investigation with permanent plots.

Population Structure

Diameter class distribution for the three dominant tree species *Acacia seyal*, *Acacia tortilis* and *Balanites aegyptiaca* follows an inverse J shaped function. As can be seen in Figure18 *Acacia tortilis* has higher population compared than *Acacia seyal* and *Balanites aegyptica*. A diameter size class distribution that drops exponentially with increasing DBH as seen in the *Acacia tortilis* is a characteristics of species with good rejuvenation (Swain, 1998) cited in (Kindeya, 2003). Such a distribution is often referred to as an inverse J-shaped function.

Flat distribution curves indicate a lack of recruitment and perhaps change in species composition (Hall and Bawa, 1993; Kindeya 2003). In general it can be said that dense cactus cover has brought about a positive impact on vegetation replenishment by restricting the accessibility of utilizing this species. As indicated in the figure *Acacia tortilis Acacia seyal,* and *Balanites aegyptiaca* had 107, 85 and 76-stem hectare, respectively in the lower diameter class. Moreover, there was a continuous representation of *Acacia tortilis* and *Balanites aegyptica* in all diameter classes, which show the continuity of natural regeneration, and recruitment into higher size classes. On the other hand *Acacia seyal* was totally absent in the 5th, 6th, and 8th diameter classes. These indicate that there was selective harvesting for household utilization such as poles for fencing and construction of bird scare controlling points.

In the arid and semi-arid environments cactus pear plays an important role both economically as well as ecologically (Le Houerou, 2002). However positive interaction of cactus with other vegetation is of particularly significant. Cactus pear excludes herbaceous plants, primarily due to competitions for space and sunlight. According Ueckert (2004) dense stand of cactus commonly eliminates herbaceous plant production on 25% or more of the surface area of some pastures. From the analysis of stem diameter distribution it can be seen that the juvenile population of *Acacia tortilis*, *Acacia seyal* and *Balanite aegyptiaca* under dense cactus area in Facha Gama area of Raya Azebo wereda of Southern Tigray are increasing. Other studies in Tigray Region (e.g. TFAP, 1996;MUC, 1996) describe opposite trends of population decline. These increase in juvenile population in the present work is attributed to the fact that cactus protects those species from heavy grazing pressure and trampling by grazing animals.

CONCLUSION AND RECOMMENDATIONS

We investigated the current status, use, potentials and threat of the cactus pear in Raya Azebo Woreda, Southern Tigray using socio economic studies and environmental analysis. The majority of the farmers interviewed believed expansion of cactus to be advantageous, as it is the only plant that survives severe drought and the only animal feed that is easily available during drought seasons. Farmers who considered the expansion of cactus disadvantageous indicate that it harbors wild animals that destroy crops and pray on domestic animals, while also invading grazing lands. While most people were not willing to control cactus by mechanical clearing, with regard to constraints for control land insecurity was ranked as the prime problem followed by shortage of labor and material scarcity.

With respect to utilization of cactus, respondents put utilization for human consumption and for animal feed first and second followed by use of cactus for fuel wood, and for live fence. People realize that cactus fruits, despite their high nutritional value, have some negative aspects such as problem of constipation and glochids. Similarly the extensive utilization of cactus as animal feed has also some negative health effects such as physical injury (blindness) and death that arise when livestock are feed on roasted pads with high temperature. The perception of farmers on effect of cactus on other vegetation is similar. Most of the farmers believed that cactus eliminated grass cover and reduced the natural vegetation. However, they also note that it has positive impact by protecting wood clearing by restricting accessibility. Farmers also believe that cactus improves soil through decomposition of plant materials and by conserving moisture.

Cactus had an effect on vegetation, where by as the cactus cover increased, the average cover of woody vegetation declined. On the other hand cactus had a positive effect on regeneration and recruitment of juveniles. Regeneration and recruitment of juvenile wood species was found to be higher under high cactus cover than in cactus free areas. The soil analysis study indicated that cactus had a positive effect on soil fertility by increasing soil organic matter, and adding phosphorus to the soil.

While cactus plays an important role in the livelihood of the population, it has become invasive and difficult to control for people with limited resources. The expansion of cactus to the arable lands has to be arrested. It was observed in this study that, although the fertile Raya plain get more and more infested with cactus, no coordinated controlling attempt has so far been made. The best use of the Raya plains appear to be tied with use of ground water for irrigation through government investment and investor attraction programs. In the absence of irrigation schemes, total eradication of cactus may not be feasible or desirable as it is related to survival in the drought prone area of southern Tigray.

Based on the findings of the study the following are recommended:

The expansion of cactus pear to arable lands needs to be arrested:

- By utilizing the plant for animal feed using efficient technologies such as mechanical choppers-through cooperative programs and projects.
- By distributing invaded land to landless youth.
- By creating awareness on propagation means of cactus and by setting rules and regulations that help in minimizing propagation.

Value should be added to the existing stand by increasing the potential use of cactus through:

- Expanding the utilization of the plant as green vegetable for human consumption,
- Processing the fruit to jams and marmalades.
- The insect that thrives on cactus and produce the carmine dye (cochineal) should be introduced for commercial purposes.

The positive effect of cactus on soil fertility particularly the high content of available phosphorus, the most limiting plant nutrient, needs further investigation to explore the possibility of the plant to be integrated in the existing production systems.

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Table 1. Respondents response to the expansion of cactus in the area

Preference	Number of respondents	% of respondents
Highly advantageous	22	20
Advantageous	59	53.6
Disadvantageous	26	23.6
Very disadvantageous	2	1.8
Total	109	99.09

Table 2. Response of respondents on the main constraints to control cactus invasion in the area

Constraints	Number of respondents	% of respondents
Land security	47	42.7
Labor shortage	22	20
Material scarcity	5	4.5
Others	36	32.7
Total	110	100

Table 3. Respondents response to the problem associated with cactus pear

Problems	Number of respondents	% of respondents
Harbor crop pest and wild animals	102	92.72
Invade crop land	85	77.27
Induce diarrhea in animals Total	37	33.36
Hinder activities by restricting mobility	26	23.63
Physical injury	16	14.54

Table 4. Respondents response for utilization ion of cactus in order of priorities

Purpose of utilization	Number of respondents	% of respondents
Fruits for human consumption	105	95.45
Animal feed	104	94.54
Live fence	102	92.72

Table 5. Respondents ranking on negative health effect of cactus according their severity

Negative health effect	Number of respondents	% of respondents
Causes bloating	43	39.09
Physical injury	13	11.81
Throat infection	13	11.81
Total	25	22.72

Table 6. Respondents response on purpose of cactus planting.

Purpose of plantation	Number of respondents	% of respondents
Back yard live fence	89	80.9
Live fence for crop field	84	76.36
For animal feed	62	56.36
For food security motive	41	37.27
For wind break	38	34.54

Table 7. Respondents response on the effect of cactus on natural vegetation

Effect of cactus on vegetation	Number of respondents	% of respondents
Suppress growth	50	45.45
Inhibit growth	27	24.54
Occupies space	12	10.09
Suffocate the plant	18	16.36
Total	107	97.2

Table 8. Respondents response how cactus improves soil fertility

Effects of cactus on soil fertility	Number of respondents	% of respondents
Cactus plant material decompose faster	62	56.36
Cactus conserves soil moisture	18	16.36
The field is not plowed for long time	5	4.54
Total	85	77.27

Table 9. Mean percent organic matter for different sites at 0-15 cm and 15-30 cm-soil depths

Treatment	(%)Organic matter content * at 0-15 cm soil depth	(%)Organic matter content * at 15-30 cm soil depth
Cactus cleared area	3.19±0.62a	5.10±1.77a
Arable land	3.48±0.36a	4.59±1.67a
Decayed cactus pile	6.06±1.34a	6.65±1.68a
Vegetated area	6.37±1.59a	3.49±0.29a
Dense cactus area	8.99±0.96b	4.29±0.62a

**Means in the same column followed by the same letter are not significantly different at α+0.05*

Table 10. Mean values of total nitrogen for different sites at 0-15cm and 15-30 cm soil depth

Treatment	(%)Total nitrogen* at 0-15 cm soil depth	(%)Total nitrogen * at 15-30 cm soil depth
Vegetated area	0.05±0.02a	0.08±0.06a
Cactus cleared area	0.10±0.02a	0.06±0.01a
Cactus pile	0.12±0.05a	0.12±0.10a
Arable land	0.21±0.02a	0.08±0.03 a
Dense cactus	0.25±0.11a	0.35±0.11a

**NS, Not significant*

Table 11. Mean values of available phosphorus for different sites at 0-15 and 15-30 cm soil depth

Treatment	Available phosphorus (ppm) * at 0-15 cm soil depth	Available phosphorus (ppm)* at 15-30 cm soil depth
Vegetated area	39.03±15.59a	30.47±1.47a
Arable land	72.60±12.91a	43.59±8.78a
Cactus cleared area	88.06±11.84a	67.30±15.27a
Dense cactus	596.35±65.67b	97.47±17.61a
Cactus pile	660.05±44.43b	210.32±83.47b

** Means in the same column followed by the same letter are not significantly different at α=0.05*

Table 12. Mean value of EC for different sites at 0-15 cm and 15-30 cm soil depth.

Treatment	EC ds/m Values* at 0-15 cm soil depth	EC ds/m Values* at 15-30 cm soil depth
Dense cactus	0.36±0.01a	0.22±0.04a
Cactus cleared area	0.29±0.09a	0.42 ±0.03a
Vegetated area	0.15±0.03a	0.20±0.04a
Arable land	0.15±0.02a	0.19±0.01a
Decayed cactus piles	0.73±0.18b	0.94±0.23b

** Mean in the same column followed by the same letter are not significantly different at α=0.05.*

Table 13. Mean values of pH for different sites at 0-15 cm and15-30 cm soil depth

Treatments	pH values* at 0-15 cm soil depth	pH values* at 15-30 cm soil depth
Vegetated area	8.29±0.10 a	8.53±0.03b
Cactus cleared area	8.32±0.21a	8.00±0.13a
Arable land	8.51±0.10a	8.71±0.08b
Dense cactus	8.91±0.03b	8.48±0.04b
Decayed cactus pile	9.05±0.11b	8.56±0.09b

** Means in the same column followed by the same letter are not significantly different at α=0.05.*

Table14. Mean values of bulk density for different sites at 0-15 and 15-30 cm soil depth

Treatment	Bulk density (g/cm^3)* at 0-15 cm soil depth	Bulk density (g/cm^3)* at 15-30 cm soil depth
Dense cactus	0.95±0.05[a]	0.99± 0.08[a]
Arable land	1.15±0.01[b]	1.18± 0.04[b]
Vegetated area	1.17±0.03[b]	1.22± 0.02 [b]
Cactus cleared area	1.23±0.05[b]	1.29±0.05 [b]

** Means in the same column followed by the same letter are not significantly different at α=0.05.*

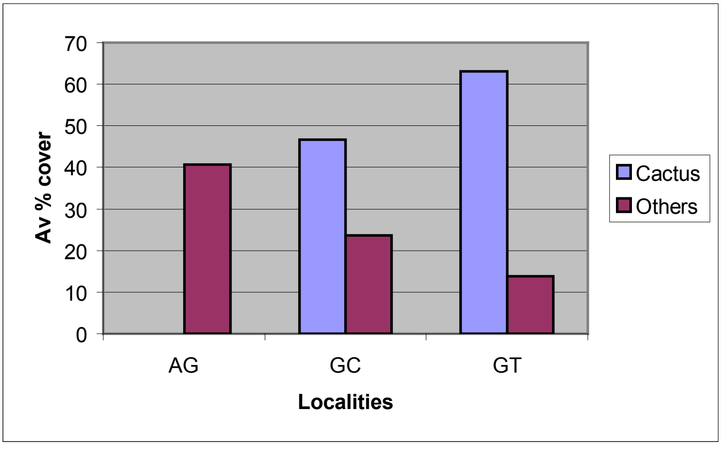
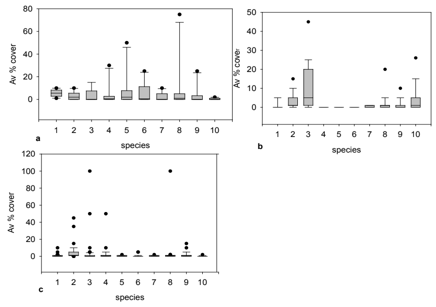
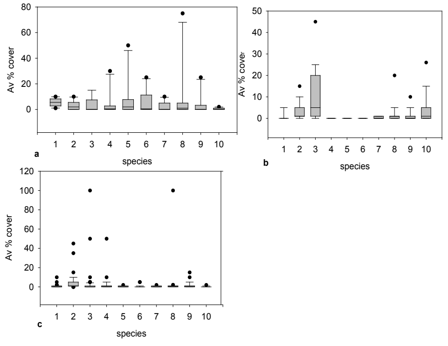


Figure 1. The relationship between cactus cover and average cumulative percent vegetation cover in three sites. Adi Golo (free of cactus invasion), Genda Chafe (intermediate cactus invasion) Gera Tesfay (complete cactus invasion).





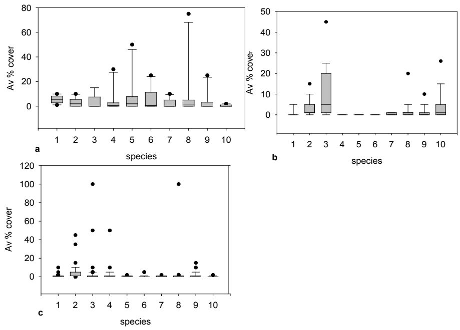


Figure 2.The effect of cactus cover on the average percent cover of ten dominant woody species (1 =Acacia seyal 2 =Acacia tortilis 3 =Balanites aegyptiaca 4 =Carisa edulis 5=Cordia ovalis 6=Dchrostachis cinera 7=»Kamjale» 8=Lonchocarpus laxiflorus 9=Pterolobium stellatum 10=Prosopis juliflora. The Box indicates the average covers and the whiskers indicate the ranges while the black dots shows extreme values.

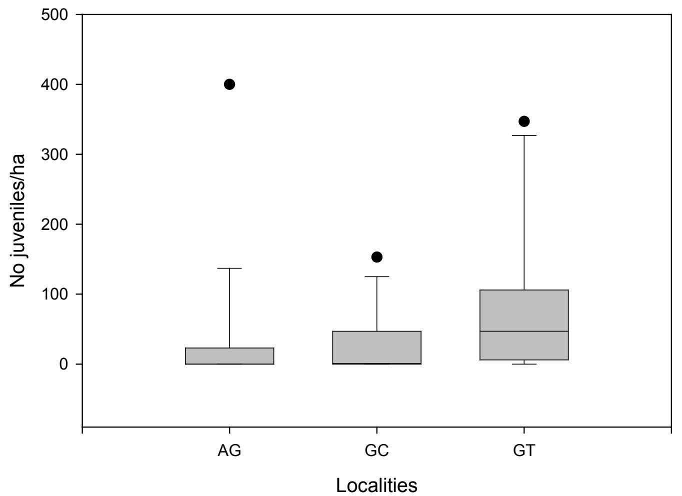


Figure 3. Distribution of juveniles at three localities 1= Adi Golo (AG) (free of cactus invasion) 2= Genda Chafe (GC) (intermediate cactus invasion), 3= Gera Tesfay (GT) (complete cactus invasion)

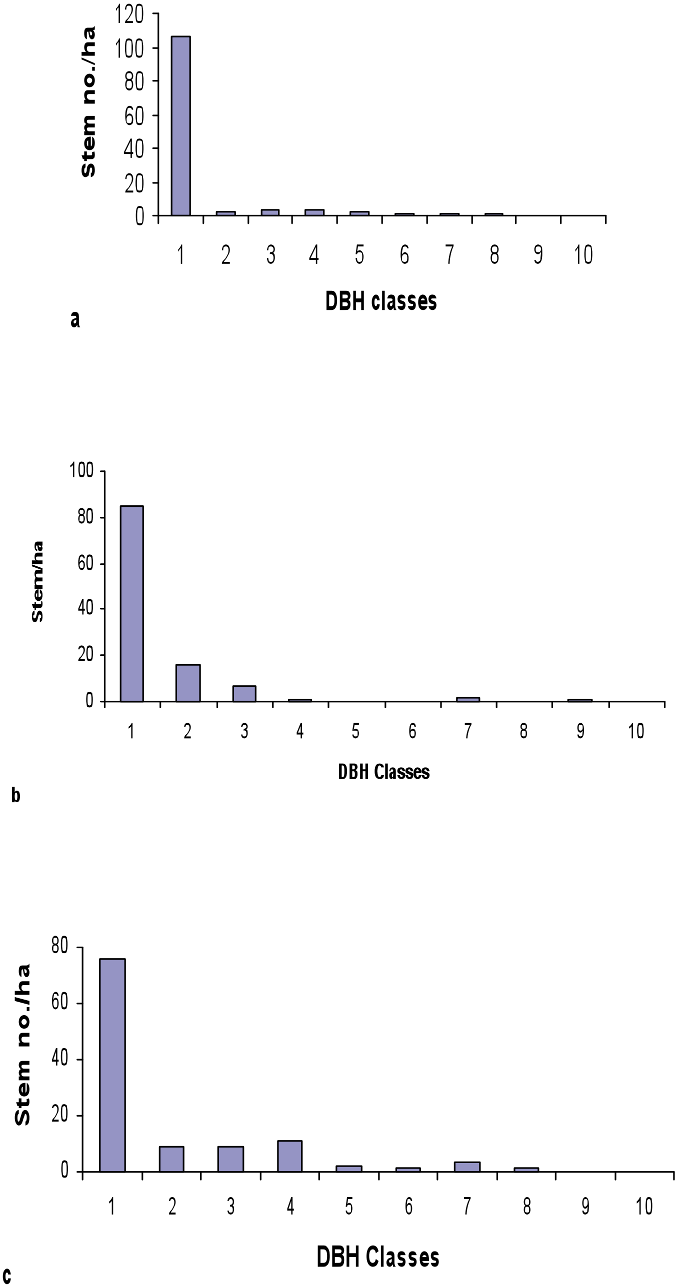


Figure 4. Population structure of a) *Acacia tortilis* b) *Acacia seyal* c) *Balanites aegyptica*. The numbers in the x-axis stand for the following DBH/SBH classes: 1=<2.6, 2=2.6-7.5, 3=7.6-12.5, 4=12.6-17.5, 5=17.6-22.5, 6=22.6-27.5, 7=27.6-32.5, 8=32.6-37.5, 9=37.6-42.5, and 10=>42.5. The bars represent the numbers of stems/ha.

MANAGING PRICKLY PEAR INVASIONS IN SOUTH AFRICA.

Helmuth Zimmermann
Pretoria, South Africa

ABSTRACT

At least eleven different Opuntiae are invasive in South Africa, including, the prickly pears Opuntia ficus-indica. O. stricta, O. aurantiaca, O. monacantha, O. lindheimeri, O. humifusa and O. engelmannii and the "cholla" prickly pears Cylindropuntia (Opuntia) fulgida, C. imbricata, C. leptocaulus and C. tunicata. Extensive and expensive chemical and mechanical control programs were applied to six of the eleven species since the beginning of the 20th century but with limited success. Successful control on six species was only achieved after extensive research into biological control involving eight host-specific natural insect enemies that were introduced from the Americas which were the cactus moth, Cactoblastis cactorum, the cochineals, Dactylopius opuntiae biotype "opuntia", D. opuntiae biotype "stricta", D. austrinus, D. ceylonicus, D. tomentosus biotype "tomentusus", D. tomentosus biotype "fulgida" and the stem boring weevil Metamasius spinolae. The biological control of O. lindheimeri, O. humifusa and O. engelmannii and C. tunicata is unsatisfactory or absent and initiatives are underway to introduce additional biological control agents that would provide satisfactory control of these species. The most dramatic and damaging invasions were caused by O. ficus-indica dating back to the 19th century. By 1920 nearly 800 000 ha were invaded in the Eastern Cape Province alone. The successful biological control of other prickly pears, including O. monacantha (India, Australia, Mauritius, South Africa) and O. stricta and O. inermis (Australia), encouraged South African entomologist to investigate the feasibility of biological control of O. ficus-indica. The desirability of the biological control of a species that is both invasive but also useful, particularly the commercial spineless cultivars of O. ficus-indica, generated heated debates at the highest political levels for many years while the invasions increased exponentially. The severity and continuous damage caused by ever increasing invasions eventually convinced authorities to release the cactus moth, Cactoblastis cactorum and the cochineal D. opuntia biotype "opuntia" which collectively controlled about 80% of the invasions by O. ficus-indica in South Africa. In retrospect this was a gamble which fortunately turned out positively because sufficient invasions remained that are now extensively utilized and commercial cultivation of spineless O. ficus-indica and O. robusta for both fruit and fodder production can continue despite limited inputs to control the two biological control agents/pests. The cactus moth also plays a substantial role in reducing the populations of several other invasive Opuntia species. The discovery of host-adapted biotypes within the cochineal species D.

opuntia and D. tomentosus in the Americas has opened up new opportunities to control new prickly pear weeds, for example O. stricta and C. fulgida resp. The history and lessons learned from the many successful biological control projects against prickly pears and other invasive cacti e.g. Cylindropuntia species in South Africa, provide guidelines and possible solutions to many other similar invasions of Opuntiae in other parts of the world, including Ethiopia.

INTRODUCTION

There are about 180 species in the Cactaceae that are cultivated in South Africa, mainly as ornamentals (Glen 2002). Of these about 15 species have been identified as being invasive and these are subject to some level of compulsory control under the Agricultural Resources Act 43 of 1983 of South Africa (Henderson 2001). These include seven species in the Genus *Opuntia* and four species in the Genus *Cylindropuntia* (previously included in the Genus Opuntia), collectively known as Opuntiae (prickly pears and "chollas") (Anderson 2002). Except for *Opuntia ficus-indica* and the various cultivars of *O. robusta* which were both deliberate introductions (Annecke & Moran 1978), all the other species were introduced illegally, as ornamentals or through the nursery trade. In relation to all the other naturalized genera in the Cactaceae, there is a disproportionally high number of invasive species coming from the Opuntiae. New invasive species are identified on a regular basis despite efforts to prevent their introduction.

O. ficus-indica is a typical "conflict-of-interest" species because it is invasive on the one hand and useful on the other hand, and this makes legislation for management and control very complicated (Annecke & Moran 1978). This paper provides an overview of the major problem species and their control and management in South Africa.

THE PROBLEM SPECIES

Table 1 lists the invasive species in the Opuntiae with their options for control and their present status as weeds in South Africa. Except for *O. aurantiaca* which is sterile, all other species produce fruit which are eaten by animals which then serve as vectors for further spread. All species also reproduce vegetatively which further contributes to their rapid densification and spread. All invasive species are very spiny and are problematic because they reduce grazing, cause injury to stock and negatively affect biodiversity (for complete overviews on invasive cactus species see Moran & Zimmermann 1984 and Zimmermann *et al.* 2008).

CONTROL METHODS

Chemical control

Herbicidal applications are widely practiced in South Africa to control invasive Opuntiae. Prior to 1985, 2,4,5-T and Picloram in paraffin or diesel was widely applied against many Opuntiae (Moran & Annecke 1979; Zimmermann 1979). Because of the high costs of these herbicides and the damage to non-target species, MSMA (Monosodiummethane arsonate) was later registered for cactus control and it replaced the hormone-based herbicide as from 1985 onward. MSMA is highly systemic in succulents, relatively inexpensive, water based and is used in spot-spray and stem-injection applications (Zimmermann 1989). Large state-subsidized programs were in place to encourage landowners to control invasive cacti (Moran & Annecke 1979). More than 107.5 million liters of ready mix 2,4,5-T and Picloram herbicides were issued to farmers free of charge between 1959 and 1978 for the control of mainly *O. aurantiaca*. Similar subsidies were in place for the chemical control of *O. ficus-indica, C. imbricata* and *C. fulgida*. Although these control efforts did reduce invasions temporarily, they were unsustainable because of the rapid regrowth of the cactus invaders and the exorbitant and escalating high costs of these programs. Other solutions had to be found.

Before biological control the Kruger National Park (KNP) embarked on a chemical control campaign in an effort to eradicate or control *O. stricta* invasions. Less than 1000 ha were invaded in 1989 when chemical control was initiated. By 2002 more than US$300 000 was spent on chemical control and the infestation continued to increase seven fold during this time. Chemical control, although succeeding to kill individual plants, has not at any stage succeeded in managing the invasions in the KNP, and nor has it stopped its increase, distribution or density (pers. com. L. Foxcroft).

Biological control

The history of biological control of cactus weeds dates back to 1913 when the cochineal insect, *D. ceylonicus,* was introduced for the biological control of *O. monacantha* which has become a major weed along the southern and eastern coast of South Africa. This program was highly successful and provided hope for other similar control programs (Moran & Zimmermann 1984: Zimmermann *et al*. 2008). The next highly successful biological control project was, however, not coming from South Africa, but instead from Australia where two biological control agents, namely, the cactus moth, *Cactoblastis cactorum,* and the cochineal, *Dactylopius opuntiae,* provided spectacular control of *O. stricta* and *O. dillenii (inermis)* between 1929 and 1934 (Dodd 1940: Mann 1970). This provided the incentives for South Africa to control O. *ficus-indica* using the same insects. Although *O. ficus-indica* had already invaded close to 800 000 ha by 1930, there were many landowners, mainly in the cooler highlands, that regarded *O. ficus-indica* as a useful species, mainly for its fruit and fodder (Beinart 2003). The cultivated spineless varieties of *O. robusta* were also regarded as very important as an emergency supply of fodder during droughts. These fodder varieties would also be affected by the two proposed natural enemies. This conflict of interest and lack of information on the host-specificity of the cactus moth, prevented the release of this insect for many years. Discussions whether or not to release these agents continued for many years and it was also highly politicized (Annecke & Moran 1978; Beinart 2003). The release of the cactus moth was eventually approved in 1934 followed by the release of the cochineal, *D. opuntiae,* four years later in 1938.

The cochineal proved to be the better of the two biological control agents. The cactus moth was unable to kill large plants but was very effective in killing small plants and is crucial in preventing regrowth (Zimmermann & Malan 1981). The ability of the moth to locate isolated small plants proved to be most valuable. Today, due to the combined damage caused by mainly these two insects, *O. ficus-indica is* considered to be under excellent control in South Africa and only remains as a minor problem in a few areas (Annecke & Moran, 1978). The remaining populations are now actively utilized by the informal sector, mainly for its fruit, and contribute substantially to the livelihood of many people (Beinert 2003). Previously invaded areas are kept free of regrowth by the two agents.

Although both natural insect enemies are now regarded as pests in commercial cultivated cactus pear plantations, good control of these two insects species is possible and cactus pear production can continue and is even expanding. It seems that we, rather more by good fortune than by sound judgment, have stumbled across two biological control agents which have resulted in a desirable compromise in which prickly pear has been reduced in most areas to low densities that are tolerable or even desirable (Annecke & Moran 1978).

Other early, but less dramatic successes in South Africa, were the biological control of *O. aurantiaca* with the cochineal *D. austrinus*. *C. cactorum* plays a less significant role in the biological control of this weed. An integrated control program has been designed that allows for maximum benefits from the cochineal and chemical control (Moran & Zimmermann 1991). A mass-rearing program of the cochineal is now in place that provides landowners with insect inocula where cochineal populations are very low or have died out. Chemical control is reserved for areas where cochineal is less effective (Moran & Zimmermann, 1991a).

A similar outcome has been recorded with the biological control of *C. imbricata* with another cochineal, *D. tomentosus* biotype "*imbricata*". The insect is particularly effective against small plants but takes a long time to kill large plants with woody stems. An integrated control program prescribes the felling of large plants or treating the stems with a herbicide only after the cochineal has defoliated the plants and only after it has killed off the small plants that are usually concentrated around the larger plants (Moran & Zimmermann, 1991b). This may take up to 4 years.

New cactus weeds are becoming invasive on a regular basis and include the three prickly pears, O. *humifusa*, *O. stricta, O. engelmannii* and two "chollas", *C. fulgida* and *C. tunicata*. Although *D. opuntiae* and *D. tomentosus* are found naturally on these plants in their native range, the insect populations that were introduced to South Africa for the control of *O. ficus-indica* and *C. imbricata* were ineffective on these species in South Africa.

Host specific biotypes

All nine known cochineal (Dactylopius) species are extremely host specific (De Lotto 1974). Some species have host-specific biotypes which can narrows down the specificity to a single species. This explains why some introductions were ineffective despite the fact that the insect was recorded on that host in its country of origin. Studies eventually revealed the existence of such host-specific cochineal biotypes within *D. opuntiae* and D. *tomentosus* (Githurie *et al.* 1999; Hoffmann *et al.* 2002; Mathenge *et al.* 2009; Volschansky *et al.* 1999; Zimmermann *et al.*2008). The consequence of these findings was the release of two host-specific biotypes that provided successful biological control of two new cactus invaders. They are:

Opuntia stricta

Opuntia stricta was first recorded from the Kruger National Park in South Africa in the fifties but it only became seriously invasive from 1989 onward when populations increased exponentially. Chemical control was unable to stem the invasions (Foxcroft *et al.* 2004).

After identifying and testing the host-specific cochineal *D. opuntiae* biotype "*stricta*" it was released on *O. stricta* infestation in the Kruger National Park in 1999 after previous attempts to establish the *D. opuntiae* biotype *"opuntia"* failed. The control was phenomenal (Foxcroft & Hoffmann 2000; Foxcroft *et al.* 2004). An integrated control program which includes treating isolated plants (outliers) along the periphery of the 70 000 ha infestation and a mass-rearing facility that provides cochineal for redistribution to ensure maximum returns from biological control, is now in place. Other infestations of *O. stricta* in other parts of the country are also controlled biologically.

Cylindropuntia fulgida

Although *C. fulgida* has been in South Africa for more than 50 years, it only became seriously invasive from 1970 onward. Recent infestations in Zimbabwe and along the northern border with Zimbabwe are particularly alarming because of the loss in grazing, injury to stock and because of its potential to spread downstream towards the KNP, the Transfrontier Parks and Mozambique. Although C. *fulgida* has been recorded as a host of the cochineal, *D. tomentosus* in Mexico the South African insects that were used for the biological control of *C. imbricata,* did not provide any significant control of the weed when released on infestations in the Northern Cape Province. A new cochineal biotype of *D. tomentosus* from Mexico collected on C. *cholla* (probably a sub-species of C. *fulgida*) was tested and showed prolific growth on the South African C. *fulgida*. First releases were made along the Limpopo River in November 2008 and six months later many plants were already dead and the insect was spreading fast to neighboring plants.

The significance of host-specific biotypes.

It is highly unlikely that new natural enemies will be released against invasive Opuntiae if they feed and develop on any of the commercial *O. ficus-indica* and *O. robusta* cultivars unless a cost-benefit study would show that the advantages of controlling an invader far exceeds the value of cactus pears (*O. ficus-indica* and *O. robusta* and their cultivars). The global invasions of *O. dillenii/stricta* in countries like Madagascar, Ethiopia, Saudi Arabia, Yemen and Ghana are of particular concern, because the affected countries are unlikely to find the resources to control the invasions chemically or to control them by any other means. Although the host specific cochineal biotype of *D. opuntiae* biotype "*stricta*" may not provide sufficient control on its own, it will certainly make a substantial contribution towards reducing populations to more tolerable levels without a risk to *O. ficus-indica*. The additive effect of the cactus moth, C. *cactorum*, will increase the chances towards acceptable control quite substantially although damage to cultivated cactus pears will occur.

Early Detection and Rapid Response Program

It is widely accepted that the most cost-effective means of preventing invasions of new alien plant invaders is by means of early detection followed by a rapid control program that should be aimed at eradication or containment of the invasions before they have reached a stage where conventional control methods become ineffective or uneconomical. The key to success is to have an effective surveillance and monitoring program in place that involves many stakeholders that would be able to identify new invaders. This requires careful planning and the coordination of many dedicated individuals in both the Government and in the private sectors that can assist in detecting new invaders. Whether or not to eradicate a new detection will depend on detailed risk analyses of the suspected invader by experts. Newly discovered invasions of C. *tunicata* and C. *rosea* in South Africa are likely to be followed by an eradication program. The Early Detection and Rapid Response Program consist of a staff of about 12 botanists and technicians that are coordinating the Program and that are operating from 4 centers in the country.

Efforts to detect new invaders at an early stage of invasion are supported by new initiatives to improve pre- and post border inspections of plant introductions and to cooperate with the nursery industry on screening new ornamentals for weediness. It is common knowledge that most of the new invaders entering the country come through the nursery trade. This applies in particular to the ornamental cacti.

The Working for Water Program

The Working for Water Program is a government initiative that addresses the problem of invasive alien plants in South Africa. The Program started in 1995 as an initiative to remove invasive alien species (mainly trees) from important water catchments and rivers in order to increase the annual water run-off. At the same time the Program provides much needed employment to unemployed and disabled people, and also provides training in many skills related to invasive alien species. Since about 2004 the Program has expanded its mandate to control all invasive alien species, including the cactus weeds which are primarily rangeland weeds, and not only those associated with water conservation. Their annual budget stands at about US$70 million per year and up to 20 000 people are employed. The Program relies heavily on biological control and this applies in particular to cactus invaders which are not known to deplete surface and underground water resources significantly as other plant invaders do. The Program is also the main funding agent for new research in biological control of invasive alien species, including Cactaceae (Van Wilgen 2004)

CONCLUSIONS

Cactus, and in particular the Opuntia invaders, are amongst the most difficult to control, either chemically or mechanically, and hence the concerted efforts to employ biological control. Biological control of cactus weeds has an excellent track record and this can be attributed to sharing biological control agents with Australia who initiated several of the projects mentioned above (Julien & Griffiths 1998: Moran & Zimmermann 1984). The high success rate of cactus biological control projects can also be attributed to the uniqueness of the cactus family, the few economic species in the family and the high degree of host-specificity of its associated insect phytophages. The chances of biological control of new cactus invaders are thus good.

There are several new Opuntia invaders emerging in Africa and it is highly unlikely that any control method, other than biological control will be appropriate to counter these invasions. Invasions of *O. dillenii/stricta* in the south east of Ethiopia are most alarming and controlling this species by means of increased utilization as is the case with *O. ficus-indica* , is not an option.

An early detection and rapid response program is probably the best investment for Africa because of its cost-effectiveness. Such a program could be managed at a Pan-African level. Many of the known invasions are at the early stages of invasion.

Naturalized spineless *O. ficus-indica* plants sooner or later become invasive as has happened in South Africa, Yemen, Ethiopia, Eritrea and Saudi Arabia. Introduced *O. ficus-indica* are usually spineless but once naturalized they convert back to the spiny forms which are more resistant to animal feeding and to harsh climatic conditions. It remains to be seen if utilization will be able to reduce these invasions to manageable levels. Chemical and mechanical control is also not an option.

Selected and carefully managed biological control could reduce invasions of *O. ficus-indica* to such levels where the resource can be further utilized and where populations stabilize at acceptable levels (Brutsch & Zimmermann 1995). The South Africa experience can serve as a model for such an approach.

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Table 1. Important invasive Opuntioideae (prickly pears) in South Africa and their status of control.

Species	Control methods	Biological control agents established	Status of control
Opuntia aurantiaca	Chemical control Biological control	*Cactoblastis cactorum.* *Dactylopius austrinus.*	Excellent biological control in hot and dry areas. Selective chemical control in some high rainfall areas.
Opuntia ficus-indica	Chemical control Biological control.	*Cactoblastis cactorum.* *Dactylopius opuntiae ("opuntia" biotype).* *Metamasius spinolae*	80% of infestations controlled with insects. Some remaining infestations controlled chemically but mostly utilized.
Opuntia engelmannii	Limited chemical control.	*Dactylopius opuntiae* (ineffective). Limited damage caused by *Cactoblastis cactorum*	Control is inadequate and infestations are increasing and becoming problematic.
Opuntia humifusa	No control.	None. Some minor damage caused by *Cactoblastis cactorum*	Control is inadequate. Infestations are increasing at an alarming rate.
Opuntia monacantha	Biological control.	*Cactoblastis cactorum.* *Dactylopius ceylonicus.* *Dactylopius opuntiae*	Highly effective biological control by mainly D. ceylonicus. Occasionally populations flare up along the south coast.
Opuntia stricta (dillenii)	Biological control. Limited chemical control.	*Cactoblastis cactorum.* *Dactylopius opuntiae biotype "stricta"*	Excellent biological control. Outliers are controlled chemically.
Opuntia (Cylindropuntia) fulgida	Biological control.	*Dactylopius tomentosus* biotype "fulgida".	Effective biological control. Outliers controlled chemically.
Opuntia (Cylindropuntia) imbricata	Biological control Chemical control	*Dactylopius tomentosus* biotype "tomentosus"	Biological control effective on small plants and seedlings. Large plants are defoliated and then killed by felling or limited chemical treatment.
Opuntia (Cylindropuntia) leptocaulus	Biological control	*Dactylopius tomentosus* biotype "imbricata".	Excellent biological control.
Opuntia (Cylindropuntia) tunicata	Chemical control	None	Infestations are increasing at an alarming rate.

STATE OF COCHINEAL INTRODUCTION AND PRODUCTION IN TIGRAY

Tesfay Belay[1] and Antonio Bustamente[2]
[1]Tigray Agricultural Research Institute, P O Box 492, Mekelle, Ethiopia
[2]E-Foodsafe PLC, Cochineal Natural Red for the Food Industry.
Mekelle, Tigray Region, Ethiopia
E-mail to jab@foodsafe.cl

ABSTRACT

Cactus pear (Opuntia ficus-indica), locally known by the vernacular name "Beles" is in the genus Opuntia of the family Cactaceae. Cactus pear and other plants in the family are of new world origin and are all introductions when found in Africa and other parts of the world outside of Latin America. Spread to areas outside of its area of origin should have been aided by humans and partly birds.

Cactus pear is an introduction to Tigray, Northern Ethiopia. Cactus pear coverage is estimated to be around 35, 000 hectares.

A workshop was jointly organized by University of Mekelle and the University of Wiesbaden-Polytechnic, Germany in 1997 pave the way to introduction of alternative uses of the abundant resource, cactus pear. This was later on followed by an FAO-TCP project in 2002 which put into action some of the suggestions that emerged from the earlier initiative. One of them was the introduction of a cochineal industry that would be based primarily on the abundant cactus pear resources in the southern and eastern zones of Tigray.

The cochineal insect was therefore introduced from South Africa to Tigray in April 2003 after a Pest Risk Analysis indicated that its introduction was safe. Permission was therefore sought from the competent ministry in Addis. Freedom from unwanted organisms was also verified through rearing of the cochineals to several generations. Experimental field release also proved the host specific nature of the insect to only Opuntia ficus-indica. The final release of the insect for commercial production was affected after a permission from the competent authorities was secured. The need to search for companies that can produce and market cochineal insect was obvious and a Chilean company food-safe showed strong interest to be involved in cochineal production in the southern zones of Tigray. Subsequently the company was granted cactus infested land in January 2007. The company started its colonies with the insects introduced from South Africa and maintained here in Tigray. The company has so far developed around 122 ha of the land and has for the first time exported dried cochineals to the world market. Carminic acid content of cochineals reared in Tray ranged from 21-23% and was considered as the best quality cochineal. The company also becomes a

source of employment for more than 120 Ethiopians. Cochineal business proved to be a suitable employment opportunity for the young and poor women provided that they are given the right training.

Cochineal production thus proved to be lucrative opportunity for dryland areas of Tigray for it is possible to harvest 3-4 times a year, is not affected by significant rain failures and there exist an abundance of cactus pear resource that is sometimes considered as a nuisance. There is therefore a need to familiarize and convince our farmers to start thinking of cochineal production especially in areas where there is an abundance of cactus and also the need for farmers to start the business with the establishment of cactus plantations in low rainfall and hilly areas.

INTRODUCTION

Cactus pear (*Opuntia ficus-indica*), locally known by the vernacular name "Beles" is in the genus *Opuntia* of the family Cactaceae (Nobel, 2002). Cactus pear cactus and other plants in the family are of new world origin and are all introductions when found in Africa and other parts of the world outside of Latin America. Spread to areas outside of its area of origin should have been aided by humans and partly birds.

Cactus pear is very important in arid and semiarid regions. It has the ability to grow on marginal lands and to produce more as CO_2 concentration increases (Le Houerou and Corra, 1980) and hence its cultivation is likely to increase in the face of climate change.

According to Nobel (2002) humans have consumed cactus for more than 9000 years and cactus pear is considered to have significantly contributed to the development of the Mexican people. Cactus is now cultivated in over 20 countries primarily for fruits and large areas are also devoted to forage and fodder (Le Houerou, 2002). To offset this values, cactus pear was considered as weed in South Africa, Yemen and Australia and people have spent a great deal of resources to control them. In some countries, insects introduced to control cactus pear are currently considered as major pests of cactus with the changing values of cactus pear plant itself with time.

Cactus pear cactus in Tigray

Cactus pear is an introduction to Tigray, Northern Ethiopia and is believed to have been introduced from the Mediterranean region around 1847 (Kibra, 1992). It might also be possible that there were multiple introductions for there were recent reports (Habtu, 2005) that attribute the introduction of cactus pear to the Southern parts of Tigray to Muslim pilgrimage returning from Mecca around 1920. It might also possible that there were separate routes of introduction to the much southern parts of Ethiopia (Bale and Harar areas) because they are not bordering Tigray.

Cactus pear met suitable edaphic and climatic conditions that enabled the plant to become one of the most abundant and dominant species in the drylands of Northern Ethiopia. In Tigray alone, cactus pear covered around 35,000 hectares of land (SAERT, 1994). According to the same source, about 19 652.5 hectares of the cactus pear covered land is found in South Tigray. Melaku (1997) also reported 11830 hectares as wildly growing and the rest, 7821 hectares as planted by man.

Current use of cactus pear cactus in Tigray

Fresh cactus fruits are widely consumed during the rainy season where the fruit is in abundance. It is also a source of cash for school children and these days has become an occupation for adults and women as there is a steady increase in the price of the fresh fruits. In south Tigray, much of these fruits are harvested from the wildly growing prickly opera cactus plantations (Haile et al., 2002). Cactus pear cladodes are also used as animal feed especially during drought periods and the dry season where farmers cut, burn spines and chop cladodes to facilitate feeding by livestock.

Cactus pear is also used in soil and water conservation programs in the region (Haile et al., 2002) Farmers in South Tigray use cactus pear as live fence in backyards and farm fields. Farmers also use the old and dried cactus pear cladodes as fuel wood particularly where there is no other vegetation available.

Potential use of cactus pear cactus

The tender cactus pear cactus cladodes are consumed as a vegetable in Mexico. This tradition has been introduced through a joint project of FAO and Mekelle University. This project enabled a local NGO, Mums for Mums, to acquire the skill and now a number of NGOs are scaling it up in different parts of the region and a lot needs to be done in the future so that this component contributes to food security.

The vast areas of cactus pear in South Tigray could also a potential for cochineal production for there were various opportunities: absence of significant insect pests and diseases in Tigray that could hamper cochineal production, production costs will also be low because cochineal production will depend on the naturally growing cactus pear plantations and the many farmers have cactus backyards indicating that the culture is already rooted. There also exist a number of cactus by-products that can be obtained from cactus and these include edible oil from cactus seeds, sauce, jams, marmalade, candy from cladodes and fruits, shampoo, soaps, thickeners from mucilage etc.

The Carmine cochineal

The carmine cochineal insect is known by the latin name *Dactylopius coccus* O. costa. It belongs to family Dactylopidae in the Order Hemipter. It is the only species reared for the purpose of carminic acid (colorant) production (Roderuez et al., 2002). Cochineal is also the name of the insect and its pigment (Portillo and

Vigueras, 2002). The cochineal insect is very specific to Opuntia species: *Opuntia tomentosa*, *Opuntia ficus-indica* and *Opuntia decumana* (De Lott, 1974).

Current state of cochineal introduction and production

In 1997, a workshop was jointly organized by University of Mekelle and the University of Wiesbaden-Polytechnic Germany, to encourage alternative uses (for food, feed, as a raw material for small scale industries etc.) of this abundant resource, cactus pear. This was followed by an FAO-TCP project implemented by Mekelle University in 2002 -2004 that put into action some of the suggestions that emerged from earlier initiative. One of them was the introduction of a cochineal industry that would be based primarily on the abundant cactus pear resources in the Southern and Eastern parts of Tigray.

The cochineal insect was introduced from South Africa to Tigray and the introduction was possible in April 2003. The introduction of the carmine cochineal insect was supported by the FAO-TCP project hosted by Mekelle University. A pest risk analysis was performed and results indicated that its introduction would be safe (give reference). The risk was considered low because the insect has to be cultivated to survive over the long term. Once introduced (cochineal introduction permit no 1020), the cochineal insect was kept in partly conditioned glasshouse and was reared to five generations on detached cladodes. Freedom from unwanted organisms was also conformed. The permission for a field release was obtained from the Federal Ministry of Agriculture and Rural development (ref. no. 21/126/1.1 dated 4/01/97). Accordingly the insect was released at three locations on the 12th of September 2004: *Tsehafti* area of *Wejerat, Embachra* area in *Mehoni* and *Endayesus* compus of Mekelle University. The performance of the carmine cochineal insect in the field was very encouraging and was also found to be very host specific (Tesfay, 2006).

Satisfied with the performance in the field, we requested permission from the Ministry of Agriculture and Rural Development on 01 March 2007 for wider release of the insect for commercial use. Permission was then granted on the 12th March 2007 in the Tigray region. The insect was then allowed to multiply at the inoculation sites of Endayesus comapus, Tsehafti and Mehoni areas where the insect was originally introduced for experimental release. Side by side we should have searched for market opportunities outside Ethiopia as there is no knowledge about the insect in country. With the help of Dr Helmut Zimmerman of the Plant Protection Research Institute of South Africa Foodsafe Ethiopia started developing nurseries on April 2007 for the multiplication of cochineal insects at *Fachagamma* area of the *Raya Valley* in Southern Tigray. The company was using insects that were multiplied at the inoculation sites of *Tsehafti, Embachara and Endayesus* areas of Tigray. Foodsafe has so far developed 135 hectares of land into an ideal cochineal farm and is expecting to expand to 300 hectares.

The company has the first export of dried cochineal insects in April 2009 and is believed to have continued since then. The carminic acid content of the cochineals produced in the Tigray region ranged from 21-23% and was much higher than what was reported in the literature. The favorable environmental conditions should have contributed to the increased carminic acid content of the cochineals produced in the Tigray region of Northern Ethiopia. It has also created a job opportunity for more than 120 Ethiopians in the Raya valley in the last three years and is expected to continue in the years ahead. The company has also demonstrated a skill on the rearing and production of carmine cochineal to the area much known for rain failures.

Opportunities to introduction of cochineal insect to Tigray

- Suitable environmental conditions: Cochineal insect was introduced to *Tsehafti* and *Embachara* areas of the southern zones of Tigray. It was also introduced to *Fachagama* areas of *Mehoni* by the food safe Ethiopia. The environmental conditions of our area are suitable to cochineal production as can be seen by the excellent adaptation and proliferation of the insect.
- Abundance of volunteer cactus in Tigray region: There is abundance of wild cactus outside of the arable lands and this resource was least utilized. Cochineal introduction can be an alternative source of income by farmers, In Chile for example from 330 ha of cactus, 110 ton (336kg/ha) dried cochineal was obtained. Similarly, in Peru on average 265kg/ha dried cochineal was obtained. Cactus vegetation in Peru is similar to that in Tigray and practically no care is given to cactus. So taking the Peru production model as a benchmark, from 75ha natural cactus plantation infested with cochineal, 19.8 ton or 19875 kg cochineal can be obtained. When converted into money, with the existing price of dried cochineal of 25 birr/kg dried cochineal, the community at *Tsehafti* can get around 500 000 birr in this area alone. (75 ha cochineal infested areas). Suppose 50 households participate in cochineal collection on the indicated area, each household gets 10,000 birr/year.
- Cactus pear in the wild is dominating other indigenous tree and other plant species and may be a threat to biodiversity in the future. According to Habtu (2005), as cactus cover increased, the woody species declined and this would obviously signify the obvious threat of cactus pear if expansion is not checked or utilized.
- Cactus pear that farmers introduced into their farms as hedges is also encroaching to their farm lands and farmers spend a lot of energy or labor removing the cactus bushes.
- The series of mountains in *Mehoni* and *Wejerat* areas of Southern Tigray are predominantly invaded by cactus and while the cover is very good for arresting erosion and degradation, indigenous biodiversity is at risk.
- Cactus pear in the mountains and some of the flat lands are not managed at all and are inaccessible.
- Flat lands of *Mehoni* area in Southern Zone of Tigray infested with cactus

are being given to investors or developers and are often seen bulldozing to remove the cactus plantation and damp it with no use

- Market opportunities: There is access to cochineal market in our area, because food safe Ethiopia has an office in Mekelle and is ready to purchase fresh or dried cochineal collected by farmers or other interest groups.
- Abundant labor force: There are many landless farmers that can take cochineal production as their business besides our subsistence farmers can take cochineal production and harvesting on natural cactus plantation as an off-farm income source.
- Cochineal harvesting season: Cochineal insect is abundant mainly at the dry season. The dry season is ideal off-season activity carried out by farmers as farmers will not of short of time in the dry season.
- Suitability of our rainy season for cochineal production: Our environment is suitable for cochineal production especially at times of rain failures for the insect does not like strong rain showers. It is therefore possible to harvest 3-4 times a year.
- Knowledge on cochineal production: There are people with the knowledge on cochineal production at Mekelle University and the Tigray agricultural research institute. Besides, the investor on cochineal production at *Fachagama* himself is knowledgeable on cochineal production and he is ready to train farmers who volunteer to be involved in cochineal production.
- Benefits generated so far from the investment on cochineal production are as follows:
  - a cochineal nursery established and 122 ha of cactus plantation infested with cochineal. The nursery will serve as source of insects for further expansion and also source of seed for out grower farmers and other interested farmers.
  - Job opportunity so far for 70-120 farmers from the locality of *Fachagama*.
  - Contribution towards improved work culture and discipline in the area.
  - Investor support for farmers that would like to be involved cochineal production in training and technical support.
- No natural enemies of cochineal in Tigray/Ethiopia: Cochineal is an introduced insect and there are no natural enemies that can infest and infect cochineal in our country. This is a very good opportunity for the expansion of the cochineal business in our region.
- Input for some processing industries: Currently dried cochineal insects are exported but eventually cochineal processing can be started at home and processed cochineal may serve as an input/colorant to food processing factories. According to some sources beef industries consume about 75% of the cochineal, cosmetics use 15% and 10% is used for pharmaceuticals and artistic purposes. For example *Saba silk* is a small cottage industry in Addis (Ethiopia) and this small industry has started using cochineal for drying silk clothes. There are no many beef processing industries in our country but there is Pork meat processing plant at *Debrezeit* and it may in the future utilize cochineal dye as an input.

- Cochineal is a source of easy money especially in areas where there are established cactus plantations. This was seen in the outskirts of Mekelle town bordering Mekelle university where cochineal harvest become a source of income for poor school boys and girls and households as they were harvesting cochineals consecutively for four months starting June to September. Up to 152 boys, girls and women were involved in this business and so far around 1100 kg (=44000 birr) of fresh cochineal was harvested from an area of scattered cactus plantation on approximately 7 ha. I am concerned about school boys; in Europe this is not seen as a good procedure since it involves exploitation of youth people at low costs)

Threats and challenges to cochineal introduction

- Cochineal spread and expansion to cactus fruit producing areas: Cochineal insect has the ability to spread and expand quickly over wider areas as its spread is aided by wind and humans. The spread becomes serious especially if the cochineal is not harvested and put into use. This was evident at *Tsehafti* village of the *Hentallo Wejerat Woreda*.
- Dissemination pathway: Cochineal spread from one location to another is aided by wind and humans. This therefore makes it to cover wider areas.
- Reduced fruit productivity of cactus: Cochineal feeds heavily on cladodes and the number of fruits per cladode was very much reduced. Cochineal insect also infests the fruits and fruit size is very much reduced thus lowering the market value of the fruits.
- Cochineal not acceptable by the community of Hentallo wejerat: The community at Tsehafti village of the Hentallo wejerat woreda could not accept the cochineal insect as a beneficial insect despite existing market opportunities. This could be due to the fact that the community was not consulted before the introduction of the insect to the locality and were reluctant to embrace cochineal as an alternative income source.
- Cochineal population at Mekelle University a threat to other areas: Cochineal maintained at Mekelle University could not be limited to Mekelle university compound alone and have instead invaded cactus areas outside of Mekelle University. Many consider this invasion as a threat in the near future to cactus plantations in the Eastern zones of Tigray.
- No regional quarantine or legislative control: There are no laid out mechanisms or quarantine laws for the control of spread of the insect in country.
  - This also applies to the investment at *Fachagama* for there is a need to limit cochineal expansion to the investment areas and others where the insect is allowed to be multiplied.
  - Besides there is no zone as such assigned for cochineal production in our region and there is projected forecasting about the spread of the insect overtime.
- Low price of cochineal in Tigray: The current price of fresh cochineal in Tigray by the food safe company is 35 Birr/kg. The price is not that attractive when seen from the point of view of being anew product to our area.

- Problems with out-grower farmers: Out grower farmers at *Endamehoni Woreda* have attended trainings on cochineal production and have started establishing cactus plantations. But their plantations where cochineals were introduced were destroyed by anonymous people and this could be due to conflict of interest.
- Cochineal outside investment areas: Cochineal nearby the investment areas of *Fachagama* need to be protected too as cochineal may invade these places. There are also some indications that the insect is migrating outside its intended range.
- Utilization of seed cochineals: Seed cochineals were collected from the experimental release sites. Seed collection therefore need to be done in a way that will not aid the further spread of the cochineal.
- Follow-up by the woreda: The Raya azebo woreda office of agriculture and rural development is not making follow-up of the cochineal. This can therefore be considered as one challenge to the regulated expansion of cochineal in the area.

THE WAY FORWARD

- So that the community reaps maximum benefits from cochineal harvest, there is a need for a concerted effort to convince the community by the local administration.
- The current price of fresh cochineal harvest is very low. With the increase in world market prices of agricultural products, the price of cochineal is also expected to increase. So the respective institution needs to engage the investor in productive discussion so that the prices of the fresh produce can be increased accordingly.
- Establish quarantine regulation to control and limit the spread of the insect in our region:
    - There is a need for availing information on the biology of the insect to woreda experts.
    - There is a need to aware relevant development experts involved in the cactus development or planting of cactus into central and western zones of Tigray about the need to make sure their freedom from cochineal.
    - The investor need to exercise some care when collecting seeds of cochineal so that it will not spread outside the intended areas.
    - The need to establish buffer zone between cochineal production sites and fruit production sites.
- Screening of insecticides is also very important. So far *Dimethoate* is the only identified insect that can be used to control the insect. But there is a need to further identify systemic insecticides that could be used in the control of cochineal.
- There is a need to state or enact laws that delimit cochineal production sites from other areas so as to restrict the spread of the insect to other sites.
- Creating various cooperatives, youth or women, and providing them with the required trainings and information. Provide support to such groups so that they plant cactus on degraded lands for production of cochineal.

- Provision of trainings to development agents and others interested in cochineal production.
- Encourage out growers to continuing to produce cochineal but the problems encountered need to be thoroughly explored with the key involvement of local administration.

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CONTRIBUTIONS OF PRICKLY PEAR CACTUS TOWARDS ACHIEVING HOUSEHOLD FOOD SECURITY IN TIGRAY: THE CASE OF *TABIA KIHEN* IN *KILTE AWLAELO WEREDA* OF EASTERN TIGRAY, NORTHERN ETHIOPIA

Meaza Taddele[1], Workneh Negatu[2], Abbadi Girmay[3]
[1]Tigray Bureau of finance and economic development, Mekelle, Ethiopia [2]Addis Abeba university, Addis Ababa, Ethiopia [3] Tigray Agricultural Research Institute (TARI), P.O.Box 492, Mekelle, Ethiopia, email: abbadig@yahoo.com

ABSTRACT

Kihen, the study site, is characterized by long periods of drought and unreliable rainfall compounded by excessive human and livestock pressures. Farmers adopt different coping mechanisms, such as the introduction of prickly pear, popularly known as Beles. The main objective of this research was therefore, to assess the contribution of cactus to household food security and to identify the major production and marketing constraints. Based on the sampling frame, household heads were stratified into cactus-growers and non-growers. A systematic random sampling method was used to select 120 respondents, of which 90 were cactus grower and thirty non-grower household heads. The descriptive analysis revealed that, of the overall contribution of the different coping strategies in filling the food gaps, safety-net followed by cactus stood as the most important coping mechanisms among the cactus growers. On the other hand, among the non-growers, large share of the rating goes to safety-net. Cactus holding and family size showed a positive and significant value whereas gender showed a negative but significant association with income of the grower households. Taking together the income obtained from cactus, crop and animal production, almost all cactus grower farmers tend to have better income than the non-growers do. The current study revealed that cactus is the major source of food, livestock feed and income in the study Tabia. The women-headed households were also found to benefit more from the cultivation of cactus as compared to the male-headed households. This is a good indication that any support that help to boost cactus production, management and post-harvest handling and improved access and marketing network will ultimately increase the income and benefit of women-headed households from cactus. Improving access to market and transportation facility, improving post harvest handling practices and reliable market could enable the farmers to sell their produce at reasonable prices with improvement in their bargaining power as well as reducing losses that could occur during the transportation and marketing of the fruit. The socioeconomic

factors associated with cactus production, that affects the household income, and possible policy directions and incentive strategies are discussed.

INTRODUCTION

Tigray is a region in northern Ethiopia where more than 85% of the population is directly dependent on agriculture for its livelihood. The land, where about 12% is marginal, stony, rocky and bare steep slope, is also exposed to severe erosion and deforestation. Long periods of drought and unreliable rainfall, compounded by excessive human and livestock pressures on the land also affect the region (REST and NORAGRIC, 1995).

Cactus pear has become popular and easily adopted in the region because of its high degree of resistance to drought and high temperatures. It is adaptable to poor fertility soils, has excellent productivity, which it owes to its high water use efficiency, and to the economic role it can play in increasing the efficiency and economic viability (FAO, 1995). This is why there is an increasing expansion of *Cactus pear* in Tigray particularly in the backyards. About 360,000 ha, close to 5% of the total land area in the region is covered with cactus pear, of which about half was planted while the remainder is wild (Brutch, 1997).

The demand for prickly pear cactus fruit and pad is increasing as drought and land degradation increases. Farmers usually plant prickly pear cactus on land, which presently cannot be used for other crops, due to its steep slope or stony soils (FAO, 1995). In Tigray, cactus pear cultivations are predominantly found on marginal lands and its cultivation has ever since been encouraged due to ideal edaphic and climatic conditions, and has flourished to become the most commonly cultivated and naturalized plant in the country particularly in the Tigray region. Currently, cactus pear is playing a crucial economic role and is serving as a source of food, animal feed, fuel wood, and in some cases, as a means of additional income, thereby increasing the efficiency and economic viability of small and low-income farmers (Brutch, 1997).

Cactus is also playing an ever-increasing role in animal nutrition, especially since 1960s, when it served as the standing feed resource to enable animals survive critical periods of prolonged drought and dry seasons. There were indications that cactus growers have higher ownership of livestock heads per household than the non-growers (Birhane, 1997).

The importance of cactus is rising from time to time. Past research findings have indicated that cactus pear has become an integral part of the culture and economy of Tigray, serving as a source of seasonal household food, income and employment, as livestock feed and other environmental benefits (Fitsum, 1997; Mitiku et al., 2002). However, these studies conducted in the region were more of qualitative and focused more on the agronomic traits of the crop. Information on the level of contribution of cactus pear production to household food and feed security in the region is limited particularly in the study area. The overall objective of this study is to assess the contribution of cactus to household food security and to identify the major production and marketing constraints. The study is particularly aimed assessing the role of cactus as source of food, income, animal feed and assess production and post harvest constraints.

MATERIALS AND METHODS

Description of the Study Area

The study was undertaken in *Tabia Kihen, Kilte-Awlaelo Woreda* of the Tigray Regional State, Eastern zone of Tigray, and is located between 33^{0}24′30″-13^{0}36′52″N and 29^{0}28′30″-30^{0}38′33″ E and the altitude ranges from 1900 to 2300 meters. According to the Woreda Finance and Economic Development office, the total population in the Woreda was 119,493 of which 49 % were males and 51 % females. The total number of household heads in the woreda was 23,200. 18 % were female-headed households. The average family size per household was 5.

The study site, *Tabia Kihen*, comprised three administrative villages and its total population was 6,478. Forty-nine percent of the total populations were as males while 51% were females. The total number of household heads was 987 and 18% were female-headed households.

Research Design: Data Collection Methods and Sampling Techniques

The sample Tabia, *Kihen*, one of the major cactus growing Tabias in Kilte Awlaelo Woreda (Eastern zone of the Tigray region), was selected using purposive sampling. This *Tabia* was chosen because of its above-average endowment with the prickly pear cactus. Three villages were included under the *Tabia* and sample households were taken from all three villages. This study made use of both primary and secondary data. Formal and informal methods of data collection were used. The formal method of data collection consists of administering a structured questionnaire to sample household respondents whereas the informal method took form of focus group discussion and key informant interview.

The sampling procedure was based on data obtained from the *Tabia's* Annual Report (2007) that indicated nearly 75% of the farming community in the study area as endowed with cactus pear. The total population living in each village was collected from *Tabia* administrative office that also assisted in developing the sampling frame and in the identification of cactus grower farmers. Based on the sampling frame, household heads were stratified into cactus-grower and non-growers. Systematic random sampling was used to select a total of 120 respondents (12.2% of the total HHs), of which 90 were cactus growers and thirty non-grower household heads.

Variable Specification and Hypothesis

Dependent variables: In this particular study, the effect of cactus as food and feed on the total income as well as livelihood of the households was investigated. To assess the contribution of cactus to each household, total income (including income earned from cactus) was used as a dependent variable to fit the regression model specified. The total income transformed into an ordered sequence (ordinal variable) based on the cut-off given in the methodology part of this study was also used as a dependent variable to model the ordered probit regression model and Linear discriminant analysis.

Independent variables: independent variables considered include Oxen ownership. donkey ownership, growers/non-growers grouping, literacy (discrete variable), age, farm size, cactus holding, TLU, family size, dependency ratio, and gender (Sex).

Data Collection and Analysis

The data collected includes household socioeconomic features in terms of cactus production, its contribution to household income, marketing, resource endowments (land size, livestock, labor and other assets), family composition (sex, age, education status and skill), household expenditures etc. The qualitative and quantitative data collected were analyzed using descriptive statistical techniques and multivariate models including advanced regression model.

Model formulation:

Multiple regression analysis A regression model that involves more than one regressor variable (multiple regression) was used to model the impact of cactus on the household income level.

Stepwise regression analysis: To identify the variables that contributed to the income obtained from cactus production (as fruit and feed), and compare the income level among cactus growers, a stepwise regression, a procedure that evaluates a small number of subset regression models by either adding or deleting regressors one at a time, was employed. The procedure requires two cutoff values, one for entering variables and one for removing them. The alpha-to-enter and alpha-to-remove used was 0.15 (MINITAB, 2003).

Ordered probit regression: Income acquired from several sources such as crop and livestock products as well as cactus (as a fruit and feed), was used to classify the respondents into three income levels: [1] 2000-7000 Birr (low-income households), [2] 7001-18000 Birr (intermediate-income households) and [3] income level greater or equal to 18001 (high-income households). The basis for classifying the households into three categories was mainly based on the five years strategic plan of the region (BoFED, 2006) that households having an income of 18001 or above considered as food secured households. The analysis was made using STATA (STATA, 2003).

RESULTS AND DISCUSSION

Basic socioeconomic characteristics of the sample respondents

Kihen, one of the major cactus pear growing *Tabias* in the region and a rural area with a population size of 119493, was used as sample *Tabia* in order to assess the contribution of cactus to household food security. The demographic characteristics of the sample households by sex, age, educational level, and occupation are stated as follows: The respondents were composed of 90 cactus growers and 30 non-grower households, and of the total 120 respondents 71.7 % were male while 28.3% were female-headed household. From among the 90 cactus growers and 30 non-growers, 30% and 23.3% were female-headed households, respectively. The age range of the cactus grower respondents was 17-80 years, while the corresponding figures for the non-growers were 18-67 years. The major form of economic activity for all 120 respondents was farming.. The second important source of employment among the cactus growers and non-growers was participation in safety-net program. In the safety-net program, the community provides labor for cash or grains. Household size of the respondents ranged between 2 and 10 persons per household. The land area per household ranged from 0.25 to 3.0 ha. The total cactus plantation area owned household respondents ranged from 0.06 to 0.75 ha. Relatively more households among the female-headed households (26%) had no oxen than the male-headed households (8%)

Correlations among ownership of land, livestock and household characteristics

There were highly significant but moderate level of correlations between the number of oxen and donkeys owned ($r = 0.46$, $p < 0.001$), household size and number of oxen owned ($r = 0.47$, $p < 0.001$), TLU and household size ($r = 0.448$, $p < 0.001$), and between household size and farm size ($r = 0.462$, $p < 0.001$). There were also similarly significant but weak positive correlations between farm size and total cactus land holding ($r = 0.27$, $p < 0.01$), between the farm size and the number of oxen owned ($r = 0.258$, $p < 0.01$), and between age and farm size ($r = 0.323$, $p < 0.001$).

Cactus grower and non-grower households and food deficit months

From among the cactus grower households, 86% experience some form of food shortage in the last three years while only 14.4% were indicated as food non-deficit households during the same period. On the other hand, there were relatively more food non-deficit households among the non-growers (33%).

Food deficit households and means of filling gaps in food shortage

The respondents stated several mechanism of coping with household food shortages in the *Tabia* during the food deficient months of the year. One of the mechanisms that was described by the respondents include consuming whatever food is available in an economical way. For example consuming cereals in the form of *Kolo* and soup with the objective of stretching the resource in such a way that it lasts longer. Besides, consuming cactus pear, collecting wild leafy weeds, employment in the safety-net program, sale of livestock and employment as daily laborers and participating in other off-farm activities were also indicated as alternative means of filling the household food deficit.

Use of cactus fruit as source of household food and income

The cactus pear was intentionally introduced into the area with the objective of using the fruit for household consumption and for the market, as the respondents asserted. However, as livestock feed became critical in the area, the use of cactus as livestock feed started to become important. The respondents were asked to rank the importance of cactus in terms of its use as food, feed and source of income and the respondents gave different weight to the value of cactus with regard to its use as food, feed and source of income. About 50% of the respondents gave much importance to the use of cactus as source of animal feed, some 33% gave the highest weight for its use as food while the least percent of growers appreciate cactus as a source of income (Figure 1).

Forty percent each of the cactus grower respondents ranked cactus as the second most important source of household food and livestock feed. Only 30% identified cactus as second in terms of its value as a source of household income

Food uses of cactus

The consumption of the fruit is the most common form of cactus use in the region (Figure 2). Only recently does few growers started to use the cactus pad in the form of salad and roasted. In the current study, the majority of the growers consume only the fruit. Some 19% of the growers, however, identified themselves as users of both the fruit and cactus pads, the latter in the form of salad and cooked. Only 4% of the growers have mentioned that they make jam from the cactus fruit.

Feed shortage and means of filling feed shortages

In response to whether the respondents had faced feed shortage in the last years, the respondents asserted that almost all respondent households experienced shortage of livestock feed during the last three years. Two percent of the growers, however, identified themselves as feed non-during the last three years.

In order to understand the pattern of feed use in the *Tabia*, a feed calendar was constructed from the information collected from both the cactus grower and non-grower households (Figure 3). According to the respondents, straw, crop stubble, cactus, hay and grazing on natural and communal pastures are common sources of animal feed. Crop residue is the main feed source during the period from January to August. Most households use cactus pads to fill the feed shortage or as supplement to straw or hay feeding during the months of July to December. Cactus fruit peel (skin of the cactus pear fruit) is also used as a favorite livestock feed starting from mid June to August, during a period when the fruit is available. Hay is usually available during the months of February to May as the supply of this type of feed is very limited.

Coping mechanism of feed shortage in Tabia Kihen

In order to alleviate the shortage of feed several mechanisms were indicated as being practiced in the *Tabia*. The most commonly described means of filling feed gap was the use of cactus pad as livestock feed. This was indicated by both cactus growers (88 %) and non-growers (87 %).

Cactus non-growers households buy cactus pads from grower households for the purpose of feeding their animals. The usual method of transaction of cactus is that agreement is entered between owner of the cactus plantation and the buyer to use the cactus grown on a specified area of cactus plantation. Under this agreement only cactus pads can be cut and taken leaving the main stems behind. The buyer has a right to keep taking cactus pad from the plantation for a period of three months and the contractual agreement is terminated at time of cactus flowering.

The second most important mechanism of filling household feed shortage is purchasing of straw, as indicated by 63 % and 59 % of the non-growers and growers, respectively.

Cactus is still considered as a feed that is used whenever there is a problem of feed shortage, and most growers and non-growers are comfortable to using cactus as animal feed. The use of cactus as livestock feed is becoming a culture and as a major source of livestock feed.

Cactus pad is commonly used to feed cattle, sheep and goats, and camel. About 59% of the respondents utilize cactus as a feed for sheep and goats while the majority of the respondents (94%) use cactus pad and fruit peel to feed their cattle.

Trends in cactus area expansion

Cactus has been expanding since its introduction into the study area. Currently, about 20% of the respondents have enlarged their cactus holding while 80% have not to due to various reasons. One of the major reasons for limited expansion of cactus in the area is the limited availability of land and in only one case; a female-headed household had indicated that she was not able to expand her cactus holding for the fact that expanding cactus holding requires construction of stone fences which requires labor. The plantations have to be protected from livestock by constructing fences around the plantation. Otherwise, it would be difficult to grow cactus plantations. There fore, labor shortage could limit cactus expansion.

Reasons for expansion of cactus in the *Tabia*

According to the respondents, cactus is grown in the area to serve as a source of household income, livestock feed, household food, and for its functional benefits in soil and water conservation. Only some 20% of the respondents indicated that they have enlarged their cactus area holding in the last few years. The reason for expanding of cactus land holding varied among the respondents. The reasons listed include need for increasing income, livestock feed, household food, and for gully stabilization. 20% of the respondents expanded their cactus land area to increase the household income and livestock feed. The rest had various reasons for expansion including increased demand for food, feed, income and also for gully stabilization.

Handling of cactus pear fruits

Cactus pear is one of the most perishable fruit types. Unless the fruit is taken to the market or consumed with out delay, it can easily be spoiled within a few days of picking. According to the respondents, the number of days that a fruit of cactus can tolerably be kept after picking is two to three days.

Collected cactus fruit is packed in metal crates, wooden boxes or hand woven grass baskets. The packing of cactus fruit in woven baskets is done mainly when the fruit is to be transported fully or partly by carrying on human head. Metal crates are used when transportation of the fruit is to be made on donkey back while wooden boxes are used to transport either on donkey back or by vehicle. The metal crates are made from a used metal barrel.

Transporting of cactus to the market is mainly done using donkeys, by carrying on human back or head, or using vehicles. The range of estimated fruit loss during transportation of cactus to market was between 0 and 25 %. About 74.5 % of the respondents estimated that fruit loss is below 10 % while 25.5 % of the cactus grower respondents estimated that losses could reach 10 to 25 %.

The cactus grower respondents were asked to indicate whether they collect their cactus fruit at the right time, before the fruit gets over-ripened. About 34% of the growers indicated that they usually collect their fruit at the right stage of maturity and avoid over-ripening by conducting timely collections. On the other hand, the majority of the cactus grower respondents (66%) fail to collect all cactus fruit before the fruits get over-ripened.

The loss of cactus fruit while standing on the plant and resulting due to various factors was indicated to be 10% or less by 40 % of the cactus grower respondents while the estimate given by another 22% of the respondents was 15 to 30% loss of fruit within the plantation. Only few, about 3 % of the respondents indicated a loss that could reach 50 % of the total cactus fruit harvest. To the contrary, some 34 % of the respondents indicated that there is no loss of cactus fruit yield occurring while the fruits are attached to the plant

Problems associated to marketing of cactus

Constraints to marketing of cactus, as indicated by the respondents, include absence of market place in Mekelle, high transport cost, poor transport facility, distance to market and fluctuation of market price, and theft while selling in the market. About 78 % of the respondents mentioned that there is no a specific market in Mekelle where cactus could be sold. This usually exposes those producers who sell in Mekelle harassments and fines by municipal workers. The fine for bringing in a donkey load of cactus to the market was 10 Birr. The second most important problem indicated by 26 % of the respondents was the fluctuation of cactus fruit market price. The third important constraint indicated by 19 % of the growers was the existing poor transport facility while fourth important marketing constraints were distance to market and theft by youngsters at market places.

Estimated household income from cactus fruit, feed and sale of livestock, and value of cereal and pulse production

The total income of the respondent households was estimated from the value of their crops harvested, value of estimated cactus fruit harvest, estimated value of cactus pad as animal feed, and estimated annual sale of livestock and livestock products. The non-grower households had total income range that was a sum of the income approximated from the value of crops and sale of livestock and was in the range of 2370 to 16400 Birr per year, with a mean income of 6582 Birr for that particular year. Income from off-farm activities and safety-net was not included in the calculation. The mean income of the cactus non-grower female headed households was about 50% of the estimated mean income of the cactus grower male-headed households. On the other hand, the estimated total income among the cactus growers was in the range of Birr 7300 to 36207, with an overall mean of 15058.65. The total calculated income for the female headed households in the cactus growers group was in the range of Birr 7300 to 36207, with a mean total income of 14292.65. On the other hand, the calculated total income for the male headed households in the cactus growers group was between 8335 and 33538, with an overall mean of 15386.93.

Expenditure of income earned from selling cactus fruit

The respondents indicated that the income generated from the sale of cactus fruit is spent on purchasing of food in the case of food deficit households, for domestic consumables, clothing, to cover costs of sending children to school, for the purchase of improved seed and house construction materials . The amount of money spent on the above items and services could vary from household to household. Nevertheless, the importance of the income generated from the cactus business to cover the costs of household consumables, clothing, and costs of sending children to school were indicated by 92, 97 a d 74% of the respondents respectively. The importance of cactus for covering costs of purchasing food items was indicated by only 42% of the households. On the other hand, 48% of the respondents indicated that part of the income generated from the cactus business is spent on the purchase of improved seed.

Econometric Analysis

Multiple regression analysis

A multiple regression model was specified based on the explanatory variables defined in the materials and methods section of this document and the total income as a dependent variable. The total income was estimated from several sources such as crop and livestock products as well as income derived from cactus as a fruit and feed.

Prior to the interpretation of the result, the explanatory variables were checked for the possible existence of multicollinearity (near-linear dependencies). The maximum VIF value in the model was about 3 that was less than 10, and possible to conclude that none of the regressor variables were involved in multicollinearity problem (Table 1). The overall adequacy of the model as tested by R^2 and R^2_{Adj}. was so high, 84.6 % and 81.5 % respectively and the model is suited to select the potential explanatory variables and properly predict the income level, as the $R^2 prediction$ was also satisfactory that the model can predict 81.52 % of the variability in new data (Table 1).

Ordinary least square (OLS) results

Variables such as oxen ownership, TLU, farm size and cactus holding have a positive and significant influence on the probability of increased income level in the study area, in agreement with *a priori* expectations (Table 1).

Number of oxen was found to affect positively to the overall income of the households studied. Oxen power is the most critical production factor and the main source of traction for ploughing.

The more number of oxen one has, the higher the possibility that he/she will rent-in additional land and generate more income (Kidane, 2001). It could also enhance the income of the households through increased production as well as oxen rental incomes. Nevertheless, this variable failed to potentially discriminate between the growers and non-growers; however, households who didn't have oxen at all were relatively low in the grower's category than in the non cactus growers (see Table 10). Total livestock holding as measured by TLU, was also found to be an important variable in improving the overall income of the households and consistent with *a priori* expectations. Besides their significance as a source of food and energy for the household, livestock ownership could reduce income volatility and risk, and induce the households to invest more on other issues. The link between income and livestock ownership could have resulted from the association between livestock and cactus holding. In this study, farmers who own cactus were found to have large number of livestock than the non-growers. This was because of the fact that cactus growers could better fulfill the feed requirements of their livestock and thus are in a better position to keep larger livestock size than non-growers. This finding is in agreement to the results of Berhane (1997), he also indicated that cactus grower households own larger number of livestock heads than non-growers.

Farmers who have a larger cactus plantation have relatively better income that came from the cactus sell as a fruit and source of feed. The association between farm size and income was resulted from sell of farm produce, including crop product sell. Moreover, grower/non-grower grouping has also found to affect the income level as the coefficient is large and positive, showing that farmers who grow cactus have better income than the non-growers.

Stepwise regression analysis

To identify a useful subset of predictors that well discriminate among cactus growers, based on their income from cactus sell as a fruit and the estimated income when cactus used as a feed, stepwise regression model (adds or removes variables based on their contribution) was run using income as a dependent variable and other explanatory variables as independent (Table 33). Apparently, cactus holding and family size showed a positive and significance value whereas gender showed a negative but significant association with income of the grower households (Table 33). As all households used as an input in this analysis were growers, farm households with large cactus holding had relatively better income from cactus sell that enhances investment on human capital such as family health, school etc.

The positive association of family size and income was probably due to better cactus market participation of the households who have large family members particularly those who have large number of young girls and boys. Cactus marketing usually requires more labor particularly that of young girls and boys and sometimes women, to transport cactus fruit into nearly by market places.

The negative sign associated with gender suggests that women-headed farm households had better income that came from cactus sell (see Table 2). In men-headed as well as women headed households, women contributing labor time to harvesting cactus and post harvest sales of the cactus fruit and the income obtained from it, thus remain under women's control. The close relation of women and cactus farms often explains women's predominance in harvesting and post harvest management of cactus as cactus is usually grown as a home garden crop within the homestead. Moreover, income controlled by women has a positive and significant influence on the calorie consumption of the household (Kennedy and Peters, 1992) as well as family health (Thomas, 1990). Promotion of non-cereal crops such as cactus, therefore, seems to have high potential in increasing women's gainful employment in agriculture. Cactus production can be oriented towards food security or income generation depending on the concern of the households, thus a policy support is required for promoting its production and marketing at large scale.

The stepwise regression model terminates with the final reduce model: $\hat{y} = 767 + 7492 cactusholding + 9\ familysize \square 390 gender$, and the R^2 and R^2_{Adj} was significantly large, 94.7% and 94.6% respectively that indicated the importance of the model (Table 2).

Ordered probit regression model

Ordered probit regression model were estimated based on the income level status of the households studied (Table 3). The household income level of both the cactus growers and non-growers were categorized into three classes: [1] 2000-7000 Birr, [2] 7001-18000 Birr and [3] >18000 and the income groups were used as a dependent variable in the ordered probit regression model.

Description of the income groups

The income groups along with the number of samples in each group are given in Table 34, and the income groups are significantly different from one another.

The income level of the non-growers was concentrated in the first two categories. In the medium income, group 2, the overall contribution of cactus to the total income reached 85.15% (see Table 4), the average income of the non-growers and growers were 9626.1 Birr, and 12963.6 Birr respectively (Table 34). In the higher income group (group 3), the cactus contribution was within the range of 15.1%-68.48% (Table 35) and their average income was 24055.0 Birr (Table 3). In-group 1, which constitutes members from non-cactus growers, the contribution of cactus to their income was nil and the average income of this group was only 4552.3 Birr (Table 3).

Influential variables in the ordered probit regression analysis

In the ordered probit regression analysis, variables such as TLU, farm size and cactus holding are positively and significantly associated with the increasing level of income (Table 5). All those three variables appeared to influence the level of income of the households studied and their signs are in complete agreement with *a priori* expectations.

A similar result was also obtained in the regression analysis estimated by ordinary least squares (OLS) given above (see Table 1). Being a source of energy (draught power and cow-dung for fuel) and food, households with large livestock holding likely to generate more income that enable them to engage in more diverse crop production activities, including cactus production.

Farm size was also found to have a positive and significant effect on total income as expected (Table 5). Households with large farm size have better income from crop production, as those farmers are potential users of improved technologies such as improved seed than the householders with relatively smaller sized plots.

Cactus holding was also found to be the most influential variable that well discriminates among the income groups (Table 5). Large cactus holding could serve the households, not only as a source of income from cactus fruit sell, but also as an important input in animal production, being an important source of feed that, in turn, sustains large livestock holding. Taking together the income estimated from cactus as a fruit and feed (excluding income obtained from crop and animal products), most of the grower farmers have better income than most of non-growers, that showed the significant contribution of cactus to the household income. Lumping together the income obtained from cactus, crop and animal production, almost all grower farmers tend to have better income than the non-growers and the contribution of cactus to the grower households reached 85.15% (Table 4).

Donkey ownership showed a negative but significant association with the income groups (Table 36). A limited contribution of donkey ownership to the total income level was found in this study as the mean donkey holding was so minimal, only 0.91 (see Table 2). Most of the cactus grower households have on average one donkey as a transport animal and this was probably due to the simple reason that most of the villages are relatively located in a short distance to the main road and easily accessible. Nevertheless, only the number of donkey per household was used as an input for estimating the regression coefficient. Had the contribution of donkey as a means of transport and renting were estimated in monetary terms, the contribution of donkey to the total income would have a positive effect.

CONCLUSION

From the current study, it is understood that cactus is the major source of food, livestock feed and income in the Tabia. The income collected from the sale of cactus is helping the cactus growers to cover the cost of household items, for buying grain food and improved variety seeds, covering school fee for their children, and cost of other necessities. Therefore, efforts that improve the management and utilization of the cactus crop could help attain food security, and improve the livelihood of the cactus grower households in *Tabia Kihen*.

- Though other cereal, horticultural, and irrigable crops have been covered under the agricultural extension system, the negligence of this crop from being included in the regional extension system could have contributed for the low productivity of the crop. Therefore, this calls for focused and integrated support to the improvement and management of cactus production from the agricultural extension system.
- The women headed households were found to benefit more from the cultivation of cactus as compared to the male-headed households. This is a good indication that any support that help to boost cactus production, management and post-harvest handling and improved access and marketing

network will ultimately increase the income and benefit of women headed households from cactus.

- Though training on the use aspect of cactus fruit and pad was given to a very limited number of cactus growers, only a very small fraction of the households are making use of the fruit, the pads as salad or cooked food, and making of jams from both the fruit and young pads. It has been indicated that both the fruit and cactus pads can be used as a source of food and since the availability of the cactus pads is almost all year round, households could have access to cactus pads that can be consumed in the form of salad or cooked *nopalitos*. Therefore, there is a need to familiarize the use of cactus pads, and provision of training on the preparation and utilization of cactus from both the fruit and cactus pads.
- The women headed households were found to benefit more from the cultivation of cactus as compared to the male-headed households. This is a good indication that any support that help to boost cactus production, management and post-harvest handling and improved access and marketing network will ultimately increase the income and benefit of women headed households from cactus.
- Improvement in the marketing and transporting facility would enable the farmers to sell their produce at reasonable prices with improvement in their bargaining power as well as reducing losses that could occur during the transportation and marketing of the fruit. Currently the market for cactus was so thin and stochastic, that constantly changing and farmers in the study area have no market insurance mechanism that would enable them to cope with risk *ex post*. Thus, they are more risk averse because they have no alternative insurance mechanisms, choosing to be self-sufficient in food production in order to insure themselves. As a result, cactus is filling the food and feed gap of the households currently though the market potential of the crop is there. Access to an improved and better functioning market in the study area could provide farmers with alternative means coping risk.

RECOMMENDATIONS

Based on the results of our findings the following recommendations are forwarded:

- There is a need for training on the processing, and post harvest handling of cactus in the area.
- Access to market has to be improved so that farmers can get the best benefits from the cultivation of the crop.
- There is a need for support from research and the extension system in order to increase the productivity and management of cactus in the Tabia.
- There is a need for the establishment of agro-processing factories in the region which could process the surplus cactus produce in the area and add value to the crop.
- In the region, land that is not suitable for cultivation including hill sides have been distributed to land less youths with the objective of providing a means of

income generation for the land less youth and at the same time increasing the productivity of the land and conservation of the soil and natural vegetation. Cactus is known to perform well in poor fertility soils. Cactus can do well under such non-productive or less productive lands. Therefore, planting of cactus on such less productive soils could increase the productivity of the land, be source of income for such disadvantaged people, and serve as source of pollen for bees.

- Organizing the cactus growers into cooperatives could enhance their marketing power, create access to training facility and serve as a means of exchanging experience and knowledge on the culture and management of cactus that intern could help improve the productivity of cactus in the area.
- The diversity and type of cactus in the area is not known. There is a need of identification and characterization work on cactus types in the area. Besides, better performing varieties of cactus that are suitable for both fruit, *nopalitos* and that have best processing qualities have to be introduced and tested in the area.

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Table 1. Result from multiple regression

Attributes	Coef.	Std. Err	T	P	VIF
Constant	2166	1057	2.05	0.043	
Ox	737.1	380.8	1.94*	0.056	3.0
TLU	411.1	159.7	2.57**	0.011	2.8
Gender (sex)	603.4	597.3	1.01	0.315	1.3
Age	-11.03	19.84	-0.56	0.580	1.3
Family size	133.5	149.3	0.89	0.373	2.0
Dependency ratio	-21.5	264.1	-0.08	0.935	1.3
Literacy	160.6	528.7	0.30	0.762	1.3
Growers/non-growers	1713.4	751.1	2.28**	0.025	1.9
Donkey ownership	-410.0	507.3	-0.81	0.421	1.5
Farm size	239.5	137.7	1.74*	0.085	1.6
Cactus holding Ha	7563.7	545.1	13.87***	0.000	1.8
N	120				
R^2	84.6%				
R^2 adj	81.5%				
R^2 Prediction	81.52%				
Regression MS df =11	3674586746**				
Residual MS df = 108	6687018				

** P<0.10, ** P<0.05, *** P<0.01; Source: Model output*

Table 2 Stepwise regression of income of cactus growers

Attributes	Coef.	T	P
Constant	767		
Cactus holding Ha	7492	39.01***	0.000
Family size	90	1.89*	0.062
Gender	-390	-1.71*	0.090
N	90		
R^2	94.7%		
R^2 adj	94.6%		
R^2 Pred	91.1%		

** P<0.10, ** P<0.05, *** P<0.01; Source: Model output*

Table 3. Descriptive statistics of the income category of the grower/non-grower Households

Income group	Grower[1]/ non-grower[0] category	N	Mean	SE	Min.	Max.	F-value df = 2
1	0	18	4552.3	348.6	2370	6905	150.74**
2	0	12	9626.1	781.2	7155	16400	
	1	73	12963.6	340.9	7300	17882.3	
3	1	17	24055.0	1314.3	18135	36207.1	

***P<0.01; Source: Model output*

Table 4. Percent contribution of cactus from the total income

Income group	Cactus contribution %			
	N	Mean	Min.	Max.
1	18	0	-	0
2	85	39.86	0	85.15
3	17	50.99	15.1	68.48

Source: Model output

Table 5. Ordered probit regression estimation of income groups

Attributes	Coef.	Std. Err	Z	P>Z
Ox	0.3172874	0.29237	1.09	0.278
TLU	0.2809297	0.1117785	2.51**	0.012
Gender sex	0.1952033	0.4375603	0.45	0.656
Age	0.0240413	0.0153877	1.56	0.118
Family size	0.064973	0.1222642	0.53	0.595
Dependency ratio	-0.1492292	0.2089005	-0.71	0.475
Literacy	0.1757058	0.3947081	0.45	0.656
Donkey ownership	-0.9854454	0.3990477	-2.47**	0.014
Farm size	0.2217338	0.1167061	1.9*	0.057
Cactus holding Ha	4.528771	0.9894919	4.58***	0.000
N	120			
LR x^2 10	123.74			
Prob $> x^2$	0.0000			
Pseudo R^2	0.6399			
Log likelihood	-34.810684			

** P<0.10, ** P<0.05, *** P<0.01; Source: Model output*

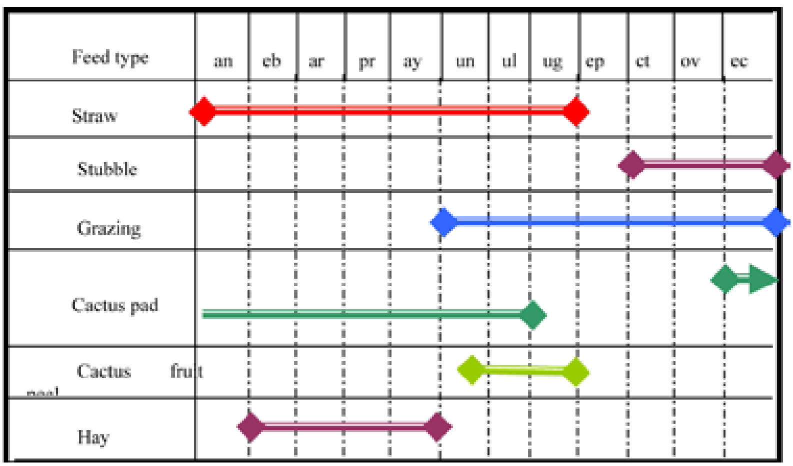

Figure 3. Feed calendar in *Tabia Kihen*

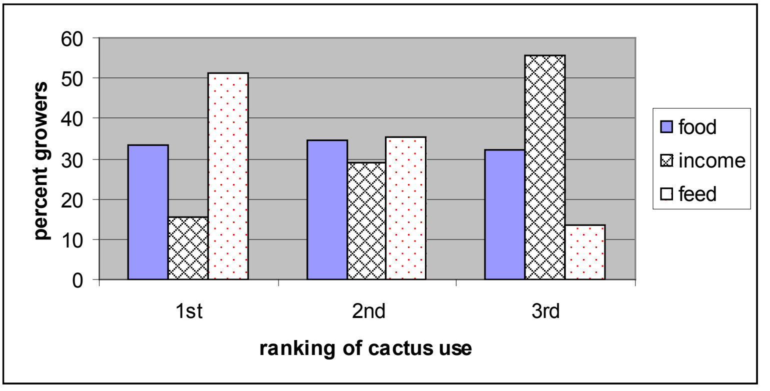

Figure 1. Ranking of value of cactus in terms of its food, feed and income

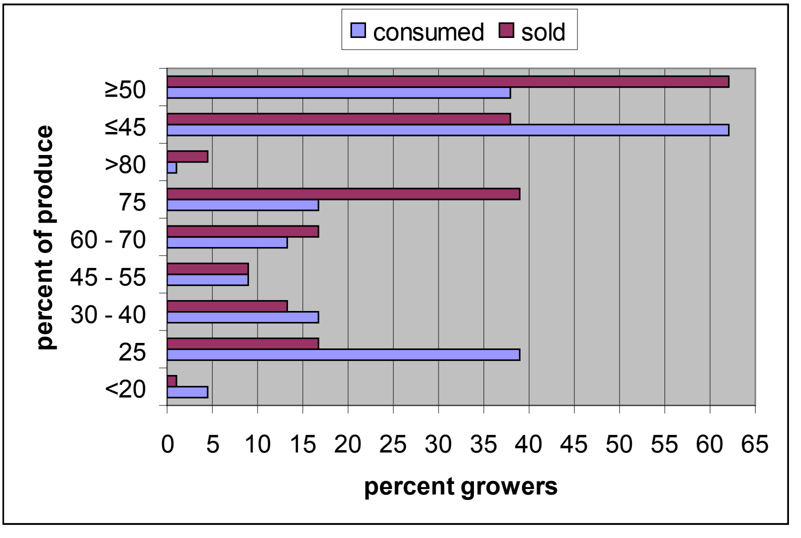

Figure 3: Percent of cactus fruit consumed and sold by percent respondents

CHEMICAL AND NUTRITIONAL CHARACTERIZATION OF BELES IN EASTERN ZONE OF TIGRAY REGION, ETHIOPIA

Haileselassie Tsegay[1], Fetein Abay[2] and Ibrahim Fitiwy[2]
[1]Agriculture and Rural Development Office Tigray, Mekelle, Ethiopia
Emaile:hailekad@gmaile.com
[2]Mekelle University, P O Box 231, Mekelle, Ethiopia

ABSTRACT

This research was conducted in 2008 in Ganta-afeshum and Erob Wereda Eastern Tigray Ethiopia. The objective was to characterize the fruits of cactus pear plant and document the differential uses. Chemical and nutrition analysis was performed at Mekelle University laboratory in 4 and 6 varieties collected from Ganta-afeshum and Erob Weredas respectively. Two to three matured fruits were randomly taken in 3 replications from each variety. Following the descriptor for cactus developed by FAO morphological characterization was also performed on a total of 40 varieties from both Weredas randomly in 3 replications

Morphological, chemical and nutritional data were analyzed using one way analysis of variance (ANOVA) with JMP computer program. In addition multivariate analysis including clusters and principal component analysis were analyzed with MINITAB 14. In case of socio-economic survey, 16 variables of the social survey analyzed for regression and some descriptive statistics.

The result on nutrition content showed a significant variation at $P<0.05$ in TSS% (total soluble solid) and ASC% (vitamin C). The result of this study indicates that nutrition of local 'Beles' has the same content with most common fruits such as apple, peach, orange, avocado and grapes. In cluster analysis the original 6 local 'Beles' varieties sampled from main growing Weredas of the Region were grouped into 4 clusters. Cluster I include most available varieties in their farm backyard and are assumed as good quality varieties by the community while variety in cluster IV (cheguar) showed high in most chemical and nutrition contents. In regard morphological features almost all the traits showed significant variation at $p<0.05$ in fruit weight, Pulp percent, seed number, Abort seed number, Abort seed percent and soon. Some trend also observed, out of 18 varieties collected from Ganta-afeshum 5 varieties are grouped in two clusters V and VII and cluster IV also comprise 10 varieties all are from Erob Wereda. This trend showed communities in both Weredas are growing cactus pear fruits selectively and good quality varieties in their backyard, but high diversity were observed in Erob varieties collected from communal plantation. This diversity of genetic material could be potential

resource for further improvement and development of the fruit plant. Therefore, by crossing and/or grafting good quality traits of members of cluster V and VI one could improve the abort seed, percent, peel weight and flesh percent per fruit on selected varieties of other members of the clusters.

INTRODUCTION

Cactus pear is a dicotyledonous plant of the cactus family (Cactaceae) native to central Mexico and the Caribbean. It is extensively used as food for humans and feed for animals. The plant has been and is being domesticated as an important fruit crop in many areas of the world although wild populations are still exploited (Mondragon, 2001). The cactus pear is cultivated in more than 30 countries primarily for its fruit, but also the young cladodes are used as vegetable and mature ones as cattle feed. Cactus pear is cultivated in Tunisia, Italy and Brazil, with about 70,000, 100,000 and 300,000 ha of land devoted to its cultivation, respectively (Garcia de Cortazar and Nobel, 1992). Besides, Algeria, Argentina, Chile, Mexico and South Africa grow cactus on considerable area of land.

According to Schinvar (1995), more than 300 species of *Opuntia* are distributed across the American continent but only three species O*puntia albcarpa sp.novo, O. ficus indica (L)* Miller, and O. *robusta* Wendel var. *larreyi* are important for horticultural purposes. Vast arrays of species are still found in the wild, while backyards contain mostly varieties selected by farmers. Production at commercial level started in the 1960s and is based on outstanding plants taken from rural households where they provide food for the family (Mondragon and Perez, 1996). Orchards used foundation material obtained from plants bearing large fruit size, high color, and good flavor. The clones were named based on specific fruit and plant traits.

As a plant with Crassulacean Acid Metabolism (CAM), cactus pear is able to withstand drought. It is cultivated in small tracts traditionally devoted to maize and beans production, with low revenues (Mondragon, 2001). Medical research has found value in cacti as a raw material for products to treat hypoglycemia, diabetes, high blood cholesterol levels, and obesity (Mondragon and Perez, 1996). This plant is also able to thrive in high CO_2 environments (Nobel and Israel, 1994 cited in Mondragon and Perez, 1996). Cacti have received attention as a crop to fight global pollution and desertification (Mondragon and Perez, 1996). Production depends on intensity of farming practices, orchard size, and environmental factors such as late frosts and rainfall. Small orchards northwest of Mexico City obtain 8-10 t/ha with minimum effect of alternate bearing. However, growers in semiarid regions obtain less than 5 t/ha, with low labor inputs and low crop management. Due to dependence on a narrow base of varieties, there is a temporary (three months) market saturation (Mondragon and Perez, 1996), which is associated with falling prices and low returns.

In Tigray region of Northern Ethiopia, cactus pears are eaten as a snack, and sold peeled and slightly chilled by street vendors. Harvest season starts late in June and extends through September. However it is possible to widen the market window if other varieties are marketed. The cactus pear can be used in many ways in diverse sectors, utilizing different parts of the plant. In the food sector, besides consumption of the fresh fruit, jams, alcoholic and soft drinks, syrups, candied fruit and flour can be produced from the plant and oil extracted from the seeds. The young cladodes are eaten as a vegetable (for example in Mexico) or made into other products. For cattle feed it is mostly used fresh, but it can also be ensiled so as to utilize cuttings from processes using the plant in other ways. The different parts of the plant can also used in industry (dyes, mucilage, pectin, organic fertilizer, biogas), in the pharmaceutical sector (in the treatment of diabetes, obesity, inflammation, etc) and in the cosmetics industry (Chessa and Nieddu, 1997). In addition, *Opuntias* are used as ornamental plants. The study was conducted with the objective to characterize the local Beles fruits of the cactus pear plant and document chemical and nutritional contents.

MATERIALS AND METHODS

This study was conducted during 2008-2009 crop season in Ganta-afeshum and Erob Weredas of Eastern zone of Tigray region Ethiopia. 2-3 mature fruits were taken for analysis of different chemical and nutrition contents. In 10 local varieties collected from both Weredas in 3 replications, Dry matter%, Moisture%, Ash%, TSS%, Crude Protein%, Sucrose%, Fat%, Ascorbic acid%, Titratable acid /citric acid/%, and Minerals such as, Calcium%, Magnesium%, Potassium%, Sodium% and Phosphorus% were determined.

The procedures followed in the measurement of chemical and nutrition contents were as follows: matured, fresh fruit pulp was desiccated for 24 hours at 65^0c in drying oven then allowed to cool. When dried it was ground then analyzed for Crude protein, Fat, and the minerals. Fresh fruit after being blended to form a puree and then filtered using filter paper were analyzed for Titratable acid (TA), Sucrose (SUC), Total soluble solids (TSS) and Ascorbic acid (ASC). Detailed procedures for determination of the various components are described below:

- **Sucrose content**: sucrose was determined by applying a filtrate smear drops on automatic Refractometer
- **Titratable acidity**: Titatable acid was determined by pipetting 10ml of filtrate into a beaker diluting to 125ml, and titrating with 0.1N NaOH to pH 8.1.
- **Ascorbic acid**: Ascorbic acid (vitamin C) was determined by adding 1.5g of oxalic acid to filtrate juicy and titrating with standardized iodine solution using spatula tip of the starch as indicator.
- **TSS**: Total soluble solids were determined when filtrate smear was desiccated for 24 hours in dried oven then digested using kjeldahl method and measured by spectrophotometer with correct wave length.

- **Minerals**: the minerals contents were determined from the oven dried sample after digested using kjeldahl method for cations (Na^+, K^+, Ca^{++} and Mg^{++}) using absorption atomic spectrophotometer while for phosphorous atomic spectrophotometer with correct wave length for each minerals was used.
- **Crude protein**: Crude protein was determined from the oven dried sample after digested using kjeldahl method. The ammonia was distilled into boric acid and methyl red solution as indicator, using atomic spectrophotometer. Crude protein was calculated as N*6.25.
- **Fat**: Fat was determined from the oven dried sample. Oil was extracted with diethyl ether using Labcon fat extractor.

Chemical and nutrition data were subjected to analysis of variance (ANOVA) with JMP 5 computer program. Mean separation was performed using Least Significant Difference Test (LSD) at $P<0.05$ level of significance. In addition multivariate analysis cluster and principal component analysis were made using MINITAB-14 computer program

RESULT AND DISCUSSIONS

Chemical and nutrition content of local Beles varieties were found to be different. One way of analysis of variance was made to compare the varieties. The result on chemical composition is not significant different while the nutrition content showed significant difference at $P<0.05$ in TSS% (Total soluble sold) and ASC% (Vitamin C) (Table 1). Mean value for TSS% and ASC% ranged from 12.9g/100g and 0.06g/100g, respectively (Table 1). In TSS% Cheguar differed significantly from Qeyeh ashak, Mayzebezho and Atsmi while no significant difference were observed with Lematse and Tsaeda Beles. Tsaeda Beles however do not show any significance difference with the other varieties.

Regarding ASC % Cheguar was significantly different from *Qeyeh-ashaq, Atsmi, Tsaeda-Beles and Lematse*. However no significant difference was observed between *Cheguar* and *Mayzebezho* and *Mayzebezho* (Table 2). The nutrition content of 'Beles' (cactus pear) was also compared with other common fruits and some vegetables (Table 3). 'Beles' was in medium range in energy (50 kcal./100g) that is the same with apple, orange, and pineapple; In moisture cactus pear is the same with apple, avocado, grapes, guava, orange, and pineapple, and in sugar content (15 %) that was above apple, avocado, carrot, lemon, orange, papaya, peach, pineapple and tomato. In vitamin C content, cactus pear is in the same range with peach, grapes, carrot and banana (Pimienta, 1990; Schmidt-Hebbel *et al*.1990, Sepùlveda and Sáenz, 1990) cited in Sáenz, 2000. Mean value for protein and fat content was 6.7 % and 2.73 %, respectively that is greater than all except in fat in avocado. In this particular study fat and protein was found greater than all mentioned fruits.

The dendrogram obtained from the hierarchical cluster analysis grouped the original 6 varieties into four clusters (Figure 1) and means of chemical and nutrition content in each cluster were given in analysis from 6 'Beles' varieties (Table 4). *'Qeyeh-ashak', 'Lematse'* and *'Tsaeda-Beles'* are grouped in cluster I while '*Atsmi', 'Mayzebezho'* and '*Cheguar*' are grouped in independent cluster II, III, and IV respectively.

In cluster analysis mean value of each cluster for chemical and nutrition contents shows from small to large variation were observed in traits such as Ash%, ASC%, TA%, N%, and all minerals such as Ca%, Mg%, Na%, K% and P% shows small variation while in traits such as Dry-matter%, Moisture%, TSS%, Sucrose% , Fat% and Crude-protein% shows large variation. These traits might be influenced by environmental, management and genetic difference.

Variety '*Qeyeh-ashak***'** is characterized by high content of Sodium, Phosphorous and low in Ascorbic acid but the most available and first in area coverage in their backyard and socially accepted variety in overall uses. Variety '*Cheguar*' is characterized first from other varieties in chemical and nutrition contents score 9 out of 15 traits at maximum range such as, Ash, TSS, Sucrose, Ascorbic-acid, Titratable-acid, Crude-protein, K, and P, but low in Na, FAT, and Dry matter high in all traits doesn't mean quality variety, but this cluster members can be a source of good quality genes to transform to selected varieties. Variety '*Lemats*' also characterized by high content in Phosphorous and first in quality measurement of the local community but has small area coverage due to spineless in the pad and fruits because it is palatable and easily damaged by animals and human intervention. Variety '*Mayzebezho*' also characterized highest in FAT and Moisture but low in K, TSS, and Sucrose. Variety '*Atsmi*' also characterized by low in Ash, Mg, Na, and P, but high in Dry matter.

In general almost all 'Beles' varieties in this study shows in the acceptable range from 12 to 17% in terms of TSS described for commercial varieties described by Mondragon (2001). A total of 7 principal components were extracted, though the first three principal components with eigenvalue greater than 2.5 were considered significant for this particular study. The original seven variables were then reduced to three independent linear combinations, principal components (PC) of the variables. The first two components scores were plotted to aid visualization of the overall variability among the 'Beles' varieties (Figure 2).The first three principal components explained 84.31% of the total variation and each component explained 38.51%, 29.07% and 16.78% of the total variation first, second, and third principal components respectively. A summary of the composition of variables in the first three principal components, eigenvalues and eigenvectors is given in (Table 5).

Principal component I was strongly associated with traits such as contents of Ash %, Fat %, TSS %, Sucrose %, Ascorbic-acid %, Titratable-acid %, Nitrogen %, crude-protein %, Potassium % and Phosphorous % almost all the traits used in the study except Na%, Mg%, Moisture% ,and Dry-matter%. All these traits except Na%, Fat%, and Dry-matter% had positive loading in this component. In the first component which maximized the differentiation among the varieties, was associated with high content in Ash (%), Fat (%), TSS (%), Sucrose (%), Ascorbic-acid (%),

Titratable-acid (%), Nitrogen (%), Crude-Protein (%), Potassium (%) and Phosphorous (%). Basically all the traits mentioned are characteristic of cluster IV '*cheguar*'. Second principal component TSS (%), Dry-matter (%), and Potassium (%) (With positive loading), and Ash (%), Ascorbic-acid (%), Crude-Protein (%), Magnesium (%), Calcium (%), and Moisture (%) (Negative loading) had significant contribution. In fact all the traits mentioned here are characteristic of cluster II '*Atsmi*'**.**

CONCLUSION AND RECOMMENDATIONS

Nutritional and chemical contents was statistically analyzed significantly difference at $P<0.05$ was observed among varieties and some local varieties fit the international quality parameters. Therefore, there is opportunity for selection of best quality fruits for local and international markets.

This fruit is the most readily available source of fresh fruit during summer providing valuable minerals and vitamins to the community. Various uses of this plant is so far limited to fruit consumption and animal feed in this region without transforming to commercial and other products such as, biogas, cosmetic, beverage and medicinal purposes. The community and the country will not benefiting from this potential and unutilized resource. The result obtained from chemical and nutritional variations can serve as base material to select quality and internationally accepted cactus fruit to start up commercial and industrial production system.

Recommendations put forward are as follows: There is a need to focus in the extension service to provide new technologies and promote new plantation in their backyards and watersheds in special way for commercial production: initiation of supplying cactus pear fruit to super market and improve the traditional handling methods to attract whole beneficiaries; creating linkage with other fruit suppliers and assessing local and international markets is critical. Generally this plant is a valuable genetic resource for the arid and semi-arid zones of the world. It needs focus to keep the genetic material in in-situ and ex-situ ways.

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Table 1. Descriptive statistics of chemical and nutrition content of 'Beles' of Eastern Tigray

Variable	Site	N	N*	Mean	SE	Mean	S.D.	C.V.
DM	1	18	0	17.72	0.38	1.60	9.01	14.20
	2	12	0	19.24	0.46	1.60	8.29	17.06
Mos	1	18	0	82.28	0.38	1.60	1.94	80.25
	2	12	0	80.76	0.46	1.60	1.97	76.74
Ash	1	18	0	1.85	0.06	0.30	14.76	1.40
	2	12	0	2.12	0.15	0.54	25.44	1.01
Fat	1	18	0	2.52	0.32	1.34	53.36	0.58
	2	12	0	3.17	0.29	1.01	31.79	1.68
TSS	1	18	0	12.94	0.34	1.46	11.28	9.74
	2	12	0	12.87	0.28	0.95	7.39	11.88
SUC	1	18	0	14.92	0.33	1.40	9.39	11.94
	2	12	0	14.91	0.28	0.96	6.46	13.06
T.A.	1	18	0	0.32	0.03	0.14	45.33	0.03
	2	12	0	0.24	0.04	0.14	57.77	0.12
Asc	1	18	0	1.20	0.17	0.74	61.48	0.34
	2	12	0	1.05	0.16	0.56	53.88	0.39
N	1	18	0	1.22	0.10	0.43	35.20	0.71
	2	12	0	0.82	0.07	0.25	30.91	0.43
CP	1	18	0	7.62	0.63	2.68	35.20	4.42
	2	12	0	5.09	0.46	1.57	30.91	2.70
Ca	1	18	0	0.13	0.01	0.06	42.87	0.04
	2	12	0	0.11	0.02	0.06	53.78	0.06
Mg	1	18	0	0.04	0.002	0.01	21.58	0.03
	2	12	0	0.04	0.003	0.01	29.44	0.03
Na	1	18	0	0.09	0.02	0.07	79.97	0.04
	2	12	0	0.15	0.02	0.06	38.03	0.05
K	1	18	0	0.40	0.03	0.11	27.84	0.26
	2	12	0	0.51	0.04	0.14	27.08	0.29
P	1	18	0	0.10	0.01	0.03	25.12	0.04
	2	12	0	0.12	0.01	0.03	23.32	0.08

DM: Dry matter, Mos%: Moisture percent, TSS%: Total soluble solids, ASC%: Ascorbic acid/ vitamin C, CP: Crude protein, SUC: Sucrose and TA: Titratable acid
Sites 1: Erob; 2: G/afeshum

Table 2. Mean comparison in Nutritional content of cactus pear varieties in Eastern Tigray

Cactus pear variety	TSS (g/100g)	ASC (g/100g)
Cheguar	14.23 a	2.24 a
Mayzebezho	11.69 c	1.44 abc
Qeyeh-ashak	12.13 c	1.35 b
Atsmi	12.59 bc	0.94 bc
Tsaeda-Beles	13,17 abc	0.89 bc
Lematse	13.70 ab	0.68 c

Table 3. Nutrition contents comparison of Beles varieties (cactus pear), avocado, apple, banana, carrot, grapes, guava, lemon, mango, orange, papaya, and tomato (Source: Nevo, 1996)

Fruit type	Energy Kcal	Water %	Fat %	Protein %	Sugar %	Vit C %
Apple	49	84 0		0.4	11.8	0.00001
Avocado	126	81	10	2.0	7.0	0.017
Carrot	88	76	0	1.2	2.2	0.002
Guava	11	92	0	0.6	17.0	0.22
Lemon	64	83	0	0.6	3.0	0.03
Mango	72	81	0	1.0	15.0	0.05
Orange	12	96	0	0.0	10.6	0.049
Papaya	60	84	0	0.0	8.0	0.046
Peach	48	87	0	1.0	7.9	0.007
Pineapple	32	91	0	0.0	12.0	0.025
Tomato	36	89	0	1.0	1.9	0.07
cactus pear	11	81.7	2.73	6.7	14.98	0.25

Table 4. Mean of Chemical and Nutrition contents for each cluster

Cluster	I	II	III	IV
DM	18.6	16.3	20.5	17.3
MOI	81.4	83.7	79.5	82.7
ASH	1.99	2.06	1.7	2.23
FAT	2.9	3.26	2.89	1.54
TSS	12.93	11.54	13.09	14.1
SUC	14.88	13.99	14.79	16.5
ASC	0.047	0.05	0.07	0.08
TA	0.19	0.18	0.25	0.33
N	1.01	1.18	0.93	1.31
CP	6.3	7.4	5.6	8.19
Ca	0.11	0.17	0.12	0.13
Mg	0.037	0.04	0.03	0.04
Na	0.13	0.13	0.09	0.09
K	0.45	0.32	0.47	0.55
P	0.11	0.1	0.09	0.12

DM: Dry matter, MOI: Moisture, TSS: Total soluble solids, ASC: Ascorbic acid (vitamin-C), CP: Crude protein, SUC: Sucrose and TA: Titratable acid

Table 5. Eigenvalue, % of variance, % cumulative and eigen vector for Chemical and Nutrition content of 'Beles' varieties of Eastern Tigray

Nutrient	PC1	PC2	PC3
DM	-0.003	0.413	-0.12
MOI	0.130	-0.413	0.12
ASH	0.282	-0.284	0.096
FAT	-0.386	-0.066	-0.053
TSS	0.297	0.285	-0.009
SUC	0.374	0.143	0.003
ASC	0.305	0.165	0.349
TA	0.341	0.123	-0.004
N	0.245	-0.25	-0.178
CP	0.246	-0.251	-0.177
Ca	-0.0003	-0.306	0.462
Mg	0.099	-0.323	-0.049
Na	-0.169	-0.032	-0.545
K	0.305	0.31	-0.061
P	0.29	-0.092	-0.507
Eigenvalue	5.78	4.36	2.52
% of variance	38.5	29.1	6.8
%cumulative	38.5	67.6	84.4

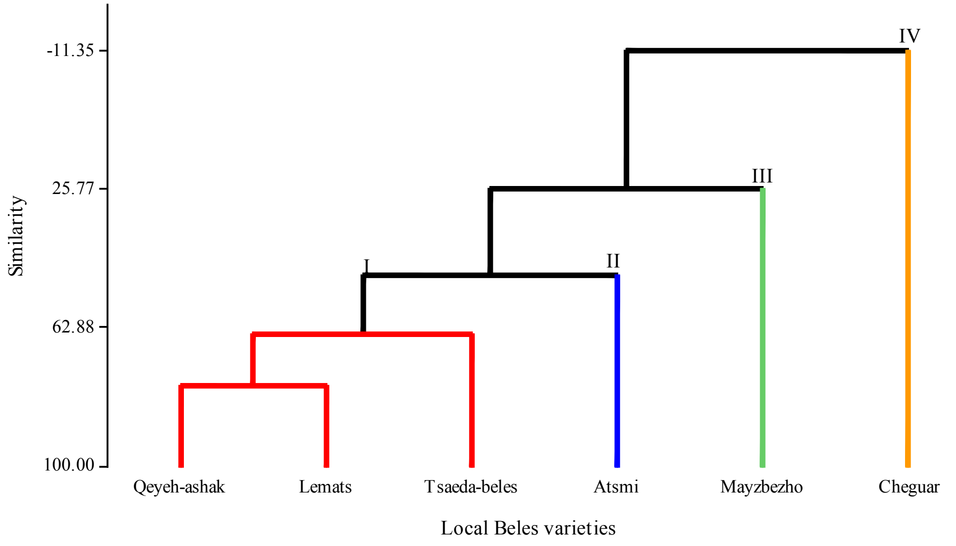

Figure 1. Dendrogram of chemical and nutritional content of 6 common 'Beles' varieties with Ward Linkage and Squared Euclidean Distance Linkage

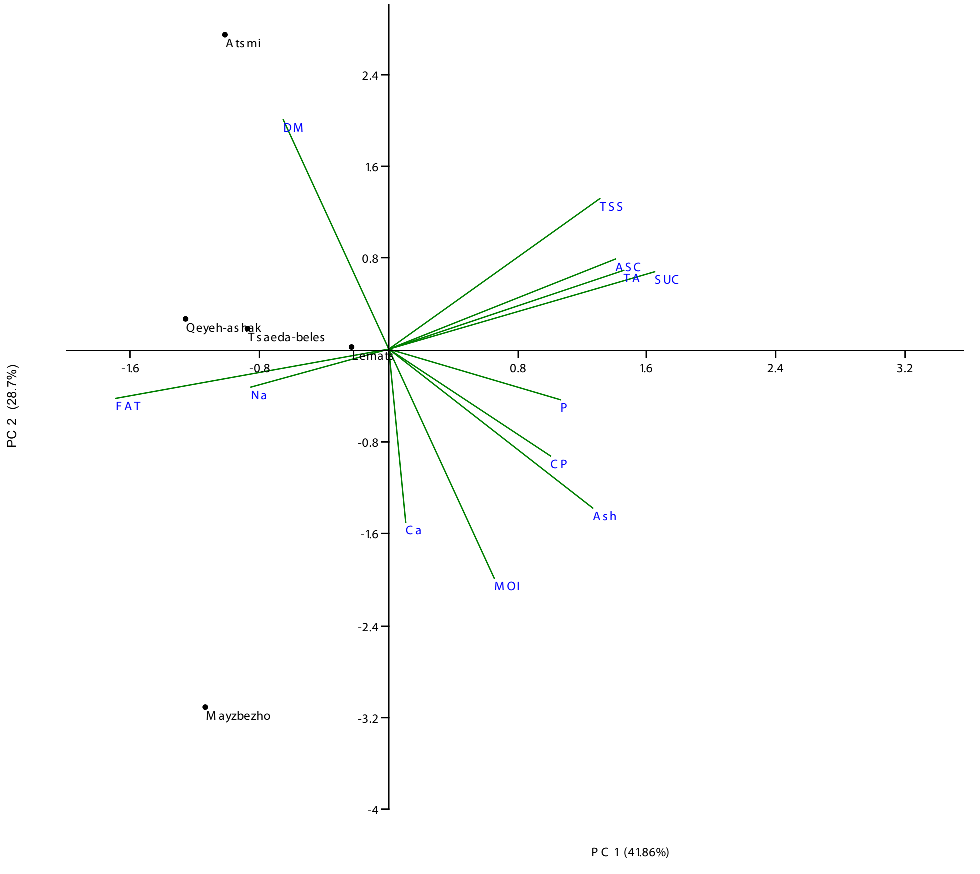

Figure 2. Ordination of the chemical and nutritional contents using two principal components score.

THE CACTUS DEVELOPMENT PROJECT (HCDP) AND THE ROLE OF CPPI AS A REGIONAL PLATFORM IN TIGRAY REGIONAL STATE, NORTHERN ETHIOPIA.

Tesfay Alemseged
Helvetas Cactus Development Project
Helvetas Ethiopia, Mekelle, Ethiopia
Email:tesfay@gmail.com

ABSTRACT

Introduced to Tigray during the mid-19th century, cactus (Opuntia ficus-indica) is nowadays a crop that renders huge potential and livelihood sources for small farmers and traders. To exploit the full potentials of the crop the regional state and other partners have identified the following priorities; enhancement of institutional systems, food security, land restoration and protection, and income generation respectively. After the international workshop held in Mekelle (2004) a regional umbrella program "Cactus Based Production and Processing Initiative (CPPI)" was launched. Various partners have joined the initiative by launching projects committed to the CPPI. Helvetas Cactus Development Project (HCDP) is the technical assistance and contribution of Helvetas for the CPPI. The project focuses on three major pillars: household's empowerment, enhancement of cactus-based product value chains and enhancing institutional capacities of CPPI stakeholders.

In realizing these objectives various training activities were carried out to a total number of 17,062 beneficiaries. The training packages are focused on improved management, production, harvesting, packaging, transportation, marketing, food processing, silage making, cactus flower collection, drying, packaging etc. A number of promotional programs, demonstrations as well as networking efforts were successfully conducted in collaboration with various partners. As a result, encouraging outcomes have been obtained. A series of awareness campaigns has resulted in attitudinal changes of rural and semi-urban communities in their outlooks towards the values and uses of cactus. Considerable numbers of households have started including cactus pads/leaves into their daily diets and prepare cactus silage and feed their cattle. A large number of households have started appreciating the benefits of cactus and started using cactus as an important source of household income and attaining household food security. Exemplary cactus based small businesses have emerged as a result of these efforts.

Despite the above achievements we have a long way to go in improving the current practices and transforming in to a commercial production. This paper

emphasizes on the impact of the cross-sartorial intervention, regional endeavors, challenges and experiences and sets out viable institutional, regulatory and technology support strategies aimed at improved utilization of the crop.

INTRODUCTION

Historical records of in pre-Hispanic times indicate Cactus (*Opuntia ficus-indica*) has been utilized by man for various purposes, where it played a major role in the agricultural economy of the Aztec empire in Mexico. With maize (*Zea may*s) and agaves (*Agave spp*.), they represent the oldest cultivated plants in Mexico. Opuntias are now part of the natural landscape and the agricultural systems of many regions of the world.

Opuntias are widely occurring plants in arid and semi-arid climates of Ethiopia. In Tigray, cactus pear locally known as "Beles" was introduced in the mid-19th century by missionaries. Since then it has flourished and become one of the most common plants in the region. Cactus is now very much part of the culture and livelihood of these people in spite of its limited use. The surplus fruit (Figure 1) is generally wasted due to lack of capacity and knowledge of its full utilization and processing potentials.

A large proportion of households (35%-78%) in north-central Tigray have cactus gardens. The use of the plant in Tigray, both as food and fodder resource has sustained human life in the past decades. Significant increase both in the number of growers as well as the coverage was noticed after the 1984 major drought. The cactus culture has been increasingly adopted by various farming communities in response to the climatic change and natural resources degradation.

Despite the wide use of cactus as strategic crop in adapting climatic change and associated moisture stress and declining soil depth and fertility in the region, , the plant until recently was regarded as a famine deterring plant by various research and development actors as well as by the farmers themselves. Since 2003 an extensive efforts were done in promoting the wider potentials of the crop including the use of the young leaves (nopalitos) as a supplementary food sources (Figure 2). However further efforts are demanded so that people accept and incorporate the young leaves into their traditional dishes. Despite the promotion efforts being done for the last 5 years, nopalitos is not yet fully accepted as staple food mainly due to the conservative food habits of the farming communities.

Following the first regional survey and proposal by Tesfay Alemseged, (1993) on the utilization of cactus as a supplementary source of food and forage integrated within the watershed management program, cactus was in principle considered a strategic crop among research and development communities (Co.SAERT, 2004). Since 1993 cactus development was accepted as one of the building blocks associated with the watershed component of Co.SAERT. However, due to institutional failures in realizing sustainable agriculture and environmental rehabilitation in Tigray (SAERT), the integration of cactus program within the watershed and environmental interventions was not realized.

In order to achieve visible success in realizing the multipurpose and strategic advantages of the crop and provide a sustained effort to the initiative the presence of a cross-sectoral institutional framework (common platform) was a critical priority. After the 2004 international workshop held at Mekelle, the cactus production and processing initiative (CPPI) was realized as a regional platform. The Cactus Production and Processing Initiative (CPPI) is a multi stakeholder program which tries to integrate the efforts and projects of various institutions and organizations towards the full development of the cactus plant. CPPI was aimed at contributing to regional and national food security and wealth creation (Figure 2.). For the last 5 years, Helvetas Ethiopia served as the secretariat of the initiative and played a significant role in supporting the networking and coordination activities among the stakeholders, and providing institutional support to different organizations that work on the development of cactus. This paper emphasizes on the overview of Helvetas Ethiopia's contributions as well as the impact of the cross-sectoral intervention, regional endeavors, challenges and experiences. It also sets out viable institutional, regulatory and technology support strategies aimed at improved utilization of the crop.

CACTUS IN TIGRAY

Opuntias are broadly characterized by the presence of spines, succulent stems with a green cortex and lack of foliage leaves. Opuntias are multi-functional plants that play an ecological role in soil and water conservation practices, producing fruits and vegetables for human consumption, forage for livestock, biomass for energy purposes, live fences and windbreaks, bee forage and numerous by-products including beverages, drugs, dyes and cosmetics.

Even though cactus is grown in almost every part of Tigray, the major prickly pear cactus fruit producing zones according to Tesfay Alemseged (2003) are the eastern and southern zones. Cactus is estimated to occupy about 36,000 hectares of land or about 11.2% of the total rangeland of the region, with the largest proportion being found in Eastern Tigray. In Tigray, there are about 47 varieties of cactus as identified by farmers. Out of these, only three are preferred and provided with relatively good management by farmers. The remaining 44 varieties are kept as reserve when there exist scarcity of production.

The cactus plant was primarily regarded as a famine food used by people for coping with drought. Its importance thus increases with the manifestation of famine and drought. However, its use has over time surpassed this phenomenon due to increasing vulnerability to drought and the ever increasing uncertainty of other cultural crops in the region.

TRADITIONAL USES OF CACTUS IN TIGRAY

In Tigray cactus, known locally as Beles, is mainly used as fresh fruit in human consumption and the cladodes as animal fodder. Cactus in Tigray provides four major benefits to farmers: 1) source of cash from the sale of the fruit and its cladodes, 2) source of human food, 3) source of animal feed and 4) source of household energy. In addition to the above cactus is beneficial to farmers as fencing material, nectar for honeybees and as a means of biological conservation (Figure 3) which is planted on terraces, bunds and farm lands.

To farmers, cactus allows cash earning through the sale of fruits and renting out cactus gardens to temporary tenants, who mostly use the plant parts as forage/ fodder to their animals (Figure 4.).

Its fruits are eaten directly by people (a phenomenon which happens mostly in the period between June and September) and often as a substitute for other staple foods (Figure 1). For livestock it is a continuous source of feed and is available throughout the year. Most cattle and other animals in the region depend on it entirely during periods of feed shortages, which occur for no less than five months during the year. The demand for cactus is increasing as drought and land degradation continues to increase in the region and elsewhere. Farmers usually plant cactus on stony homesteads and sloppy lands which could no more be used for other crops.

FOOD SECURITY IN TIGRAY

In Ethiopia the extent of food insecurity, which is primarily caused by drought, environmental degradation and low access to and availability of food, has become very alarming. As much as 45% of the nearly 80 million Ethiopian population is affected in drought years. This chronic situation is frequently aggravated by unexpected shocks, and, on average, over five million people (referred to as the chronically food insecure) have been enlisted for a daily relief food year after year over the last decade, even in years when weather and market conditions appear to be favorable. Drought-prone areas with low and variable rainfall, high population density and low natural resource endowments, of which the north-eastern zone of Tigray is a major one, are particularly affected. Nearly half (16) of the weredas (districts) of the region are drought prone and highly food insecure. Annual crop production figures in these districts show that only 27% of the annual food demand of the people is met each year, while the recorded annual food deficit of these districts is 73%. The major reasons for this are: small land holding sizes of subsistence farmers, poor land fertility, low asset levels of farmers, recurrent drought and other hazards of pests, etc, increasing population pressure, low access to markets, etc.

In many parts of Tigray, especially the eastern and southern parts, cactus is used in several ways that enhances certainty towards food security of the people. In some areas, especially in Eastern Tigray where Helvetas runs major operations, cactus constitutes the most important and at times the sole plant resource on which people depend as their major source of livelihood. Moreover, in Tigray, people nowadays tend to grow cactus due to declining soil productivity and recurrent drought and as major way of coping mechanism to stress and famines. There is therefore, an increasing expansion of prickly pear cactus in Tigray, which is explained not only by the plant's strong adaptability but also by farmers' increased need for the plant in view of the degree of environmental degradation (Figure 5) and increased danger of famine.

THE RELEVANCE OF CACTUS TO FOOD SECURITY IN TIGRAY

To quite a large number of areas in Tigray, cactus, as indicated above, constitutes a very important plant resource on which people largely if not entirely depend for their livelihoods. In a pilot (model) village known as Kihen, where Helvetas Ethiopia operates, this situation is manifested quite vividly (Figure 6). The area is a severely degraded one where in relatively good harvest years a farmer is only able to obtain an average of 0.3 tons or less of wheat per year. Often, the village is also known to have received no harvests due to late, erratic or near absent rains during the major cropping seasons of June to September.

The village and its surroundings are noted for their high land degradation, soil erosion and total deforestation (no vegetation) except for the cactus plant, which has become the clear survivor and on which life in the village centers around. In this village one finds the cactus plant in the backyards of every villager fenced by dry masonry rocks (Figure 5). This is also true of many villages in the eastern and southern zones of Tigray. In eastern zone of Tigray, where cactus has been grown for several decades, more advanced cactus cultivation, specialized cactus use, and thriving cactus markets (specially of the fruits) are common sights, as opposed to cases in other areas of the region and elsewhere in the country.

THE STATUS OF CACTUS PRODUCTION IN TIGRAY

Cactus is a plant that is commonly grown in confined homesteads. However, despite contextual uncertainties in creating an enabling regulatory and legal environment associated with the use of hillside-marginal lands limited attempts are observed in planting cactus in "communal" areas. Hence, due to inadequate legal and regulatory support and associated openly accessed hillsides commercial cultivation of the plant could not be realized. As a result of successful promotion efforts being made in recent years the general understanding of the potentials of the crop is widely understood by the public at large. However, due to the absence of specialized know-how, tailor-made regulatory and extension support as well as deep rooted traditional and cultural effects the crop as well as the natural potentials (hillsides) still remains to be underutilized. Despite inadequate institutional support in strategically integrating the crop within the regional and national development programs its immense potentials in attaining food security and wealth creation has got a wider acceptance.

In Tigray, very few pioneering efforts are done in initiating homemade products such as jams, juices, pickles, creams, shampoo, lotions, animal feed, etc (Figure 2 and 8). However, cactus based agro-processing practices are not yet exercised. Knowledge sharing and exposure activities are considered to be an important strategies in facilitating technology transfer associated with industrial processing of jams, juices, pickles, creams, shampoo, lotions, liniments, dyes, medicaments, fiber, animal feed, etc.

Moreover, no significant research, agricultural extension work or private investment activity has to date been carried out in plant improvement, crop production, processing and marketing, and changing traditional attitudes and beliefs that continue to hinder the full exploitation of the plant.

PROMOTION OF IMPROVED UTILIZATION POTENTIALS

As opposed to other countries like Mexico where cactus use started since the last 5,000 years, and where one always finds nopalitos (tender cactus pads) in the normal daily diets, in Tigray despite the recent promotion efforts the use of nopalitos for human consumption, its inclusions in the daily meals still remains to be a challenge (Figure 2).

The current state of utilization of cactus at regional level therefore can be summarized to be in its early stage. This can be mainly attributed to various reasons that relate to finance, capacity and know-how. In other countries that have histories of long years of cactus use traditions and expertise, cactus has been known to be used and commercially exploited in a wide range of purposes including but not limited to: the food industry for the production of canned food and beverages; the cosmetic industry for the production of different creams, lotions, shampoo, etc., the medical industry for the production of different drugs against diabetes, cholesterol, obesity, etc., for suppressing malaria mosquito, for the production of dyes, etc.

THE CPPI CONCEPT

The Cactus Production & Processing Initiative (CPPI) concept was first developed close to the end of 2003 by the Ethiopian Social Rehabilitation & Development Fund (ESRDF), the Bio-economy Association and Helvetas Ethiopia through a close working collaboration with the regional government of Tigray. The CPPI is a multi-institutional concept and a common platform which brings together the works of farmers, local government, research institutions, NGOs, and the private sector in realizing common vision. This platform is designed to steer cactus related multi-disciplinary and multi-partner operations and realize an integrated and cost effective development in such a way that the work of one reinforces and feeds into the other for better results.

The overall goal of the initiative is to develop the full potential of cactus in order to contribute to food security, wealth creation and environmental rehabilitation through: the use of cactus as a value added food and feed; the agro-processing of cactus; the promotion of high quality apiculture; the production of botanicals; the use of cactus to promote biofertilizers and alternative energy (biogas); and the use of cactus for the enhancement of ecological succession.

The CPPI is a regional platform which is currently coordinated by the Agriculture and Rural Development Bureau (BoARD) of the regional government. Moreover, the CPPI is led by a steering committee which consists of all relevant stakeholders including but not limited to the Bureau of Agriculture and Rural Development, Helvetas Ethiopia, Mekelle University, Tigray Agricultural Research Institute, Bureau of Trade, industry and Transport (BoTIT), Relief Society of Tigray, and the Tigray Agricultural Marketing Promotion Agency (TAMPA).

The CPPI steering committee is also now engaged (through a technical committee of experts) in the preparation of a five years strategic plan that is believed to provide the means for the maximum utilization of the plant and for giving the plant more attention than otherwise was the case in the past.

Since the inception of the CPPI concept note, Helvetas Ethiopia has played valuable roles in organizing and financing the January 2004 workshop which resulted in the production of an indicative program document, networking among stakeholders, organizing and facilitating steering committee meetings, preparing documents relevant to the works of the CPPI steering committee, acting as and assuming delegations as the focal and temporary linkage organization of the CPPI, etc.

THE HELVETAS ETHIOPIA CACTUS INTERVENTION

Following the acceptance of the CPPI concept by Tigray regional government and the undertaking of an international workshop on cactus, Helvetas Ethiopia committed itself to making a contribution to the initiative. The Helvetas contribution focused on knowledge management and institutional support of the processes and sub-projects of the CPPI and the establishment of a national network.

During the first phase (2004-2006) the objectives of the project were focused at contributing to a practical knowledge base and education concerning cactus and its products; supporting the CPPI program as a facilitator; establishing knowledge-based networks on cactus locally, regionally and nationally.

In collaboration with its partners and the local communities, Helvetas has since January 2004 accomplished a number of activities including the establishment of the Mekelle Biofarm. During the second phase a total number of 9,403 beneficiaries were trained on various fields, specifically in cactus management, production, processing and marketing activities (Figure 7).

The second phase of the project (2007-2009) was emphasized in facilitation and support for the enhancement of cactus-based product value chains to increase access to local and external markets. The project was engaged in facilitation and support of household empowerment and enhancement of institutional capacities of main CPPI stakeholders aimed on exploiting the multipurpose use of cactus for improved income & food security.

During the second phase a total number of 7,659 beneficiaries were trained on various fields, specifically in cactus-based value chain enhancement, orchard management, processing and marketing activities.

In line with the environmental rehabilitation objectives of the initiative various promotional efforts were made at various levels, starting from farming households up to the regional cabinet. Both phases of the project has created a better insight on the strategic importance of the crop and its potentials for constructing sustainable hillside livelihood in Tigray. In line with these successful results were achieved on identifying strategic institutional and regulatory gaps associated with empowering local communities and utilizing local resources (Beles, hillside, labor etc.) at their disposal to realize rural prosperity. The above efforts have impacted the creation of a regional knowledge base on the role of cactus in adapting to climate change, combating desertification/ controlling soil erosion on hillsides.

On the top of the extensive training operations facilitated during both phases which benefit 17,062 farmers various promotional tasks were implemented. Among others the production of a quarterly cactus and food security newsletter, the use of promotional posters, exclusive promotional music and drams, documentary films, radio and TV programs has significantly impacted the public understanding. Besides knowledge and information exchange was facilitated among the CPPI stakeholders, various consultation forums and food fairs were organized. The establishment of six cactus promotion and marketing centers at various levels were also realized in collaboration with various partners. The creation of strong partnerships with various bureaus, offices, organizations was successfully implemented as a major strategy. In meeting the goals and objectives of the CPPI, Helvetas Ethiopia has also supported the works of other local NGOs who actively work in the development of the plant in various ways. The importance of cactus based knowledge sharing and its relevance to the initiative

The current cactus production system is manifested by subsistent traditional practices and orchards which are confined within small fenced homesteads. Marketing practices in the region are therefore, based on fruit gathering using traditional containers. Due to the above mentioned constraints specialized cactus farmers are still inexistent in the region.

Therefore, the utilization of appropriate production tools and equipment, quality improvement of fruit and pads from homestead, emerging commercial farms on sloppy lands as well as existing wild stands, strengthening of technological and agribusiness capacity and promoting a business climate are considered as instrumental in consolidating the technological and management capacity of the newly emerging improved farming practices. Technology Transfer efforts in this regard can be focused in promoting and optimizing viable hillside & HH orchards for fruit and forage production.

Transforming the existing traditional production system in to semi-commercial production needs the dissemination of technologies associated with quality fruit production, including post-harvest handling as well as cactus vegetable and forage production. Tapping to the existing state-of-the art utilization systems can be used as reference benchmarks in realizing a viable agro-industrial and crafts production.

Furthermore, integrated regional efforts are important to evaluate the national markets and establish viable marketing plans for different value-added products. Establishment of viable herds of small ruminants with mixed feeding patterns, establishment of viable small agro-industrial processing businesses for cactus fruit and pads is considered to be instrumental for integrating livestock production with the initiative. Development of viable commercial value-added cactus chains (business linkages, market information, policy implementation, logistics, support services and trade and retail structures) in this regard can enhance capacity and self-reliance of the local community. In this regard, intensive awareness rising, information, training, extension, festivals, demonstrations and export promotion efforts are considered as ideal strategies in enhancing value-added cactus chains. The newly established cactus products promotion center in Mekelle in this regard will contribute in facilitating knowledge, expertise, technology transfer and promotion.

Generally speaking strengthening cactus based knowledge base and extension activities and the involvement of NGOs and other development actors is very essential to unleash the regional potentials and serve the envisaged goals of the CPPI

CONCLUSION

Since its introduction into Tigray over 168 years ago, cactus has managed to come out as a clear survivor amidst all the environmental degradation existing in the region, mainly because of its high water use efficiency and its high tolerance for dry conditions. Because of its wide range of uses a large number of people in the region depend on cactus for their livelihoods. However, low levels of knowledge, institutional weaknesses and socio-political conditions have hindered advanced cactus production, processing and marketability.

Since the inception of the CPPI, Helvetas Ethiopia and its partners are working towards the maximum utilization of the potentials of cactus for increased food security and wealth creation in the region and elsewhere in the country. However, much work remains to be done in terms of production, knowledge sharing, extension, processing and marketing in order to realize the goals and objectives of the CPPI and assure the utilization of the full potentials of the cactus plant.

In this regard the creation of an institutional capacity to facilitate community empowerment and realization of a regulated hillside user rights associated with Beles based livelihood security interventions is considered as a priority strategy.

As a result the promotion of regulated access to hillsides can be ensured through empowering local communities and creating an enabling environment that fully grants them to decide on using their local resources.

Integrating a Beles based environmental governance component is believed to be the basis for ensuring spatially and temporally dynamic community-based property right systems in the existing openly accessed hillsides.

In view of supporting the farming communities in the drier weredas tailor-made extension packages need to be designed to suit for specific ecological setup associated with the use of cactus as a prime entry point.

Promotion of appropriate technologies, expert advice, specialized training on agribusiness support and initiatives in value-added activities in control, cultivation, harvest, post harvest, processing, packaging and agro-industrial utilization of cactus are considered as strategic components designed to realize the objectives of the CPPI.

Capacity building components associated cactus growers can be effectively initiated as a complimentary community empowerment schemes in model learning location of the region.

Moreover, the promotion of common visions and coordinated institutional perspectives that ensure an efficient implementation of complex and integrated Beles development programs can be facilitated through integrated regional efforts.

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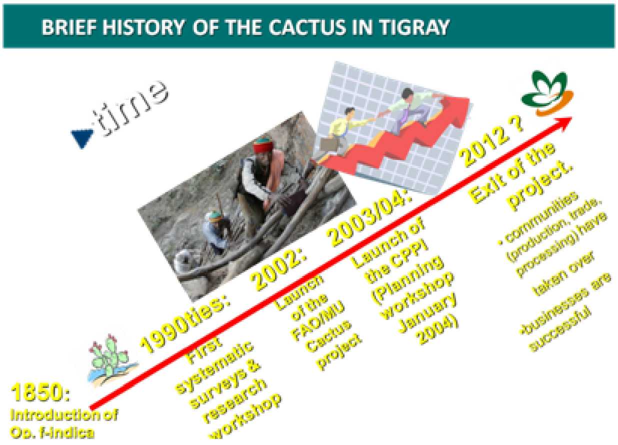

Figure 1.Brief history of cactus in Tigray

Figure 2.Cactus fruit gathering center near Adigrat

Figure 3.Tender green cactus leaves (nopalitos)

Figure 4. Cactus pads planted along contour lines in a Barley field for fruit, forage & soil conservation purposes

Figure 5. Stall feeding of cattle on chopped cactus beside a homestead in Kihen village, Tigray

Figure 6.Green patches of cactus in the highly deforested Kihen village

Figure 7. Transporting cladodes for fodder

Figure 8. Homemade cactus Marmalade and pickles

LIST OF PARTICIPANTS

Abadi Girmay
Tigray Agricultural Research Institute,, Mekelle, Ethiopia,

Abay Woldu
Tigray Bureau of agriculture and rural development, Mekelle, Ethiopia,

Abdurahman Omar
Somali research Institute, Jijiga, Ethiopia,

Abiyot Aragaw
Ethiopian Institute of Agricultural Research, Woere, Ethiopia,

Abraha Gebremariam
Farmer, Hintallo Wejerat district , Wejerat, Ethiopia,

Abraha Kebede
Alamata Agricultural Research Center, Alamata, Ethiopia, abrha96@yahoo.com

Abule Ebro
Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia,

Adehana Seyum
Tigray Land Administration Agency, Mekelle, Ethiopia,

Adugna Abraha
Tigray Agricultural Marketing promotion Agency, Mekelle, Ethiopia

Alemnew Tagele
Amhara region Agricultural Research Institute, Bahirdar, Ethiopia,

Amaha Kassahun
Ethiopian Institute of Agricultural Research, Nazareth, Ethiopia,

Antonio Bustamente
Cochineal Natural Red for the Food Industry, Mekelle,, Ethiopia, jab@foodsafe.cl

Asamene Gebrehawariat
FAO project office in Amahara region, Woldia, Ethiopia,

Asmare Dagnew
Ethiopian Institute of Agricultural Research, Melkassa, Ethiopia,

Awet Estifanos
TARI, Mekelle, Ethiopia, aweyetir@yahoo.com

Azimitachew Ayele
Addis Ababa University, Department of genetics and plant breeding, Addis Ababa, Ethiopia, azimitachewa12@gmail.com

Berhanu Wolde
World vision Ethiopia, Mekelle branch, Mekelle, Ethiopia,

Chris Annen
Helevtas Ethiopia, Mekelle, Ethiopia,

Daniel Dauro
Southern Agricultural Research institute, Hawassa, Ethiopia,

Daniel Hailu
TARI, Mekelle, Ethiopia, Danielzelelew@yahoo.com

Debar Alemseged
Food safe Ethiopia, Mehoni, Ethiopia,

Dechasa Dugassa
Oromiya Bureau of agriculture and Rural development, Addis Ababa, Ethiopia,

Etsegenet Kiflu
Ethiopian Institute of Agricultural Research, Debrezeit, Ethiopia,

Eyasu Abraha
Mekelle Agricultural Research Center, Mekelle, Ethiopia, Gebre32@yahoo.com

Eyasu Mesgena
Erob district office of agriculture and rural development, Dowhan, Ethiopia,

Eyob Kahsay
Axum Agricultural Research Center, Axum, Ethiopia, ek_golla14@yahoo.com

Fekadu Wondimagegne
Ministry of agriculture and rural development, Addis Ababa, Ethiopia,

Feseha Bezabih
Bureau of Agriculture and Rural Development, Mekelle, Ethiopia,

Fetein Abay
College of dryland agriculture and natural resources, Mekelle University,, Mekelle, Ethiopia,

Fikru Haile
Bureau of Agriculture and Rural Development, Mekelle, Ethiopia,

Fiseha Yaye
Bureau of Agriculture and rural development, Mekelle, Ethiopia, fiseha.yaye@yahoo.com

Fitsum Lemlem
Bureau of Agriculture and Rural Development, Mekelle, Ethiopia,

Gebregziabeher Gebreyohannes
Tigray Agricultural Research Institute (TARI), mekelle, Ethiopia, gebregy@yahoo.com

Gebrehiwot Hailekiros
Aheferom District office of agriculture and rural evelopment, Enticho, Ethiopia,

Gebrehiwot Hailemariam
TARI, Mekelle, Ethiopia, Gbiru2000@yahoo.com

Gebremedhin Berhe
Tigray Bureau of agriculture and rural development, Mekelle, Ethiopia,

Gebremichael Negusse
Mekelle Agricultural Research Center, , Ethiopia, Gebre32@yahoo.com

Gebretsadik Reda
Tigray Bureau of agriculture and rural development, Mekelle, Ethiopia,

Getachew Aragie
FAO project office Woldia, Woldia, Ethiopia,

Ghidey Gebremedhin
Tigray Agricultural Marketing promotion Agency, Mekelle, Ethiopia. ghidey2003@yahoo.com

Girmay Asemelash
Tigray Bureau of agriculture and rural development, Mekelle, Ethiopia,

Gizachew Abata
Amhara Bureau of agriculture and rural development, Bahir Dar, Ethiopia,

Habtemariam Atey
Small scale cactus fruit processor, Adigrat, Ethiopia,

Habtu Lemma
Tigray Food Security Coordination Office, Mekelle, Ethiopia,

Hadera Alemayehu
SLM-GTZ, Mekele, Ethiopia,

Hagos Gebru
Tahetay Adeyabo district office of agriculture and rural development, Sheraro, Ethiopia,

Hailay Tsige
GTZ-SLM Tigrat, Mekelle, Ethiopia,

Haile Kiros
Tigray Bureau of agriculture and rural development, Mekelle, Ethiopia,

Hailemichael Abraha
Cactus fruit trader, Adigrat, Ethiopia,

Hailemichael Gessesse
Dimtsi Woyane Tigray, Local Raio station, Mekelle, Ethiopia,

Haileselasie Gebremedhin
Bureau of Trade and Industry, Mekelle, Ethiopia,

Haileselassie Teka
Kilete-Awelaelo district office of agriculture and rural development, Wukro, Ethiopia,

Haileselassie Tsegay
Tigray Bureau of agriculture and rural development, Mekelle, Ethiopia, hailekad@gmaile.com

Haileselassie Wores
Tigray Bureau of agriculture and rural development, Mekelle, Ethiopia,

Hailu Adane
Tigray Bureau of agriculture and rural development, Mekelle, Ethiopia,

Hassen Ali
FAO Addis, Addis Ababa, Ethiopia,

H.E. Hector Valezzi
Embassador, Mexican Embassy, Addis Ababa, Ethiopia,

Ibrahim Fitiwy
College of dryland agriculture and natural resources, Mekelle University,, Mekelle, Ethiopia,

Kebede W/tsadik
Haramaya University, College of Agriculture, , Diredawa, Ethiopia,

Kelayu Adhana
Tigray Science and Technology Agency, Mekelle, Ethiopia,

Kibrom Hadush
Cactus fruit trader, Adigrat, Ethiopia,

Kibrom Tadesse
Bureau of Trade and Industry, Mekelle, Ethiopia,

Kidane George
Ethiopian Institute of Agricultural Research, Melkassa, Ethiopia,

Kidanemariam Shiferaw
Ganta Afeshum district office of agriculture and rural development, Adigrat, Ethiopia,

Kinfegebriel Woldemariam
FAO project office in Tigray, Mekelle, Ethiopia,

Kiros Gebreyesus
Tigray Bureau of agriculture and rural development, Mekelle, Ethiopia,

Mammo Kiflu
Tigray Bureau of agriculture and rural development, Mekelle, Ethiopia,

Markus Ischer
Helevtas Ethiopia, Addis Ababa, Ethiopia,

Masresha Fetene
Addis Ababa University department of Biology, Addis Ababa, Ethiopia,

Meaza Tadelle
Tigray Bureau of finance and economic development,, Mekelle,, Ethiopia,

Mehari Birhane
Bureau of Trade and Industry, Mekelle, Ethiopia,

Mehari Teamerat
Relief Society of Tigray, Mekelle, Ethiopia,

Mehari Woldu
TARI, Mekelle, Ethiopia, Mehari127@yahoo.com

Melese Harife
Abergelle Agricultural Research Center, Abiy Adi, Ethiopia, tumay@yahoo.com

Mesfin Woldu
Mekelle urban agriculture office, Mekelle, Ethiopia,

Mezegebe Tsegay
Bureau of Agriculture and Rural Development, Mekelle, Ethiopia,

Mitiku Haile
Mekelle University, , Mekelle., Ethiopia ,

Mitselayl Kiflay
Ecopia Plc (Ecological Products of Ethiopia, Addis Ababa , Ethiopia,

Mohammed Abduletif
Afar Agricultural Research institute, Semera, Ethiopia,

Molla Biyadegelegne
Mereb –Leke district office of agrioculture and rural development, Ramma, Ethiopia,

Muez Teare
Bureau of Agriculture and Rural Development, Mekelle, Ethiopia,

Mulualem Kidane Mariam
Bureau of Information, Mekelle, Ethiopia,

Mulugeta Gebreselassie
Tigray Bureau of Agriculture and Rural development, Mekelle, Ethiopia, mulgeb12yahoo.com

Negusse Hagazi
TARI, Mekelle, Ethiopia, niguseh5@yahoo.com

Rutha Tsegai
Ecopia plc, Addis Ababa, Ethiopia,

Saba Gebreyohannes
Helevtas Ethiopia, Mekelle, Ethiopia,

Seifu Bekelle
Seygis consulting, Addis Ababa, Ethiopia, Seygis@gmail.com

Susan Minaeie
FAO-SSG, Agribusiness, Addis Ababa, Ethiopia,

Tadesse Yehualashet
Bureau of Agriculture and rural development, Mekelle, Ethiopia, tadyohd@yahoo.com

Tesfamariam Assefa
Tigray Bureau of agriculture and rural development, Mekelle, Ethiopia,

Tesfay Alemseged
Helvetas Cactus Development Project, Mekelle, Ethiopia, tesfayalemseged@gmail.com

Tesfay Belay
TARI, Mekelle, Ethiopia, belayreda@yahoo.com

Tilahun Geletu
Oromiya Agricultural Research Institute, Addis Ababa, Ethiopia,

Tirfinesh Yimer
Tigray Bureau of agriculture and rural development, Mekelle, Ethiopia,

Tsegay Okubay
Tigray Agricultural Marketing promotion Agency, Mekelle, Ethiopia

Twelde Yedeg
Hentalo-wejerat district office of agriculture and rural development, Adigudom, Ethiopia,

Woldegabriel Woldehawaria
Tigray Bureau of agriculture and rural development, Mekelle, Ethiopia,

Woldeyessus Gebremariam
Tigray Bureau of agriculture and rural development, Mekelle, Ethiopia,

Workneh Negatu
Addis Ababa University, Addis Ababa, Ethiopia,

Yemane Hadgu
Cactus trader, Mekelle, Ethiopia,

Yosef Abraha
The Yordanos Hotel , Mekelle, Ethiopia,

Zewdu Atsebeha
Small scale cactus fruit processor, Adigrat, Ethiopia,

Enrique Arias
FAO, Rome, Italy, enrique.arias@fao.org

Paolo Inglese
Dipartimento di Colture Arboree, Università di Palermo, Palermo, Italy, pinglese@unipa.it

Innocenza Chessa
Dipartimento di Economia e Sistemi Arborei, Università degli Studi di Sassari, Sassari, , Italy, chessa_i@uniss.it

Eunice W. Githae
Department of Land Resource Management and Agricultural Technology, University of Nairobi, Nairobi, Kenya, egithaeh@gmail.com

Kaltouma Achahour
Sahara Caactus, Sidi Ifni, Morroco, achakal@hotmail.com

Helmuth Zimmermann
Consultant, PPRI , Pretoria, South Africa,

Brigite Kauf
Helevtas Zurich, Zurich, Switzerland,

Esther Kunhe
Helevtas Zurich, Zurich, Switzerland,

Kasper Grossabacher
Helvetas Zurich, Zurich, Switzerland,

Thomas Mbeyela
National Artificial Insemination Centre, Department of Farm Management and Nutrition, Arusha, Tanzania,

Ali Nefzaoui
General Coordinator of FAO-ICARDA Cactusnet. Livestock and rangeland scientist, ICARDA North Africa Program, a.nefzaoui@cgiar.org

Milton T. Makumbe
Ministry of Agriculture, Mechanisation and Irrigation Development (AMID), Henderson Research Institute, Mazowe, Zimbabwe