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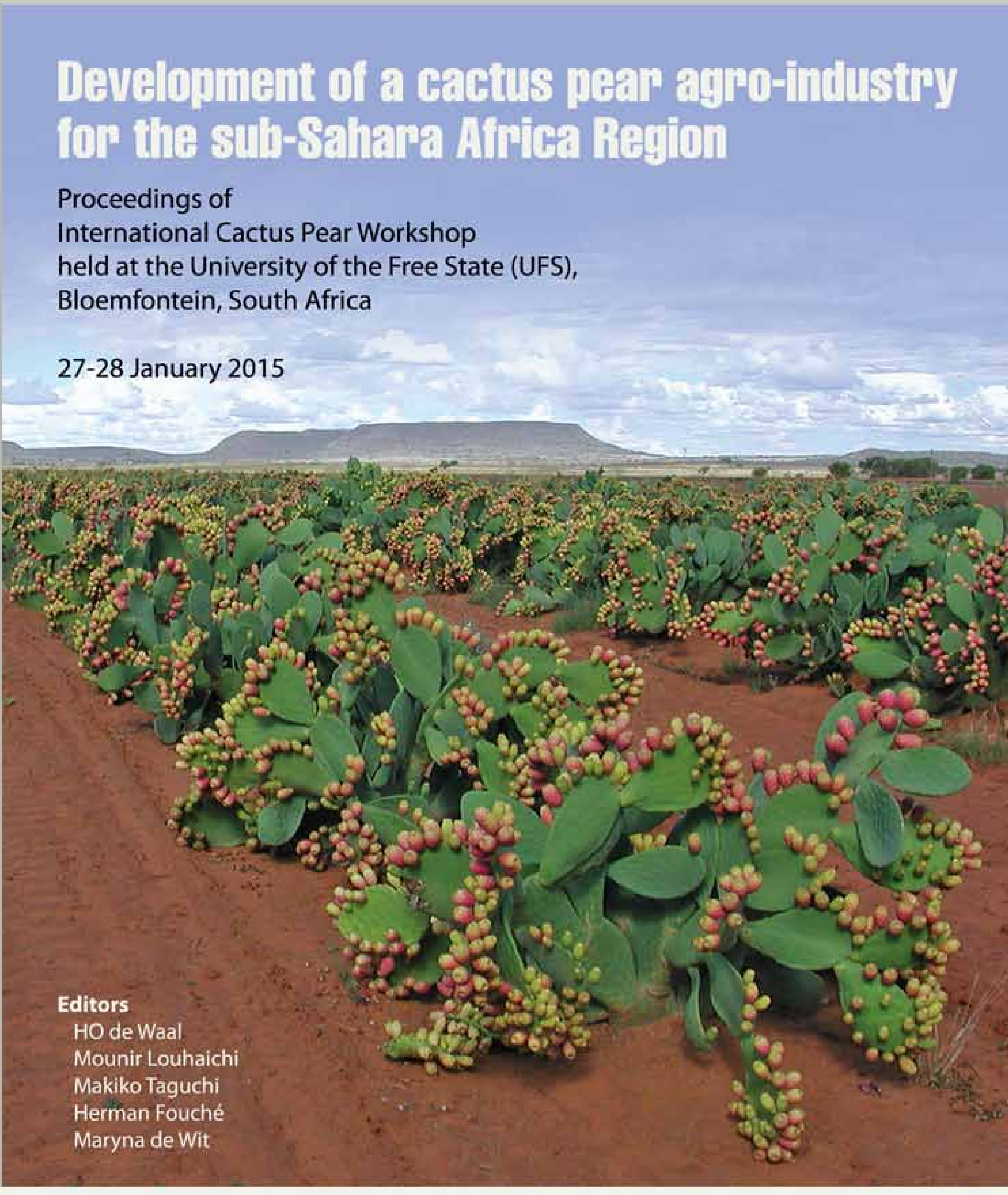
Development of a cactus pear agro-industry for the sub-Sahara Africa Region

Proceedings of
International Cactus Pear Workshop
held at the University of the Free State (UFS),
Bloemfontein, South Africa

27-28 January 2015



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CACTUSNET
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Foreword

Cactus pears are well-known for various reasons in South Africa. They were introduced to the Cape more than 300 years ago and later transported by pioneers to the interior of the subcontinent. Spiny forms gradually resulted in dense, impenetrable thickets in some regions, specifically the Eastern Cape. These invasions of so-called prickly pears severely impacted on agriculture, despite it being utilized by people and livestock.

In the early 1900's spineless cactus pears *(Opuntia ficus-indica* and *O. robusta)* were imported from the Burbank collection in California to Grootfontein in the Eastern Cape. The past few decades, fruit production from spineless cactus pear *(O. ficus-indica)* cultivars for local markets and export has gained momentum. The plants are pruned annually to stimulate production of quality fruit and the fresh cladodes are used as livestock feed.

The Cactus Pear Team, a group based at the University of the Free State (UFS) in partnership with the Agricultural Research Council (ARC-API, Bloemfontein), initiated a research and development programme to support the growing spineless cactus pear industry. Demands on the scarce water resources created a need to find alternative sources of animal feed; specifically crops that use water more efficiently. This focus is in line with initiatives to mitigate the negative impact of global warming. One alternative plant with the potential for widespread production is the spineless cactus pear *(O. ficus-indica)*. It is well adapted in dry environments, producing large yields of cladode dry matter and fruit and is a versatile multi-use crop with applications for humans and animals.

The Free State Department of Economic Development, Tourism and Environmental Affairs joined the Cactus Pear Team when the initiative was broadened with the Spineless Cactus Pear *(O. ficus-indica)* Development Programme at the Oppermansgronde, a farming community in the dry south-western Free State Province. Production of spineless cactus pear is now promoted as a multi-use crop to form the basis of vibrant agro-businesses.

Processing of cactus pears is still limited in South Africa, but the development of agro-businesses is rapidly gaining momentum. Fruit is processed to form jams, marmalades and syrups. Fruit juice can be consumed fresh or processed as fruit jelly; fruit pulp can be frozen, used in ice cream desserts, or blended with other juices such as apple and grape juice. Various processed products for human consumption are also derived from fresh and dried cladodes.

At the UFS, cladodes are processed and used in balanced livestock diets. Cladodes are cut in strips, followed by sun-drying and coarsely grinding the sun-dried cladode strips. The water content is reduced, making the material less bulky and easier to transport, store, and incorporate in balanced livestock diets. Recently, another initiative was started by developing practical methods to mash excess cactus pear fruit and preserve the mashed fruit with dry straw and hay as kuilmoes; a high water content livestock feed, akin to conventional silage.

The past decade the Cactus Pear Team has interacted with specialists and attended several International Congresses. In 2012 five specialists visited Mexico, Chile and Argentina to gain first-hand experience on current focus and cactus pear initiatives in these countries. They also attended the VIII International Congress on Cactus Pear and Cochineal during October 2013 in Palermo, Italy. In the plenary session, Dr. Ali Nefzaoui, the outgoing General Coordinator of the FAO-ICARDA CactusNet presented a review of *"Twenty Years of Steady Efforts: Lessons learned and Food for Thoughts."* He eluded on the value of cactus pears and made a strong case for the FAO-ICARDA to include sub-Sahara and specifically the southern African region as a major intervention area for future activities.

In addition to customary scientific interactions with scientists and other role players at the Congress in Palermo, the opportunity was welcomed to renew old and make new acquaintances with specialists from several continents. During discussions with specialists and members of the FAO-ICARDA CactusNet, it was suggested that South Africa should consider arranging an international workshop on cactus pear.

Encouraged by the verbal international support, the Cactus Pear Team started liaising and initiated arrangements for an **International Cactus Pear Workshop** with participation by invited international specialists as well as local scientists, producers and other role players. The envisaged workshop was to target sub-Sahara Africa and specifically southern Africa as a major intervention area in the focus of FAO-ICARDA CactusNet. Key aspects such as horticultural practices, pests and diseases, genetic resources, animal food, human food, pharmaceuticals, medicine and industrial uses were clustered as four themes in the programme, namely: genetic resources, human food, animal food, and industrial applications.

Definite outcomes were envisaged, such as informing the local spineless cactus pear research and development programme to identify needs and priorities, establish local and international networks, explore the possibility of attracting international funding, and enhance the role of the scientific grouping in sub-Sahara and specifically southern Africa.

A group of International Advisors interacted with the Cactus Pear Team and other South African colleagues at the Oppermansgronde where the spineless cactus pear is promoted as a multi-use crop for agro-businesses.

At the conclusion of the Workshop the group of International Advisors assisted the Cactus Pear Team to conceptualise and develop a **Sub-Sahara Africa Region Framework for Cactus Pear Research & Development.** The identified outputs and activities in the Sub-Sahara Africa Region Framework are presented in the **Proceedings of the International Cactus Pear Workshop** and can be used for implementation by relevant role players.

The **International Cactus Pear Workshop** at the UFS in Bloemfontein was attended by 59 persons from 14 countries, namely: Argentina, Botswana, Brazil/USA, Chile, Ethiopia, France, Italy, Jordan, Mexico, Mozambique, Namibia, South Africa, Tunisia and Zimbabwe.

The **International Cactus Pear Workshop** was presented with the goodwill, support and sponsorship of the

- *Food and Agriculture Organization (FAO) of the United Nations (UN)*
- *International Center for Agricultural Research in the Dry Areas (ICARDA)*
- *International Technical Cooperation Network on Cactus Pear (CactusNet)*
- *Mexican Ministry of Foreign Affairs - the Mexican International Cooperation Agency (AMEXCID)*
- *South African Department of Science and Technology (DST)*
- *University of the Free State (UFS)*

It was a privilege to receive and host the large group of esteemed international and national participants at the **International Cactus Pear Workshop** on the campus of the University of the Free State in Bloemfontein. Many old acquaintances were renewed and new and lasting friendships made.

Keep well.

Cactus Pear Team
Bloemfontein, UFS

WELCOME addresses

Sub-Saharan Region of FAO-ICARDA CactusNet

Cactus pears played an important role in the South African Agricultural sector for more than 300 years. The spiny genotypes became invaders in the Eastern Cape in 1850's and that damaged the popularity of this promising crop. A hundred years ago the Burbank (spineless) genotypes were imported as a drought forage and played an important role in the arid regions of the country. An exciting period started about three decades ago when the fruit potential was investigated and the crop became a semi-intensive crop. During the proceedings of this workshop it will be demonstrated that this is one of the most versatile crops in the world. This crop has the potential to mitigate drought risk of many African countries and to stabilise the food base of man and animal.

Under the encouragement and support of FAO-ICARDA CactusNet it was decided to organise a Workshop in South Africa. The aim was to firstly give local interest groups exposure to the cream of the world's cactus pear researchers and secondly to develop a cactus pear research and development framework for the sub-Sahara Region of the international FAO-ICARDA CactusNet.

We are very privileged to welcome the participants to this prestigious event. It was a dream come true to have you all here, and we welcome you as old friends. We hope that you will enjoy your stay here and we want to thank you in advance for your valuable contribution over the next few days to this Workshop.

A special word of thanks to Ms. Makiko Taguchi (FAO, Rome) and Prof. HO de Waal (UFS) for managing the bureaucracy and make the final arrangements in the space of two months over the traditional Christmas and New Year holiday period in South Africa. Well done!

A special thanks to the Cactus Pear Team and the Organising Committee for spending many hours in high spirit and devotion to let this happen.

Prof. HO de Waal (Convener)
Dr. Gesine Coetzer
Mr. Willie Combrinck
Dr. Maryna de Wit
Mrs. Albie du Toit
Dr. Herman Fouché
Mrs. Reanette Rademeyer
Prof. Wijnand Swart

We hope that this is the beginning of a long partnership with very exiting outcomes.

Herman Fouché

Coordinator: Sub-Saharan Region of FAO-ICARDA CactusNet

Food and Agricultural Organization (FAO) of the United Nations (UN)

FAO (Food and Agricultural Organization of the United Nations) is honoured to support this important International Cactus Pear Workshop for development of a cactus pear agro-industry for the sub-Sahara Africa Region. Deep gratitude goes to the University of the Free State for their commitment to make this workshop happen, in particular Prof. HO de Waal and the Cactus Pear Team for their tireless work. Equally, Dr. Herman Fouché's effort as the CactusNet Sub-Sahara Africa coordinator to make this event successful must be mentioned and thanked. Last but not least, the gratitude extends to the government of Mexico for their support in bringing the Mexican experts to this key event.

FAO is a founding member of the FAO-ICARDA Technical Cooperation Network on Cactus (CactusNet) since its birth in 1993. The network has been steadily growing as an international group of people dedicated to research and development and utilization of cactus. Currently the General Coordinator is Prof. Paolo Inglese from the University of Palermo and Dr. Mounir Louhaichi from ICARDA as Deputy Coordinator. I have had the pleasure to be involved in this dynamic group since 2011.

FAO's overall goals are: the eradication of hunger, food insecurity and malnutrition; the elimination of poverty and the driving forward of economic and social progress for all; and, the sustainable management and utilization of natural resources. We have put forth a new paradigm for sustainable production intensification called "Save and Grow" to move towards achieving this goals.

Faced with the challenges of climate change - more specifically drought conditions - in this region and beyond, cactus pear (*Opuntia* spp.) is gaining more interest globally. The versatility or multiple uses of this crop is outstanding, and I believe it can contribute to improving livelihoods of many in the region. In alignment with the "Save and Grow" approach, the crop can contribute to rangeland restoration, integration of crop and livestock systems, provide more opportunities for people, especially women to have income generating possibilities with the value chain approach.

FAO is committed to continue supporting CactusNet and its activities to promote the use of this underutilized crop. The outcome of this workshop will be a key in the advancement of cactus pear in the region.

Makiko Taguchi

Agricultural Officer, Plant Production and Protection Division CactusNet FAO focal point

International Center for Agricultural Research in the Dry Areas (ICARDA)

Dear colleagues and friends of the FAO-ICARDA CactusNet,

It is my pleasure to participate in this workshop and to contribute to the development of a Sub-Sahara Africa Regional Framework for Cactus Pear Research & Development.

On behalf of the International Center for Agricultural Research in the Dry Areas (ICARDA), I would like to express my gratitude to the host country and in particular the University of the Free State (Bloemfontein, South Africa) for hosting this event and for their generous hospitality.

Though I am new to the Cactusnet (I was nominated during the last congress held in Palermo in November 2013), I feel like I have been with this large family for many years. This network brings together the best scientists/experts globally on cactus pear and cochineal that are committed to the mission of the network. Last year through the Cactusnet we were able to introduce elite accessions from Latin America (Brazil) and Europe (Italy) to South Asia (India and Pakistan) as well as West Asia (Jordan and Lebanon). Several factsheets have been produced and many more will come soon.

Sure we have a lot of work ahead of us as we are facing great challenges including climate change (in particular recurrent droughts), land degradation and desertification, biodiversity loss, food insecurity, instability and limited funding opportunities. However, working together we can overcome these challenges and create opportunities.

As you may know ICARDA is leading the CGIAR Research Program on Dryland Systems with some 80 institutions cooperating in research sites extending from South and Central Asia to West Asia, Eastern and Southern Africa, North Africa, West Africa, and the Dry Savannas. It provides a new platform for testing and delivering technology and policy packages on a much wider scale. The program combines the strengths of international research, regional bodies, and local partners. It aims to develop new technologies, new livelihood opportunities, and strengthening local institutions, enabling policies to support technology adoption, and ultimately higher incomes and better lives for the poorest and most vulnerable households. As a result the FAO-ICARDA Cactusnet is in a good position to share expertise on cactus pear in many countries. Recently work has been done in India, Pakistan and Jordan to promote *Opuntia ficus-indica* as forage and prior and current work continues in North Africa and Gulf region as well.

I am sure most of you had a chance to surf through our new website. If you have not, please do so by visiting http://www.cactusnetwork.org/home.html. We are open to any constructive feedback. If you have good suggestions that enhances the content of the website, please let us know. Also, try to share with us relevant materials including publications (papers, manuals, and factsheets), photos, and web links to enrich the site. I would like to take this opportunity to ask those who are not member of the CactusNet to join and become an active member. There is no membership fee and the application process only takes a couple of minutes to complete.

Finally, I would like to thank the Cactus Pear Team at the University of the Free State in Bloemfontein, South Africa for their hard work in taking care of all the logistics and offering us a rich program in a very nice venue for this Workshop. Special thanks also go to FAO for their continuous support of the network and to the Government of Mexico for sponsoring the participation of the Mexican delegation.

I look forward to a successful workshop that will lead to the prior set goal of developing of cactus pear (*Opuntia* spp.) agro-businesses for the sub-Sahara Africa Region.

Thank you for your attention.

Best regards

Mounir Louhaichi

Deputy General Coordinator: FAO-ICARDA CactusNet

International Technical Cooperation Network on Cactus Pear (FAO-ICARDA CactusNet)

Dear Colleagues and friends,

I wish to thank our colleagues, particularly HO, Herman and their group, for having organized this meeting that brings the CactusNet to South Africa again, almost 20 year after the II ISHS Cactus Congress was held in Midrand by Marco Brutsch. I cannot forget that when I began to work on cactus pear, the first book I was able to read was 'Spineless Prickly Pears' written by A.B. Wessels. My memories, our memories honour this great scientist and dearest friend.

I do not want to underline, once more, the importance of being here, that is so clear to all of us. I do want to remind, first to myself, and to all of you what this group has been able to accomplish in the last 20 year.

The idea of having a network came out in 1992 during the 2nd International Congress on Cactus Pear and Cochineal held in Santiago de Chile. It was during the spare time between the sessions and during wonderful lunches and banquets that the idea took its shape. We were lucky enough to have a good friend at FAO headquarters whose love for cactus is second only to hot chili pepper! We soon had the charter ready and in August 1993, in Guadalajara, Mexico, the network had its official establishment, with 14 participating countries that soon became 23.

If one goes to check the objectives and the recommendations of the 1st meeting, it will be clear that the network never lost its track: from technical FAO bulletin and books (3), to newsletters, seminars, symposia, technical support to rural people, and participation to FAO regional projects.

I can, with no doubt, say that we have been working so hard to set a new deal of knowledge and technical competence on all aspects concerning cactus pear ecology, physiology and utilization, that will remain a corner stone to anyone interested in this species now and the years to come.

When we started, there was neither any scientific cooperation nor any kind of common view or strategy. We have recently celebrated the VIII ISHS congress and if you go to the ISHS website you can download all the last 6 issue with 275 articles, starting from South Africa 1996. Cactus pear is now a well-recognized fruit tree crop worldwide and even more important is its role as forage crop. I remember how a great member of our network, a great agronomist, Dr. Henry Le Houérou supported the idea of increasing the knowledge on cactus pear in arid areas. Together, we wrote to FAO to ask for including *O. ficus-indica* and related species in FAO statistics. We failed, because, as they wrote 'there is no reliable stats in all countries were the species is cultivated'. So cactus is still under 'miscellaneous' and I strongly believe this is a great mistake that does not pay for the great role that this species play in developing countries where most of FAO interest should be.

Technical cooperation with new Countries or developing Countries has been also undertaken. Just have a look on FAO website; you will see our cactus pear is the 'crop of the month'! Ethiopia, Cuba, Bolivia, Algeria, Argentina, Jordan and Morocco are some of the Countries where FAO technical projects are taking place. Thanks to the network, in Tigray (Ethiopia), families now use 'nopalitos' in their diet and improved their small backyards with new cultivars. Thanks to the network, Argentina, Libya, Pakistan, Algeria and Jordan have new experimental orchard with varieties from all over the world. We have a common 'language' to describe new accessions, since we published the 'Descriptor list' in 1997. When I go back to see what we have now and what we used to have 20 years ago, I know we have paved a new, comfortable, road.

I know we have been working not only for science, for our personal achievements, but most of all, for a common dream that became a daily project for each one of us.

This network, dear friends, is unique. It is unique in terms of scientific achievements and technical cooperation; it is unique in terms of sharing friendship and knowledge with no limits; it is unique in terms of re-generating ideas and objectives. Its strength depends on individual efforts as well as on the capacity to rely on our colleagues and to act as a group, always.

We need to thank FAO and, then, ICARDA for their visionary and continuous support. We have to thank not only the Institutions, but the people themselves. You do not need me to tell you their names, you all know them, but since paper will stand the test of time, I want to recognize the work being done by Enrique Arias and Makiko Taguchi on the side of FAO and Ali Nefzaoui and Mounir Louhaichi for ICARDA.

The network has new jobs to accomplish. The first one is to work on the 2nd edition of the glorious FAO Plant Production and Protection Paper 'Agro-ecology, cultivation and uses of cactus pear' that celebrates its 20 years in 2015. I am officially been asked to endorse my request to FAO for a 2nd edition to be published early in 2016. We will be working on it to deliver the contributions within 2015. It is strongly requested and we have to do it, again!

Africa, to conclude, is one of our major targets. Indeed, cactus pear is a cash crop in some countries, but it is even a more important key crop for subsistence agriculture in semi-arid regions of the world.

To develop cactus pear knowledge in Sub-Sahara Africa is one of our most important goals. We need a tight cooperation to accomplish it. We need to develop good documents for the decision makers and clear information for the stakeholders, the donors and the rural people.

We are here to work on this target together with our South African colleagues who are strongly committed to this goal.

We can do it; we want to do it, because we know cactus pear is a treasure, a wonder, a real major crop. This network is a treasure itself; your friendship is a treasure to me.

Thank you for your kind attention and enjoy the meeting.

Paolo Inglese

General Coordinator: FAO-ICARDA CactusNet

Cactus pear fruit production: orchard planting and management of *Opuntia ficus-indica*

GIORGIA LIGUORI AND PAOLO INGLESE

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Abstract

Cactus pear (*Opuntia ficus-indica* L. Mill.) is cultivated in a wide range of environments with large differences in crop potential, orchard systems and management. These differences may be related to temperature and rainfall range (water availability) but also to the day/night length and, of course, to soil characteristics. This leads to considerable variability in the field and in fruit quality. Crop value heavily depends on crop variability in terms of fruit size, which is the major factor for fruit price in Europe. The increase of crop value very much depends on regular cultural practices such as irrigation and fruit thinning, but it is also dependent on plant crop yield and architecture.

CULTIVARS

Cultivars for fruit production can be distinguished by the colour of the fruit peel and ripe flesh, which can be purple-red, yellow-orange, white-cream or greenish. Red, yellow and white fruit are present in all the cultivated areas whilst green fruits, with a white-greenish flesh, can be found only in Chile and Peru (Mondragon-Jacobo and Pimienta Barrios, 1995). Cultivars differ also in terms of plant shape, vigour, fertility, cladode and fruit size, fruit ripening time, seed count and ability to reflower (Barbera and Inglese, 1993; Pimienta Barrios, 1990; Wessels, 1988).

In Italy, the germ plasm of Sardinia and Sicily have been investigated and described with major differences occurring for fruit size, flesh firmness, fruit ripening time. However, the absolute lack of any commercial nursery activity account for most of field variability which is usually encountered in the Sicilian industry. No more than 12 accessions have been described in Sicily, including a low seeded one and a spineless which are considered unstable mutations. The best-appreciated fruits by the international markets have a yellow-orange flesh, such as *Gialla,* however, consumers unfamiliar with this fruit are highly stimulated by red fruits, which they buy first, because of their intense colour. Fruits with white or greenish flesh are relevant only for regional or local markets, and their international trade is not relevant.

PRE-PLANTING OPERATIONS

The soil should be ploughed to a depth of 60-80 cm, in order to ensure a good drainage, alternatively the soil should only be cross ripped with a chisel to improve drainage and avoid alteration of soil profile. In sandy soils and soils free from weeds, pre-planting operations could be restricted to single holes in the rows.

Management of the cladodes before planting

It is recommended to use bordeaux paste, as well as 0.4 ml of methridathion or 1 g litre^{-1} of copper oxichloride, for cutting disinfection prior to planting.

Planting material

Single or multiple cladode cuttings are commercially utilised for orchard establishment. Single cuttings can be one- or two-years-old, and their surface area and dry mass have a significant influence on successful field rooting and subsequent budding. A surface area of 500 cm^2 or a dry mass of 70-100 g allow a good plant growth. Other sources of variability of cladode rooting and subsequent plant growth in the field involve the age of the mother plant and its sanitary conditions, planting depth, cladode surface area that is left above-ground, soil temperature and soil water content (Brutsch, 1979; Wessels *et al.*, 1997). Multiple cuttings are made of a 2-year-old cladode bearing, on its crown-edge, one or two 1-year-old daughter cladodes. The advantage associated with the multiple cladode cutting is the rapid formation of plant structure, which results in early fruiting after planting, while it requires a larger number of planting material that increases planting costs.

- The rows should be oriented north-south to maximize PAR (Photosynthetically Active Radiation) interception and cladodes faces perpendicular to the rows.
- Depth of the hole in the row: 50 cm; eventually the hole should be filled with cow manure or hand fresh soil with 30 g of N.
- Cladodes should be planted upright with the cut end in the ground, and is recommended to place half of the cladode underground.
- Cladodes should be irrigated soon after planting.

Planting time

Late spring is the period for planting in the Mediterranean area, considering that root and cladode reach their highest growth rate during late spring and early summer (Wessels, 1988), and soil water content in late spring is high enough to allow root development in areas with winter rainfall. Planting at the end of the summer slows down the development of the root system and the canopy due to low winter temperatures and reduced daylight.

Orchard design

Orchard design, in terms of plant layout and spacing, include a) hedgerow systems, with plants placed closely within the row, and b) squared or rectangle lay out, with plants trained to a globe, and well separated from each other.

Modern or hedgerow plantations utilise 2 m within the row and 6 m in between (835 plants ha^{-1}). Such close spacing increases the number of fertile cladodes on hectare basis, in the early stages of orchard life and results in continuous canopies, which require high pruning frequency and intensity to avoid within-plant shading and reduction of fruit quality. Pruning are usually left on the ground in the alley and eventually chopped mechanically.

If trees are spaced in a rectangular or squared layout, plants are usually trained to a bushy-type globe. In Italy, plant spacing ranges from 4 x 6 m (416 plants ha^{-1}) to 5 x 7 m (290 plants ha^{-1}).

PLANT TRAINING AND PRUNING

Cactus pear plants are usually trained in the form of a globe with 3-4 main stems and a high number of fertile cladodes mostly distributed around the outer portion of the canopy. Correct pruning may regulate resource allocation among the various canopy sinks and maximise light distribution within the canopy to support cladode growth, flower bud formation and fruit growth.

Cortazar and Nobel (1992) showed a marked increase of vegetative vs. reproductive growth as a result of high density planting systems; Inglese *et al.* (1994) investigated the source to sink relationship on mature fruiting plants, indicating a massive carbon flow of assimilates among cladodes of different age and the competition of fruit vs. cladode growth, with their relative strength changing along with the developmental stages of the seasonal growth of fruit and cladodes (Inglese *et al.*, 1999). Most of actual photosynthesis is made by current season and 1-year-old cladodes, while older cladodes serve as a pool of stored carbohydrates and N, which can be used to support fruit and current-season cladode growth (Inglese *et al.*, 1994; Nerd and Nobel, 1995).

Flower buds differentiate in terminal, well-exposed 1-year-old cladodes whose dry weight exceeds a minimum value for its surface area by at least 33 g (Garcia de Cortazar and Nobel, 1992).

Moreover, cladode shading affects fruit growth in terms of size and ripening time (La Mantia *et al.*, 1997). To avoid alternate bearing, the plant must produce every year the same number of new cladodes which will be fruitful one year after being formed; new cladodes develop on 2-year-old and even older cladodes. Thus, to get an accurate seasonal balance between vegetative and reproductive growth, the plant needs a constant number of 1-year-old (fruit production) and 2-year-old cladodes (new cladode production). As a rule of thumb, no more than two daughter cladodes should be retained on a parent cladode to maximise their development.

The number of fruiting cladodes that should be left on the plant depends on plant spacing and range from 100-120 for 350-400 plants ha-1 to 20-30 for 1,000-1,200 plants ha^{-1}.

Pruning recommendations:

In the first two years, remove inner cladodes and those oriented downwards, horizontally or close to the ground (Photo 1); it is recommended to clean the pruning tools with Bordeaux paste after use.

- Leave no more than 2 daughters cladodes on a parent cladode;
- remove developing cladodes from fertile parent cladodes;
- avoid pruning during rainy or cold periods;
- avoid summer pruning, unless for summer growth;
- control the plant height at 2-2.5 m.

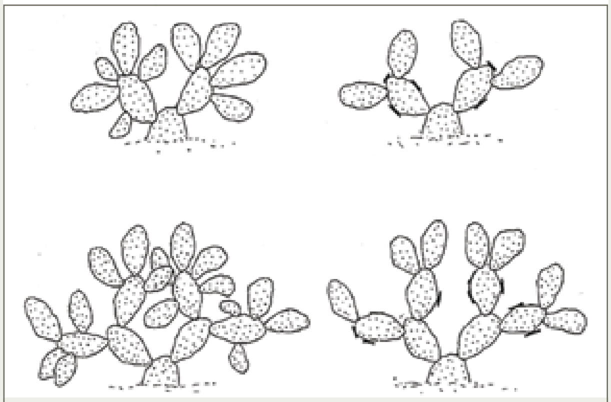

Photo 1. Pruning during second and third year from planting.

NUTRITION AND FERTILISATION

The common fertilisation practice in Sicily is to supply 80-100 kg N ha^{-1} in spring (60%) and in summer, through fertigation, at spring flush removal time and soon after fruit set (40%). Urea and 20-10-10 are commonly applied.

FRUIT THINNING

Cladodes bearing from 3 to 7 flowers are the most common and account for 50%-60% of plant fertility, but well-exposed cladodes might bear, along their crown-edge, even 25 or 30 flower buds, most of them setting fruits. Fruit growth rate and harvest size decrease with fruit number per cladode, when more than six fruits are left on a fruiting cladode (Inglese *et al.*, 1995). Thinning times are from 2 weeks before bloom to 2 weeks after set, is recommended to maintain no more than 6 fruits for each cladode. Thinning must be applied together with irrigation to get a significant increase in fruit size and percent flesh (La Mantia *et al.*, 1998). The effect of fruit thinning depends also on the number of fruits per cladode prior than thinning; the longer the time the fruits are retained on the cladode, the strongest being the effect of the fruit number on final fruit size (La Mantia *et al.*, 1998).

IRRIGATION

In the Mediterranean areas of southern Italy, the plant requires supplementary irrigation to get adequate yields and fruit quality. Both cladode fertility and fruit growth benefit from irrigation. Several authors reported that 2 to 3 irrigations (60-100 mm), applied during the earliest stages of fruit development (within 40 d after bloom), increases yields, fruit size and flesh percentage.

If irrigation is applied only two to three times during the dry season, the use of furrows may be an easy-to-apply and inexpensive method. Localised micro-sprinklers, which cover a relatively large soil surface area with small volumes, meet the characteristics of the cactus pear shallow root system. Drip irrigation can be also utilised, particularly when irrigation is applied during most of the season, as it occurs in Israel. Seasonal volume ranges from 60 to 80 mm in Italy.

HARVEST

The harvesting season of cactus pear fruits lasts for a relatively long time. In the northern hemisphere the main summer crop lasts from late June to mid-September depending on cultivar and environmental conditions. The earliest crop comes from late July at the foothills of the Etna Volcano and the late crop comes in October-November as a result of the removal of the main spring flush (Barbera *et al.*, 1992). A winter crop comes in winter time (December to March) as a result of a second scozzolatura and plant growing under plastic tunnels applied at the end of November when temperature are too low to allow regular fruit development and sugar accumulation (Liguori *et al.*, 2006).

Fruits are delicate and require care in picking and handling. Fruits should be picked at peel colour breakage, manually with thick gloves and glasses to avoid injuries from glochids. It is recommended to start picking early in the morning, when glochids are wet and stick to the fruit. The cut must include a thin layer of the parent cladode to prevent rapid loss of fruit weight and preserve storability.

OUT-OF-SEASON CROPS

In Italy, a second flowering is obtained as a result of the complete removal of the spring flush of flowers and cladodes (scozzolatura) (Liguori *et al.*, 2006) (Photo 2-3). The spring flush removal (SFR) takes place when the main bloom occurs, between the end of May and the last week in June in the northern hemisphere, and in October in the southern hemisphere. The new flower buds develop on the fertile cladodes of the natural flush, and the reflowering index, defined by the ratio of second versus first flush flowers, is highest for cladode with a natural fertility of 5-10 flowers, then it sharply decreases with 1st flush flower number. Removal time affects cladode reflowering rate; removing flowers at a pre-bloom stage results in the highest reflowering rate, whilst removing the spring flush after petal shedding reduces reflowering by up to 50% to 70%.

A new strategy has been recently developed, which allows growers to get out-of-season crop in late winter or early spring (Liguori *et al.*, 2006). The strategy is based on the potential of the plant to reflower even after a double spring flush removal: the first in early June with the removal of the spring flush and the second in late June with the removal of the second,

Photo 2-3. Complete removal of the spring flush of flowers and cladodes of *O. ficus-indica* (scozzolatura).

Photo 4-5. Out-of-season production of *O. ficus-indica* trees in PVC tunnel.

induced flush. The rate of this second reflowering (third flush) is very uneven, ranging from 20% to 40%. The plant will bloom during the first half of August and the fruit would ripen in December, with a fruit development period (FDP) of 100-140 days (Liguori *et al.*, 2006).

However, temperatures in December stop fruit growth and ripening and thus covering the plants with PVC tunnels create the condition for regular fruit development which may last from January to March, depending on covering time and environmental conditions (Photo 4-5). This out-of-season crop result in excellent fruit quality in terms of fruit size, flesh percent (peel thickness) and sugar content of high commercial value. Intense research activity is undergoing to get stable reflowering rate and manage fruit ripening time to meet market demand (Liguori *et al.*, 2006).

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Feeding prickly pear cactus (PPC) to ruminants

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Abstract

Arid and semi-arid areas in Mexico cover more than 50% of its territory and are characterized by extreme climatic conditions. Under these conditions livestock production is limited due to forage scarcity, therefore, it is necessary to find plants that are adapted to these adverse conditions and that can be used as forage for livestock. One of these plants is prickly pear cactus (PPC). PPC conveniently mixed with other agricultural products and by-products can be used during critical periods of the year (drought) for at least maintenance levels in livestock diets. Availability, chemical composition and low cost have made this plant an alternative in the feeding of livestock in these areas. This work presents experiences on the utilization and nutritional value of cactus. In addition, alternatives that may allow a better utilization of this valuable resource of arid and semi-arid areas of Mexico are presented.

INTRODUCTION

Prickly pear cactus (PPC) is widely used as feed for beef and dairy cattle, goats and sheep. The PPC is mostly used by small producers, because at certain times of the year, it is the only food they have available for feeding their animals. Some experts believe that management (cutting and transport) and use of PPC, is very bulky and costly in relation to the nutritional value, however, when compared with other forages in terms of water use efficiency it is an important resource for arid areas. Besides its availability, the chemical composition and low cost, makes it an appropriate source of forage for livestock producers.

MATERIALS AND METHODS

The chemical composition of PPC is affected by various factors such as the age of the plant, season of the year and plant parts. In general, the characterization of the nutritional content of PPC (Table 1) is that it is a plant with high water content, medium energy content, high in calcium (Ca) and potassium (K), medium fibre, low protein and phosphorus (P) (Table 2). The acid-detergent fibre (ADF) is about 15 to 16% and the neutral-detergent fibre (NDF) about 32 to 37% (Valdez, 2010).

Despite its importance as forage, the mineral content of the PPC has been rarely analysed, however, among the few reports available are those cited by Bravo (1978) in his book The Cacti of Mexico and Fuentes *et al.* (2003). According to published reports, the major minerals in cactus pears are Ca and K, and to a lesser extent magnesium (Mg), silica (Si) and sodium (Na) and small amounts of iron (Fe) and aluminium (Al), predominantly in the form of chlorides, sulphates and phosphates. Fuentes *et al.* (2003) concluded that PPC can meet the requirements of minerals such as Ca, Na, K and Mg but not P, copper (Cu) and manganese (Mn), whereby the cactus can be considered as an important source of minerals throughout the year.

Species used as forage

Fuentes *et al.* (2003) indicated that in north-eastern Mexico, *Opuntia lindheimeri* varieties Subarmata and Tricolour, *O. cantabrigiensis, O. imbricata, O. robusta, O. ficus-indica, O. streptacantha, O. leucotricha* and *O. microdasys* are among the main species of *Opuntia* used as fodder for livestock and wildlife. All these species and varieties used as forage have abundant spines, large and hard, causing problems in animals, when they are not burned. In some cases mortalities as a result of starvation occur because the muzzles of animals are injured and they could not swallow anymore. In the case of blinding PPC *(O. microdasys)*, which as its name suggests, causes blindness in animals such as goats and sheep; the abundance of small spines emerging from the ground when touched penetrate the eyes of animals.

According to a study by Lopez and Rodriguez (1982) some features that have made PPC an important

Table 1. Chemical composition of prickly pear cactus *(Opuntia* spp.*)* as forage. Source: Ensminger *et al.*, 1990.

Specie	Dry matter	Crude protein	Nitrogen free extract	Ether extract	Crude fibre	Ash
O. robusta	10.4	4.4	57.6	1.7	17.6	18.6
O. lindheimeri	11.6	4.1	66.3	1.0	16.2	25.5
O. ficus-indica	11.3	3.8	77.1	1.4	17.6	13.1
O. rastrera	14.4	2.8	40.2	0.8	16.2	40.1
O. engelmanii	15.1	3.3	60.3	1.2	3.6	31.6
Mean	11.1	4.1	67.0	1.3	17.1	19.1

Table 2. Nutritive value of prickly pear cactus and corn and sorghum grains. Source: NAS, 1972.

Nutrient	PPC	Corn	Sorghum
Dry matter (%)	20.6	87.0	88.5
Organic matter (%)	81.1	----	----
Ash (%)	18.9	1.6	2.4
Crude fibre (%)	13.4	2.4	2.6
Protein (%)	4.8	8.6	8.9
Sheep (Digestibility)	50.0	74.0	67.0
Cattle (Digestibility)	34.0	78.0	57.0
Goat (Digestibility)	60.4	----	----
Energy (%)			
Sheep (TDN)	54.0	83.3	86.0
Cattle (TDN)	58.8	77.3	80.6
Minerals			
Calcium	9.16	0.05	0.03
Phosphorous	0.12	0.35	0.32
Potassium	2.53	0.31	----

food for cattle, goats, sheep, horses, donkeys, mules and wildlife in arid and semi-arid areas of the country (unlike other desert plants) are its high palatability, high digestibility, accessible in field management, transport resistance, abundance, recovery rate and productivity. Other important features of PPC mentioned by Hamilton (1992) are the ease of establishment, survival mechanism because of the spines, evergreen, making it attractive to livestock, it is a dual-purpose plant that helps maintain ecological balance, long life, high biomass production, tolerance to cold and heat, adaptability to a wide range of soils, disease resistance, plants do not compete with grasses due to their root system, low maintenance cost and high availability. Its use is more common among small producers, as is sometimes the only option for keeping animals in critical times of the year, such as winter and drought, which are the reasons why it is considered an emergency food, although some producers use it throughout the year.

Processing methods

The production of PPC for forage is variable, because the production techniques used are very poor and in most cases the PPC is grown wild. The characteristics of PPC make it difficult for cattle grazing to access this feed, so livestock producers have created various practices to make this food accessible to animals. Traditionally, the PPC is utilized as feed for grazing livestock by cutting the edges of the PPC pads standing in the field or by burning the whole plant or individual pads of the PPC which in turn is chopped into small pieces with hand tools. Another way to use it has been by cutting the pads, take them to a feedlot where it is chopped and offered to animals. This practice is useful for feedlot livestock.

It has also been observed than when PPC is are ensiled, the fermentation and organic acid production causes the spines to soften, so there is no need to cut and burn the spines before animals can consume it.

During this process, there is also an opportunity to add compounds such as urea or ammonium sulphate to increase the protein content of the ensiled cladodes.

Dairy cattle producers have adapted forage mills to process the PPC, making it faster and more efficient to use the PPC because it requires no burning of the spines before feeding. There are two types of grinders, namely mobile grinders with a processing capacity of 5 ton/h which is moved to the feed bunkers for processing and larger stationary or a fixed grinder with a processing capacity of 1.5 ton/h and where the PPC is transported to it to be chopped and then distributed to the feedlots.

Animal performance

During the spring, summer and fall ruminants generally consume forbs and grasses and browse consumption is reduced, while during the winter and early spring consumption of browse species is increased (Cook, 1972). During the winter and early spring (dry months) the consumption of prickly pear cactus is also increased (Merril and Taylor, 1981).

Dairy cattle

In a study by Fuentes (1991) in seven dairies with a total of 447 dairy cows, daily consumption of PPC ranged from 20-30 kg of PPC/cow, with an average consumption of 25.7 kg. The PPC was burned and chopped and although it was provided throughout the year, its use was increased during critical times of the year. In each of the dairies, animals also received different supplements, which contained corn stover, alfalfa, sorghum, grasses or agave. The level of milk production ranged from 14-18 kg per cow per day with an average of 15.4 kg. Under these conditions, the PPC supplied 4.5% of net energy for lactation, 12.2% protein, 46.0% crude fibre an about 100.0% Ca and 15.0% of P as recommended (NRC, 1978), to meet the requirements of dairy cattle with these levels of production. In another study by Fuentes (1992), cows consumed up to 20 kg of PPC per day between January to May; the PPC was burned and chopped manually and supplemented with commercial feed, corn, wheat, and corn silage. The milk yield per cow per day varied from 8-12 kg. On the other hand, cows from dairies where PPC was processed mechanically, consumed between 25 and 40 kg PPC per day; the PPC was supplemented with commercial feed, corn, sorghum and alfalfa and produced between 10 and 16 kg of milk per cow per day.

Beef cattle

In relation to beef cattle on rangeland in Coahuila, Fuentes (1991) reported that the consumption of PPC of 685 animals ranged from 10-20 kg per animal per day, which was supplied as burned and chopped material. The animals grazed on rangeland and some animals received corn stover supplement with molasses, urea and a commercial concentrate. The daily gains ranged from 0.1-0.6 kg with an average of 0.34 kg per animal per day. Under these conditions PPC contributed 7.8% of net energy for maintenance, 20.6% protein, +100.0% Ca and 50.0% P of those recommended (NRC, 1984). Lopez (2013) fed a complete diet to Beefmaster cattle in a feedlot. The diet included PPC which was treated with a cellulose enzyme to improve fibre utilization. The PPC represented 20% of the diet and suggested that higher average daily gains (1.03 kg) for those animals compared with the animals that received a diet without PPC (0.75 kg). Lopez (2013) concluded that the use of cellulolytic enzymes in diets containing PPC helped to increase the performance of animals, thereby obtaining attractive returns for small and medium producers.

Goats and sheep

Feeding goats and sheep with PPC in northern Mexico (Fuentes, 1997) is mainly done in two ways; cut and carried to a feedlot, then burned and chopped, which is then offered to the animals, and on the rangeland the edges of the pads are cut to remove spines before animals can eat it. In these areas, it is customary to give burned PPC in situ and sheep and goats can consume an average of 3 to 5 kg (fresh basis). In the case of goats grazing freely, goats are given PPC in pens where they are milked. The increased consumption of PPC is presented in the winter or drought, which decreases considerably in the rainy season since other plants are found. In the case of goats it is estimated that daily consumption of PPC fluctuates between 3 to 9 kg (fresh basis) and when animals are kept in stables up to 11 kg per day is consumed by adult animals. Even though goats consume PPC in different states such as natural, burned and dried, a study by Lopez *et al.* (2003) indicated that goats prefer to consume burned PPC as compared with PPC with spines.

Rivera (2012) evaluated the feasibility of feeding sheep with PPC silage to which urea and molasses were added. The daily ration included 2.40 kg of corn silage and 0.56 kg of triticale hay (T1, control). Animals assigned to a second diet (T2) received the same ration plus 0.32 kg of PPC silage with molasses and urea. The results showed that those animals consuming PPC silage had higher ($P<0.05$) daily weight gains (99.6 g) as compared to the animals that did not receive it (63.8 g). It was concluded that the inclusion of PPC with urea and molasses supplemented in the diet of sheep increased the weight of the animals that consume it (Rivera, 2012). Based on these results, applying forage conservation methods such as silage and the addition of other products such as molasses and urea are good alternative to take advantage of the plant species that are considered as invasive in some places. Producers should consider taking advantage of PPC as food and lower the costs of feeding.

Fuentes *et al.* (2012) evaluated the effect of PPC silage supplemented with molasses and urea added to goats. Diet T1 (control) included 1.54 kg/day corn silage and 3.72 kg/day triticale hay, while diet T2 included the same ration and 0.22 kg/day of PPC silage on a dry matter basis. The results indicated that the inclusion of PCC silage to which urea and molasses were added, improved weight gain in animals by 115% - from 0.0584 kg gain/day in the control treatment to 0.141 kg/day in the treatment with PPC silage. Therefore, it was concluded that the use of PPC silage supplemented with urea and molasses is a good alternative for goat farmers in arid and semi-arid areas. Both studies agree with the practical recommendations mentioned by Nefzaoui and Ben Salem (2003), who suggested the inclusion of molasses when making PPC silage with no fruits.

Alternatives to improve PPC digestibility

The use of PPC as forage in arid areas of northern Mexico has been mainly from wild cacti, which is causing overexploitation, so producers must look for alternatives that allow sustainable use of this natural resource.

Enhancing the digestibility of the plant may help reduce the quantity needed for feed. One possibility in this regard is provided by the treating PPC with compounds that increase biomass and quality in terms of digestibility. Such compounds are yeast, ammonium sulphate, urea, and brewery by-products. Studies by Murillo *et al.* (1994) and Torres (1993) indicated that the in vitro protein digestibility of PPC increased from 27.73% in the control treatment to 61.62%, 93.93 and 76.83% with yeast treatments, yeast + ammonium sulphate and yeast + urea, respectively. The use of brewers by-products (BB) have been a suitable alternative to improve digestibility of PPC. A study by Fuentes *et al.* (2013) determined the in vitro dry matter digestibility (IVDMD) and the in vitro organic matter digestibility (IVOMD) of fresh and ensiled PPC with additional BB and 10% molasses at different times of incubation. Differences ($P<0.05$) were found in the IVDMD and IVOMD of fresh and ensiled PPC, higher values were obtained for fresh PPC compared to ensiled PPC, when no BB were added. On the other hand when BB was added, higher IVDMD and IVOMD were observed ($p<0.05$). The IVDMD and IVOMD were different ($P<0.05$) at different incubation times, with higher values at 72 hours of incubation. The addition of BB to improve both IVDMD and IVOMD offers a good alternative when ensiling PPC.

Problems with diarrhoea may be encountered with the use of PPC when consumption is very high (>50% of the total consumption of dry matter), which is easily corrected with the addition of hay or straws to the diet.

CONCLUSIONS

The PPC play an important role in the feeding of ruminants in arid and semi-arid areas, especially during critical periods of the year. There is a need for research to evaluate the use as well as methods to improve the nutritive quality of this valuable resource of these areas.

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Global use of cactus as livestock feed

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Abstract

Global human population is rising and it is expected to reach 9.5 billion people by 2050. Because drylands cover 40% of global area and host more than two billion people, dryland agriculture and livestock production in arid and semi-arid regions will play an increasing role to feed human population. World livestock (cattle, sheep, goat, and buffaloes) have increased by 60% in the past 50 years, but in Africa this increment was 178%. Likewise, grain price has increased steeply during the last decade. Alternative feeding sources are necessary to keep production costs low in livestock production systems. This is particularly true in regions were grains are imported. Rangeland productivity is considered low if compared to cultivated pastures, therefore, a 2-3 fold increase in livestock population, such as the one observed in Africa, increases the pressure on natural resources of native rangelands. Selected cactus varieties are among the options to increase forage production in arid and semi-arid regions. If properly managed, *Opuntia* and *Nopalea* varieties might produce 50-60 times more forage per unit land area than native rangeland vegetation in semi-arid environments. Agronomic practices such as organic fertilization, improved varieties, weed control, planting method, harvesting management, and irrigation, even in minimal amounts, have increased cactus yield in semi-arid regions. A variety of feeding systems are used and each one might be better suited for a specific region. Examples of feeding systems include, but are not limited to, cut-and-carry/green-chop operation, browsing, silage, and dry pellets. Cactus must be fed with other feeding sources rich in crude protein and fibre. Cactus also provides energy, vitamins, minerals, and good-quality water for the livestock. Greater productivity of cactus compared to native rangelands fits well into small farming systems, leading to greater land use efficiency. In addition, increasing productivity in smaller areas has potential to reduce the pressure on natural resources of native rangelands.

Introduction

Global human population will increase by 32% from 2014 to 2050, reaching 9.5 billion people (FAOSTAT, 2015). This increase in population poses a challenge for world agriculture and puts greater pressure on earth's natural resources (Dubeux *et al.*, 2011). More outputs are expected from agricultural systems per unit land area. At the same time, there is an urgent need to preserve global biodiversity and natural ecosystems, reduce carbon (C) emissions from agriculture, and improve C sequestration by terrestrial ecosystems. One alternative to conserve natural ecosystems and reduce pressure on their natural resources is to intensify agriculture production in small areas. Intensification is achieved by increasing the inputs and outputs per unit land area. Economic viability of resource use and availability of natural resources will dictate the nature of inputs utilized.

Drylands cover approximately 40% of global land area and host more than two billion people (UNSO/UNDP, 1997). In many regions, drylands are overpopulated, leading to an increasing pressure on natural resources such as soil, water, fauna, and vegetation. Natural resources in drylands vary widely, including different vegetation structure and function, soil classes, rainfall amount/distribution, and fauna. In many of these areas, however, there are common characteristics such as erratic rainfall, shallow soils with low water storage capacity, and a prolonged dry season (Dubeux *et al.*, in press). In this scenario, annual grain crops do not perform well. Productivity is low and the risk is elevated. Perennial crops are a possible alternative to increase sustainability of agriculture and livestock production systems. In arid and semi-arid regions, cactus might fit well, depending on the local ecological conditions.

In the upcoming years, drylands will increase their importance in the food supply to attend the increasing demand from human population. Cactus can play a major role in this scenario, providing forage for livestock and reducing the pressure on native rangelands. This review addresses the potential of cactus as livestock feed.

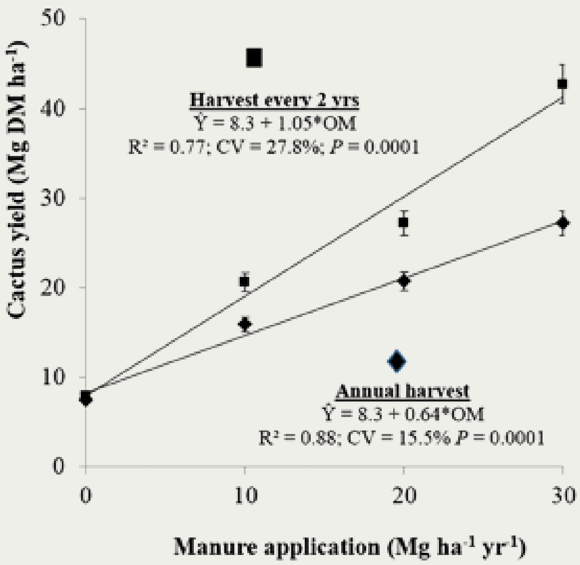
Cactus agronomic potential and rangeland productivity

Rangeland productivity in semi-arid areas varies with natural resource availability and climate. Carrying capacity is usually low, due not only to reduced net primary productivity, but also to encroachment with non-forage plants, particularly in overgrazed conditions. In Brazil, carrying capacity in native semi-arid rangelands (Caatinga) ranges from 12 to 15 ha/animal unit (Lira *et al.*, 2009), but in years of severe drought, at least twice as much of this area is needed to support the same stocking rate. Dean and Macdonald (1994) observed a reduction in the stocking rates of South African rangelands from 1911 to 1981. They concluded that reduction was due mainly to reduced utilizable primary productivity of rangelands. Drinking water availability and spatial distribution of water sources in the landscape is also a limiting factor for livestock production in semi-arid rangelands (Klintenberg and Verliden, 2008). Selected varieties of spineless cactus can be used as a feed resource to provide both forage and water for livestock.

Cactus adaptation and fitness to semi-arid environments reduces the risk of livestock operations. In fact, if properly managed cactus could be the basis for livestock production systems in these regions. Annual dry matter productivity up to 20 Mg DM ha^{-1} (and 180 Mg ha^{-1} of good-quality water) has been frequently observed in the Brazilian semi-arid rain fed systems (Lira *et al.*, 2009). This productivity contrasts with the low productivity of annual crops such as maize (500 to 600 kg ha^{-1} of grain harvested in an average year), and even with the native rangeland, which produces approximately 5-6 Mg DM ha^{-1} yr^{-1} of total biomass, but mostly composed of non-utilizable forage. The utilizable forage portion ranges from 10-15%, i.e., 500 to 900 kg DM ha^{-1} yr^{-1}. As a result, the carrying capacity of the rangeland varies from 12-15 ha/animal unit while a cactus orchard intensively managed can provide forage for 4 animal units/ha, i.e., a productivity 60 times greater than the one observed in native rangelands. Establishing small-intensive cactus orchards for forage production may alleviate the grazing pressure on native rangelands, contributing for their restoration. Alternative production systems of cactus for forage are also available, including intercropping with cash crops, alley cropping with tree legumes, or other less intensive systems. Cactus pads left behind after pruning in orchards dedicated mainly to fruit production is also an important forage source in places where fruit production is the main system. Productivity will vary from system to system, but choices need to be evaluated in order to select the best production system for each region.

Management practices affect cactus net primary productivity. In Brazil, research on cactus was initiated in the 1950's and since then, productivity has increased. The major practices that lead to increase in productivity were improved varieties, plant spacing, organic fertilization, weed control, and harvest management. If soil fertility and moisture is not limiting cactus growth, greater plant population per unit area is essential to increase cactus yields. Dubeux *et al.* (2006) contrasted between low (5,000 plants ha^{-1}) vs. high (40,000 plants ha^{-1}) plant population density at four different locations in the semi-arid region of Brazil. Higher plant density at least doubled the yields, increasing by 3-fold in one of the sites. These authors also observed plant response

Figure 1. Cactus (*Nopalea cochenillifera* Salm Dyck) yield as affected by manure application and harvest management; Caruaru, PE. Souza (2015). Yields are expressed in Mg DM ha^{-1} obtained in one biennial harvest or the sum of two annual harvests.



to P fertilization when soil Mehlich^{-1} P was <10 mg kg^{-1}. Organic fertilization is perhaps one of the most important practices to increase cactus yield. Linear responses up to 30 Mg ha^{-1} yr^{-1} of manure (OM basis) were recently observed by Souza (2015) in a *Nopalea cochenillifera* orchard under rain fed conditions in the Brazilian semi-arid (Figure 1). It is important to note that these experimental years occurred in years drier than the local historical average. Harvesting every two years was more advantageous at greater productivity levels.

Recent data has also demonstrated the importance of irrigation to increase cactus productivity. Annual dry matter yield up to 19.6 Mg ha^{-1} was observed on *Opuntia ficus-indica* drip-irrigated with only 10 mm monthly (Lima, G.F.C., personal communication). It is important to mention the poor quality of the water used ($C_4S_1T_3$ according to Pizarro, 1985) with high salinity and chloride levels. With this small amount of water it is possible to produce cactus in places where cactus was not traditionally planted before because of warm temperatures during the night and water deficit. Snyman (2004) observed that a water application of only 13.6 mm and 11.6 mm for *O. ficus-indica* and *O. robusta* was enough to fill up the cladodes in plants submitted to water deficit. Rainfall use efficiency (RUE) varies with management. Dubeux *et al.* (2006) reported an average RUE of 18 kg DM ha^{-1} mm^{-1}, with values ranging from 5 up to 35 kg DM ha^{-1} mm^{-1}. Greater plant population density leads to greater RUE with large variation among sites.

Cactus chemical composition and digestibility

Cactus chemical composition varies with species, environment, and management practices. In general, cactus have high concentrations of minerals, non-fibre carbohydrates (NFC), digestibility, pectin, oxalates, and moisture content (Dubeux and Santos, 2005; Ben Salem and Abidi, 2009). Nitrogen, NDF, and ADF concentrations are often lower than the values observed in other forages (Tables 1, 2, and 3). Ben Salem and Abidi (2009) indicated that cactus crude protein concentration is also low in quality due to greater proportion of soluble N as opposed to true protein. They also observed that cladodes of *O. ficus-indica* f. inermis are low in essential amino acids and the most limiting are cysteine, methionine, and arginine. When feeding cactus, protein supplementation seems to be the best management option to balance

Table 1. Nutritive value of cactus cladodes in varying cactus species

Species	DM	CP	NDF	ADF	NFC	MM	TDN	Source
				g kg^{-1}				
O. ficus-indica	107	50	253	217	532	142	637	Melo (2002)
O. ficus-indica	---	---	---	---	---	---	659	Mendes Neto *et al.* (2003)
O. ficus-indica	94	42	358	260	503	83	---	Oliveira *et al.* (2007)
O. ficus-indica	126	44	262	200	618	---	---	Wanderley *et al.* (2002)
O. ficus-indica	94	49	328	242	480	---	---	Bispo *et al.* (2007)
O. ficus-indica	99	40	365	169	473	97	---	Torres *et al.* (2009)
N. cochenillifera	103	55	373	202	424	126	---	Torres *et al.* (2009)

Table 2. Cladode macronutrient concentration in varying cactus species

Species	N	P	K	Ca	Mg	S	Source
			g kg^{-1}				
O. ficus-indica	11.9	1.7	33.1	18.4	5.9	1.7	Teles *et al.* (2004)
O.engelmannii	21.1	2.0	36.9	38.1	18.4	---	Nobel *et al.* (1987)
O.engelmannii	5.9-13.2	0.2-0.6	12.4-19.4	55-156	6.4-14.2	---	Nobel *et al.* (1987)
O. ficus-indica	9.0	1.6	25.8	23.5	---	---	Santos (1990)
O. ficus-indica	6.7-7.9	1.1-2.0	---	14.9-20.8	---	---	Santos *et al.* (1996)
O. ficus-indica	20.6	4.7	33.4	34.4	7.4	6.1	Dubeux Jr. *et al.* (2010)
N. cochenillifera	6.7	1.0	12.1	---	---	0.9	Dubeux Jr. and Santos (2005)
N. cochenillifera	10.5	1.6	8.3	---	---	1.9	Dubeux Jr. and Santos (2005)
N. cochenillifera	---	4.0 – 4.6	25.6 – 68.0	---	---	---	Souza (2015)

Adapted from Dubeux and Santos (2005)

true protein and essential amino acids for livestock. It is also important to note the low levels of NDF and high levels of NFC observed in cactus cladodes. When formulating ratios, it is important to balance the fibre and non-fibre carbohydrates, providing an effective fibre source from roughage, as recommended by NRC (2001). In this case, the fibre from cactus should be considered non-effective. As a result, other fibre source must be added to the diet, in conjunction to the protein supplementation. Levels of NFC should also be limited up to 40% in the diet.

Processing and feeding systems

Cactus is usually cut fresh and fed to livestock. In some cases, it is chopped either manually or by cactus choppers, specially fabricated for this purpose. Vilela *et al.* (2010) tested different cactus processing (knife-chopped or machine-chopped) and different feeding systems (concentrate fed separately or in a total mixed ratio). Nutrient intake and milk fat concentration were lower when the cactus was knife-chopped but milk yield was similar. Considering the nutritional limitations with regards to protein and effective fibre, cactus should be fed in total mixed ratio (TMR). Benefits of feeding cactus in TMR include a better synchronization of protein and energy sources in the rumen, resulting in a more efficient nutrient utilization by ruminants. Processing cactus also enhances its use with urea, one of the cheapest N sources for livestock. Melo *et al.* (2003) tested increasing levels of urea (0.0; 0.8; 1.54; and 2.40%; diet dry matter basis) as a replacement of soybean meal for lactating dairy cows. Fat corrected milk yield per cow was reduced from 18.8 to 17.5 kg cow^{-1} d^{-1} with increasing urea levels, however, no deleterious effect of urea inclusion was observed in the health of the animals. The authors concluded that an economic assessment of the diet ingredients must be performed to guide the decision of urea inclusion level. In another study, Cavalcanti *et al.* (2008) tested the replacement of Bermuda grass Tifton 85 (*Cynodon* spp.) hay by cactus enriched with urea on the milk production and water intake of dairy cows. Cactus levels in the different diets were 0; 12.5; 25.0; 37.5; and 50.0%. Increasing levels of cactus/urea increased energy intake and milk yield, decreasing linearly the water consumption by dairy cows. Several feeding trials with replacement levels of different ingredients by cactus were performed during the last decade. Different objectives were addressed such as replacing cactus by grain (e.g., maize), cactus by roughage, cactus + urea by protein concentration (e.g. soybean meal and cotton seed meal). These studies are summarized in Table 4.

Table 3. Cladode micronutrient concentration in varying cactus species

Espécie	Fe	Zn	Mn	Cu	B	Na	Source
				mg kg^{-1}			
Opuntia engelmannii	73.0	31.0	92.0	4.3	23.0	179.0	Nobel *et al.* (1987)
Opuntia engelmannii	38-72	6-12	18-43	3.3-4.6	1-8	42-120	Nobel *et al.* (1987)
Opuntia ficus-indica	128.0	62.0	182.0	7.1	---	---	Teles *et al.* (2004)
Opuntia ficus-indica	89.5	108.6	686.8	6.5	---	---	Dubeux Júnior *et al.* (2010)
N. cochenillifera	59.0	70.0	430.0	4.0	---	143.0	Dubeux Júnior e Santos (2005)
N. cochenillifera	77.0	83.0	499.0	4.0	---	135.9	Dubeux Júnior e Santos (2005)

Adapted from Dubeux and Santos (2005)

Green chop is the most common use of cactus for livestock feeding, but other uses are also found in different regions. In Mexico and North America, it is commonly observed the use of wild spiny cactus. Usually the thorns are burnt with propane and the livestock browse thereafter (Maltsberger, 1989). Cactus silage mixed with other ingredients have been tested successfully (Abidi *et al.*, 2013) and this might be an option to preserve cladodes after pruning in fruit orchards. Cactus pad might be stored under shade up to 16 d without changes in chemical composition and not compromising animal performance (Santos *et al.*, 1998). Sun dried cactus has also been tried with successful results with no differences observed when replacing coarsely ground cactus (de Waal *et al.*, 2013). One possible advantage to dry cactus is to reduce transportation costs and make commercialization of cactus pellet viable. If fed on site, perhaps it would be better to keep the water in the cladodes because it will serve as an important water source for the flock (Gebremariam *et al.*, 2006), which is particularly important in semi-arid areas. Attempts to ferment cactus with yeast or *Aspergillus niger* prior to feeding livestock have been made with successful results in the increase of protein (Oliveira, 2001; Araújo *et al.*, 2005). Although technically viable, economic considerations must be made to guide decision considering the intensive labour effort needed during the processing (Ben Salem and Abidi, 2009). It is important to note that the formation of true protein occurs in the rumen. Feeding urea and minerals along with cactus will promote ruminal protein formation in a less labour-intensive process.

Table 4. Summary of feeding trials using cactus for livestock

Replacement	Levels tested	Effect observed	Source
Cactus (OFI) by sorghum silage	0, 12, 24, and 36% of cactus replacing sorghum silage	Quadratic effect on nutrient digestibility	Andrade *et al.* (2002)
Corn by Tifton 85 hay (TH) or by soybean hulls (SH); All diets had 74% OFI (DM basis);	Corn was 14% of diet 1; replaced by same level of inclusion by TH or SH	Fibre source had no effect on nutrient intake and utilization	Santos *et al.* (2010)
Tifton 85 hay by cactus (OFI)	37, 47, 57, 67, and 77% of cactus (replacing Tifton hay)	Water intake and urine output increased with increasing cactus levels	Vieira *et al.* (2008)
Soybean hulls (SH) replacing Tifton 85 hay (TH); diet contained 60% OFI	0, 25, 50, 75, and 100% of replacement	Replacing TH with SH resulted in a concentrate-type ruminal fermentation (i.e. low pH and high VFA conc.)	Souza *et al.* (2009)
Soybean meal by urea+cactus	Urea inclusion levels: 0; 0.8; 1.54, 2.40%	Milk yield reduced with increasing levels of urea; fat and protein yield not affected	Melo *et al.* (2003)
Cactus replacing elephant grass hay	Cactus replacement levels: 0; 14, 28, 42, and 56%	Increasing levels of cactus improved nutrient intake and utilization	Bispo *et al.* (2007)
Nopalea cochenillifera (NC) replaced *Opuntia ficus-indica* (OFI)	Replacement levels: 0, 25, 50, 75, and 100%	No effect on intake and digestibility. NC can replaced OFI 100%.	Torres *et al.* (2009)
Cactus meal – dried cactus (OFI) replacing corn grain	Replacement levels: 0, 25, 50, and 75%	Inclusion of cactus meal did not affect digestibility of DM, OM, NDF, TC, EE, and CP.	Veras *et al.* (2002)
Cactus (OFI) replacing sorghum silage (SS)	Cactus inclusion in the diet, replacing SS: 0; 12; 24; and 36%	No effect on intake and milk yield of dairy cows. Feed efficiency increased with increasing levels of cactus	Wanderley *et al.* (2002)
Cottonseed meal replacing soybean meal on diets with 53% cactus (DM)	Cottonseed meal replaced 0, 25, 50, 75, and 100% of soybean meal	Milk yield, nutrient intake, and nutrient digestibility were not affected by replacement	Silva *et al.* (2009)
Cactus replacing maize grain and Tifton 85 hay	Cactus levels in the diet: 0, 12, 25, 38, and 51%	No effect on milk yield and composition, except for a decrease in long-chain fatty acids. Microbial protein yield was not affected as well.	Oliveira *et al.* (2007a, b)

OFI = *Opuntia ficus-indica* Mill.

Animal performance

Several trials have been done with dairy cows, growing cattle, sheep, and goats. In general, cactus inclusion in the diet is beneficial and results will depend on what feed cactus is replacing. Replacing poor quality roughage such as straw or low-quality hay by cactus usually increases animal performance as long as the nutritional limits of NFC and NDF, as described previously in this review, are balanced. Cactus can also totally replace concentrate feeding such as corn with no effect on milk yield (Oliveira *et al.*, 2007a). Some results demonstrating the animal performance are summarized in Table 5.

CONCLUSIONS

Cactus will play an increasing role providing feed for livestock production in arid and semi-arid regions in the upcoming years. Intensive cactus production has potential to sustain livestock production and reduce pressure on native rangelands, and at the same time increase livelihood in rural areas. Expanding current land area planted with cactus depends on government policies and programmes. Successful stories occurred in regions where small farming predominates and stakeholders such as government agencies, researchers, producer associations, and retailers were targeting the same goal of developing and diversifying activities in rural areas.

Table 5. Summary of animal performance on feeding trials using cactus for livestock

Animal	Cactus level	Performance	Source
Dairy cow	41%	17.5 kg cow^{-1} d^{-1}*	Melo *et al.* (2003)
Dairy cow	51%	20.3 kg cow^{-1} d^{-1}	Oliveira *et al.* (2007)
Crossbred steers	50%	0.84 kg $steer^{-1}$ d^{-1}	Torres *et al.* (2003)
Lamb	28.3%**	0.12 kg $lamb^{-1}$ d^{-1}	Véras *et al.* (2005)
Lamb	288 g $lamb^{-1}$ d^{-1}	0.04 kg $lamb^{-1}$ d^{-1}	Gebremariam *et al.* (2006)

*Fat corrected milk yield – 3.5% fat; **Sun-dried cactus

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Spineless cactus pear as livestock feed in South Africa

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Abstract

New feed sources are needed for livestock because of scarce water resources and in view of climate changes the feed crops must be efficient users of water and suitable for dry areas. Spineless cactus pear *(Opuntia ficus-indica)* meets the requirements. Cactus pear *(Opuntia spp.)* was reported in 1772 in South Africa and 22 spineless cultivars were imported in 1914 from the Burbank Nursery, USA. Spineless cactus pear *(O. robusta)* was established in the Karoo by farmers as drought tolerant feed crops and the cladodes fed to livestock. Cultivars of *O. ficus-indica* have been promoted for export of cactus pear fruit. The plants are pruned to stimulate fruit quality and yield cladodes that can be utilised by livestock. The high water content of cladodes restricts its use by livestock to the close proximity of orchards. Dry cladodes makes it is easier to process, transport and store material for longer periods. Sun-dried, coarsely ground cladodes were included in balanced diets to replace lucerne *(Medicago sativa)* hay without marked effects on feed intake, digestibility, rumen variables, and growth of young sheep. Sheep drank more water at higher levels of sun-dried cladodes and water retained in the distal gastrointestinal tract (GIT) is excreted as wetter faeces and not as urine. This phenomenon is widely perceived to be diarrhoea. Growth and feed conversion of young Dorper lambs on feedlot diets supplemented with sunflower oilcake, confirmed the importance of high quality natural protein for lambs. Partially dried cladodes are increasingly fed to livestock by farmers. Recently, mashed cactus pear fruit was preserved on straw and hay as kuilmoes and it created a new use of spineless cactus pear as feed for ruminants.

INTRODUCTION

The University of the Free State is promoting sun-dried spineless cactus pear *(Opuntia ficus-indica)* cladodes (De Waal *et al.*, 2015b) and fruit (De Waal *et al.*, 2015a) as major ruminant feed sources. Cactus pear, specifically the spineless form, is underutilised as a multi-use crop in South Africa and this situation needs to be addressed urgently.

Ruminant livestock production

Ruminant livestock utilises veld (natural pasture or rangeland) and planted pastures as major feed sources. In South Africa veld comprises about 80% of the land available for agriculture (De Waal, 1990). Veld is grazed by ruminants, namely domesticated cattle, sheep and goats as well as indigenous wildlife; it is also utilised by other herbivores species such as domesticated equines and wildlife species. In parts of South Africa planted pastures are produced under rain fed conditions or irrigation and it is grazed by ruminants. Veld and planted pastures, the primary feed sources for ruminants are augmented by feeds produced by the South African animal feed manufacturing industry (AFMA, 2014).

According to the AFMA (Animal Feed Manufacturers Association) 11,380,587 tons of animal feed was produced in 2013/14, including 2,057,788 tons for dairy cattle and 3,297,788 tons for beef cattle and sheep (AFMA, 2014). Some of the feeds for beef cattle and sheep are used to supplement ruminants on veld and planted pastures, but most manufactured feeds are used to finish large numbers of cattle and sheep in feedlots.

Cattle and sheep consume a variety of diets in feedlots, but only require four basic feed categories in the diets. For ruminants, good quality roughage such as hay (grasses or legumes) and silage form the basis of diets. Secondly, animal performance is improved by increasing the digestible energy content of diets with the inclusion of high energy feeds such as grain and grain by-products; the latter being derived from the human food industry. Thirdly, to achieve the required high growth rates by young ruminants the crude protein (CP) content of diets are balanced by including high protein feeds such as oilcakes (plant origin), non-protein nitrogen (NPN) and distillers by-products; the latter contains protein of microbial origin. The fourth feed category required to balance ruminant diets is minerals and additives.

Water resources in South Africa are limited and scarce water is increasingly prioritized for the human population. In view of the negative effects of climate change crops that are more efficient users of water, especially in dry regions, are needed. Spineless cactus pear *(O. ficus-indica)* fits the requirements, although some still regard it as a non-conventional feed resource (Negesse *et al.*, 2009). In reality spineless cactus pear is an underutilized multi-use crop in South Africa.

Cactus pear species

Cactus pear (*Opuntia* spp.) originated on the central plateau of Mexico (Inglese, 2010) and was utilized by people in Mexico in pre-Hispanic times. It played a major role in the agricultural economy of the Aztec empire and, together with maize (*Zea mays*) and agave (*Agave* spp.) opuntias are the oldest cultivated plants in Mexico (Reynolds and Arias, 2001). The presence of *Opuntia* spp. was first reported in 1772 in South Africa (Barbera, 1995). There is evidence that only spineless forms were introduced to South Africa more than 250 years ago and these have since reverted back to the original spiny form over a period of about 200 years (Zimmerman and Moran, 1991).

In South Africa a distinction is made between green-leafed spineless cactus pear (*O. ficus-indica* and *O. fusicaulis*) and blue-leafed spineless cactus pear *(O. robusta)* (Felker, 1995; De Kock, 2001). Following Burbank's work in California (Burbank, 1913; De Kock, 2001; Barbera, 1995; Felker, 1995) Grootfontein (Middelburg, Eastern Cape Province) introduced 22 spineless cactus pear cultivars as forage for livestock in 1914. The *Opuntia* spp. are regarded as weeds, namely those that were introduced into a country outside their native habitats and became naturalized (Brutsch and Zimmermann, 1995; Zimmermann, 2010). Spiny cactus pear has invaded about 800,000 ha in South Africa, mainly in the Eastern Cape, and had to be controlled during the 20th century with biological control. An Act was created that applied specifically to the spiny form, prohibiting the uncontrolled diffusion of the plants (Barbera, 1995; Brutsch and Zimmermann, 1995; Zimmermann, 2010).

Cactus pears are associated with the semi-arid zones of the world (Sáenz, 2000). It is tolerant to drought, but an important characteristic of *Opuntia* spp. is the ability to produce large quantities of fresh cladodes, under relatively unfavourable conditions (Nobel, 1995; De Kock, 2001; Ben Salem *et al.*, 2002). Luther Burbank, pioneer of spineless cactus pear in the USA (De Waal *et al.*, 2015a), stated "The *Opuntias*, from root to tip, are practically all food and drink and are greatly relished by all herbivorous animals ..." and, with specific reference to his breeding programme with the spineless cactus pear, concluded "The work is still in progress, but on a still larger scale and now these improved *Opuntias* promise to be one of the most important food-producers of this age ..." (Burbank, 1913).

Opuntia spp. are important livestock feeds in several countries (Felker, 1995; De Kock, 2001; Lopéz-Garcia *et al.*, 2001; Nefzaoui and Ben Salem, 2001; Reynolds and Arias, 2001; Ben Salem *et al.*, 2002; Tegegne, 2002; Negesse *et al.*, 2009; Woldu, 2009; Nefzaoui, 2010; Nefzaoui and Ben Salem, 2001), particularly during droughts and seasons of low feed availability (De Waal *et al.*, 2007; Tegegne *et al.*, 2007; Nefzaoui, 2010). The high water content of *O. ficus-indica*, about 100-150 g dry matter (DM)/kg also serves as water source for livestock in dry regions (Ben Salem *et al.*, 1996; De Kock, 2001; Tegegne *et al.*, 2007; Negesse *et al.*, 2009; Nefzaoui, 2010; De Waal *et al.*, 2012). Using cactus pear as livestock feed is a particularly attractive option because of its high water use efficiency (UWE) to produce DM (De Kock, 2001; Tegegne, 2001).

Cladodes are used in several ways, but it is easy to utilize spineless cactus pear directly by allowing animals to browse the plants; it requires little labour (De Kock, 2001; Nefzaoui and Ben Salem, 2001) but it is not advised because of undue damage to plants. However, if the animals are not controlled there is risk of overutilization, especially if other forage is absent or scarce (De Kock, 2001; Nefzaoui, 2010). Utilization by livestock with less waste is possible by chopping the cladodes (chaffing) before feeding. Chaffed cladodes can also be dried, milled and stored for later use during droughts or to feed fresh cladodes and increase DM intake (De Kock, 2001; De Waal *et al.*, 2007).

Cactus pear fruit production

Spineless cactus pear *(O. ficus-indica)* cultivars are grown in South Africa to produce fruit for local markets but also to export (Claassens and Wessels, 1997). In the past decades production has increased to export fruit (De Waal *et al.*, 2007). In South Africa, about 300 ha spineless cactus pear are cultivated for fruit production (Terence Unterpertinger, 2012, personal communication); an estimate of the area planted with spineless cactus pear for livestock feed is not available, but it may be several hundred ha.

Production of quality spineless cactus pear fruit is stimulated with pruning and it creates the opportunity to utilize cladodes as livestock feed. However, the high water content of fresh cladodes creates logistical challenges (De Waal *et al.*, 2007), because large volumes of cladodes must be processed and dried for easier transport to where it is needed as livestock feed. Practical methods are needed to process and dry cladodes which will enable farmers with smaller orchards to store the dried cladodes for longer periods as livestock feed.

Cactus pear fruit is produced seasonally, yielding large quantities of fruit in a relatively short period of about two months in summer, namely from about January to March (De Waal *et al.*, 2015a). Not all the fruit is suitable for human consumption, thus creating an opportunity to utilise another component of spineless cactus pear as livestock feed. Unless kept in cold storage the fruit cannot be stored for a lengthy period. An option was explored to preserve mashed cactus pear fruit longer by absorbing it on hay and straw, yielding preserved high moisture livestock feed, akin to conventional silage (De Waal *et al.*, 2015a).

Sun-dried cladodes and mashed fruit preserved on straw and hay can be used by ruminants, provided it can compete with conventional feeds. As discussed previously, South Africa has a well-established animal feed manufacturing industry (Anonymous, 2014). It is not easy to enter the market as a viable option unless the feed has a competitive advantage. Spineless cactus pear has a distinct advantage because it yields large quantities of DM as cladodes and fruit from less water compared to most feed crops. However, to compete effectively in the livestock feed industry with other feed sources the cladodes must be dried and processed and the fresh fruit must be preserved in a practical way as animal feed.

MATERIALS AND METHODS

Processing and drying of cladodes

Spineless cactus pear cladodes have been included in balanced diets for sheep since 2004 at the UFS (De Waal *et al.*, 2013). Some lucerne (*Medicago sativa*) was substituted with sun-dried, coarsely ground cladodes in diets and the effects on voluntary feed and water intake, digestibility of diets, rumen variables, and growth of young Dorper sheep was determined at the UFS. Fresh cladodes (*O. ficus-indica* cultivar Algerian) were used in trials with young sheep (Zeeman, 2005; Einkamerer, 2008; Menezes, 2008). Shiningavamwe (2009) also used cladodes of *O. ficus-indica* (cultivar Algerian) in Namibia and conducted trials with young Dorper lambs at the Bergvlug Experimental Farm, about 35 km east of Windhoek.

Initially the processing was basic and cladodes were cut with a butchers' knife in strips of about 20-25 mm and dried in the sun on wire mesh racks or concrete floors; plastic sheets were less effective because of water condensation and moulding (Zeeman, 2005). Later Einkamerer (2008) cut the cladodes in strips of about 15-25 mm with a single-machete (mounted on a wooden surface) and dried them in the sun on corrugated iron roofs of sheds. As suggested by Woldu (2009) these procedures are suitable for small-scale processing.

Menezes (2008) introduced a major improvement to accelerate processing. Cladodes were cut in 15 mm strips with a specially designed cladode cutter (HO de Waal and Willie Combrinck, 2008; unpublished data). It comprises 20 circular steel saw blades, mounted in-line 15 mm apart on a shaft, and powered by a small internal combustion engine. The cutter increased the rate of processing markedly. With a flywheel mounted in-line on the shaft, wear and tear on the small engine was still high and eventually it had to be replaced with an electric motor. The basic principles of this prototype was scaled up and used in Limpopo to cut large quantities of cladodes in orchards.

In Namibia cladodes were cut in strips of about 15-20 mm using an electric powered forage harvester and transported in bulk with plastic containers to Bergvlug. The cladode strips were dried in the sun on corrugated iron sheets which were placed flat on the ground; thus it was easier to move the material quickly indoors during sudden rain showers (Shiningavamwe, 2009). Except for the study in Namibia where rainy weather resulted in drying periods of 14-18 days (Shiningavamwe, 2009), the cladode strips were considered to be sufficiently sun-dried after 6-10 days to be ground in a hammer mill through a 20 mm sieve (Zeeman, 2005; Einkamerer, 2008; Menezes, 2008).

According to several authors (De Kock, 2001; Nefzaoui and Ben Salem, 2001) dried cladode strips should be ground through a sieve with 6 mm apertures. However, even with 20 mm sieve apertures the sticky juice from sun-dried cladode strips tended to clog up the hammer mill. Ostensibly the mucilage in the cladodes (Sepúlveda *et al.*, 2007) forms the sticky juice in the sun-dried cladodes; the hammer mill had to be cleaned frequently. After being ground through a 20 mm sieve, the sun-dried material still needed drying in the sun for 2-5 days (depending on the season) on a dry, concrete surface while being turned over daily to prevent moulding (Zeeman, 2005; Einkamerer, 2008; Menezes, 2008).

Diet formulation

The composition of spineless cactus pear cladodes varied (Table 1), but the range for constituents corresponded well with literature and shows the high water content of fresh cladodes (Zeeman, 2005; Einkamerer, 2008). The low OM content confirms the high ash content of cactus pear cladodes; specific mineral content was not analysed.

Table 1. Chemical composition of *Opuntia ficus-indica* cultivar Algerian cladodes

Chemical constituent	Zeeman (2005)	Einkamerer (2008)
Dry matter (g DM/kg fresh cladodes)	99.0	110.0
Organic matter (g OM/kg DM)	806.1	774.6
Crude protein (g CP/kg DM)	84.0	76.5
Ether extract (g EE/kg DM)	16.6	14.1
Acid-detergent fibre (g ADF/kg DM)	168.7	163.6
Neutral-detergent fibre (g NDF/kg DM)	243.9	254.5
Gross energy (MJ/kg DM)	13.624	14.035

Diets have been described in detail for trials (Zeeman, 2005; Einkamerer, 2008; Menezes, 2008). Zeeman (2005) started the UFS programme by formulating four diets with incremental levels (as fed) of 0, 120, 240, and 360 g/kg sun-dried, coarsely ground cladodes to substitute some lucerne hay (Table 2). The lucerne hay was also ground through the 20 mm sieve, while the other feeds were included in the physical form in which they are commercially available. Zeeman (2005) found very little effect of cladode inclusion at the lowest level (T12, Table 2), therefore, diet T12 was omitted by Einkamerer (2008) and Menezes (2008). As the level of sun-dried cladodes was increased (Table 1), inclusion of lucerne hay was decreased, therefore, the CP content of diets T12, T24 and T36 was balanced iso-nitrogenous with inclusion of an NPN source (feed grade urea) (Table 3).

Table 2. Air-dry composition of the diets fed to young Dorper sheep [Zeeman (2005); Treatment diet T12 was omitted by Einkamerer (2008) and Menezes (2008)]

Feed ingredient (kg air dry)	Treatment diets* T0	T12	T24	T36
Sun-dried, coarsely ground cladodes	0	120	240	360
Coarsely ground lucerne hay	660	535	410	285
Yellow maize meal	300	300	300	300
Feed grade urea	0	5	10	15
Molasses meal	40	40	40	40

* Inclusion levels of sun-dried, coarsely ground cladodes (*Opuntia ficus-indica* cultivar Algerian): T0 – 0 g/kg; T12 – 120 g/kg; T24 – 240 g/kg; T36 – 360 g/kg

Shiningavamwe (2009) advanced the research focus by formulating typical feedlot diets for young lambs (Table 4). The aim was to provide at least 170 g CP/kg in the diets, therefore feed grade urea was used to increase the CP content of the conventional (Control) feedlot diet T0. The diet T0 was compared with diets T1 and T2 (Table 4) when some ingredients were substituted by sun-dried cladodes and, secondly, comparing two nitrogen (N) sources to balance diets at 170 g CP/kg (as fed). In diets T1 and T2, some lucerne hay was replaced by sun-dried cladodes at levels of 330 and 300 g/kg (Table 4). Substituting lucerne hay with sun-dried cladodes in diets T1 and T2 decreased the CP content. Nitrogen was added in diet T1 (NPN, feed grade urea), while natural protein (sunflower oilcake meal) was used in diet T2. As precautionary prophylactic to prevent acidosis on diets with high starch content, 15 g feed lime/kg was added to all diets (Table 4).

Cactus pear fruit processing

As part of the multipurpose utilisation of spineless cactus pears the seeds were separated from the fruit pulp (De Waal *et al.*, 2015a). Cactus pear fruit was mashed in a large blender which is designed to mash large volumes of fruit; yielding undiluted fruit mash. In a second procedure water was added to the fruit while mashing and the seeds removed by centrifugal

Table 3. Chemical composition of the diets fed to young Dorper sheep (Menezes, 2008)

Chemical constituent	Treatment diets*		
	T0	T24	T36
Dry matter (g DM/kg feed)	876.3	886.4	815.5
Crude protein (g CP/kg DM)	163.9	157.7	161.0
Acid-detergent fibre (g ADF/kg DM)	338.1	231.8	199.8
Neutral-detergent fibre (g NDF/kg DM)	516.3	368.2	365.0
Ether extract (g EE/kg DM)	16.9	24.2	22.2
Organic matter (g OM/kg DM)	906.3	884.4	871.2
Gross energy (MJ/kg DM)	22.36	17.06	15.98

*Inclusion levels of sun-dried, coarsely ground cladodes (*Opuntia ficus-indica* cultivar Algerian): T0 – 0 g/kg; T24 – 240 g/kg; T36 – 360 g/kg

Table 4. Composition of three feedlot diets fed to Dorper lambs (Shiningavamwe, 2009)

	Treatment diets*		
Feed ingredient (kg air dry)	T0	TI	T2
Sun-dried, coarsely ground cladodes	-	330	300
Coarsely ground lucerne hay	577	255	190
Yellow maize meal	358	340	275
Feed grade urea	10	20	-
Sunflower oilcake meal	-	-	180
Molasses meal	40	40	40
Feed lime	15	15	15

* T0 - conventional feedlot (Control) diet; *Opuntia ficus-indica* cultivar Algerian based diets T1 and T2 – 330 and 300 g/kg sun-dried, coarsely ground cladodes, with different nitrogen sources (T1 – NPN and T2 – natural protein)

force; yielding diluted fruit mash. The oil was later extruded from the seeds. Diluted mashed fruit (peel and pulp minus seeds) and undiluted mashed cactus pear fruit (peel, pulp and seeds) were added by weight (5:1) in duplicate in large plastic bags to coarsely ground wheat straw or maize hay or lucerne hay. The hay or straw and mashed fruit were mixed by shaking and rotating the bags. Visible pockets of air were pressed from the bags, then tightly closed with baling twine to exclude air and prevent spoiling and stored for nine months (De Waal *et al.*, 2015a).

RESULTS AND DISCUSSION

Feed and water intake and urine and faeces excretion

The DM intake (Tables 5, 6, 7 and 8) was not affected significantly by sun-dried cladodes in diets (Zeeman, 2005; Einkamerer, 2008; Menezes, 2008; Shiningavamwe, 2009).

As shown in Table 5 and 6, young sheep drank significantly more water on diets with increasing levels of sun-dried cladodes (De Waal *et al.*, 2006; Einkamerer *et al.*, 2009). After consuming diets containing sun-dried cladodes for a period of only seven days (Menezes *et al.*, 2010), water intake (Table 7) of young Dorper wethers was higher, but due to the short trial period the differences were not significantly different.

For diets with increasing levels of sun-dried cladodes (Table 5) the DM excreted in the faeces decreased, but the values were not statistically (P>0.05) different (Zeeman, 2005; De Waal *et al.*, 2006). In the study by Menezes *et al.* (2010) inclusion of sun-dried cladodes caused production of wet faeces within a few days which was ascribed to the higher water intake by the sheep consuming sun-dried cladodes and thus mucilage. Einkamerer *et al.* (2009) also reported production of wet faeces by sheep following ingestion of sun-dried cladodes. Although sheep drank more water with increasing levels of sun-dried cladodes in the diets, urine excretion (Table 5) showed little increase (De Waal *et al.*, 2006). Therefore, the increased water intake was mostly excreted as wetter faeces and not as urine.

Table 5. Feed and water intake and urine and faeces excreted by young Dorper sheep on different treatment diets (Zeeman, 2005)

	Treatment diets			
Variables	T0	T12	T24	T36
Feed intake (g DM/day)	1148.3^{a} ± 66.2	1119.2^{a} ± 153.5	1104.3^{a} ± 118.8	1085.9^{a} ± 162.7
Water intake (ml/day)	2235.5^{b} ± 190.6	2695.3^{ab}± 595.5	2949^{ab} ± 592.0	3189.3^{a} ± 775.6
Urine (ml/day)	779.1^{a} ± 150.3	811.8^{a} ± 212.4	844.8^{a} ± 160.2	949.7^{a} ± 191.4
Faeces (g DM/day)	375.9^{a} ± 22.6	365.8^{a} ± 61.2	343.1^{a} ± 41.5	308.1^{a} ± 50.9

*Inclusion levels of sun-dried, coarsely ground cladodes (*Opuntia ficus-indica* cultivar Algerian): T0 – 0 g/kg; T12 – 120 g/kg; T24 – 240 g/kg; T36 – 360 g/kg

^{a,b} Means with different superscripts within a row differ significantly ($P<0.05$)

Table 6. Water intake and urine excreted by young Dorper sheep fed different diets (Einkamerer, 2008; measured during the last feed intake and digestibility period - Cycle 3)

	Treatment diets*				
Variable	T0	T24	T36	P	CV (%)
Feed intake (g DM/day)	1368 ± 69^{a}	1345 ± 46^{a}	1317 ± 61^{a}	0.9039	13.858
DM digestibility (coefficient)	0.714 ± 0.004^{a}	0.732 ± 0.007^{a}	0.756 ± 0.004^{b}	<0.0001	2.055
Water intake (ml/day)	3031 ± 273^{a}	3597 ± 206^{a,b}	3927 ± 272^{b}	0.0683	21.748
Urine (ml/day)	1147 ± 133^{a}	1254 ± 100^{a}	1301 ± 87^{a}	0.7188	26.936

*Inclusion levels of sun-dried, coarsely ground cladodes (*Opuntia ficus-indica* cultivar Algerian): T0 – 0 g/kg; T24 – 240 g/kg; T36 – 360 g/kg

^{a,b} Means with different superscripts within a row differ significantly

Nefzaoui and Ben Salem (2001) and Nefzaoui (2010) also referred to the severe laxative effects when spineless cactus pads are fed to sheep; it is not a disease symptom, but the food passes fast through the animal's digestive system and as a result digestion is poorer. The faeces excreted by sheep fed diets containing sun-dried cladodes were softer in consistency and contained visibly more water than faeces produced on diets without cladodes and in all studies reported here, the wetter faeces produced by the sheep lacked the customary foul smell associated with diarrhoea (De Waal *et al.*, 2006) and it was ascribed to the water-binding capacity of mucilage in cladodes which was still present in the faeces.

Digestibility of diets

Apparent DM digestibility coefficients (Table 6) of diets were relatively high and increased significantly with inclusion of sun-dried cladodes (Einkamerer *et al.*, 2009). This was attributed in part to the decreasing levels of lucerne hay in the diets. Results by Zeeman (2005), Menezes (2008) and Shiningavamwe (2009) showed similar trends, although the apparent DM digestibility coefficients were not always significantly different.

Growth of young sheep

The young Dorper castrates (wethers) in the studies by Zeeman (2005), Einkamerer (2008) and Menezes (2008) varied in age and body mass and it may have influenced the relative differences in feed and water intake, faeces and urine excretion and also changes in body mass. However, the general effect of sun-dried cactus pear cladodes in diets was consistently present. The overall effects of the different diets on the sheep were small and the diets have been utilized well.

There were no significant differences in most carcass characteristics considered by Shiningavamwe (2009), suggesting that carcass quality was not markedly affected by inclusion of sun-dried cladodes in the feedlot diets for Dorper lambs or by the N source (Table 4). The young Dorper lambs fed three diets obtained very similar prices per kg carcass (Table 8). However, the Dorper lambs fed diet T1 did not reach the target slaughter weight of 35 kg, even after 91 days in the feedlot. Therefore, the lighter carcasses at slaughter fetched a lower total price per carcass. The results by Shiningavamwe (2009) is in support of other studies, namely natural dietary protein and

Table 7. Feed and water intake and faeces and urine excretion by young Dorper sheep on different treatment diets (Menezes *et al.*, 2010)

	Treatment diets			P	CV[1]
Variables	T0	T24	T36		
Feed intake (g DM/day)	1096 ± 84.8	1296 ± 80.9	1087 ± 95.8	0.24	13.06
Water intake (ml/day)	1993 ± 75.1	2431 ± 265.3	2295 ± 273.8	0.42	17.35
Faeces excreted (g DM/day)	345a ± 20.1	351a ± 21.0	250b ± 21.1	0.02	11.39
Urine excreted (ml/day)	921 ± 33.8	960 ± 42.9	948 ± 144.4	0.95	16.38

*Inclusion levels of sun-dried, coarsely ground cladodes (Opuntia ficus-indica cultivar Algerian): T0 – 0 g/kg; T24 – 240 g/kg; T36 – 360 g/kg

[1]Coefficient of variance (%)

[a,b] Means with different superscripts within a row differ significantly (P <0.05)

Table 8. Performance of young Dorper lambs in a feedlot (Shiningavamwe, 2009)

	Treatment diets *				
Variable	T0	T1	T2	P	CV[1]%
Initial live body weight (kg)	21.23±0.55[a]	21.13±0.46[a]	21.67±0.50[a]	0.730	9.13
Final live body weight (kg)	35.46±0.11[a]	32.43±0.53[a]	35.60±0.64[a]	0.057	11.0
Total weight gain (kg)	13.90±0.41[a]	11.30±0.09[a]	13.93±0.32[a]	0.064	25.6
Average daily weight gain (ADG) (g)	180.6±3.7[a]	125.4±0.8[b]	181.0±2.9[a]	<0.001	24.6
Feed intake (kg DM/day/head)	1.147±0.050[a]	1.131±0.071[a]	1.209±0.022[a]	0.538	7.3
FCR (kg DM intake/kg gain)	6.07±0.73[b]	8.25±0.27[a]	6.11±0.16[b]	0.036	10.9
Cost of diet/kg (N$)	3.14±0.01[a]	2.42±0.02[b]	2.70±0.01[b]	0.001	0.9
Cost of diet/head/day (N$)	3.71±0.18[a]	2.73±0.19[b]	3.26±0.01[b]	0.007	5.7
Feeding period (days)	77	91	77		

*T0 - conventional feedlot diet; Opuntia ficus-indica cultivar Algerian based diets T1 and T2 – 330 and 300 g/kg sun-dried, coarsely ground cladodes, with different nitrogen sources (T1 – NPN and T2 – natural protein)

[a,b] Means with different superscripts within a row differ significantly (P < 0.05)

[1] Coefficient of variance

N$=Namibian dollar (2009)

specifically amino acids, is necessary for proper soft tissue development in young growing lambs and should therefore be provided in sufficient amounts.

Rumen function and composition of digesta

Two studies focussed specifically on processes in the rumen (Zeeman, 2005) and in the total gastrointestinal tract (GIT) of sheep (Menezes, 2008).

Zeeman (2005) reported that inclusion of sun-dried cladodes in diets had no significant (P<0.05) influence on the rumen ammonia (NH_3) concentration. It varied consistently between 9.4 and 58.5 mg NH_3/100 ml rumen fluid, with a peak at 2 hours post feeding (Zeeman, 2005). Furthermore, inclusion of sun-dried cladodes in the diets had no effect on the rumen pH which consistently ranged between 6.3 and 7.2 (Zeeman, 2005). The inclusion of sun-dried cladodes also had no significant (P<0.05) effect on the rumen volatile fatty acids (VFA) concentration or the proportions of the acetate, propionate or butyrate in the total VFA pool in the rumen. There was no significant (P<0.05) difference in the in sacco DM disappearance in the rumen, again suggesting no effect on the microbial activity in the rumen (Zeeman, 2005).

According to Menezes (2008) the chemical composition of the digesta collected from different parts of the GIT of sheep fed on the three diets appears not to have been changed by the inclusion of sun-dried cladodes up to a level of 360 g/kg diet. Most changes that were observed at the end of the first 7-day trial period occurred in the reticulo-rumen, omasum and in the lower GIT (colon and rectum) and very little changes were noted in the digesta contents of the small intestine. According to Menezes (2008) no visible pathologic alterations were detected histologically in the mucosa of the GIT of Dorper sheep when ingesting sun-dried cladodes to a level of 360 g/kg in diets for a period of 14 days. Menezes (2008) concluded that the reasons and mechanism whereby wet faeces are produced when sheep is fed diets containing considerable amounts of sun-dried cladodes were not histologically demonstrable.

Preserving mashed cactus pear fruit as kuilmoes

The fruit of 12 spineless cactus pear cultivars, produced at three different localities in South Africa, comprised on average 55.6% pulp (with the seeds) and 44.4% peel (De Wit, 2014, unpublished data). The sugar in cactus pear fruit pulp comprises 53% glucose and 47% fructose (Sáenz, 2000). According to De Wit (2014, unpublished data), the sugars in pulp comprised 58% glucose and 42% fructose and in the peel it was 54% glucose and 46% fructose. These sugars in the pulp and peel of the mashed cactus pear fruit were present as substrate for microbial fermentation (De Waal *et al.* (2015a).

According to De Waal *et al.*, 2015a) the composition of the undiluted and diluted mashed cactus pear fruit varied little (Table 9).

Treatment effects of preserving undiluted and diluted mashed fruit on straw and hay (De Waal *et al.*, 2015a) are presented in Table 10. Diluted mashed fruit yielded in kuilmoes with a significantly (P<0.05) lower DM content compared to kuilmoes produced from undiluted mashed fruit. Removal of seeds also had no significant (P<0.05) effects on the NDF, ADF and fat content (Table 10).

The pH of the kuilmoes containing undiluted mashed cactus pear fruit (Table 10) was significantly (P<0.05) lower than kuilmoes containing diluted mashed fruit. A pH below 4.0 prevents growth of undesirable microbes (Adesogan and Newman, 2010), therefore, the batches of kuilmoes were all well preserved (De Waal *et al.*, 2015a). According to De Waal *et al.* (2014) the straw or hay used to produce the different kuilmoes types had no significant (P<0.05) effect on the pH of the respective kuilmoes treatments; the pH of the kuilmoes treatments ranged from 3.80 to 3.86.

Cactus pear seed oil has great potential (Sáenz, 2000) and De Waal *et al.* (2015a) suggested it may be a viable option to dilute mashed fruit with water to separate the seeds by centrifugal force before the mashed peel and pulp is absorbed on straw and hay and preserved as kuilmoes. The next step is to begin evaluating the kuilmoes with ruminant livestock.

Table 9. Composition of straw, hay and undiluted and diluted mashed cactus pear fruit (De Waal *et al.*, 2015a).

	OM	CP	NDF g/kg DM	ADF	Fat
Wheat straw	902.4	45.9	744.9	479.6	7.67
Maize hay	965.4	47.1	796.4	478.1	8.87
Lucerne hay	916.8	169.4	462.9	406.5	9.18
Undiluted mashed cactus pear fruit	886.5	44.2	281.4	82.7	5.00
Diluted mashed cactus pear fruit	907.4	55.6	280.5	76.6	4.42

Table 10. The treatment effect of undiluted and diluted mashed cactus pear fruit after being stored as kuilmoes for more than nine months (De Waal *et al.*, 2015a)

Mashed cactus pear fruit	pH	DM g/kg	OM	CP	NDF g/kg DM	ADF	Fat
Undiluted (Um)	3.72±0.1[a]	297.5±12.5[a]	911.9±14.8[a]	96.2±32.1[a]	532.4±96.6[a]	401.4±25.6[a]	19.2±3.8[a]
Diluted (Dm)	3.93±0.1[b]	191.7±51.9[b]	912.1±24.1[a]	96.8±50.1[a]	664.7±138.8[b]	472.0±42.0[b]	7.2±6.4[b]

[a,b] Means with different superscripts in a column are significantly different (P < 0.05).

The CP content of cladodes is low (Ben Salem *et al.*, 2002; 2004; De Waal *et al.*, 2013) and requires additional N in diets containing cladodes. According to De Waal *et al.* (2015a) cactus pear fruit also has a low CP (Table 9). When mashed cactus pear fruit is preserved on lucerne hay as kuilmoes no additional N is needed for ruminants.

CONCLUSIONS

Sun-dried spineless cactus pear *(O. ficus-indica)* cladodes and kuilmoes (mashed cactus pear fruit absorbed on straw or hay) can be utilised as major ruminant feed sources. The cactus pear, specifically the spineless form, is still underutilised as a multi-use crop in South Africa and this situation needs to be addressed urgently. Two of the largest cactus pear fruit producers in South Africa have started to utilise the cladodes in considerable sections of their fruit producing orchards as feed for livestock. On one farm the cladodes are shredded in strips and partly dried for a few days in the sun before feeding it in a cafeteria system to cattle in a feedlot. A major initiative is now needed in South Africa to increase the total area under cultivation for this multi-use crop for utilisation by people and livestock.

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Applications of geo-informatics in cactus pear R&D: Case study of habitat suitability mapping of *Opuntia ficus-indica* (L.) Mill.

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Abstract

Cactus pear (*Opuntia ficus-indica* (L.) Mill.) has been suggested as a sustainable crop for the dry regions of the world because it is used for a variety of products including: green fodder and fodder reserves for livestock, fruit and pads for direct human consumption, and high value organic oils in marginal agricultural regions. Cactus is being considered for introduction into new regions for these qualities. Because importation, site testing, and evaluation can take years, it is important to predict which locations are most suitable for the cultivation this species. We developed a niche habitat model that employs a weighted sums multi-criteria decision analysis approach to predict areas most likely for suitability. The model utilizes climatic, elevation, and other variables in a raster format along with the positions of known plantations of cactus to define the environmental or niche tolerance of the plant. The niche tolerance is then applied to environmental variables for the area of interest to determine which sites most closely resemble the conditions under which cactus thrives. The result is a theoretical habitat suitability index for the new area or region. For our model, we chose a scale of 30 arc seconds or approximately 1 square km and our area of interest was the eastern Mediterranean region. Suitability maps were produced using data from WorldClim climate layers and the GTOPO30 elevation models.

INTRODUCTION

Cactus pear (*Opuntia ficus-indica* (L.) Mill.) has been planted for forage reserves and human consumption in arid and semi-arid regions for centuries for its ability to grow in harsh conditions characterized with high temperature, lack of water and poor soil. Cactus pear has a high water use efficiency because it has a waxy cuticle that reduces evaporation from photosynthetic surfaces, lacks true leaves, and succulent stems (pads) that can store water. It also employs Crassulacean Acid Metabolism (CAM) to reduce water loss. Estimates of water use efficiency vary from 1 kg dry matter (DM) produced per 250 kg of water (De Kock, 1980) to 1 kg DM per 300 kg of water (Le Houérou and El Barghati, 1982). Cactus has been used extensively as a fodder crop for livestock because of its capacity to produce biomass, (Nefzaoui *et al.*, 2013). Cactus is limited in its distribution by freezing temperatures but tolerates high temperatures well. Areas in the semi-arid climatic zone with a mean annual rainfall between 400–600 mm are optimal for cactus, although it may grow in areas with as little as 200 mm year^{-1}, if soils are deep and permeable (Nobel, 2009). Our objective was to design a computer program in the R language that would use existing climatic and topographic databases to predict and map cactus suitability for the eastern Mediterranean region. We chose a weighted sum model (WSM) in a multi-criteria decision analysis (MCDA) approach to predict areas most likely for successful cactus plantations.

MATERIALS AND METHODS

Multi-criteria decision analysis allows managers to formalize a decision-making process so that the key factors upon which decisions are made are explicitly stated and applied (Greene *et al.*, 2011).

We constructed an application within a Geographic Information System (GIS) context that used existing locations of successful cactus *(O. ficus-indica)* plantations, coupled with climatic and topographic databases to define ecological niches of this species (Louhaichi *et al.*, 2015). The computer program was constructed in R (R Core Team 2014) in the Kinetic Resource Environmental Spatial Systems (KRESS) Habitat Suitability Analysis Module (HSAM) that allows the user to import locations where cactus plantations have been deemed successful. The program extracts climatic and topographic parameters for known cactus sites and constructs frequency histograms that display the frequency of occurrence versus the value range of the data set. This data is standardized so that each parameter extracted occupies a range from 0 to 255 (1 bit). This allows for meaningful inferences between parameters with different native ranges, for example temperature and precipitation. Locations were coded in simple comma separated values (CSV) in a text file with the longitude, latitude, elevation, plant genus, species, variety/accession, year the plantation was established (if known), estimated annual yield of pads, fruits, oil, soil classification, soil depth, plant vigour, observer, organization, email, and phone number. The latitude and longitude was then used to extract information by location from other world-wide databases that contain climatic and topographic information. Climate data was from the WorldClim Database (Hijmans *et al.*, 2005) and the topographic database used was the GTOPO30 elevation dataset (USGS 2015). Both these databases are at approximately the same scale (30 arc seconds or 1 km^2). Other variables could be added if they are in either ASCII Raster or Band Interleaved by Line (BIL) format.

We constructed a computer program in R (R Core Team 2014) the Kinetic Resource Environmental Spatial Systems (KRESS) Habitat Suitability Analysis Module (HSAM) that allows the user to import locations where cactus plantations have been deemed successful. The program extracts climatic and topographic parameters for known cactus sites and constructs frequency histograms that display the frequency of occurrence versus the value range of the data set. This data is standardized so that each parameter extracted occupies a range from 0 to 255 (1 bit). This allows for meaningful inferences between parameters with different native ranges, for example temperature and precipitation.

Cactus pear *(O. ficus-indica)* is more frequently limited by cold than by high temperatures; the maximal thermal of *O. ficus-indica* is near or exceeds 50°C (Le Houérou, 2002). The absolute minimum temperature cacti can tolerate depends on the difference between absolute and relative maximum daytime and minimum night time temperatures (Nobel *et al.*, 2002). In arid and semi-arid zones, the minimum mean annual rainfall of *O. ficus-indica* is 250 mm (Inglese and Scalenghe, 2009). Elevations above 800 m are one of the main limiting factors of cactus pear (Erre *et al.*, 2009).

In the program the user selects which parameters are important for the model based upon professional experience or literature review. The next step is to assign weights to each parameter. Important lifecycle parameters to the specific species such as minimum temperatures below freezing are weighted heavily (4.00) as contrasted with maximum temperatures which are weighted lightly (0.50). Less important, but still relevant, parameters such as mean temperatures are rated neutrally (1.00). This is used to generate tolerances for the plant in question. For this cactus example, we are using: minimum temperature, maximum temperature, mean temperature, precipitation, and elevation (Nobel, 2002).

An area of interest (AOI) is designated for analysis, and then imported into the R program KRESS HSAM. If a portion of the area of interest includes bodies of water, a true/false mask coded as 0s and 1s (0s being cells to exclude) can be applied to exclude those areas from consideration. The program then uses the tolerances and the weighted model built in the previous steps to generate a suitability value for each cell (30 arc second) in the area of interest (target area). The output from this process is a colour coded suitability map that predicts the sites that are most suitable for cactus to thrive in green, the least suitable sites in red and masked areas in black.

RESULTS AND DISCUSSION

Information from ground surveys in Tunisia and a database from the Polistes Foundation (Pickering, 2014) were used to identify locations where cactus plantations exist. In addition, a ground survey for cactus was conducted in Jordan. In the Jordan survey, roadways were driven and areas on both sides were visually searched for cactus. Local residents in villages were also interviewed in an attempt to locate plantations off roadways. Sites with cactus pear plantations were positioned with Global Position System (GPS) (Table 1). GPS locations were recorded along with the characteristics of the sites. Information from the three data sets was incorporated into an inclusive database. We then used the KRESS HSAM program to extract climatic and topographic parameters from those sites with cactus pear. The location of cactus plantations was entered into the program as a simple text (CSV) file where the position of each known stand of cactus was identified in the first two columns; longitude and latitude).

Table 1. A portion of the cactus pear database from Jordan.

Longitude	Latitude	Elevation (m)	Name	Observer	Institution
35.73029445° E	32.31199387° N	634	Ajloun 2	M. Louhaichi	ICARDA Jordan
35.76379720° E	32.73796881° N	233	Akraba	M. Louhaichi	ICARDA Jordan
35.79672792° E	32.47325498° N	783	Al Mazar	M. Louhaichi	ICARDA Jordan
35.74137225° E	32.32435486° N	732	Ajloun	M. Louhaichi	ICARDA Jordan
35.73029445° E	32.31199387° N	634	Ajloun 2	M. Louhaichi	ICARDA Jordan
35.76379720° E	32.73796881° N	233	Akraba	M. Louhaichi	ICARDA Jordan
35.79672792° E	32.47325498° N	783	Al Mazar	M. Louhaichi	ICARDA Jordan
35.74137225° E	32.32435486° N	732	Ajloun	M. Louhaichi	ICARDA Jordan
35.75749186° E	32.48097356° N	642	Inbah	M. Louhaichi	ICARDA Jordan
35.78267681° E	32.43290313° N	870	Erhaba	M. Louhaichi	ICARDA Jordan
35.87479017° E	32.21722786° N	228	Jarash Valley	M. Louhaichi	ICARDA Jordan
35.79401107° E	32.68635863° N	355	Kufer Soom	M. Louhaichi	ICARDA Jordan
35.77569089° E	31.63178790° N	711	Madaba	M. Louhaichi	ICARDA Jordan
36.35091148° E	32.29984434° N	651	Mafraq	M. Louhaichi	ICARDA Jordan
35.69093021° E	32.65395683° N	339	Malka	M. Louhaichi	ICARDA Jordan
35.77604414° E	31.84752106° N	726	Naour	M. Louhaichi	ICARDA Jordan

The KRESS HSAM program then was used to predict areas in the eastern Mediterranean region that are suitable for cactus plantations. Output from this analysis includes: number of rows and columns, x lower left, y lower left, cell size, minimum value, maximum value, mean value, standard deviation, cell count, and cell sum. Also produced are graphical representations of the parameters including a frequency histogram (Figure 1) and a choropleth map (Figure 2), where higher values are plotted as green, and lower values as red.

Larger datasets provide a larger measure of precision, and thus better approximate the suitability index generated by KRESS HSM. It is also important to include all controlling variables. For example, we know that cactus does not thrive in salty soils. Cactus pear is not tolerant of dissolved salts in its rooting zone. The growth, increase in dry weight, of cactus was 60% of the control when plants were grown in a salinity environment of 50 mol m^{-3} NaCl and about 20% at 150 mol m^{-3} NaCl (Nerd *et al.*, 1991).

The model can be made less robust with complete soil data. This model was based on a limited data set of known cactus plantations and did not include soils data. We are in the process of obtaining more locations of robust plantations and more complete soils information to create a more accurate model. As cactus is introduced into new areas, the model can

Fig. 1. Worldwide locations of cactus pear (*Opuntia ficus-indica* (L.) Mill.) used for determining climatic and topographic tolerances and the species environmental niche.

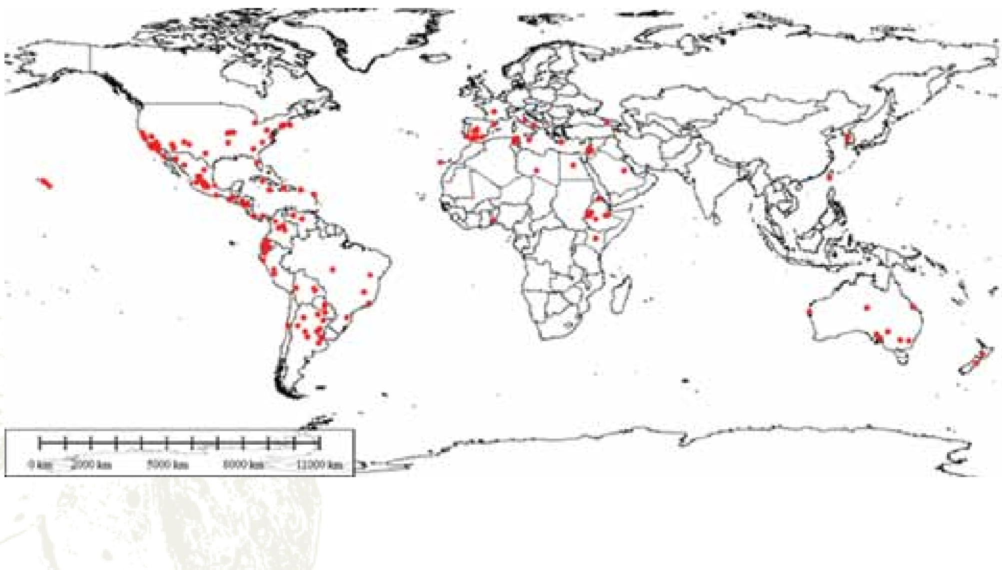
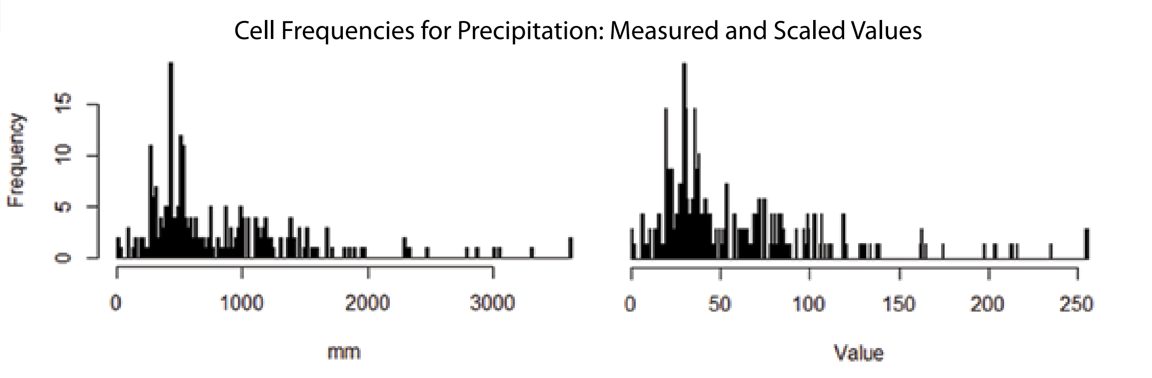


Fig. 2. Histogram of precipitation for cactus pear (*Opuntia ficus-indica* (L.) Mill.) extracted from the combined worldwide and regional database. Precipitation in mm is given on the left and scaled values (0 to 255) on the right.



be verified and modified to conform to results on the ground. We suggest that our approach can indicate sites with higher probabilities of success for cactus plantations and provide insight on the environmental tolerance of this species.

CONCLUSIONS

The niche models constructed and the land suitability maps generated identify locations where cactus pear should grow in the eastern Mediterranean region. Plantings in theoretically suitable areas will be prioritized based on the WSM score for locations with the highest values planted first. Planted sites will be evaluated for success or failure through time to determine if this simple and direct modelling approach has value in a broader context. Simultaneously, we will continue to log sites where cactus grows and expand baseline information so models can be refined as more information becomes available.

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Recent advances in cactus agro-industries: ingredients and foods

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Keywords: cactus pear leathers, cladodes powder, *Opuntia ficus-indica*, vinegars, betalains microparticles

Abstract

In the last years some new products from cactus pear fruits and cactus cladodes are being developed to increase the industrial alternatives and the use at rural levels, along with satisfying the demand of consumers for healthy food and natural food ingredients. Dehydrated products from coloured cactus pear pulp (fruit leathers), vinegars and toppings are alternatives to be produced at low cost with simple technologies. Cactus powder was studied as a source of dietary fibre, following the influence of the cladodes' development in properties as the content of the different type of fibre (soluble or insoluble) and total phenolic content. The powders' viscosity and the influence of the temperature and pH were followed. The soluble fibre content, generally low in vegetables, is a positive feature in cactus fibre as a food ingredient. Purple cactus pear fruits as source of betalains could be an alternative to artificial red colorants generally considered as potentially hazardous to human health. Research about betalains separation by membrane technologies, and later protection by encapsulation for applying in food models, is being developed by our group.

INTRODUCTION

New and traditional alternatives to process cactus pear and young cladodes or pads, also called "nopalitos", are welcome especially for the artisanal, small and medium scale enterprises. This development can yield benefits for the arid and semi-arid areas and rural agriculture. Many technologies to use cactus pear and cladodes are described in details by Sáenz *et al.* (2013).

Dehydration is one of the oldest technologies used extensively at the rural level and cactus pear pulp could be processed as pulp leathers or sheets (Ewaidah and Hassan, 1992); Sepúlveda *et al.*, 2000 and Sepúlveda *et al.*, 2003). The attractive colour of the fruit pulp (purple, red, yellow, pink) promotes the pulp to be used in other ways, such as vinegars and, toppings, using similarly simple technologies (Morales *et al.*, 2009; Prieto *et al.*, 2009).

On the other hand, cactus cladodes were recognized many years ago as a Mexican folk medicine to contribute to a healthy diet. One of the components that are making young cladodes so interesting is dietary fibre. In many countries the dietary fibre consumption is lower than the recommended allowances and one of the vegetables that can improve this deficit is the consumption of young cladodes ("nopalitos") as green vegetables, as processed cladodes, or powder included in different foods and beverages. Phenolic compounds, recognized by their antioxidant activity, are also present in the cladodes, contributing to their healthy properties.

Moreover, the coloured cactus pear (purple and yellow) is a potential source of betalains (Stintzing *et al.*, 2005), natural water soluble pigments. Some studies have been done by our group using the cactus pear as a colorant in concentrate juices (Sáenz *et al.*, 2013; Sáenz *et al.*, 2012a), but recently microencapsulation of betalains is reported as a new technology to protect betalains (Sáenz *et al.*, 2009; Vergara *et al.*, 2014).

METHODS AND MATERIALS

Coloured cactus pear sheets

There are several studies on dehydration of cactus pear pulp in thin layers, to obtain snack type chewable products. This kind of food is known as sheets, leathers or fruit bars, differing in thickness and moisture content, being thinner and of lower moisture, while the sheets with higher moisture in the bars can reach up to 20%. Some experiments used cactus pear pulp blend with quince or apple pulp to improve the acidity (Sepulveda *et al.*, 2000; Sepulveda *et al.*, 2003). Dehydrated sheets, which were wrapped in cellophane for storage, are shown in Figure 1.

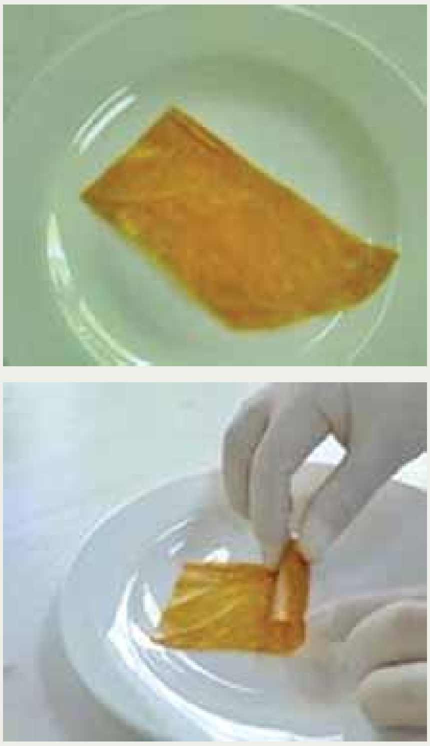


Figure 1. Cactus pear sheets from coloured cactus pear pulp.

Vinegars, toppings and microparticles

Fermentation, one of the oldest food preservation techniques has been applied to obtain products from different fruits, among them from cactus pear. Perez *et al.* (1999) studied cactus pear vinegar using yellow ecotype, with two types of substrate for acetic acid fermentation; this is needed for fermentation prior to 13.5 ºGL and cactus pear juice with sugar addition until 22 °Brix. For the first process *Acetobacter pasteurianus* was used and for the second *A. xylinum.* The vinegar showed in both cases yellow intense amber colour, being clean and bright, with a fresh and frank acetic acidic aroma. In another study, Prieto *et al.* (2009) developed types of balsamic vinegars from coloured cactus pear juices (purple, green and yellow), making products of attractive colour, pleasant aroma and good sensory acceptability. The three types of vinegar were positively evaluated by the judges, the purple cactus vinegar with the highest sugar content and lowest volatile acidity was evaluated the best. The pigments (betacyanins and betaxanthins) make the vinegars more attractive, the yellow and purple cactus pear vinegars were the most attractive for the sensory panel, as compared with the green cactus pear vinegar which shows a light brown colour, which appeared less attractive.

Among the concentrated products are sauces, jams and concentrate juices (Sáenz, 2000). Morales *et al.* (2009) developed dessert sauces (toppings) from coloured cactus pear pulps with excellent results while preserving the functional compounds and maintaining an attractive colour. The bioactive compounds of coloured toppings are shown in Table 1. In the previously mentioned products, betalains play a key role, and in the last year some studies about the use of betalains as food colorants emerged as a potential for this fruit. Betalains from red beet root are used since many years in the food industry having the same pigments than the cactus pear fruit. Therefore, no new regulations are needed for the use of cactus pear betalains as food colorant because they are accepted by the FDA from U.S.A. and also by the European regulation. Betalains are water soluble pigments showing also antioxidant activity (Azeredo, 2009), in addition cactus pear pulp also contains polyphenols that enhance the healthy properties of the fruits and by-products. Colorant powders prepared using microencapsulation technology to protect them from different factors such as O2, light, enzymes, water activity, etc. and their stability to the temperature also have been studied (Sáenz *et al.*, 2009; Vergara *et al.*, 2014). There are fruit of different "red" colours (peel and pulp) and the yield obtained is very important, especially in colorants for foods.

Table 1. Bioactive compounds in two coloured cactus pear toppings.

Bioactive compounds	Purple topping	Yellow topping
Carotenoids$^{(1)}$ (µg g^{-1} of edible pulp)	0.186 ± 0.001	0.021 ± 0.001
Total phenolics (mg GAE L^{-1})$^{x(2)}$	350.50 ± 15.25	131.48 ± 5.72
Betalains$^{(2)}$	81.06 ±1.83	63.80 ± 1.86
Betacyanins (mg BE Kg^{-1})^{y}	66.09 ± 1.03	0.92± 0.00
Betaxanthins (mg IE Kg^{-1})^{z}	14.97±1.53	62.88 ± 1.86

(1) Means ± standard deviation. n= 2; (2) Means ± standard deviation. n= 3;
^{x}GAE: gallic acid equivalent; ^{y}BE: betanin equivalents; ^{z}IE: indicaxanthin equivalents. (Morales *et al.*, 2009)

In a collaborative project with Mexico, we are using ultrasound to improve the betalains yield extraction, but the results show improvement in the polyphenols yield but not the betalains yield (Sáenz *et al.*, 2014).

The purification of betalains by membrane technologies before their microencapsulation was studied by Vergara *et al.* (2014), following the kinetic degradation of betanin (the main betacyanin). The membrane is a selective barrier, allowing the cross of certain components of a mixture and retaining other mixture components (Cheryan, 1998). The non-thermal separation technique is a suitable technique that avoids betalain damage by the use of high temperature processes (Cassano *et al.*, 2010). Before the ultrafiltration process, the pulp was diluted and microfiltered. The differences between the pulp and the microfiltered extract can be observed in the Table 2. The UF extract was a clarified solution (0 NTU) because the mucilage was separated, remaining in the retentate, during the membrane process. The total soluble solids and total sugar content of the ultrafiltered extract (UF) were significantly lower than in the cactus pear pulp (CP). Furthermore, there was no difference in the betacyanin and betaxanthin content between the UF and CP extracts; however the total polyphenol content was significantly higher in the UF extract than in CP. The betalain microparticles obtained were prepared with a chemically modified food starch derived from waxy maize (Capsul®) as encapsulating agent. The betacyanins and betaxanthins degradation rate constant (k_{obs}) at 60°C of both systems (CP-C and UF-C) as shown in Table 4. Thus, the betacyanin and the betaxanthin degradation rate constants were significantly lower for UF-C than for CP-C. The mucilage content and/or the higher sugar content of cactus pear pulp could affect the stability of betanin by increasing the water available in the microparticles for reactions (Vergara *et al.*, 2014). Those microparticles have been tested by our group in soft-drinks, yogurt and dry mixes (C. Sáenz, unpublished data).

Table 2. Physical and chemical characteristics of cactus pear pulp (CP) and ultrafiltered (UF) cactus pear extract.

Parameters	CP	UF
Moisture (%)	86.1 ± 0.2 [b]	91.9 ± 0.5[a]
Total soluble solids (ºBrix a 20ºC)	14.0 ± 0.1 [a]	8.1±0.0 [b]
Total sugars (%)	13.2 ± 0.0 [a]	9.2±0.3 [b]
Turbidity (NTU)	2453 ± 64.2 [a]	0.0±0.0 [b]
Betacyanins (mg BE/100g)	25.4 ± 0.2 [a]	24.8 ± 4.3 [a]
Betaxanthins (mg IE/100g)	8.5 ± 0.1 [a]	8.8 ± 1.2 [a]
Total phenolics compounds (mg GAE/L)	535 ± 4.4 [b]	660±25.0 [a]

CP, cactus pear pulp; UF, ultrafiltrated extract; BE: betanin equivalent; IE: indicaxanthin equivalent; GAE, gallic acid equivalente. Different letters means significant diferences between systems (p≤0.005). (Vergara *et al.*, 2014)

Figure 2. Cactus powder from mature cladodes.

Cactus cladodes powder and dietary fibre

Dietary fibre is greatly appreciated because it is scientifically recognized for its role to prevent some illnesses, like gastrointestinal disorders and the reduction of serum cholesterol levels (Goristein *et al.*, 2001; Villanueva-Suarez *et al.*, 2003; Feugang *et al.*, 2006); dietary fibre in cactus can vary by age and product form. One of the first studies of the composition of cactus cladodes was that of López *et al.* (1977) cited by Pimienta (1990) where the author observed that the one year old cladodes show less crude fibre (12% dry matter) than the oldest ones (four years old) with 17.5% dry matter. Gallardo *et al.* (1997) and Zambrano *et al.* (1998) studied some properties of crude, young cladodes (1-3 months), as a source of fibre. The dried product had 20.4% of dietary fibre as well as other interesting physicochemical characteristics: water absorption (5.8 g g^{-1}), water retention (4.7 g g^{-1}), organic molecules absorption (0.69 g g^{-1}), and cationic exchange (0.49 meq [H^+] g^{-1}), which could explain the role of "nopalitos" in the intestine. Later, Sáenz *et al.* (2010) obtained cactus powder from mature cladodes (Figure 2), reporting a total dietary fibre content of 42.99 g 100 g^{-1}, and a ratio of 2:1 for insoluble fibre to soluble fibre.

The proportion that can be included of cactus cladodes powder in foods is completely different depending if

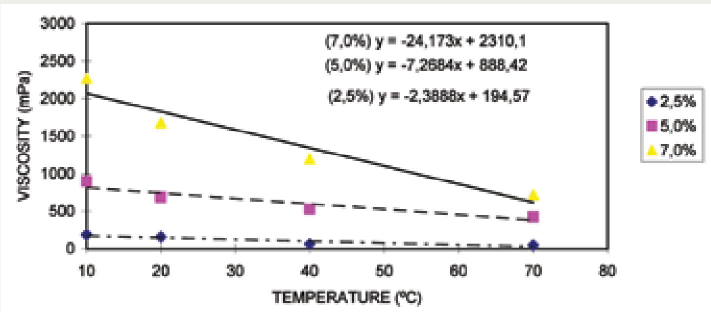
Table 3. Dietary fibre and Total phenolics compounds of purified powders from cactus powder.

Treatments	IF (g 100g^{-1})	SF (g 100g^{-1})	TDF (g 100g^{-1})	IF:SF	TP (mg gallic acid 100g^{-1})
CCP	30.0^{a}	24.7^{a}	54.7^{a}	1.2:1.0^{a}	1431.6 ^{a}
PFP-20	63.6^{b}	18.7^{b}	82.3^{b}	3.4:1.0^{c}	709.3^{b}
PFP-90	61.7^{b}	21.8^{b}	83.5^{b}	2.9:1.0^{b}	613.7^{c}
PCP-20	60.6^{b}	20.7^{b}	81.3^{b}	2.9:1.0^{b}	684.1^{b}
PCP-90	58.4^{b}	23.7^{a}	82.1^{b}	2.5:1.0^{b}	657.0^{c}

Different letters means significant differences at $p \leq 0.05$.
CCP: cactus cladodes powder; PCP-20: purified coarse powder washed at 20ºC; PCP-90: purified coarse powder washed at 90ºC; PFP-20: purified fine powder washed at 20ºC and PFP-90: purified fine powder washed at 90ºC. TDF: total dietary fibre; (SDF) soluble dietary fibre; IDF: insoluble dietary fibre. TP: total polyphenols (Sáenz *et al.*, 2012b).

food is solid or liquid. The sensory characteristics of the powder and its mucilage content limit the addition of this ingredient in formulated foods (Sáenz, 1997; Sáenz *et al.*, 2010). In beverages another parameter that influences the addition level is the pH, as well as the concentration of the fibre and the temperature of the dispersion. Figure 3 shows the viscosity behaviour of a cactus cladodes powder (water suspension) at different temperatures, different concentrations, and at pH 4 (Sáenz *et al.*, 2010) that is commonly the pH of many foods (Figure 3).

Figure 3. Viscosity behaviour of a cactus cladodes powder (water suspension) at different temperatures, different concentrations and at pH 4.



The property of certain types of dietary fibre (pectins, gums, carrageenan, etc.) to form highly viscous solutions is widely known (Anderson *et al.*, 1994). The viscosity is an important characteristic both for the formulation of foods and also because their influence in the intestine bowl formation and transit. At higher temperatures the effect in the viscosity is less affected by the concentration of the nopal powder, the curve slopes are smaller than at higher temperatures (Sáenz *et al.*, 2010). This behaviour is important to be considered in order to formulate new foods and obtain a good acceptability because, as it is well known by the food technologists, the texture is one of the most important parameters in the acceptability of foods after the appearance.

Studies show different rates of inclusion of dry powder in various foods. Sáenz *et al.* (2002a) replaced different proportions of wheat flour with cactus powder (from mature cladodes) in biscuits with good results up to 15%, but also observed that the inclusion of cactus powder in preparing a vegetable soup powder affected the viscosity of the soup negatively when the addition of powder is close to 15%. This behaviour is associated with the mucilage (mostly arabinogalactans), that are part of the soluble dietary fibre (Sáenz *et al.*, 1999; Sáenz *et al.*, 2004). Other studies in powdered dessert formulations show that the inclusion of cactus powder, up to 16%, gives product a good texture (Sáenz *et al.*, 2002b). Ayadi *et al.* (2009) included cactus powder (2-3 years) in dough for cakes showing that a maximum of 5% cladodes powder can be used to have acceptable quality cakes. Studies on other food forms would be helpful to establish acceptable rates.

Larrauri (1999) reported that an "ideal dietary fibre" should be as concentrated as possible, weak in taste, colour, texture and odour and have a balance composition between soluble and insoluble fractions. In order to reach these characteristics Sáenz *et al.* (2012b) develop processes for the preparation of food fibres which include washing to remove sugars, drying to improve the shelf-life and milling to improve the quality of the final product. These technological processes have the aim to reduce the negative characteristics of the powder, mainly the herbal flavour and mucilaginous texture, to be used as a functional ingredient and to enrich foods with a natural fibre source. Table 3 shows the phenolic compounds content and the dietary fibre of one of purification treatments assayed. The purification process increased the IDF:SDF ratio [ratio of insoluble dietary fibre to soluble dietary fibre], ranging between

Table 4. Betacyanins degradation rate constant at 60°C of CP-C and UF-C microparticles.

System	$10^3\ k_{(obs)} \pm DS\ (days^{-1})$	r^2
CP-C	8.2 ± 0.0003 [a]	0.98
UF-C	7.2 ± 0.0002 [b]	0.99

Different letters show significantly differences between systems (p<0.005). (Vergara *et al.*, 2014)

2.5:1 and 3.4:1. It is generally accepted that fibre suitable for use as a food ingredient should have an IDF/SDF ratio close to 2:1 (Jaime *et al.*, 2002). Higher temperature during washing showed high retention of SDF which, according to Gorinstein *et al.* (2001), could be due to the formation of a gel structure related with the presence of mucilage. Reducing the washing temperature reduced close to 50% the phenolic content (Table 3) (Sáenz *et al.*, 2012b).

Other by-products may also be obtained from the fruits and cladodes of cactus pears, e.g. mucilage as a thickening agent (Sáenz *et al.*, 2004) and oil from the seeds (Yeddes *et al.*, 2012).

In conclusion, the plants of *Opuntia* genus can play a great role in agriculture, in the fight against desertification, in the production of new foods and functional ingredients, in helping overcome poverty to the inhabitants of depressed agricultural arid or semi-arid lands.

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An overview of the medicinal uses of cactus products

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Abstract

Cacti have been used for centuries by ancient civilizations to cure diseases and to heal wounds. Cactus cladodes, fruits, and flowers have been traditionally used in folk medicines in several countries. Cladodes are still used for gastric ulcer treatment and for its healing activity as therapeutic agents. The properties of the infusions of cactus dried flowers to prevent prostate cancer and urological problems are also well-known. Recent scientific investigations confirmed that cactus products may be efficiently used as a source of phytochemicals, such as mucilage, fibre, pigments and antioxidants. An overview is presented of recent scientific reports about the medicinal properties of cactus products. Scientific studies in experimental models confirmed that lyophilized cladodes have a significant anti-ulcer effect, protective effect against gastric lesions as well as anti-inflammatory activity. Diet supplementation with cactus pear fruits in healthy humans has decreased the oxidative stress, and, therefore, improve their overall antioxidant status. Cactus pear fruits have also been studied as an ovarian-cancer preventive. Their ability in suppressing carcinogenesis of *in vitro* and *in vivo* models has been assessed. The antiviral action of cactus cladode extracts have been successfully conducted against viruses such as herpes, HIV-1 virus and influenza A. *Opuntia ficus-indica* cladodes were supplied to hypercholesterolemic rats and a marked decrease in cholesterol and triglycerides levels was found in plasma samples. Experiments concerning the hypoglycaemic effects of *O. streptacantha* cladodes have been confirmed in diabetes mellitus non-insulin-dependent patients. Moreover, consumption of young cactus cladodes has shown to reduce obesity and blood glucose. Functional properties of cactus products can be exploited more efficiently in the food, cosmetic, and pharmaceutical industries if appropriate research is encouraged.

INTRODUCTION

Nowadays, there is increasing evidence that some food constituents may have beneficial effects on the health of consumers beyond their nutritive action. The use of natural sources such as some herbs and fruits has played fundamental roles in human health care. About 80% of the world's population use traditional medicine for health care, which is based predominantly on plant materials. A range of scientific investigations of medicinal plants and fruits have indicated the properties that are responsible for their beneficial effects could be attributed to the presence of biologically active substances. These chemical compounds, namely phytochemicals are generally nonessential nutrients (Nazareno, 2014).

In today's lifestyle the human body is exposed to the deleterious action of numerous sources of pro-oxidants. Reactive oxygen species (ROS) and free radicals are constantly formed in the human body by normal metabolic function. When the generation of harmful agents greatly exceeds the cell's protective system, serious oxidative stress occurs, and the accumulation of damage will result in pathophysiologic events.

Antioxidant phytochemicals are involved in the redox balance of normal physiological functions and against the pathogenesis of various diseases such as neurodegenerative disorders, e.g. Alzheimer's and Parkinson's diseases, heart conditions, cataracts, cancer, inflammatory processes, premature ageing and atherosclerosis, among others (Halliwell and Gutteridge, 1999). Phytochemicals with antioxidant properties promote a healthy status by protecting against the oxidative damage induced by ROS (Prakash and Gupta, 2009).

Several studies demonstrated that both cactus fruit and cladodes contain substantial quantities of important nutrients, minerals and vitamins, as well as antioxidants; the cactus plant also appears to be an excellent source of phytochemicals of nutraceutical importance (El-Mostafa, 2014). The cactus plant can be exploited in total because its bioactive components can be extracted from different parts of its anatomy: flowers, fruit, cladodes, roots and seeds (Nazareno, 2014).

CACTUS USES IN TRADITIONAL MEDICINE

Cactus plants have been used by Native Americans for centuries as a dietary supplement. More recently, cladodes, fruits, and flowers have been traditionally used in folk medicines in several countries. Cladodes are still used for gastric ulcer treatment and for its healing activity as therapeutic agents. The properties of the infusions of cactus dried flowers to prevent prostate cancer and urological problems are also well-known. Cactus pear fruit has been used for a long time in traditional medicine as a treatment for different pathologies, such as ulcers, dyspnoea, and glaucoma, as well as for liver diseases, to heal wounds, and fatigue. The consumption of cactus fruits and their juices has traditionally been recommended for their diuretic effect, functions as hypoglycaemic agent, anti-allergic, analgesic and anti-inflammatory actions, and for gastritis relief.

SCIENTIFIC ASSESSMENTS OF CACTUS MEDICINAL PROPERTIES

Recent scientific reports have highlighted the presence of natural cactus molecules, which may have high potential interest in human health and medicine. The main objective of this review is to collect data based on scientific research conducted on cactus products. The compilation of the latest studies in model systems, in cell lines and *in vivo* with experimental animals and, in some cases, in humans according the different medicinal properties reported are shown in Table 1.

Different studies have demonstrated significant reductions in oxidative stress markers in patients and the prevention of chronic pathologies by cactus products, this action has been ascribed to the antioxidant capacity of cactus fruits.

The antiviral action of cactus cladode extracts have been successfully conducted against viruses such as herpes, HIV-1 virus and influenza A.

Remarkable anti-inflammatory effects of indicaxanthin have recently been demonstrated in an animal model of acute inflammation (Allegra *et al.*, 2014).

The liver performs a fundamental role in the regulation of diverse physiological processes, and its activity is related to different vital functions, such as metabolism, secretion, and storage. The liver has the capacity to detoxify endogenous and exogenous substances of the body, as well as to synthesize useful agents. Hepatic diseases continue to be among the principal threats to public health, and they are a global problem. Liver cells, tissues, structure, or hepatic function damages can be induced by bacteria or viruses as biological factors and by autoimmune diseases as well as by the action of different drugs and toxic compounds and excessive consumption of alcohol.

The use of natural medicines for the treatment of hepatic diseases has a long history; this empirical evidence becomes an innovative field of study. In general, liver-protective fruits, as well as plants, contain a variety of chemical compounds, such as phenols, coumarins, lignans, alkaloids, carotenoids, flavonoids and organic acids to name a few.

The first scientific report where *Opuntia ficus-indica* was used against hepatotoxic substances was by Wiese *et al.* (2004); they reported that cactus reduced the hangover symptoms after consuming alcohol in excess.

More recently, Ncibi *et al.* (2008) reported the reduction of the hepatic toxicity induced by the organophosphorus insecticide chlorpyrifos by using an extract of *O. ficus-indica* cladodes and significantly normalizing biochemical parameters. More recently, investigations developed by the same group explored the hepatoprotective effects towards benzo(a)pyrene. It has also been reported that cladode extracts might have a hepatoprotective effect against aflatoxicosis in mice, probably acting by promoting the antioxidant defence systems (Brahmi *et al.*, 2011).

Recent studies indicate remarkable anticancer activities displayed by cactus pear extracts. The chemopreventative and anticancer activities of crude extracts from plants belonging to the Cactaceae family as well as the main active constituents have been reported presenting *in vitro* and *in vivo* assays. These properties have recently been well reviewed and compiled (Harlev *et al.*, 2013a).

NUTRACEUTICAL PRODUCTS

Currently dietary supplements based on dehydrated cladode flour are also commercially available to take advantage of the numerous health benefits of cladodes. Several manufactured products are currently available in the nutraceutical market as biscuits, tortillas, cereal bars mixed with flaxseed, soups, snacks and toasts. Nopal pills are available because cactus fibre helps in reducing body weight by binding dietary fat and increasing its excretion, thus reducing dietary fat available for absorption.

A diverse range of functional foods are prepared using cactus fruits as ingredients in juices, marmalades, candies, liquors and syrups and offered as healthy foods. Cereal bars, dessert preparations, ice cream and other manufactured foods using cactus fruits are proposed to take advantage of the medicinal properties of cactus plants. On the other hand, fruit processing for juice and jams yields as residues, large amounts of seeds. The cactus pear fruit contains tough seeds that represent 10-15% of the pulp weight. The seeds are ground or pressed to obtain the oil as a lucrative product of the plant. The fruits contain a large number of seeds but the oil content is relatively low; oil constitutes 7–15% of the whole seed weight. Approximately 1 ton of these tiny seeds are needed to extrude 1 L of oil. Cactus seed oil comprises up to 80% unsaturated fatty acids (Ennouri *et al.*, 2005). The linoleic acid content of the seed oil varies between 61.4 and 68.9% and it contains less than 1% α-linolenic acid, while oleic acid content varies between 12.4 and 16.5% (lower than that of cotton seed). Therefore, although the seed oil content is relatively low, the fatty acid composition indicates that it has potential for the health and cosmetic market (Labuschagne and Hugo, 2010). The *Opuntia* seed oil is obtained by cool pressed seeds and some of its main applications are being developed by the cosmetic industry. The seed oil is destined for cosmetic product production, and it sells at a very high price as organic oil for anti-age and anti-wrinkle purposes.

Table 1. Review of the scientific evidence regarding the medicinal properties of cactus.

Studied cactus species and active part of the plant	Studied System-Reference
Antiviral action	
O. streptacantha cladode extract	Intracellular virus replication inhibition and extracellular virus inactivation (Ahmad *et al.*, 1996)
Opuntia spp. cladodes	Guinea pigs (Fernández *et al.*, 1992, 1994)
Anti-hyperlipidemic effect and cholesterol reducing action	
O. robusta fruits	Non diabetic hyperlipidemic humans (Wolfram *et al.*, 2002)
O. ficus-indica cladode	Rats (Galati *et al.*, 2003)
O. ficus-indica seed oil	Rats (Ennouri *et al.*, 2006a)
O. ficus-indica seeds	Rats (Ennouri *et al.*, 2006b)
Cactus pear seeds and oil	Rats (Ennouri *et al.*, 2007)
O. ficus-indica var. Saboten	Mice (Oh *et al.*, 2006)
Antiobesity factor	
Opuntia spp. cladode	Humans (Frati Munari *et al.*, 2004)
O. megacantha	Diabetic rats (Bwititi *et al.*, 2000)
O. lindheimeri	Diabetic pigs (Laurenz *et al.*, 2003)
Hypoglycemic and antidiabetic effects	
O. ficus-indica, O. lindheimeri, and *O. robusta*	Diabetic rats (Enigbocan *et al.*, 1996)
O. streptacantha	Humans (Meckes-Lozyoa, 1986)
O. monacantha cladode extract	Diabetic rats (Yang *et al.*, 2008)
O. ficus-indica seeds	Rats (Ennouri *et al.*, 2006a)
O. ficus-indica seed oil	Rats (Ennouri *et al.*, 2006b)
O. streptacantha	Humans (Frati Munari *et al.*, 1991 and 1992)
O. filiginosa fruit extract	Rats (Trejo-González *et al.*, 1996)
Anti-inflammatory actions	
O. humifusa extracts	Nitric oxide-producing macrophage cells (Cho *et al.*, 2006)

O. Ficus-indica indicaxanthin	Pleurisy in rats (Allegra *et al.*, 2005b, 2014)
O. Ficus-indica cladodes	Human (Hegwood *et al.*, 1990)
Neuroprotection against neuronal oxidative injuries	
O. Ficus-indica var. Saboten flavonoid extracts	Primary cultured rat cortical cells (Dok-Go *et al.*, 2003)
Neuroprotection against cerebral ischemia	
O. Ficus-indica extracts	*In vitro* studies in cultured mouse cortical cells *In vivo* studies in gerbils (Kim *et al.*, 2006)
Antiulcerogenic effects and antigastritis	
O. Ficus-indica cladodes	Rats (Galati *et al.*, 2001)
O. Ficus-indica fruit juice	Rats (Galati *et al.*, 2003)
O. Ficus-indica cladodes	Rats (Galati *et al.*, 2002)
O. Ficus-indica var. Saboten stems	Rats (Lee *et al.*, 2002a)
O. Ficus-indica var. Saboten fruit	Rats (Lee *et al.*, 2001)
Decreasing effect on oxidative stress	
O. Ficus-indica fruit	Humans (Tesorieri *et al.*, 2004); *in vitro* human LDL (Tesorieri *et al.*, 2003)
Cactus pear fruits	*Ex vivo* human cells (Tesorieri *et al.*, 2005)
O. robusta fruits	Humans (Budinsky *et al.*, 2001)
Alcohol hangover symptoms alleviation	
O. Ficus-indica plant extract	Humans (Wiese *et al.*, 2004)
Protection against nickel-induced toxicity	
O. Ficus-indica cladode extract	Rats (Hfaiedh *et al.*, 2008)
Protection against oxidative damage induced by zearalenone	
O. Ficus-indica cladode	Mice (Zourghi *et al.*, 2008; 2009)
Diuretic effect	
O. Ficus-indica cladodes, flowers and non-commercial fruits	Rats (Galati *et al.*, 2002)
DNA damage reduction	
O. Ficus-indica fruit extract	Human peripheral lymphocytes (Siriwardhana *et al.*, 2006)
Improvement of platelet function	
Prickly pear fruits	Humans (Wolfram *et al.*, 2003)
Liver protection	
O. Ficus-indica fruit juice and extract	Liver (Galati *et al.*, 2005; Alimi *et al.*, 2012; Brahmi *et al.*, 2011; Ncibi *et al.* 2008)
Healing properties	
O. Ficus-indica cladodes	Human (Hegwood *et al.*, 1990)
Cancer preventive properties	
O. Ficus-indica fruits aqueous extracts	Ovarian and cervical epithelial cells, as well as ovarian, cervical, and bladder cancer cells (Zou *et al.*, 2005), ovarian cancer cells (Feugang *et al.*, 2010); leukemia cell lines (Sreekanth *et al.*, 2007)
O. humifusa fruit extracts	Breast cancer and glioblastoma human cell lines (Yoon *et al.*, 2009; Hahm *et al.*, 2010), (Harlev *et al.*, 2013)
P. grandifolia	Cytotoxicity against cancer cells (Sri Nuresti *et al.*, 2009; Liew *et al.*, 2012)

Opuntia spp. fruit juice	Prostate, colon, mammary and hepatic cancer cells (Chavez Santo-Scoy *et al.*, 2009)
Hylocereus spp. extracts	In vitro antiproliferative action (Kim *et al.*, 2011; Wu *et al.*, 2006; Jayakumar *et al.*, 2011)
Aqueous extracts of cactus pear	Suppressed tumor growth in femal mice xenografted with SKOV3 cells (Zou *et al.*, 2005)
O. humifusa cactus fruit powder	Decreased number of papilomas and epidermal hyperplasia in mice (Lee *et al.*, 2012)
Polysaccharides from cactus pear	Inhibited growth of tumours in mice (Liang *et al.*, 2012)
Anticlastogenic capacity - Protection against Genotoxicity	
Cactus fruit juice	Mice (Madrigal-Santillán *et al.*, 2013)
Bone density increase	
O. humifusa	Rats (Kang *et al.*, 2012)
Insulin sensitivity improvement	
O. humifusa	Rats (Kang *et al.*, 2013)
Other studies	
Fruit betalain extract	Endothelial ICAM-1 expression inhibition (Gentile *et al.*, 2004)
Fruit betalain extract	Human myeloperoxidase (Allegra *et al.*, 2005a);
Flower extracts	Beneficial effects in benign prostatic hyperplasia (Jonas *et al.*, 1998)

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A perspective on South African spineless cactus pear: research and development – an overview

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Abstract

The effect of declining water resources and increasing desertification on food security prompted the exploration of the highly water-efficient, drought-tolerant cactus pear (*Opuntia ficus-indica* and *O. robusta*) as a commercial crop for the food industry in South Africa. The cultivation of cactus pears requires low input and it has been grown widely in drier areas of South-Africa as feed crop, particularly for times of serious drought. Cactus pears also serve as a source of inexpensive nutritious food for lower income groups. Research on all human food application aspects of this multi-functional crop is reported.

INTRODUCTION

Cactus pear, formerly called the prickly pear, has long been valued in South Africa as cattle feed, as well as for its delicious, healthy fruit. The extremely spiny prickly pear has been brought to South Africa by European Settlers in 1772. It invaded huge areas of natural veld, mainly in the Karoo and Eastern Cape and had to be eradicated. In 1914, the Grootfontein Agricultural Development Institute imported 22 spineless Burbank *Opuntia ficus-indica* and *O. robusta* cactus pear cultivars, principally as a drought tolerant crop for the arid Karoo regions. Since then, 78 cultivars have been developed from the original Burbank's (Potgieter and Mashope, 2009). South Africa is the only country in the world where the Burbank cultivars are still found.

General uses and functions of the plant include food for humans and animals, security (fencing), eradication of soil erosion, by-products like humectants, carminic acid (from cochineal), additives for industrial uses (water purification and paint) and paper, natural colourants (betalains and cochineal), flowers, bio-energy (ethanol and methane gas) as well as medical and cosmetic applications (Feugang *et al.*, 2006).

The fruit comes in a variety of attractive colours, including green/white, yellow, orange, pink/red and purple. The cactus pear is a valuable source of nutrients and its composition is comparable to most other fruits. It consists primarily of water and has a soluble solids content of up to 18%. It has between 6% and 14% sugars, mainly in the form of glucose and fructose. It contains high amounts of ascorbic acid (vitamin C) at levels comparable to that found in citrus fruits, higher than that of apples, grapes, pears and bananas, which aids in staving off all kinds of diseases, improving the immune system, preventing inflammation, and generally supplying the body with chemicals that helps to process a diverse diet (El-Kossori *et al.*, 1998; Sáenz, 2000; Sáenz, 2002; Feugang *et al.*, 2006). Cactus pears also contain important minerals like iron, magnesium and calcium. The level of phosphorus in cactus pears can be compared to that of cherries, apricots and melons. Phosphorus, with calcium, helps to maintain healthy bones and tissue (Sáenz, 2000). The fruit is high in fibre (3.15 g per 110 g). The fruit (pulp, peel and seeds) and cladodes (pads) are rich sources of antioxidants, including betalains, ascorbic acid, carotenes and phenolic compounds. Cactus pear is one of only two sources of the red-purple pigment betalain, which can also be used as a natural colourant in food products.

Both *O. ficus-indica* and *O. robusta* are undervalued food sources, which have health-promoting properties that should be brought into the public domain. The entire plant has value as a health-promoting crop with nutraceutical properties (Piga, 2004, Feugang *et al*., 2006). It is an environmentally friendly and bio-degradable product. It is a wonderful resource and should be seriously considered as an alternative crop for the semi-arid regions. Through research, the hardy, economical and versatile cactus pear can open up economic opportunities in drought-stricken areas in South Africa.

RATIONALE AND BACKGROUND FOR RESEARCH PROJECTS

Research on cactus pears at the University of the Free State (UFS) is in collaboration with the South African Agricultural Research Council (ARC). The Waterkloof germplasm collection is located in the Bloemfontein district in the Free State, South Africa (GPS coordinates: 29°10′53″S 25°58′38″E). This semi-arid area is located 1339 m above sea-level and receives on average 556 mm annual rainfall. The orchard is 12 years old. This site hosts 42 spineless Burbank cultivars, 40 of the *O. ficus-indica* spp. and two from the *O. robusta* spp. Climatic data are captured via an automatic weather station, installed 50 m from the site. Mean daily values for temperature (°C) and rainfall (mm) are summarized as monthly values. The site under study is maintained under dry-land conditions, with rain as the only source of water. Two other experimental orchards developed and maintained by the South African Department of Agriculture are representative of different agro-ecological regions: Cradock in the Eastern Cape (hosting 16 cultivars) and Oudtshoorn in the Southern Cape (hosting 14 cultivars).

OVERVIEW OF FRUIT QUALITY PROJECTS

Little is known about the performance of South African cactus pear cultivars in different agro-ecological regions. Effects of locality on internal quality parameters (fruit mass, percentage pulp, total soluble solids, acidity, pulp glucose and pulp fructose) of available cactus pear varieties were examined. With only a few exceptions, no significant differences among the mean replication values for the different parameters between the three different locations (Bloemfontein, Cradock and Oudtshoorn) were observed. The differences between mean values for most individual parameters at the three localities were highly significant. Highly significant differences between the mean values for the measured characteristics were observed, not only among the locations (except for the pulp glucose values), but also for the influences of genotype and interaction between locality and genotype. Significant variation existed between mean values of the different characteristics for localities and also genotype x environmental interaction was noted. The source of variation is therefore both genetic and environmental (De Wit *et al*., 2010).

The influence of location, cultivar and season on cactus pear fruit quality

The location and environmental conditions have an influence on the quality of cactus pear fruit. The aim of this study was to determine the influence of the location, cultivar and season on fruit quality, to thus establish the most stable cultivar for fruit quality among three agro-ecological localities. Fruit quality parameters were evaluated for 11 cultivars grown in three localities in South Africa. The evaluation was done over two seasons (2008 and 2009) where parameters analyzed include the fruit mass, pulp percentage, acidity, ascorbic acid- and sugar content. Significant differences among cultivars were observed in mean values of the parameters tested at all the locations. Location contributed significantly to variation in sugar content, while cultivar contributed to variation in percentage pulp, pH and acidity. However, interaction between environment and cultivar contributed to variation in most of the parameters tested. The performance of cultivars varied between seasons and it was found that 'Meyers' was the most stable at all three locations in the first season (2008), while 'Tormentosa' performed the best in the second season (2009). According to the Additive Main effects and Multiplicative Interaction method (AMMI), 'Meyers' proved to be the most stable cultivar at all the locations over two seasons. Furthermore, it possesses substantial quality parameters compared to the other cultivars. The genetic material, agriculture location and season made a significant contribution to variation in cactus pear fruit quality. The effect of location and season interactions was significant in especially sugar and acidic levels (Shongwe *et al*., 2013).

Determination of seasonal influences on sensory attributes of South African cactus pear cultivars

This project reported on the effect of cultivar and season on sensory quality of cactus pear fruit. The sensory quality was evaluated by the Free Choice Profiling (FCP) method over the two agricultural seasons of 2007 and 2008. The five most frequently-used attributes used by the panel were sweet, sour, bitter, fruity and prickly pear, with the corresponding cultivars for season 2007 being Fresno, Robusta, Sharsheret, Malta and Amersfoort. For season 2008, the corresponding cultivars for the same attributes changed to Nudosa, Sharsheret, Robusta, Roly Poly and Ficus Indice, respectively. The FCP technique could successfully distinguish between the two seasons, but not between the majority of the cactus pear cultivars. The exception was Monterey and Robusta (*O. robusta* spp.) where FCP was able to differentiate them clearly from the rest of the cultivars. In an attempt to determine whether sensory quality of cactus pear fruit was influenced by the physico-chemical parameters, Pearson correlation analysis was performed between the physico-chemical and sensory data. Physico-chemical parameters like pulp glucose, pulp fructose and percentage pulp were correlated with sensory attributes like sweet, fruity and prickly pear. The descriptor "sweet" had a positive correlation ($r = 0.2477$) with pulp glucose and pulp fructose content ($r = 0.2636$) at a significance level of $p < 0.05$. A negative correlation at a significance level of $p < 0.01$ between the taste attributes "prickly pear" ($r = 0.4259$) and "sweet" ($r = 0.3561$) and % pulp was observed. "Prickly pear" had a positive correlation ($r = 0.3547$) with pulp pH at a significance level of $p < 0.01$ (Rothman *et al.*, 2012).

The influence of cultivar and season on cactus pear fruit quality

The aim of this study was to determine the fruit quality of cactus pear fruit. Physical/chemical quality attributes were evaluated for two agricultural seasons (2007 and 2008). The influence of factors such as rainfall and temperature on quality was determined. Highly significant differences were observed in terms of physical/chemical composition ($p<0.001$) among 33 different cactus pear cultivars over two seasons. This finding indicated that genetic differences among cultivars, as well as seasonal changes, have a significant influence on fruit quality. It was evident from this study that not only the cultivar and agricultural season, but also the interaction between the cultivar and season had significant influences on fruit quality (Rothman *et al.*, 2013).

Fruit juice

Fruit juice plays an important role in human health. In an attempt to increase the use, other than fresh consumption, cactus pear fruit juice was thermally processed (including jelly manufacture) and sensorially analyzed. Fruit from seven cactus pear cultivars used for human consumption, and an animal feed cultivar, was peeled and juice was extracted. Three thermal treatments applied included freezing (-18°C), refrigeration (4°C), and pasteurization (60°C). Ten semi-naïve panellists compared the taste, using their own descriptors and a ten point scale. Twenty four descriptors were generated. The panel was successful in distinguishing between the cultivars used for human consumption and the animal feed cultivar. Pasteurization had a detrimental effect on the flavour of the juice. Other important deductions could be drawn from this study: pasteurization changed the prickly pear and melon taste of fresh and frozen juice from Santa Rosa to bitter and astringent. Freezing and pasteurization turned the melon and prickly pear taste of the juice from Algerian to bitter and astringent. The frozen juice of Meyers had a more acceptable taste than the fresh and pasteurized juices. A frozen puree was most stable and versatile. An interesting observation was that no green or white cultivar obtained any negative descriptors after heat treatments. Descriptive sensory analysis on cactus pear fruit jellies, from seven cactus pear cultivars, compared the following textural attributes: cloudiness, smoothness, pectin content, runniness and cutting edge. Physical analysis of texture was also determined to support the sensory data. There was only a significant difference between the seven cultivars for the sensory descriptor of cloudiness. Both physical tests differed significantly between jellies from the seven cultivars (De Wit *et al.*, 2014).

Seed oils

Cactus pear seed oils were studied for the influence of cultivar, location and season on its fat content and fatty acid composition. Study materials were gathered from three South African agro-ecological regions: Bloemfontein (42 cultivars), Cradock (16 cultivars) and Oudtshoorn (14 cultivars); distinguished through its diverse environmental conditions; during two agricultural seasons (2010 and 2011). As was previously found with other seed oils, cultivar type had an effect on the oil content and the fatty acid composition of these oils. Location and season differences, resulting in dissimilar weather, climatic- as well as the soil conditions, had an influence on the oil content as well as the fatty acid composition of cactus pear seed oil. The influence of the environment was particularly observed on the oil content, whereby cooler and wetter seasons resulted in higher oil content. Furthermore, the oils originating from cultivars from the warmer environments showed higher levels of saturated fatty acids, as opposed to those from cooler environments. This observation was also similar to that reported for other seed oils. The location x season interaction also proved to have an influence on the oil content and the fatty acid profile of these seed oils (Shongwe, 2012).

Also investigated was the oxidative stability and quality of seed oils from a few selected South African cactus pear cultivars all taken from the Bloemfontein location. Five cultivars were from the *O. ficus-indica* spp. and two from the *O. robusta* spp. This trial confirmed that oil content and fatty acid profile is determined by the type of cultivar and the type of species. The stability tests (namely iodine value, refractive index, peroxide value, ρ-anisidine value, free fatty acid value and oxidative stability index (OSI) indicated variation between the cultivars and also showed influence of the type of species. Results indicated that there was a link between the oxidative stability index, oil content, some of the physicochemical properties (peroxide value and the ρ-anisidine value) and some of the fatty acids C18:0 and C18:1c9 acids. The seed oil from the *O. robusta* spp. demonstrated the lowest quality and stability values and Tormentosa had the best (Shongwe, 2012).

Seed proteins

Seed storage proteins are classified into groups based on their extraction and solubility. These classes include the water soluble (2S Albumins), those soluble in dilute saline solutions (Globulins), those soluble in alcohol mixtures (Prolamins) and those soluble in diluted acids or alkali's (Glutelins) (Shewry *et al.*, 1995). Functional properties and uses of proteins in food systems include gluten fraction formation of wheat flour in baked products, as well as its amphiphatic properties resulting in good emulsification properties. Further uses include foaming/foam-stabilizing properties, flavour binding as well as cohesive and adhesive properties in processed meats (Kinsella, 1976; Hoffman, 1980; Sosulski and McCurdy, 1987; El-Kossori *et al.*, 1998).

The aim of the investigation was to determine the amount and characterize the different seed proteins of three cactus pear cultivars (*O. ficus-indica* Algerian and Meyers as well as *O. robusta* Robusta) from three different locations (Bloemfontein, Cradock and Oudtshoorn). Results indicated that location and cultivar had no effect on the total nitrogen and total protein content. Significant differences in free amino acids levels between locations were observed. Urea and SDS polyacrylamide gelelectrophoresis (PAGE) analysis of the proteins revealed the following fractions: a 15 kDa protein bond (in the 2S Albumin group), three protein bands within the Prolamins group (Mr range of 37, 50 and 75 kDa) as well as a 40 kDa protein band in the group of the 11S Globulins (Lebeko, 2010).

OVERVIEW OF CLADODE PROCESSING PROJECTS

The suitability of cactus pear (*Opuntia ficus-indica* and *Opuntia robusta*) cladodes for the processing of a health beverage (juice)

The main aim of this research project was to investigate and determine the possibility of making a health beverage (juice) using cladodes (pads) of the *O. ficus-indica* cactus pear. Furthermore to establish whether the cladode juice with either a fruit juice or vegetable juice blend will make it an acceptable beverage meeting with consumers' preference. The nutritional value and neutraceutical potential, such as the vitamin C, iron and dietary fibre contents, contribute to the positive prospective that will come from this health beverage and can also increase the pharmaceutical, and thus the economic potential of a country.

Cladodes from two cactus pear species, namely *O. ficus-indica* (forty cultivars) and *O. robusta* (two cultivars) are available. The cultivars that were used for experiments include *O. robusta* (Robusta) and *O. ficus-indica* (Algerian, Ficus Indice and Turpin). *O. ficus-indica* (Ficus Indice) was used in the final making of the health beverage because of the lower viscosity among the cultivars tested and because of its distinct, favourable flavour and texture.

In all the experiments some form of treatment was applied - either it was left untreated (only distilled water added), a heat treatment was applied, or an acid treatment either with acetic acid (vinegar) or citric acid in different percentages such as 0.1%, 0.5%, 0.75% and 1.0%. Numerous flavours of vegetable juices and fruit juices were tested to determine which juice would fit best in terms of flavour, aroma, colour, taste and texture.

All results indicated that a heat treatment as well as an acid treatment was needed. The most effective heat treatment was to heat blanch the cladodes in boiling water for two minutes. Not only does blanching preserve the juice and inhibit microorganism growth, but it also made the mucilage less viscous. Acid treatments like acetic acid (vinegar) and citric acid was added to samples at different concentrations. Results showed that the most effective and acceptable acid treatment was 0.1% citric acid.

1. Vegetable juices

Numerous vegetable juices were tried and tested. Cladode juice was mixed with carrot juice, beetroot juice, tomato juice, and guava juice. The carrot juice had an unappealing taste and texture; therefore it was abandoned for use in further studies.

2. Fruit juices

Fruit juices that were tried and tested and failed sensorically were strawberry juice (too sour), prune juice (unappealing taste), and the peach & apricot blend (acceptable taste and texture, but was inferior to the pawpaw, orange & mango juice).

3. Final blends

The final juices that were tested were tomato juice; beetroot and strawberry juice blend; guava juice; kiwi & pear juice; and pawpaw, orange and mango juice.

A sensory consumer analyses was done to evaluate the degree of overall acceptance by consumers. The results obtained indicated that the product would be considerably well accepted, with the most overall liking and with the highest score in of all the attributes evaluated being the guava juice. The juice the consumers disliked the most was the tomato juice. The beetroot & strawberry flavour is a totally new concept and may have been unfamiliar to the panel. If one of these juices would be produced and commercialized, the most suitable juices would be the guava juice and the kiwi & pear juice. In conclusion, the data and results indicate that consumers may consider consuming and purchasing a cladode juice blend, that is, a fruit juice rather than a vegetable juice is to be marketed, and the most likable would firstly be the guava juice blend and secondly the kiwi & pear juice blend (Muller, 2013).

Cladode flour

1. Preparation

Mature cladodes (2-3 years old) were harvested at the Bloemfontein experimental site. They were washed and brushed in chlorinated water, cut in strips with a mechanical cutter and left to dry in the sun (7-10 days). Thereafter it was milled into flour.

2. Health bread

Health bread, containing different types of seeds (sunflower, linseed, etc.) and whole wheat flour was prepared. Some of the whole wheat flour was replaced with cactus pear flour in percentages of 2%, 4%, 6%, 8%, 10%, 12% and then 17% replacement.

Cactus pear flour causes the bread volume and texture to change a lot. The volume decreases and the texture become far more solid and firm. It can be ascribed to the little amount of starch available in the cactus pear flour. The brown colour of the bread also intensified and darkens when the percentage replacement of the flour increased, although it was still acceptable for the consumer (Van den Berg, 2012).

3. Oats crunchy cookies

Oats crunchy cookies were manufactured with increasing replacement levels (0%, 5%, 10%, 20% and 50%) of wheat flour with cactus cladode flour from three different cultivars, *O. ficus-indica* (Skinners Court and Morado) as well as *O. robusta* (Monterey). Cultivar had a significant effect on colour, taste and texture, but not on appearance. Increasing inclusion levels of the cactus pear flour had a significant effect on all the sensory attributes evaluated.

Significant differences were observed at the higher inclusion levels for all the cultivars. The taste that was most liked by the panel was that of the Morado 10% inclusion level sample. Up to the inclusion level of 20%, no significant differences were found in the liking for the taste of the cultivars. For the texture attribute, the highest value was given to the Morado inclusion level 10% sample, which also had the highest score for taste. A significant decrease in the liking for the appearance of all the 50% inclusion level samples was observed.

The addition of cactus pear flour increased both the soluble and insoluble dietary fibre amount, and the total dietary fibre content was proportional to the cactus pear flour addition. Fortification of wheat flour by cladode flour as a source of dietary fibre leads to a change in texture properties (Sáenz *et al.*, 2002). Cladodes like any other fibre source increase water absorption capacity of the flours and consequently the texture properties. Cladode flours were found to affect quality parameters of texture, colour and taste of the biscuits.

Regarding the protein content, there is a noticeable difference between the wheat flour in the control samples and the cladode flour samples. The protein content of flour affects the strength of dough. Since there is a shortage in protein sources, this cladode flour can be used as an unconventional source, because it has the chemical composition, amino acids profile and functional properties needed in manufacturing of food products (Absalom, 2012).

Traditional, indigenous fermented beverages

This study focused on the fermenting properties of *O. ficus-indica* cladode flour in traditional, indigenous beverages mageu and beer. The tests conducted focused on the physical and chemical analyses of samples made from different inclusion levels of the cladode flour.

The main fermenting agent involved in both products was maize meal. In the case of the beer, King Korn (sorghum/millet) was the key ingredient. Recipes used in the production of these products are still based on old recipes which were conveyed from generation to generation of Basotho consumers. These consumers are not easily influenced by modernization, and this could be seen in the manner in which the mageu and beer were, and still are prepared.

1. Mageu

The mageu is a traditional fermented drink made from cooked maize meal, that is left to sour over a period of five days. The drink would have an acidic pH and sour smell, with a fizzy taste once consumed. The presence of lactic acid bacteria and yeasts were determined microbiologically in order to confirm fermentation.

As would be expected, the pH of all samples tested had a lower pH after fermentation, than before fermentation. The presence of higher levels of lactic acid bacteria (after fermentation) in all the samples indicated that sugar had metabolized to lactic acid, leading to a lowering in the pH. The higher the inclusion of cactus meal became, the less sugar was available to lactic acid bacteria to metabolize. This led to a decreased difference between the before and after fermentation levels of the pH of samples.

As the levels of cactus meal inclusions increased, the colour of the samples got darker in comparison to the control. The best sample to continue with for sensory analyses was sample C, with a 20% cactus meal inclusion. The sample showed all the characteristics associated with the control sample of the mageu. Sample C fermented well, without any harmful pathogens present.

Sensory analyses of two mageu samples were tested. The first was the control, and the second was sample C (20% inclusion). Analyses found that the panel of consumers did indeed notice a difference between the two samples. The control mageu had an acceptance value of 8, and the cactus meal mageu a value of ± 4. The panel had therefor favored the control mageu over the cactus mageu. It is therefore clear that the cactus meal could not be used in the making of mageu at an inclusion level of 20%. It might be able to use in lower inclusion levels.

2. Beer

This traditional, indigenous beer is locally also known as "platpit" beer. The drink is made from fermented maize meal and sorghum. The fermenting process normally takes up to five days. The sorghum (King Korn in this study) is the fermenting agent. As discussed, lactic acid bacteria, yeasts, alcohol and pH levels are all determining factors in rating the success of the beer.

The first beer recipe that was tested failed to comply with food regulations set in place to safeguard human life. E.coli and other coliforms were detected in the brews of samples made using this first recipe. A second recipe (which included a cooking process) was introduced, and this proved to be microbiologically acceptable.

What was made very visible through this study is the relationship between pH, yeast, lactic acid bacteria and alcohol formation. Even though the counts of lactic acid bacteria in beer might have been low before fermentation, the addition or presence of sufficient soluble carbohydrates in the maize and cactus meal, stimulated their multiplication and subsequent lactic acid production. This increase in lactic acid, led to a decrease in the pH, rendering it more acidic after fermentation. As it was the case with the mageu, the pH levels of all beer samples were more acidic after fermentation than before fermentation.

In order to determine the amount of alcohol production in each sample, the ºBrix (°Bx) had to be measured. Once this was determined, it was evident that the samples with the lower cactus meal inclusions, had the highest °Bx after fermentation, rendering a sample with a higher alcohol reading. This was especially true for the sample made from the second recipe. The product was of great colour, and very appetizing. When all this is taken into account, it appears that a successful beer was brewed.

Sample D with a 25% cactus meal inclusion was the best sample to continue further testing with. Sample D had all the characteristics that were found in the control beer. Sample D had fermented well, and the colour difference was not disturbing.

A sensory analysis was also conducted on the beer, and two samples were used. The first was the control, and the second was sample D (25% inclusion). Analyses found that the panel of consumers did not notice a different between the two samples. The cactus beer had an acceptance value of 5.7 and control beer a value of ± 4. The panel had therefor favoured the cactus beer over the control beer. It is clear (from seeing the sensory analysis results) that the cactus meal could be used in the making of traditional beer at an inclusion level of 25%. It might be able to use in higher inclusion levels as well, with the addition of certain food additives (Van der Bijl, 2013).

Carrot cake

With the increase in the level of cladode flours in the formulation of a popular South African cake, the sensory scores for the organoleptic characteristics of the cakes decreased. The control samples (0% cactus flour) had maximum overall acceptability, whereas cakes containing 75% and 100% of cladode flour were found to be unacceptable to the panellists. The overall acceptability score for the control was 3.09 on a 5-point hedonic scale. Cakes made from blends containing 25% cladode flour did not differ significantly from the control. At 75% and 100% levels of substitution, the colour, texture, taste and general appearance changed and the overall acceptability was rated as poor. From the overall acceptability rating, it was concluded that cladode flour could be incorporated up to 25% level in the formulation of cakes (Sithole, 2012).

Cladode mucilage

1. Extraction

A patent was registered on the extraction of mucilage from cactus pears (De Wit and Du Toit, 2012).

An intensive search was launched into the 42 cultivars of the spineless cactus pears available in the Bloemfontein orchard in order to determine the cultivars containing the most and the least mucilage. Cultivars containing the least mucilage could have potential as table vegetables while cultivars with high mucilage will be used in order the extract the mucilage for commercial use. Four cladodes from each cultivar were investigated and the weight, yield, viscosity and water activity was determined. The most effective way of drying mucilage was investigated as well as the process of rehydration of the resulting powder into liquid form. It was found that the yield and viscosity relationship was different for each cultivar, moisture content does not seem to indicate the yield of mucilage from cultivars and that the average weight (size) of cladodes does not indicate the mucilage content. Six cultivars that demonstrated high yield and high viscosity namely Turpin, Gymno Carpo Algerian, Malta, Van As and Meyers as well as high yield and low viscosity namely Amersfoort, Tormentosa, Morado, R1260, Cross x and Robusta x Castillo, were indicated for further study. Freeze drying is the best method of freezing the mucilage effectively. Mucilage had to be hydrated with hot water in order to regain the characteristic viscosity it had before dehydration (undergoing research, unpublished data).

Candies

1. Turkish delight

Turkish delight/lokum was made with gelatine replacements of 0, 25, 50, 75 and 100% mucilage. A 100-member consumer panel evaluated the 0, 25 and 50% experimental Turkish delight/lokum, as well as a commercial brand, for taste, texture, overall liking and appearance. Physical analysis included line spread test, viscosity, % sag, and penetrometer measurements.

The consumers preferred Turkish delight/lokum with a very stiff texture, like that of the commercial brand. The addition of mucilage led to a significant decrease in viscosity. The 25 and 50% experimental variants did not differ significantly from the gelatine-containing control, for the sensory attributes (Mahupunyane, 2012).

2. Marshmallows

Five different formulations were used to evaluate the effectiveness of the mucilage to replace gelatin in marshmallows. These include the control (no mucilage), 25% replacement of gelatin, 50% inclusion of mucilage, 75% inclusion and 100% replacement of gelatin. After five weeks of storage, the foam became unstable: the egg white formed a layer on top, while the mucilage formed a layer in the middle. The sugar precipitated in clumps at the bottom of the container. Mucilage was found to have excellent beating properties. The foam formed in marshmallows, however, was not stable after a few weeks of storage. It could not act to replace gelatin in foam formation. It is suggested that it could, however, be used as a foaming/beating aid to be used in temporary foams (Du Toit, 2013).

Carrot cake

It was proved that mucilage can be used successfully in the replacement on oil in baked products because of its hydrocolloid properties and that there will be not much variation of colour, texture, taste and general appearance between a normal carrot cake and a mucilage carrot cake. The same observation was made in health bread, where 100% of the oil in the recipe was replaced by mucilage (Sithole, 2012; Van den Berg, 2012).

ANTIOXIDANTS

The aim of this investigation was to determine the ascorbic acid, total phenolics, betalains as well as carotenoids in eight different cultivars with four different coloured fruit from South African cultivars to determine the protective effect for health. Conventional methods were used to determine the antioxidant occurrence in the fruit pulp, edible peel, seeds and cladodes (leaves). Our findings showed that the purple cultivar Robusta had more betaxanthins and betacyanins in the fruit, seed and cladodes than any other studied cultivar with readings up to 43.2 mg/kg in the fruit. In all results the seeds and cladodes had considerably more betalains than in the fruit. Generally high ascorbic acid readings (± 50 mg/kg) were recorded for the fruit and peel but low results for seeds and cladodes. The seeds had five to eight times more total phenolics than that of the fruit and the cladodes had up to 70 times more, with Nepgen (green cultivar) measuring at 726.4 mg/L. Carotene was present in the pulp and peel with the most in the orange cultivar (12.85 µg/g,) but the cladodes had 10 times and the seeds 70 times more carotene, with a pink variety peaking 69.25 µg/g. It may be concluded that significant antioxidants are present not only in the fruit but also in the edible peel, seeds and cladodes of the *O. ficus-indica* and *O. robusta* plant proving the true value of this health promoting economically viable crop (Du Toit, 2013).

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Cactus pear by-products: a demonstration and elaboration of valuable food conserves

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Keywords: harvest, leaves, packing, pruning, sterilization

Abstract

Cactus pear is an ancient plant from Mexico that is used widely for food, beverage, forage, medicine, dye and cosmetics. Currently, products that have a natural origin are in high demand by consumers and the cactus pear is providing these products and subsequently is a highly marketable resource. Many by-products derived from cactus pears are continually developed to extend the benefits of this plant and provide added value for this important resource. The diversity of food products that can developed from the young leaves of cactus pear fruit includes juices, yogurt, sauces, jelly, salad dressing, chips, soups, alcoholic drinks, syrups and marmalade. Many cosmetics are also produced such as soap, deodorant, shampoo, lotions, sunblock, and a repellent for mosquitoes, food supplements to lower cholesterol levels, triglycerides and sugar. Additionally, produces are products that can aid in weight loss. The preparation of cactus pear requires careful handling and processing during peeling, harvesting, hygiene, sanitation operations, sterilization and packaging. Establishing appropriate infrastructure is essential if these products are to be industrialized, such as in the case of artisanal products that require specific processing such as sterilization and cleaning of all utensils that are used in the process.

INTRODUCTION

Future sustainability of world-wide arid and semi-arid areas depends on the development of sustainable agricultural systems which are formed from appropriate crop choices. Cactus pear *Opuntia ficus-indica* (L.) Mill. (Cactaceae) has an ecological role in soil conservation projects within arid zones of the world. Most of the commercially known cactus species originated in Mesoamerica (México), which are pantropically cultivated, that provide for multiple uses such as fruit, forage, vegetable (nopalitos), cochineal carmine, cosmetic and medicinal purposes and many other applications. Cactus pears (*O. ficus-indica*) are a diverse group of cultivars that is one of the most valuable genetic resources in Mexico (Corrales-García, 2009). This crop has maintained a traditionally deep link in Mexican culture, facilitating a strong ethnobotanical relationship between human and cactus pear. This has created a symbiotic relationship, very similar to that with Agave (Gentry, 1976), in which the man obtains a food source and many other benefactors and the plant receives improvement and adaptation through hybridization and selection. This relationship can be used to explain in part the increasingly large number of by-products developed from cactus pear. The purpose of this paper is to provide substantial evidence regarding the high potential for transformation of cactus pear, further than its simply utilitarian function that is most commonly known.

Cactus pear uses and by-products

Cactus pears and products derived from it are known for centuries. The Spanish-derived names "tunas" and "nopalitos" have been used interchangeably with the English-based words "cactus fruit" and "cactus pear" or "prickly pear". The use of *Opuntia* spp. as an alternative treatment to control diabetes is commonly known; this plant can be taken before breakfast by preparing a shake with joconostle mesocarpium (Figure 1a), cladode or both (Ibáñez-Camacho and Merckes-Lozoya, 1979; Bravo-Holis, 1978). The species most commonly used for this purpose include the wild *O. joconostle* Web. (Figure 1b), *O. leucotricha* DC and *O. streptacantha* Lem., and the cultivated *O. ficus-indica*

Figure 1. a) *Joconostle mesocarpium* . **b)** *Opuntia joconostle* Weber.

and *O. matudae* Scheinvar, the latter being grown commercially in the State of Mexico (Paiz *et al.*, 2010).

Prickly pear pads are consumed as a vegetable (nopalitos). This food source has been an important staple in the diet of Mexican people diet since pre-Hispanic times. The tender young pads of both *Opuntia* and *Nopalea* species, also known as nopalitos, cactus pads, cactus stems, vegetable cactus or cactus leaves, have been traditional vegetables in Mexico. These are typically consumed either fresh or as a cooked green vegetable (Rodríguez-Felix and Villegas-Ochoa, 1998).

Cactus pad chemical composition is similar to most other vegetables. They have high water content, which makes them very succulent. In addition to high carbohydrate (sugar and cellulose) availability, cactus pads also contain protein, vitamins, pectin substances, saponins, organic acids, and minerals (Table 1) (Corrales-García, 1998).

Table 1. Chemical composition of cactus pear by-products (g/100 g).

	Cladode	Juice cactus pear	Cactus pear
Protein	5.4	0.5	0.8
Fat	1.29	0.5	0.6
Crude fibre	12.0	0.2	1.0
Vitamin C	24.5	0.020	-------

Sepulveda, 1998; Paredes and Rojo, 1973.

The main processed products are nopalitos in brine, or pickled, sauce, jam, candied and others (Table 2).

With the intent of sharing the positive experiences that Mexico has had in cactus pear use, this paper provides a technical description of its alternative transformation including pruning strategies, harvesting techniques, hygiene measures, sterilization and packing.

Pruning

In traditional systems, formative pruning is done annually to clear paths and to restrict plants from growing too high to allow easy harvesting by hand. In the period of greatest production, the growers cut the terminal cladodes at mid-point in order to detain the production of young pads and to allow the plant to perform repose or dormancy and accumulate reserves for the autumn and winter (when prices rise). Fruits are harvested carefully by cutting a small amount of the attached mother cladode, which after two days falls off when the fruit is selected and packed.

Harvesting

Cladodes should be harvested 30 to 60 days after sprouting when they have a weight of 80-120 g and are 15-20 cm long. Some producers harvest by pulling and twisting the nopalitos off; however this can produce injuries to plants and rotting. Most of the growers use a knife to harvest cladodes by cutting the base to delay deterioration. For exporting the same harvest protocol for fruit is performed, with the small piece of the mother cladode attached. This practice conserves them for a longer period (Flores, 1995) (Figure 2).

Fruits are picked manually with thick gloves and glasses to avoid injuries from glochids. Picking should start early in the morning when glochids are wet and stick to the fruits. Soon after harvest, fruit is selected according to size and brushed to remove glochids. Various hand-held tools have been developed to facilitate the harvesting of cactus pear. Many of these tools consist of a cutting edge device with a basket to hold the harvested fruit. More advance designs for rapid individual fruit

Table 2. Some products and by-products from cactus pear fruit and cladodes.

Cladodes	By-products
Pickles	Pigments from the peel
Dressing	Dietary fiber
Candy	Soap
Marmalades	Shampoo
Flour	Body cream
Alcohol	Gel reductive
Beverages	
Bread	
Tortillas (Mexican food)	
Sauces	
Cake	
Jelly	
Source: Vigueras and Portillo, 2002	

harvesting have been developed including a cutting or twisting tool that is attached to an extended light-weight arm (Lara-López and Manriquez-Yépez, 1985, in Cantwell, 1995). Fruits are passed over a series of brushes with the applications of water sprays or an air suction to rap and remove the glochids. After brushing, fruits are waxed, sized (manually or by weight sizes) and packaged.

Figure 2. Nopalitos processed**. a)** Peeled, **b)** Cutting.

Hygiene Measures

Hygiene measures are always important to safeguard humans, in particular for small enterprises. In the absence of such measures, the products will be liable to contamination by bacteria, yeasts and moulds; however, preservatives cannot prevent the multiplication of germs if insanitary conditions prevail during the preparation of the products. Therefore, it is recommended that the following rules are adhered to:

1. The workers should carefully wash their hands before any product processing operation.
2. The utensils and equipment should be properly cleaned before and after use. This prevents dust and organic particle contamination.
3. The packaging, bottles and jars should be washed with a hand-operated appliance and hot water.
4. Before storage, the finished products should be washed, dried and properly labelled.

Preliminary operations

The raw materials have to be processed as soon as possible in order to avoid deterioration. Peeling facilitates the operations of cutting the raw material into pieces or into slices before processing.

Sterilization

The purpose of sterilization is to destroy microorganisms and preserve the product for long-term storage. This operation is carried out in large pots, with care being taken to place straw between layers of containers and at the bottom of the pot to avoid breakages caused by convection that results from boiling water. Before calculating the time needed for pre-sterilization (30-60 min) and following the product completion (30 min), the water must first come to a complete boil (Table 3 and Figure 3).

Through the sterilization process, prickly pear marmalade can be preserved for one year without adding preservatives.

Table 3. Sterilization times for cactus pear food.

Size of jars in mm	Sterilization of jars or bottles	Sterilization time in minutes
110	X	30-40
230	X	40-50
485	X	50-60

Figure 3. Jars sterilization.

Figure 4. Cactus pear by-products. **a)** Commercial presentations, **b and c)** Packing and label of artisanal by-products.

CONCLUSIONS

There are several alternatives for processing fruit and nopalitos. The fruit and stems can create marmalades, juice, candy, patties, salad, pickles, nectars, jams, dehydrated sheets, cookies, flour, bread, crystallizations, soup, and various other preparations. These products can be interesting alternatives with regards to processing of this plant, as well as promoting its use and cultivation.

Anything that can be done to increase shelf life of this fruit and to add value by means of processing will be significant for the inhabitants of the arid and semi-arid regions. As well, it would play an important economic role, by increasing the efficiency and economic viability of the small- and medium-size farms of low-income farmers, who aim to produce the plant for subsistence and/or to reach national or international markets.

Packing

By-products processed by heat (juice, jams, marmalade, etc.) are packed in glass bottles and jars (Figure 4).

Glass containers have the following advantages:

1. Jars and bottles are reusable.
2. Closing is very easy: a lid is used for the jars and a cap for the bottles.

A label giving the following information must be placed on the bottles and jars:

1. Nature of product and ingredients.
2. Net weight.
3. Origin.
4. Date of production and storage life.

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Prickly pear cactus family orchards: an alternative for sustainability

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Keywords: Rural development, human development, rural families, self-confidence, food sustainability, environment, economic sustainability

Abstract

Providing sustainable food security is a major challenge facing humanity. Deterioration of natural resources generates elevated poverty and land degradation, which in places can lead to desertification. In addition, forage production has become highly expensive and is difficult. The typical farming lifestyle is now threatened, as noted by 60% of all farmers being over 55 years old. The objective of this study is to provide a mechanism that can be used to improve the living conditions of rural communities through educational strategies targeted to achieve alimentary, economic, community and environmental sustainability through the development of self-confidence in rural producers. The methodology includes the implementation of strategies to improve teamwork, group solidarity and self-esteem. The stage is set to initiate productive projects that serve as the core generator for participatory processes of integrated collaboration. The main results for each of the stages were: 1) Food sustainability, all of the prickly pear orchards are currently in production and one of the groups is selling their production to a local business, 2) Environmental sustainability, rancher's herds (goat, sheep, cattle) are being fed with prickly cactus during drought periods. Only one of the communities had losses due to predation on domestic animals and low yields for the lack of irrigation and weeds. This could be related poor collaboration and a lack of a sense of belonging to the project. 3) Economic sustainability, all of the communities sell prickly pear products (to both local and visiting commercial buyers). In terms of 4) Community sustainability, collaborative activities were effective for learning simple techniques for organizing tasks. Solidarity development was accompanied by strategies for self-confidence improvement, which grows with success experiences; learning how to successfully accomplish tasks is a self-contained reward. Group problems were reduced when members felt better about themselves.

INTRODUCTION

In Mexico poverty is an essential factor in the degradation of soils, especially in rural areas, primarily due to long-term investment losses. Eight out of ten rural families are poor and of these four are in extreme poverty. According to the National Council for Evaluation of Social Development Policies, the decline in agricultural income per capita has significantly impacted poverty levels have increased from 49.5 million people in 2008 to 53.3 million in 2012. The rural population earned less than the minimum wellbeing income standard reaching 32.7 percent (Millennium, 2015).

Food sustainability is not only restricted to productivity, but a series of activities are focused on those who seek and have access to food. The UN General Assembly recognized that "providing sustainable food security and adequate housing is the greatest challenge facing humanity" (Moreno and Cantu, 2005). Another impact of poverty on peasants is that it prevents them from investing in conservation and improvement of their lands, perpetuating a deleterious cycle in which the deterioration of natural resources generates more poverty further exacerbating degradation rates, a process that eventual spirals toward desertification (Ceja, 2008). Human-related activities that contribute to desertification are over-cultivation, overgrazing, deforestation and poor irrigation practices. Forage production has become highly expensive and difficult associated with widespread soil erosion losses. In these cases, a lack of awareness concerning sustainable development is common, knowledge about nutrition and management of cactus is scarce, and the farmer's livelihood is threatened.

Natural resources, such as prickly pear, provide a solution to both ecological and economic limitations. This crop not only has a long life and highly resistant to adverse climate and diseases, but is also easy and inexpensive to establish and maintain year-round as reliable forage, vegetable and fruit (Fuentes and Murillo, 1996). According to Portilla (2002), economic participation of rural women is essential because of their contribution to employment and unpaid work in the home as well as their contribution to local development through family cohesion and purpose. The objective of this study was to improve the living conditions of rural communities through educational strategies targeted to achieve: alimentary, economic, community and environmental sustainability through self-confidence development. Therefore, education of people is a must, in order to preserve ecosystem integrity. Such education includes: awareness of the use of cactus to control erosion and promoting consumption of cactus products (Murillo and Fuentes, 1997).

MATERIALS AND METHODS

Through the implementation of strategies to improve teamwork, group solidarity and self-esteem, the stage is set to initiate productive projects that serve as the core generator of participatory processes of integrated collaboration.

Phases

1. Diagnosis of members through a survey designed to determine: previous experiences, capabilities, expectations, vision, learning disposition, self-esteem, commitment, solidarity and sense of community.
2. Selection of participants in the study.
3. Problems and solutions identification.
4. Induction to sustainability projects.
   a. Working conditions. To continue with the principles of collaborative work, all actions taken should be carried out in teams; without the participation of students or workers that perform these duties.
   b. The project is used as justification or as an excuse to continue developing solidarity, commitment, self-esteem, and sense of community, all essential for community projects.
5. Development of organizational skills.
   a. Self-esteem workshop
   b. Integration of effective work teams
   c. Participatory planning (collaborative teams)
   d. Administration skills (collaborative teams)
6. Definition of family project sustainability.
   a. Family and community orchards
   c. Livestock package (poultry, pigs, goats, sheep, etc.)
7. Project Development Processes.
   a. To promote the implementation of joint tasks for all members of the project to strengthen solidarity, increase self-confidence, ensure commitment and enhance sense of community.
   b. Conflict Resolution. Workshops based on win-win and human moral principles in order to achieve the economy of the common good.

RESULTS AND DISCUSSION

Once the diagnosis was conducted, three communities were selected and 16 families were identified that met the requirements for participation in this study (Table 1). These families had a minimum of 100 m of available land for an orchard and had the necessary agricultural and animal production skills (Figure 1). The main problems identified by the members of the three locations were the lack of organization and community solidarity, which force participants to produce and commercialize individually with the consequential low volume and low price products. More frequent solutions required organization and the development of solidarity throughout the community (Figure 2).

Table 1. Family members productive activities for each group.

Community Group	Family members Agriculture	Livestock
1	45	44
2	10	10
3	32	36

The establishment of the sustainability project showed different results. Two of the communities established their plots with collaborative team work leading to all of their prickly pear orchards are currently in production and one of the groups is selling their production to a local business. The other community

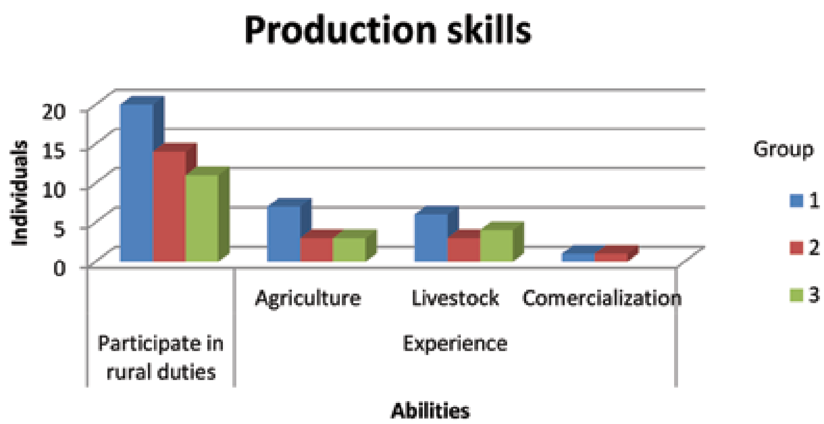

Figure 1. Production skills of the group members participating in the project.

exhibited a limited cohesion and occasional structural problems. In response, they eliminated aid from both university students and extension specialists. They also had losses due to predation by domestic animals and low yields caused by a lack of irrigation and weed invasion. These losses could be related to the fact that they did not work collaboratively and to a lack of sense of belonging to the project. When comparing the two groups of producers, it can be inferred that the esteem of a group is related to organizational development achieved by groups of rural women (Murillo *et al.*, 2011).

The process of implementation to strengthen solidarity, self-confidence, commitment and sense of community, included the use of strategies for: goal setting, effective training teams, problems faced by individuals and ways to cope with these problems. All of these techniques were applied during some production process or activity. Two of these techniques are presented as an example of the effects on the acquirement of abilities and awareness growth of the participants in this project.

The strategies to develop abilities for collaborative work and setting prices for their products were applied in two sessions. The immediate effects of the collaborative activity were: learning simple techniques for organizing tasks and time management and the distribution and allocation of tasks according to the abilities and skills of each participant. The second activity established allowed participants to learn how to determine production costs required to set prices that are both profitable and competitive. The educational effects of this price setting activity were that, in addition to production materials, there was full consideration of time and natural resources as important inputs, allowing participants to be aware of the monetary value of their work, and assigning a price to natural resources for improving their care.

With the objective of identifying and resolving personal conflicts and group dynamics, which can affect the productivity of the organization, the results of this strategy which were used in one of the participating groups of this study, are:

1. Identification of unproductive factors related to group dynamics. Some of the symptoms presented were: recurrent absence of one or more of the people; failure to accomplish assigned tasks; lack of cooperation; resistance to contribute to their group obligations; distorted communication of internal events of the group.
2. Reasons for abandonment or loss of interest to the group: excessive domestic work; permission of the spouses; maintenance activities and collecting money for school; church activities; perception of inequity in the distribution of tasks and gains.
3. Causes that may be behind the problems of the group: low gains and husbands who believe that it is not worth their continued participation in the project; they have not involved other family members and therefore do not cooperate either to the project or to the housework; only the advantages and benefits of others are perceived. "We always believe that others are better than us"; "There are always many other activities that must be performed as an obligation to the community and cannot be avoided".
4. Solutions to solve the problems raised: to convince their husbands that the project is important to them, not only through economic gains, but because they like what they do; involve other family members in the project and ask for their cooperation in both the project and the chores; define and clarify what needs to be done and how everyone in the project wins; be sensitive to time, resources and skills that each participant is expected to understand because each one obtains different benefits; organizing time to meet the objectives they have set for the group.
5. Introspective analysis, focusing on the preponderance group: after analysing the different phases, found that as survivors of a group shrink, they must work to strengthen the group by involving their children and husbands, so that they appreciate what the project means to them. They should also be looking for other productive activities within the same project

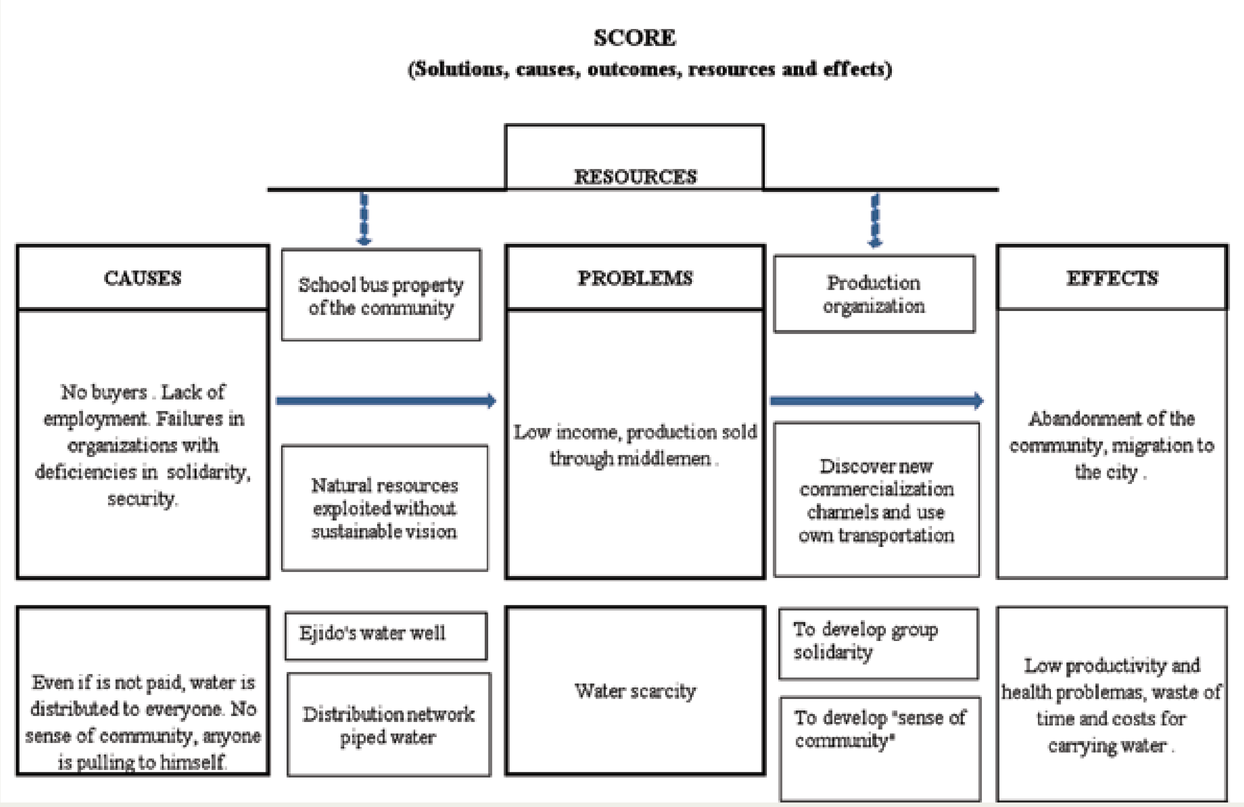

Figure 2. Problems and solutions identified by the communities.

to continue attracting the family members to collaborate in teams. As for those with excess work at home or in their businesses, they commit to carry out additional activities at home. Another commitment made was to define more clearly the activities and tasks of each one and keep track of revenues for each of them and profits for everyone to clarify how the group work and earnings were distributed.

CONCLUSIONS

The procedures used for diagnosis of the communities to be included in the project, allowed not only to select those that have the best potential, but to establish the factors limiting productivity and development of their communities. Through this participatory process, the solutions expressed were not the traditional demands of government financial support but, getting organized and developing solidarity through the community. The collaborative work technique, allowed the group to differentiate between group work and teamwork, and perform the tasks more efficiently and effectively. Problems solution strategies applied to those groups with low productivity are a successful alternative to avoid group breakup and failure of the project. When human development is considered as the core of the projects; the probability of success is higher. Cactus family orchards have become generators of: personal development, sustainability, human and social capital development and, group and community development.

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A holistic perspective of strategies for managing cactus pear diseases

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Keywords: arbuscular mycorrhizae, biological control, disease diagnosis, disease management, *Opuntia ficus-indica*, IPM, rhizosphere microbiome

Abstract

In view of the expansion of cactus pear cultivation across the globe, there is a need for a more proactive and integrated approach to managing diseases of this versatile crop. Worldwide, very few systematic studies of the aetiology of cactus pear diseases have been conducted and it is important that existing knowledge of disease management practices be integrated into a comprehensive review. Proper disease diagnosis is vital since control measures depend on proper identification of diseases and their causal agents. Inaccurate identification of a pathogen can lead to a waste of time and money. A holistic or "total system approach" to disease diagnosis and management by adhering to basic ecological principles will ensure sustainability of a cactus pear agro-ecosystem. Cactus pear growers are therefore advised to approach the challenge of sustaining orchard health in a more holistic manner by addressing soil health and in particular, the role of the root microbiome or rhizosphere. Research on the role of symbiotic microorganisms such as arbuscular mycorrhizal fungi on *O. ficus-indica* cultivation is discussed within the context of exploring novel methods to manage the health of cactus pear orchards.

INTRODUCTION

The intensive monoculture of cactus pear [*Opuntia ficus-indica* (L.) Miller] as a new crop in different geographic areas of the world, together with the selection and cultivation of superior varieties, has resulted in the appearance of many infectious diseases caused by biotic agents, such as fungi and bacteria that are not usually associated with the plant in its natural environment. Although numerous species of pathogenic fungi and bacteria have been recorded on cactus pear (Farr *et al.*, 1989; Granata, 1995; Granata and Sidoti, 2000) most pathogens cause only minor yield losses. Most recorded diseases of cactus pear have been associated with abiotic factors (Berry and Nobel, 1985) and bad management practices that predispose plants leading to secondary or opportunistic pathogens causing infection.

Disease management practices related to the cultivation of a new crop such as cactus pear are often quite different from those for traditional crops (Swart, 2009). Many ecological principles come into play which must be accommodated by developing ecologically based disease management strategies. In view of the expansion of cactus pear cultivation across the globe, there is a need for a more proactive and integrated approach to managing new diseases of this versatile crop. The adoption of a holistic approach to the diagnosis of cactus pear disease symptoms and strategies for the sustainable management of cactus pear orchards will be the focus of this review.

AETIOLOGY OF CACTUS PEAR DISEASES

Worldwide very few systematic studies of the aetiology of cactus pear diseases have been conducted. The most comprehensive reviews of infectious diseases of cactus pear are by Granata (1995) and Granata and Sidoti (2000) which are mostly based on tenuous identification of microorganisms associated with the symptoms. However, proof of their true pathogenic ability is often lacking and there are few reports where the pathogenicity of a fungal or bacterial species isolated from diseased tissue has been confirmed according to Koch's postulates under controlled conditions.

Disease complexes often occur in cacti owing to their physiology (Nerd and Nobel, 1991) and symptoms of these diseases are difficult to attribute to a specific biotic or abiotic cause. The biochemical characteristics of cacti generally are such that the evolution of disease by a biotic agent such as a fungus or bacterium is very rapid. This is because of the large amount of moisture and high concentration of sugars present in cactus tissue which provides an ideal environment and easily accessible source of nutrients for micro-organisms. The role of abiotic factors such as drought, hail damage, frost, shade or nutrient deficiencies in either predisposing cactus pear plants to infection, or in exacerbating existing infection is, however, largely unknown yet extremely important if a long-term disease prevention strategy is to be followed (Berry and Nobel, 1985; Nerd and Nobel, 1991).

Diseases of *Opuntia* spp. are usually distinct in terms of their location on the plant and the specific symptoms they are associated with. Symptoms can be broadly classified into four categories, viz.: 1) under development of plant organs; 2) over development of plant organs; 3) abnormal appearance of plant organs, and 4) necrosis, rot or death of plant organs. Specific symptoms vary greatly and include blight, necrosis, anthracnose, dieback, malformation, stunting, chlorosis, scab, dry or wet rot, wilting, and witches'-broom inter alia (Farr *et al.*, 1989; Granata, 1995; Granata and Sidoti, 2000; Tessitori *et al.*, 2006). Fungi are the most common pathogens associated with cactus pear diseases followed by bacteria and yeasts. Very few reports of viruses on *Opuntia* spp. exist and phytoplasmas were only recently reported as pathogens of *O. ficus-indica* (Cai *et al.*, 2002; Choueiri *et al.*, 2005; Granata *et al.*, 2006; Tessitori *et al.*, 2006; Wei *et al.*, 2007).

MANAGING CACTUS PEAR DISEASES

In any agro-ecosystem, interactions constantly take place between crops, insects, and pathogens and many of these are constantly being influenced by cultural activities such as tillage, irrigation and fertilization which inevitably reduce bio-diversity and create conditions for biotic (infectious and non-infectious agents) and abiotic (chemical and physical agents) factors to cause disease. It is therefore critically important that a holistic or "total system approach" to disease diagnosis and management is adopted in order to ensure that a cactus pear orchard achieves its true genetic potential in a given environment (Lewis *et al.*, 1997; Browning, 1998).

Pitfalls of disease diagnosis

Accurate diagnosis is very important and misidentification of the true cause of a particular disease symptom can lead to unnecessary waste of time and money. There are many pitfalls to disease diagnosis which the grower must be aware of in order to take the most effective corrective action. A common mistake is to attribute a specific disease symptom to an organism before determining if any abiotic predisposing factors are involved. For some plants, abiotic diseases far outweigh infectious causes of disease. Examples of the causal agents of abiotic diseases are: 1) high or low temperatures, 2) excess or deficiency of water, 3) excess or deficiency of sunlight, 4) air pollution, 5) nutrient deficiencies, 6) mineral toxicities, 7) soil alkalinity or acidity, 8) toxicity of pesticides, 9) improper cultural practices, and 10) lightning (Riley *et al.*, 2002). These agents can predispose plants to opportunistic infection by fungi and bacteria or attack by insects.

It is important to distinguish between symptoms and signs of plant disease. The latter are the observable evidence of the actual disease-causing agent and may include the mycelia of a fungal agent, fungal spores, and spore-producing bodies or bacterial slime. Indications of insects causing problems may include the actual insect, insect frass, mite webbing, and insect eggs. Signs are much more specific to disease-causing agents than are symptoms and are extremely useful in the diagnosis of a disease and identification of the agent causing the disease (Riley *et al.*, 2002).

Variations in symptoms expressed by diseased plants may result in the wrong diagnosis. It is possible that there is more than one problem present, and in some cases there may be more than one pathogen infecting a plant. Symptoms associated with these infected plants may be significantly different from the symptoms expressed in response to each of the different pathogens acting separately. The disease symptoms exhibited by multiple pathogens infecting a plant may be either more severe or less severe than if the plant were infected with just one of the pathogens (Browning, 1998; Cook, 2000).

Patterns are excellent diagnostic clues and can assist greatly in making the distinction between biotic and abiotic causes of plant damage. With problems caused by living organ¬isms such as pathogens or insects, there usually is no uniform pattern of damage. It may appear randomly on parts of a plant or on some plants in a group. Damage patterns produced by abiotic factors, such as frost or toxic chemicals, generally are more regular.

Plant diseases also involve a progression of symptoms that can vary significantly over time and it is important to look for a progression of disease symptoms on single plants and in the entire plant community or orchard. The progression of symptoms is one of the most important characteristics associated with problems caused by biotic agents. Non-progressive of symptoms usually point to abiotic causes that may have either a mechanical, physical or chemical cause. Examples of such abiotic agents are hail damage, sun scald and freezing damage.

Plant diseases can result in primary and secondary symptoms. For example, decayed roots may be a primary symptom while the toppling over of the plant and wilt are secondary symptoms. At later stages of a disease, secondary invaders may also obscure the original disease symptoms so that symptoms observed at the later stages of the disease are not typical of the symptoms developed in response to the original pathogen (Riley *et al.*, 2002).

The Integrated Pest Management (IPM) approach

In the context of crop protection, "pests" are defined as insects, diseases, or weeds that cause damage to crops, resulting in reductions in yield, crop quality, or both. These organisms constantly evolve and respond to each other, creating a diverse, complex, and ever-changing environment. The term 'pest' is therefore an anthropocentric term as there are no pests in an ecological context; in the absence of agriculture, all organisms are just part of an ecosystem (Norris *et al.*, 2003).

Critics of what is termed "conventional IPM" note that it has many shortcomings of which the emphasis remains on using pesticides as a tool of first resort despite the other control tactics that are available. Despite modern trends to replace traditional pesticides with less hazardous chemicals or non-toxic biopesticides, the approach is essentially reactive or therapeutic and only the symptoms are treated. What has been missing is an understanding of the ecological basis of pest infestations. Also missing from the conventional IPM approach are guidelines for ecology-based manipulations of agro-ecosystems. Safety problems and ecological disruptions continue to ensue and there are renewed appeals for more effective, safe, ecologically friendly and economically acceptable alternatives (Lewis *et al.*, 1997).

An ecological approach to managing diseases

The development of plant disease when seen from an ecological perspective requires a different approach to disease diagnosis and management. An agro-ecosystem is a concept used to describe a geographically and functionally coherent domain of agricultural activity and includes all biotic and abiotic components of the system and the interactions among them. An agro-ecosystem, such as a cactus pear orchard for example, has a far lower biodiversity than a natural ecosystem and is therefore less stable in terms of vulnerability to insect pests and pathogens. Various biotic and abiotic factors occurring in a specific location will, over a period of time, exert either positive or negative influences on the host plant and/or potential pathogens. Such pathogens are therefore primed to attack a weakened or predisposed plant and are thus referred to as opportunistic pathogens.

A good example of a disease caused by predisposition is root rot of cactus pear which is encouraged by poor soil conditions characterised by low pH, low permeability, and high humidity (Granata, 1995). Opportunistic pathogens that have been associated with root disease of cactus pear are mostly *Fusarium* species, including the *F. solani* species complex (Granata, 1995), *F. proliferatum* (Matsushima) Nirenberg (Mildenhall *et al.*, 1987), *F. oxysporum* (Farr *et al.*, 1989; Granata and Sidoti, 2000). Oomycetes that have been associated with cactus pear root rot are *Pythium aphanidermatum* Edson (Fitzp.) (Rodriguez-Alvarado *et al.*, 2001) and *Phytophtora nicotianae* (Cacciola and Magnano, 1988).

From the above it follows that the management of cactus pear diseases requires an integrated ecological approach where the focus is on understanding all biotic and abiotic sources of stress that can affect the overall health and productivity of an orchard. The adage that "prevention is better than cure" then becomes very relevant and compliant with four disease management principles, namely: exclusion/avoidance, eradication/inoculum reduction, protec-0tion and genetic resistance.

1. Exclusion/avoidance. A prerequisite for a proactive approach is strict phytosanitary regulation by preventing the import of propagation material and fruit from areas where specific diseases are present. It is a fact that some of the most damaging plant diseases worldwide were introduced to new ecosystems from other countries. Quarantines and pathogen-free certification programmes should be based on sound ecological principles and properly implemented in order to be effective. Avoidance of diseases can also be practiced on a small-scale by not planting in areas where specific cactus pear diseases are known to occur or in soils that are too heavy and water logged. Correct orchard practices aimed at excluding pathogens which promote or facilitate the onset of disease in existing orchards are also essential.

2. Eradication/inoculum reduction: Inoculum includes spores, mycelium, cells, sclerotia and other structures whereby pathogens overwinter and are dispersed by rain, wind or insects. The removal and destruction of diseased plant material removes inoculum is therefore an effective and cheap strategy for limiting disease incidence and severity in cactus pear orchards. Methods that eradicate or reduce inoculum for most crops include pruning, sanitation, crop rotation, soil fumigation, trap crops, and many forms of biological control. However, certain methods such as crop rotation are unsuitable for managing diseases in a perennial crop such as cactus pear and regular and thorough inspection of orchards is therefore necessary to determine the presence of diseases so that inoculum can be eliminated.

Cactus pear diseases are often exacerbated by insects attracted to sweet sticky exudations of rotting fruit thereby transmitting inoculum to healthy plants. There are numerous reports of insects such as flies acting as vectors for micro-organisms that can cause disease in *Opuntia* spp. (Harris and Maramarosch, 1980). The families Syrphidae, Otitidae and Ephydridae have been shown to be vectors of *Erwinia carotovora* subsp. *carotovora* the causal agent of cladode soft rot (Varvaro *et al.*, 1993).

Vinegar flies (*Drosophila* spp.) have been associated with the dispersal of numerous fungal pathogens that cause plant diseases (Barker, 1982; Lack, 1989; Michailides and Spotts, 1990; Louis *et al.*, 1996; Hodge *et al.*, 1997). In South Africa, at least 13 genera of mycelial fungi were identified from two species of vinegar flies of which *Mucor* spp. (43.3%; 32.0%) and *Fusarium* spp. (16.1%; 7.7%) were most prominent from *Drosophila melanogaster* and *D. hydei*, respectively (Swart *et al.*, 2001; Swart and Swart, 2002). These insects are commonly found on fallen fruit in cactus pear orchards where the larvae and adults feed on fungi and bacteria in decaying cactus pear fruit. Sap beetles (*Carpophilus hemipterus*) breed prolifically under decaying cladodes and fruit of *O. ficus-indica* in South Africa and have been associated with fungal pathogens known to cause fruit rot (Louw and Parau, 2006). Field observations showed that sap beetle adults gain access to cactus pear fruits via areoles. The potential of these insects as vectors of fungal inoculum is obvious and appropriate measures must therefore be taken to limit their occurrence on orchards.

3. Protection: Both direct and indirect approaches can be taken in designing a management strategy for ensuring the overall health of a cactus pear orchard and protecting it from diseases. The direct approach is reactive and usually entails the application of therapeutic chemicals or biological control agents (BCA's) that eliminate the pathogen and any possible insect vectors. The indirect approach is more proactive and based on ecological principles that allow for a more environmentally friendly and sustainable management strategy. It follows therefore, that if the general approach to orchard management is proactive, the possibility of disease occurring is remote.

Chemicals include various synthetic fungicides, bactericides, insecticides, miticides, nematicides and various plant extracts. These protectants are applied either as seed treatments, foliar sprays, soil drenches, pruning wound treatments or, in the case of postharvest pathogens, as sprays and dips. Diseases of *Opuntia* cladodes and fruit are generally difficult to control chemically due to the waxy epidermis which repels water based chemicals. Nevertheless, there are a number of reports of fungicides being applied to cladodes to control diseases although none of these reports confirm the efficiency of a particular product.

Fungicides are the principal method to control postharvest diseases of fruit but public concern over food safety and the development of fungicide resistant pathogens has increased the search for alternative methods. In most instances of cladode diseases described by Granata (1995), spraying with copper-based compounds was recommended. In a recent report from Egypt, cladode rot caused by *A. alternata, B. theobromae* and *F. solani* was reportedly controlled by applying Tecto, Bellis and Topsin M70 (Ammar *et al.*, 2004).

Diseases of cactus pear fruit or post-harvest spoilage are usually promoted by conditions such as wounding caused by injudicious picking and removal of spines or glochids. In Mexico, decay at the stem end of plucked fruit was shown to be caused by *Fusarium* spp., *Alternaria* spp., *Chlamydomyces* spp., and *Penicillium* spp. (Rodriguez-Felix, 2002). Storage of fruit can be improved by postharvest heat treatments (Schirra *et al.*, 2000). For example, hot water brushing has been found effective in controlling *A. alternata* in mango fruit (Prusky *et al.*, 1999) which is also one of the most frequently found pathogens of cactus pear fruit (Chessa and Scirra, 1992). Hot water treatments control postharvest diseases by direct inhibition of the pathogen and by stimulating certain host-defense responses (Schirra et al, 2000). In Greece, hot water treatments at 60°C for 30s or 65°C for 20s were used safely to control decay in cactus pear caused by *Alternaria* spp., *Fusarium* spp., *Botrytis cinerea* and *Penicillium* spp. (Lydakis *et al.*, 2005). In Argentina, hot water treatment was also efficient in reducing chilling injury, fungal development and improving the appearance of cactus pear fruit (Rodriguez *et al.*, 2005).

Biological control using antagonistic microorganisms has also been endorsed as an alternative to synthetic fungicides for postharvest spoilage. In particular, a host of yeast genera have been extensively used for the biological control of post-harvest diseases of fruits and vegetables (Wilson and Wisniewski, 1989; Punja, 1997) to protect moulding of stored grains (Petersson *et al.*, 1999), and to control foliar diseases. In a study conducted in South Africa, 10 yeast isolates were isolated from cactus pear fruit of which six belonged to the genus *Cryptococcus* (Mashope, 2007). The remaining isolates were *Rhodosporidium kratochvilovae, Hanseniaspora clermontiae, Cystofilobasidium feraegula* and *Rhodotorula mucilaginosa*. All isolates, especially *R. mucilaginosa*, displayed strong inhibition in vitro to isolates of P. virens, *F. oxysporum* and *F. proliferatum*. Subsequent studies conducted on cactus pear fruit confirmed the ability of *R. mucilaginosa* to prevent postharvest rot.

4. Genetic resistance. Selective breeding for resistance to diseases is probably the best means of preventing plant disease and genotypic characterization of cactus pear cultivars can greatly facilitate such breeding strategies (Mondragon-Jacobo and Pérez-Gonzàlez, 2000). Significant differences have been recorded between 10 South African varieties of *O. ficus-indica* with regard to their susceptibility to *Phialocephala virens, F. proliferatum* and *F. oxysporum* in a glasshouse and field study (Swart *et al.*, 2003). The same pathogens were also tested in the field on 38 South African varieties which were shown to differ significantly in their susceptibility (Mashope, 2007). The identification and exploitation of these differences aided by biotechnological techniques such as AFLP-fingerprinting can provide plant breeders with valuable information for parental selection.

The relevance of the root microbiome in managing diseases

Soil microbial communities represent the greatest reservoir of biological diversity known on earth (Gams, 2007). The health and productivity of any plant is entirely dependent on these microbes and their direct and indirect interaction with the plant (Bardgett, 2005). Direct interaction takes place via root-associated organisms that form mutualistic or pathogenic relationships with plants, and indirect effects via the action of free-living microbes that determine rates of nutrient supply and the partitioning or resources.

The rhizosphere can contain up to 1011 microbial cells per gram root (Mendes *et al.*, 2011) and the collective genome of this microbial community is much larger than that of the plant. Recent research is increasingly emphasising the importance of the rhizosphere microbiome, which consists of a complex of associated microbes, their genetic elements and their interactions, in determining plant health and productivity (Raaijmakers *et al.*, 2009). By largely ignoring the importance of these interactions and focusing more on aboveground processes, modern agriculture risks operating in a paradigm of ignorance.

The impact of the root microbiome on plant health is most clearly evidenced in disease-suppressive soils. Soil-borne pathogens grow saprophytically and compete with a myriad of microorganisms for plant derived nutrients which are exuded from the rhizosphere. Their success as a pathogen is determined by the microbial community of the soil in which infection takes place (Hoitink and Boehm, 1999).

More than 90% of terrestrial plants have mycorrhizal relationships of which the most abundant group is the arbuscular mycorrhizal (AM) fungi, the ectomycorrhizal (EM) fungi and the ericoid mycorrhizal fungi. Mycorrhizal fungi are plant symbionts that enhance plant productivity by supplying limiting nutrients such as nitrogen, phosphorus, copper, iron and zinc to plants in exchange for carbon. Other benefits conferred by mycorrhizal fungi are to provide disease and drought resistance (Smith and Read, 1997) and to increase plant hormone levels, chlorophyll content, and decreased leakage of electrolytes from diseased plant cells (Hayman 1983).

Although literature on the subject is scarce, numerous *Opuntia* spp. have been shown to harbour AM (Whitcomb, 2000). Mathew *et al.* (1991) examined the mycorrhizal status of introduced spineless cacti used as cattle fodder and found that *O. ficus-indica* had a 16.0% colonization level. Cui and Nobel (1992) examined the roots of greenhouse-grown *O. ficus-indica* and found that they had a maximal colonization level of 9%. Dubrovsky and North (2002) reported three species of the genus Glomus as inhabitants of the rhizosphere of the *Opuntia* spp. they studied.

A novel study was conducted by Konings-Dudin *et al.* (2014) to investigate the presence of symbiotic microbes inside *O. ficus-indica* seeds that would assist the survival of seedlings in nutrient poor soil (lunar regolith simulant JSC-1A) as a possible starter plant for an extra-terrestrial colony. The authors found that the endomycorrhizal fungus Trichoderma viride exhibited a close interaction with a *Glomus* species during and after germination of *O. ficus-indica* seeds on the nutrient poor soil. Both fungi grew in the root tip but the *Glomus* spp. displayed an endophytic tendency by growing in the rest of the seedling. It was furthermore found that *T. viride* increased the germination rate of *O. ficus-indica* seeds by 29.6% and 42% respectively on sterilized soil and the lunar regolith simulant. Trichoderma viride is known for its protective function in different plants and is now exploited in agriculture as a natural biocontrol agent against various soil-borne diseases (Srivastava, 2004; Doley *et al.*, 2014).

CONCLUSIONS

The cultivation of cactus pear in an intensive monoculture system presents certain challenges that are unique to this well adapted desert plant. Bad management practices and unsuitable abiotic conditions can easily predispose plants to disease caused by secondary or opportunistic pathogens that would not normally attack a single plant in its native desert environment. Good or sustainable management practices therefore imply that growers take cognisance of factors that provide a stable environment for the optimal growth of a cactus pear plant, devoid of pest and disease pressure.

By having a better knowledge of ecology, the inherent strengths of the cactus pear agro-ecosystem can be managed with more modest inputs than in a blinkered product based approach. The focus must be on understanding all biotic and abiotic sources of stress that can affect the overall health and productivity of an orchard so that the pitfalls of inaccurate disease diagnosis and 'knee jerk" management decisions can be avoided.

One of the most critical components of an agro-ecosystem is the importance of the root microbiome or rhizosphere of crop plants. Cactus pear growers are therefore well advised to approach the challenge of sustaining orchard health in a more holistic manner by addressing soil health in particular. Considerably more research is required to elucidate the role of the root microbiome of *O. ficus-indica* and specifically the role of symbiotic microorganisms such as AM fungi and management decisions that can encourage and support their activity.

Adherence to a basic principle of ecology, namely that changing one component of an ecosystem changes everything else is paramount in crop health management. A more proactive approach by optimizing the biotic and abiotic environment of a cactus pear orchard will thus ensure sustainability.

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An overview of pests (insects and pathogens) on cactus pear *(Opuntia ficus-indica)* crop of Mexico

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Abstract

It is well known that cactus crops are naturally tolerant or resistant to most insects or diseases. Crop devastation seldom occurs, rather most crop losses result from farmer neglect. In this report we review the various insect and disease causing pathogens present in cactus. Much of this information has been provided by Mexican colleagues with additional comments presented regarding future research needs. No chemical is presently registered for cactus crops in Mexico, despite the encouragement of Mexican authorities to utilize herbicide applications. For chemical companies the crop might not satisfy the economic value. However, older chemical products can be easily purchased locally. Natural or biological products are recommended for use under severe infestations by some governmental organizations. Few researchers, particularly in plant protection of cactus crops, live in Mexico, subsequently the knowledge required to develop holistic crop management programs remains inadequate.

INTRODUCTION

Nopales originate from tropical and subtropical America, and are currently distributed across all continents in a high diversity of growing conditions, wild or cultivated. In Mexico, nopales is mainly used for human food, especially among the population that lives in the metropolitan area of Mexico City. This food source is typically consumed by the population of the country with varying levels of acceptance, depending on the specific region (INEGI, 2013).

According to the Census of Agriculture (2007),which was produced by the Institute National of Statistics and Geography (INEGI, 2013), *Opuntia ficus-indica* is the most commercially important cultivated species for the production of vegetable nopal in Mexico. Commercial plantations use two production systems: a traditional system and a system which utilizes micro tunnel or intensive system technology. In the traditional system, densities of 15 to 40,000 plants per hectare are established; while that in the system of micro-tunnels is able to increase plant densities from 120 to as high as 160,000 plants per ha. The latter system also allows for high crop yield during the coldest months of the year.

Plantations are currently in a state of deterioration resulting from problems arising during the production chain, which is reflected in low producer and low profitability of the activity prices. Among the causes of this decline are little or no implementation of necessary inputs and technology, poor management and lack of pests and diseases, product losses at harvest and postharvest, and lack of promotion of the different varieties and seasonality product mainly.

In this review we summarize the main phytosanitary problems encountered in growing cactus in Mexico, with an overview of the pest and diseases, the importance of these in the nopal system and some comments derived from personal experiences.

INSECT PESTS

Globally, there are about 23 species of phytophagous insects associated with nopal. In Mexico, there are 21 species of insect pests on cactus (*O. ficus-indica*) according to INE (2005) and Mena-Covarrubias and Rosas-Gallegos (2007). The most important insect pests are as follows:

Opuntia Borer (*Cactophagus* = *Metamasius spinolae* Gyll.)

This insect species is present throughout the northern region (Chihuahua and Tamaulipas status) extending south toward the central, east and west where it is more frequent in the Bajio region, state of Mexico, Puebla, Morelos and D.F. (Méndez, 1994). It is a major pest of *Opuntia*, with a life cycle that lasts 7 to 15 months. Females lay 20-40 eggs with only one generation per year. The Opuntia borer has limited mobility and it is specific for this host plant (Mann, 1969).

The adults feed on the margins of the young pads and lay eggs inside which hatch within the pads producing larvae that feed on the plant tissue, forming galleries in the principal axes causing severe damage and eventual collapse of plant. Control measures recommended include the manual extraction of larvae and pupae and due the slow movement of adults these can be collected from the pads during the months of May to September (Luna-Vázquez *et al.*, 2012). In Mexico, CICOPLAFEST (2004) approved the application of Bacillus thuringiensis in nopal to control this insect. Also, Beauveria bassiana (250 g/200 L of water) has given promising results and applications Neem oil (10 mL/L water) (CESAVEDF, S/A).

Cochineal insect (*Dactylopius indicates* Green)

Cochineal appears during the dry months, mainly in May; during rainfall the populations tend to decrease significantly. This insect species is difficult for management and control because it produces a waxy coating for protection, has a high reproductive rate (each female lays on average 150-600 eggs) and has a life cycle that is longer than 50 days. The damage to cactus pear plants is caused by females, both nymphs and adults when they extract sap. They are generally located at the base of the spines, during a severe attack the cladodes can yellow, the fruit drop off, plants exhibit an overall loss of plant vigour, and eventually death of young plants.

In Mexico, agricultural soaps, which are based on potassium salts (2-5 mL/L of water), can be used for control and mechanical elimination of Cochineal. The natural enemy, *Chilocorus cacti* L. (Coleoptera: Coccinellidae), is very important because larvae attack the females as does Cocidivora lactilia. In Mexico, the use of particular chemical are not authorized, however under severe infestations some government recommendation include the use of Malathion 1000E (500-700 mL/ha) or diatomaceous earth (2 kg/ha). For better efficiency it is recommended to apply the chemicals directly to the insects. The cactus can be cut three days after application of Malathion; while applications with the diatomaceous earth allow plants to be cut immediately (Aguilar, 2000).

Zebra Worm (*Olycella nephelepasa* Dyar)

This insect species is common during the dry season (April to October), being able to produce up to two generations per year, the first one is more dangerous because of the absence of natural insect predators. There is usually one to two larvae per cladode because the insect has carnivals habits. They prefer to attack young pads inducing a bulged section that appears on the exterior part of the affected area. For control, growers remove the affected cladodes as soon as swelling is detected. The use of chemicals is not very effective because the insect tends to be reintroduced rapidly into the pads.

Badii and Flores (2001) indicated that there are two species of parasitoids that attack this insect in the Valley of Mexico. One is a tachinid fly (*Phorocera texana* Aldrich and Webber) (Diptera) which attack the mature larvae and kill them after transforming to pupae. The other is a braconid wasp (*Apanteles mimoristae* Muesebeck) (Hymenoptera) that attack younger larvae. Further research is needed for mass production and release for effective biocontrol.

Gray Chinch Bug (*Chelinidea tabulata* Burm)

According to Melgarejo (2000) both adults and nymphs suck sap from cladodes causing circular chlorotic spots on the affected area which become dark green area. They cause weakening of the plant, but under severe attacks the fruits and buds have poor quality. This pest appears mainly during the warm months (April to September) and prefers young plants of *O. megacantha*. The female lays 50-80 eggs, which are laid in clusters of 5-15 on pads and spines, and adults reproduce all year.

Beauveria bassiana and Paecylomices fumosoroseus can be used as biological control agents. This insect is controlled manually or by application of Neem oil (10 mL/L water) + adhefort + biocarck twice a week. Heavy infestation can be controlled with Malathion and trichlorfon (1-1.5 L/ha).

Red Chinch Bug (*Hesperolabops nigriceps* Reuter)

The red chinch bug is present in several American countries and is an important pest of nopal in major producing areas of Mexico. The insect damage is associated with “cacarizo” cactus diseases which are characterized by the presence of pustules which in various number can produces a rough appearance in the cladodes (Palomares-Pérez *et al.*, 2010).

These species are gregarious in habit and where they are abundant plants can become yellow. The red cinch bug's life cycle last between 28-35 days and females lay between 200-300 eggs. It is a sucking pest of *Opuntia*. It causes chlorosis on pads (condition in which the joints produce insufficient chlorophyll) and in large numbers can destroy plant tissue or even cause plant mortality. Cactus bugs lay their eggs on the undersides of spines, and both the adults and the nymphs feed on these cacti by biting into their skin and sucking their vascular fluids.

In general, attacked plants developed small yellow dots. If the population of nymphs and adults are high, those yellow dots (0.1-0.3 cm in diameter) might cover more than 50% of the surface pad (Palomares-Pérez *et al.*, 2010).

For control it is recommended that the same products mentioned in the Gray Chinch Bug are used (see above).

Wireworms (*Diabrotica* spp.)

Damage caused by this pest occurs in the roots and other subterranean parts of which can induce a yellowing of the stems and reduction of vigour of the whole plant. The following insecticides are applied against this pest: carbofuran, chlordane, diazinon, fonophos, heptachlor, and trichlorfon (Badii and Flores, 2001).

Blind June Beetle (*Phyllophaga* spp.)

This species is one of the most destructive insects that live in the soil, causing damage not just to cactus but also to many other crop types. The insect goes through several larval instars, feeding at the beginning on organic matter and tender roots. During their last instar, this pest can cause the most severe damage to the root system resulting in poor plant growth, wilting, and eventually death. The damage is more frequent when pad planting takes place in hole with manure application (Robles-Contreras *et al.*, 2008).

Applications of Metarhizium anisopliae + Beauveria bassiana, as well as the application of carbofuran in doses of 25 g/hole or Diazinon (20 g/hole) are mainly recommended for control.

Brown Garden Snail (*Cantareus aspersus = Helix aspersa* Muller)

According to Badii and Flores (2001) *H. aspersa* feeds on the surface of the pads and thus inhibits the chlorophyll synthesis which in turn causes the reduction of new growth. Foraging by this species causes cladodes to have a whitish scab appearance, affecting the production of new shoots in the affected parts.

This insect have many enemies, one is a large predator beetle Staphylinid called the devil's coach horse (Ocypus olens). However, this beetle will feed on ripening fruits too.

In California, the predatory decollate snail (Rumina decollate) has been released in citrus orchards with very good results. It feeds only on small snails (UC-IPM online, 2014). Also it can be used poisoned bait bran-based 78-97% plus arsenate Ca (8.32%) or metaldehyde (3.03%).

Cactus Moth (*Cactoblastis cactorum*)

SENASICA (2013) mentioned that this pest is not present in Mexico; however the danger of their presence is that our country has the greatest diversity of species of *Opuntia* in the world. According to CONABIO (2002), Mexico has more than 57 species of cactus, 38 of these are unique to our country. Approximately, nine cactus species are severely threatened and 19 have the potential for significant damage from this insect. Reports on the impact of this pest indicate the death of more than 25 million hectares of nopales in Australia and 1 million hectares in South Africa (Zimmermann *et al.*, 2007). The Mexican phytosanitary authorities have succeeded so far to avoid the invasion in the Nopal regions.

C. cactorum feeds on several species of cactus, having a greater impact in less woody species (*O. ficus-indica*, *O. streptacantha, O. megacantha* and *O. rubusta*) (Annecke and Moran, 1978).

The biological cycle of *C. cactorum* varies between 64 and 180 days, depending on environmental conditions, requiring between 845 and 1388 degree days to complete development and requires a base temperature of 13.3°C and maximum 36°C, with an optimum of 25-30°C (Legaspi and Legaspi, 2007).

The larvae cause physical damage to pierce and destroy young cladodes that still has not become woody this allows the entry of pathogens causing secondary infections that can kill cactus. Small species of cactus or small individuals of the larger species may die if severe attacks occur, although rarely does the moth destroy the oldest and woody parts of the larger species. Zimmermann *et al.* (2007) pointed out that all larval instars consume intensely internal tissue cactus and a single colony of larvae can consume two to four cladodes, causing putrefaction and decay of the plant.

For combat of this pest the release of sterile adult butterflies, and the combination of *Metarhizium* plus *Bacillus thuringiensis* is recommended.

PRIMARY DISEASES

Various diseases caused by fungi, bacteria, viruses and nematodes have been reported in growing cactus.

Chavez *et al.* (1981) conducted a study on the incidence of diseases in prickly pear in San Martin de las Piramides, State of Mexico, reporting the presence of the disease called gold spot of cladodes associated with pathogens *Alternaria* spp. and *Ascochyta* spp. Other authors have report this disease associated with *Phoma* spp. (Sandoval and Osada, 1988) and *Hansfordia* spp. (Mondragón and Acevedo, 1992). Osorio and Soto (1994) reported that *Colletotrichum gloeosporioides* was associated with the disease known as black spot in Zacatecas, Mexico with incidences of 8%.

According to Gallegos and Méndez (2000) the disease known as "Mal de oro" causes a golden yellow colour of cladodes, affecting photosynthesis, since the pads are covered by the fungus, leading to lower production, plant failure, and eventually death of the plant under heavy infestations (Pimienta, 1990). The disease was associated with *Alternaria* spp., *Phoma* spp., *Hansfordia* spp. and *Ascochyta* spp.

Another important disease is the so called black spot caused by *Pseudocercospora opuntiae*, which causes discoloration of the cuticle with small spots that are olive coloured. Over time, these spots become larger producing colours ranging from pale-dark to heavy dark with a yellow margin and the central portion depressed. The affected part subsequently dries off and detaches leaving holes that can cross the stalk. The disease has also been associated to *Colletotricum gloeosporioides* (Quezada, 2005).

The main pectinolitics bacteria found in cactus crops are *Erwinia carotovora* subs *carotovora, E. atroseptica, E. cacticida* and *Pseudomonas viridiflava* (Fucikovsky and Moon, 1990; Gijón, 1996). The incidence of these bacteria in Mexican plantations is 12-100%, depending upon environmental conditions and can affect them in any stage of development. Cladodes infected initially show a watery soft rot, starting as a small circular brown spot with wet margins, which becomes black. In old infections, the spots enlarge and coalesce, and when the integument breaks a reddish-brown exudate can be observed as tissues lose turgidity becoming soft and falling from the plant surface (Varvaro *et al.*, 1993). Infection can occur through natural openings or wounds and probably by direct contact between roots. Another source of inoculum is exudates lesions (Hernández, 1999).

Since 1967, reports suggested that the presence of viruses and phytoplasmas in cactus plants will cause proliferation of shoots and mosaics. An alteration that has recently called the attention to the cultivation of nopal is a thickening of the Cladode locally also known as "male" or "chatilla". This observation was first reported in the 60's by García (1967). Although several studies have been conducted to elucidate the cause or disease, there are no conclusive results until present. The symptoms associated with this disease are abnormal swelling of pads usually with the apex atrophied adopting a heart shape due to growth arrest in this area, mosaics, excessive proliferation of buds, reduced shoot growth and plant fruiting on the side of the cladodes. The symptoms are stronger and severe in older plantations.

Osorio (1989) indicated that the causal agent could be a mycoplasma or spiroplasma, and having infectivity to achieve transmission by grafting, although they did not achieve remission of symptoms by applying tetracyclines.

Felker *et al.* (2009) reported a Tobacco bushy top virus as the causal agent of the cladode thickening in California, suggesting the possibility that the symptoms that occur in Italy, South Africa and Mexico are caused by this virus. Meanwhile, Suaste *et al.* (2012) associated the coinfection of virus and phytoplasma 16SrXIII-Mexican group as possible causal agents of this disease.

Cano (2012) using high performance liquid chromatography (HPLC) to determine the concentration of hormones, found that indole acetic acid (IAA) is primarily responsible for the physiological disorder in cladodes thickened, causing an enlargement of cells.

Various plant pathogenic virus are currently reported that affect the cultivation of cactus *Opuntia* spp. such as Sammon´s opuntia virus (SOV), Zygocactus virus X (ZVX), Tobacco mosaic virus (TMV), Cactus virus X (CVX), Saguaro cactus virus (SCV), Cactus virus 2 (CV-2) y Tomato spotted wilt virus (TSWV) (Milbrath and Nelson, 1972; Giri and Chessin, 1975; Lastra *et al.*, 1976; Attothom *et al.*, 1978; Hausbeck and Gildow, 1991). Currently investigations in Chapingo are trying to associate soil nutrition with cladode thickening.

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A Sub-Sahara Africa Region Framework[1] for Cactus Pear Research & Development

Title	
Development of cactus pear (*Opuntia* spp.) agro-businesses for the sub-Sahara Africa Region	
Overall Objective	
Improve the livelihood of the poor and improve the resilience of smallholders and producers of cactus pear under conditions of changing climate	
Specific Objectives	
Objective 1	Collate and disseminate relevant information regarding the benefits of cactus pear to the broad society
Objective 2	Support all involved in the production, processing, retailing and consumption of cactus pear products
Objective 3	Develop and use decision-support systems to create, fine-tune and disseminate relevant information to all stakeholders
Objective 4	Support and strengthen the Organizational structures of all involved in the value chain of cactus pear from production to marketing
Objective 5	Develop and fine-tune effective technologies to identify, utilize and control invasive cactus pear species
Objective 6	Enhance the capacity of all involved in the production, processing and utilization of cactus pear products
Objective 7	Ensure that gender issues and equity are addressed and promoted in all activities

Outputs	
Output 1	**Awareness raised amongst stakeholders and perceptions changed regarding benefits of cactus pear**
Activity 1.1	Workshops, meetings and practical training sessions directed at different target audiences
Activity 1.2	Use social media facilities (websites, internet, Facebook, etc.) to reach respective target audiences
Activity 1.3	Leaflets in the local dialect with visual appeal (photographs) – make use of specialists to translate, transform and package the information [use the right horse for the course]
Activity 1.4	Effective lobbying among decision makers, NGO's, role players and the public
Output 2	**Functional professional cactus pear associations established and promoted**
Activity 2.1	Identify and support Organizational structures for producers, processors, input suppliers and retailers
Activity 2.2	Revitalise the South African Cactus Pear Growers Association (SACPGA)
Activity 2.3	Establish and support cactus pear growers associations in countries (use the SACPGA as model/template/mentors)
Activity 2.4	Establish and support an active network of sub-Sahara Africa cactus pear growers

[1] Developed at the **International Cactus Pear Workshop** (27-28 January 2015) at the University of the Free State, Bloemfontein and concluded on 29 January 2015 at the Sandveld Nature Reserve

Output 3	**Decision-support systems for cactus pear as a multi-use crop developed and established**
Activity 3.1	Identify and group the team members who can contribute regarding germplasm, cultivation practices, pests and diseases, harvesting, processing, etc.
Activity 3.2	Identify gaps in the existing knowledge base (skills, expertise and technology) (spectrum suggested in Activity 3.1)
Activity 3.3	Develop and/or fine-tune knowledge (skills, expertise and technology)
Activity 3.4	Disseminate relevant information through extension services and appropriate media
Output 4	**Cactus pear value chain and markets developed**
Activity 4.1	Conduct a market analysis for cactus pear produce [from the household to the commercial level]
Activity 4.2	Establish guidelines for cactus pear postharvest and processing technologies
Activity 4.3	Establish value chain cycles for each individual cactus pear commodity (fruit, forage, etc.)
Activity 4.4	Disseminate relevant information to all stakeholders
Output 5	**Practical options to utilize and control invasive cactus pear species developed**
Activity 5.1	Create baseline/benchmarking regarding the invasiveness of cactus pear species [draw appropriate input from experts]
Activity 5.2	Create an inventory through monitoring and assessing the status of cactus pears
Activity 5.3	Develop utilization techniques for invasive cactus pear species; among others take advantage of acquired knowledge from other counties
Activity 5.4	Develop control techniques for invasive cactus pear species [link Activity 5.4 to Activity 5.1]
Output 6	**Capacity of all stakeholders enhanced**
Activity 6.1	Assess training needs
Activity 6.2	Conduct practical and effective training of the trainers
Activity 6.3	Establish and support active specialist exchange programmes [students & scientists to create mobility in skills and knowledge exchange]
Activity 6.4	Promote and enhance active and effective networking in countries, regions and the world
Output 7	**Women get involved to ensure promotion of cactus pear in the communities**
Activity 7.1	Provide training of households in production and utilization techniques
Activity 7.2	Assess households to include cactus pear (fruit and cladodes) as a crop for family sustainability (livestock and human food)
Activity 7.3	Develop cooking recipes which include cactus pear, based on the traditions and customs of each region, as well as promoting acquired tastes
Activity 7.4	Get community involvement to promote commercial Organizations for economic benefits from cactus pear production

1. A young spineless cactus pear *(Opuntia ficus-indica)* orchard at the Oppermansgronde in the south western Free State Province – note the livestock proof fence to keep herbivorous animals out.

2. International advisors and the Cactus Pear Team at the Agriculture Building, University of the Free State before departing to the Oppermansgronde.

3. Welcoming of the international advisors and introduction of the spineless cactus pear farmers at the Oppermansgronde.

4. Mr. Johan Potgieter provides some background on the origin of spineless cactus pear cultivars at Waterkloof, a spineless cactus pear farm west of Bloemfontein.

5. Finer detail of cactus pear fruit is demonstrated by Dr. Candelario Mondragón at Waterkloof.

6. Prof. Paolo Inglese knows how to kneel and quickly peel a cactus pear fruit.

7. Walking through a section of the spineless cactus pear orchards at Waterkloof.

8. Ms. Makiko Taguchi presenting a welcome address from the Food and Agriculture Organization (FAO) to the International Cactus Pear Workshop at the University of the Free State.

9. Friends in a jovial mood at the Workshop dinner in the Centenary Hall, University of the Free State.

10. Dr. Giorgia Liguori and Prof. Carmen Sáenz in a very good mood while enjoying their dinner.

11. The *Sub-Sahara Africa Region Framework* for *Cactus Pear Research & Development* is given final touches in the shade of a camel thorn *(Acacia erioloba)* tree at the Sandveld Nature Reserve.

12. Viewing the results of invading *Opuntia stricta* after having been sprayed with herbicide.

Photo credits: Herman Fouché (1); HO de Waal (5); Willie Combrinck (2-4 & 6-12)

International Cactus Pear Workshop

Development of a cactus pear agro-industry for the sub-Sahara Africa Region

27-28 January 2015

CR Swart Building

University of the Free State (UFS)

Bloemfontein, South Africa

ICARDA Science for Better Livelihoods in Dry Areas

CACTUSNET International Technical Co-operation Network on Cactus Pear

ARC • LNR

UNIVERSITY OF THE FREE STATE UNIVERSITEIT VAN DIE VRYSTAAT YUNIVESITHI YA FREISTATA UFS UV

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