Chapter 2
South African Perspective on *Opuntia* spp.: Cultivation, Human and Livestock Food and Industrial Applications

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Abstract The effect of scarce water resources, increasing desertification and climate change on food security prompted the exploration of the highly water-efficient, drought-tolerant cactus pear (*Opuntia ficus-indica* and *Opuntia robusta*) as a commercial crop for the food and other industries in South Africa. Cactus pear, formerly called the prickly pear, has long been valued in South Africa as cattle feed and for its delicious, healthy fruit. In 1914, 22 spineless Burbank *Opuntia ficus-indica* and *O. robusta* cactus pear cultivars were imported from the USA, and South Africa is the only country in the world where this collection is still found. Both *O. ficus-indica* and *O. robusta* are undervalued food sources, with the entire plant having value as a health-promoting crop with nutraceutical properties. Through research, the cactus pear can open up economic opportunities in South Africa. 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. A second germplasm was established on the west campus of the UFS in 2018 and a third site at Roodeplaat in Pretoria. All sites hosts 44 spineless Burbank cultivars, 42 of the *O. ficus-indica* spp. and two from the *O. robusta* spp. Research on human food application aspects as well as newly developed industries of this multi-functional crop is reported.

Keywords Cactus pears · South Africa · Feed · Food · Industries · Germplasm

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Abbreviations

AFMA	South African Animal Feed Manufacturing Industry
AMMI	Additive Main effects and Multiplicative Interaction
ARC	Agricultural Research Council
Bc	Betacyanins
Bx	Betaxanthins
CAM	Crassulacean acid metabolism
CP	Crude protein
CSP	Chelating soluble pectin
CWM	Cell wall material
DM	Dry matter
FCP	Free choice profiling
FFA	Free fatty acids
GIT	Gastro intestinal tract
IV	Iodine value
m.a.s.l.	Meters above sea level
NMR	Nuclear magnetic resonance
NPN	Non protein nitrogen
ORAC	Oxidative radical
OSI	Oxidative Stability Index
PPWG	Prickly Pear Working Group
TA	Titratable acidity
TSS	Total soluble solids
UFS	University of the free state
WSP	Water soluble pectin
WUE	Water use efficiency

1 Introduction

The cactus pear (*Opuntia ficus-indica*) was introduced to South Africa (the Cape) over 300 years ago. It was carried thereafter, by settlers to arid and semi-arid parts of the sub-continent, during which the plants gradually reverted to its spiny forms over a period of approximately 150 years. Twenty-two spineless varieties of cactus pears (the so-called Burbank collection) were imported from California, USA to Middelburg in the Eastern Cape. Today the cactus pear is being promoted across South Africa as a versatile crop with multiple applications (UFS Webpage, www.ufs.ac.za, 2015).

Cactus pears, or prickly pears, are seeing renewed interest especially over the past 4 years from farmers in South Africa, due to climate change and drought as well as the plant's numerous uses. The drought conditions in many parts of South Africa help to boost interest of farmers to grow the cactus pears (Brown, 2020).

Cactus pear is generally classified as succulents and is part of the genus *Opuntia*, which includes about 160 species. Unfortunately, like any other family, the *Opuntia* family has its black sheep and includes the Jointed Cactus, Imbricate Cactus and a few others which pose a major threat to the environment. Luckily, not all *Opuntia* varieties are invaders, with the green-leafed *Opuntia ficus-indica* being one of the most common and popular edible varieties. The blue-leafed spineless cactus pear is known as *Opuntia robusta* (Fouché et al., 2020).

The Alien and Invasive Species Regulations of the National Environmental Management: Biodiversity Act defined the prickly pear as "an invasive species that must be destroyed". Fortunately, farmers can legally propagate the spineless cactus pear (Brown, 2020).

The cactus pear is one of the most versatile crops available in South Africa, but is however, not receiving the needed attention. It has outgrown its limitation to only being used as drought-tolerant livestock feed and is currently producing orchards that yield food for human consumption, fruit, oil and animal feed. It is therefore crucial to give this miracle crop more well-earned attention. It is one of the most multi-purpose crops known, with no part of the plant going to waste (Brown, 2020).

The dedicated research and development programme at the University of the Free State (UFS) on spineless cactus pear (*Opuntia ficus-indica*)—also known as prickly pear—has grown steadily in both vision and dimension during the past years. Formal cactus pear research at the UFS started with the formation of the Prickly Pear Working Group (PPWG) in June 2002 and takes place with collaboration with the Agricultural Research Council (ARC) of South Africa (UFS Webpage, 2015).

The complexity of challenges to ensure sustainable food security and reduction of the impact of food production on the environment calls for more innovation in agriculture. The need to innovate emphasises the need for partnerships and joint ventures that will enable the role-players in agricultural value chains to ensure a sustainable agricultural sector. South Africa experiences significant socioeconomic challenges, including poverty, high unemployment rates, food insecurity and economic decline. These are compounded by adverse climatic factors. The effect of declining water resources, extended droughts, increased desertification and climate change on food security and economic growth prompted the South African government to develop policies and strategies that are targeted towards coordinated, multidisciplinary,—institutional and—sectoral responses to critical national priorities. These priorities include job creation, skills and enterprise development, poverty alleviation, and food and nutrition security. Aligned to these strategies, the Agricultural Research Council (ARC) acknowledged the importance of strategic partnerships for the development of appropriate solutions (Venter et al., 2019). The objective was to establish a collaboration center on broadening the food base with the purpose of ensuring the availability of a wide range of nutritious crops. The methodology was to develop new/novel crops, food products and ingredients for enterprise development, value chains, income generation and job creation. The necessity for researchers to collaborate in addressing these complex problems is of overriding importance. By bringing expertise from various disciplines and organisations together and leveraging other important networks and partners at both national and international levels, the benefits of greater returns within agricultural value chains will be realised. Cactus pear (*Opuntia ficus-indica* and *Opuntia robusta*) is increasingly becoming an important food, forage, cosmeceutical and nutraceutical crop in South Africa. It is a drought-tolerant crop used for a diverse range of applications. It was used mainly as a source of animal feed, but recent interest in its other potential uses saw the crop establish itself as an important multi-purpose crop, which opened up opportunities for the smallholder farming sector. Cactus pear was identified as a priority crop for research and development for the collaboration centre on broadening the food base. The purpose of this paper was to discuss the collaboration involved in developing this multi-functional crop within the context of the Sub-Sahara Africa Region Framework for Cactus Pear Research and Development. The establishment of the collaboration center provided a sound foundation on which further partnerships could be explored and developed. Valuable lessons were learnt concerning the maintenance of multi-disciplinary research teams and challenges for the development and establishment of new value chains for new crops in a country (Venter et al., 2019).

2 Background

2.1 History (Introduction of Cactus Pear Plants to South Africa)

The deportation of the Moors back to their homelands from Spain as well as the Spanish expansion (Ochoa and Barbera, 2017) opened avenues for cactus plantations in the African continent in countries such as Ethiopia, Morocco and South Africa. The Cape was the first area in South Africa where the cactus plant (*Opuntia ficus indica* species) inhabited. It was cultivated for the fruit as well as living fences in this area. During the coming 150 years, from the time they were first introduced, the cactus plants gradually returned to their spiny form (Ochoa and Barbera, 2017). This resulted in the infestation of impenetrable thickets in the Eastern Cape and other regions (Beinart and Wotshela, 2011). This cacti invasion was estimated to cover two million hectares in the early twentieth century in South Africa. This impacted the agricultural sector negatively. In an effort to combat the invasion, biological control was used to salvage approximately 80% of the infested plants (Zimmermann et al., 2009). These plants were cultivated mainly for fruit and animal forage.

Beside the plants that have been reported in South Africa as early as 1772, 22 spineless cultivars were imported by the Grootfontein Research Institute (Middelburg, Eastern Cape) in 1914 from the Burbank Nursery in the United States of America (AgriOrbit, 2019). These spineless cactus pear plants (*Opuntia ficus* *indica* and *Opuntia robusta*) were established by Karoo farmers as livestock feed to mitigate the drought that was then present.

There are currently several germplasm banks which can be found in the Limpopo, Free State, Eastern and Western Cape provinces (Ochoa and Barbera, 2017). These secondary banks were established for research purposes which previously focused mainly on the use of the plant as forage (Menezes et al., 2010). With the increasing interest in the plant's application in human consumption and animal feed, particularly the young vegetables stems (nopalitos), the research focus has since shifted.

The Department of Agriculture in the Limpopo Province of South Africa has been conserving 78 accessions (including the Burbank varieties) in the largest spineless cactus pear germplasm bank in Africa at Mara Experimental Farm, Makhado (Potgieter and Mashope, 2009). The Mara Research Station is in the Vhembe district of the Limpopo Province. Mara ADC is located ±54 km West of Makhado (previously known as Louis Trichardt), Limpopo Province at 23°05′S and 29°25′E, at altitude of 961 m above sea level in the Arid Sweet Bushveld. The average annual minimum and maximum temperatures recorded are 12.7 and 25.1 °C respectively. The average seasonal rainfall is 441 mm (Mokoboki et al., 2009). The Oudtshoorn germplasm (Western Cape) collection is located 314 m above sea level (m.a.s.l.) and receives on average 239 mm rainfall. This collection hosts 14 cactus pear varieties. The trial is laid out in a fully randomised design with two replications of each treatment. A second germplasm was established in the Eastern Cape at Cradock. This germplasm collection is located 846 m.a.s.l. and receives 359 mm rainfall on average. This orchard hosts 16 cactus pear varieties. The trial is laid out in a fully randomised design with two replications of each treatment. The first germplasm collection in Bloemfontein (Free State province) was established in 2005 by the ARC. This germplasm collection is located on the Waterkloof farm, ±20 km west of Bloemfontein. It is located 1348 m above sea level (m.a.s.l.) and receives 556 mm rainfall on average. This site hosts 42 South African cactus pear varieties that are being evaluated for different uses. The trial is laid out in a fully randomised design with two replications of each treatment. There are 14 rows, each with six plots. Individual plots have five plants. The spacing is 5.3 m, adding up to the total plant population of 420 for the two replications (de Wit et al., 2010). Standard orchard practices as recommended by Potgieter (1997) are followed in all orchards. A second germplasm was duplicated and established in 2017 by the ARC and UFS on the west campus of the UFS main campus in Bloemfontein. At the same time, a germplasm collection was established at the Roodeplaat ARC experimental farm outside of Pretoria (Gauteng province). This site also hosts 42 spineless cactus pear cultivars (Fouché et al., 2020).

The cactus pear crop originated in Mexico and has a long and interesting history. Spanish explorers discovered the plants in Mexico in the 1700s and used the cladodes as vegetables on their ships. The fruit consequently were distributed all over the world. At around 1750, a South African farmer from the Graaff-Reinet district (Eastern Cape) brought two cladodes from the Cape and planted them on his farm, while another farmer from Somerset East, also cultivated cactus pears and used the cladodes to distill alcohol in the Kamdebo district. It was then used so commonly, that during the early 1860s, farmers started to complain that cactus pears invaded the land and interfered with their sheep farming. The infestation escalated to such a degree that Henry Bolus described cactus pear, in 1874, as the biggest pest between the Suurberg and Sneeuberg mountain ranges (Beinart and Wotshela, 2011).

This infestation with prickly pear was aided by their spines that were too long, making it impossible for the livestock to graze on it. As part of the control measures, two insects, Cochineal (*Dactylopius opuntiae* (1913) and Cactoblastis (cactus moth *Cactoblastis cactorium*) (1924) were imported for biological control at great costs. The popularity of this miracle plant was declining sharply (Beinart and Wotshela, 2011).

In 1914, the so-called spineless cactus pear, developed by Luther Burbank from the Burbank nursery in California, USA, was imported and planted by the Department of Agriculture at the research station Grootfontein, which is situated in Middelburg in the Cape province. In 1925, a paper that praised this new cactus pear cultivar as a valuable drought-resistant livestock feed was published (Turpin and Smuts, 1925). During this time, 22 cultivars of cactus pear were evaluated and today, this unique collection in South Africa is one of a few collections world-wide where these cultivars can be found. At first, the research focused mainly on the use of cactus pears for animal feed and, more specifically, nutrition during drought. The Cochineal-resistant blue-leafed spineless cactus (*Opuntia robusta*) was planted extensively in the Karoo and the cladodes fed to livestock. However, more recent agronomic evaluations established that cultivars with a much higher feed- and fruit production potential are available (Fouché et al., 2020).

The cactus pear fruit's potential were evaluated intensively for fruit production by the Department of Agriculture during the 1990s in the Limpopo and Gauteng provinces, and this period can be regarded as the second heyday of crop's history in South Africa. Renewed research into other uses of the crop also emerged during this period. The Cactus Pear Growers' Association and the Cactus Network (a group of interested researchers) were founded, and this resulted in an unprecedented interest in the crop. Currently at various locations in South Africa, several cultivars are being evaluated for their adaptability and production capacity. A research programme in the Free State has been initiated by the Agricultural Research Council (ARC) in 2001, where the cactus pear's potential as a feed source, among other things, is being investigated under semi-intensive conditions. Concurrently, several researchers at the University of the Free State had started research projects, investigating the plant's water consumption, its use as livestock feed, the fruit's quality and other human food applications (UFS Webpage, 2015).

2.2 *Legal Regulations*

In South Africa, some confusion as to whether cactus pear cultivation is allowed and regarding its status as an invader plant still exist. According to the Conservation of Agricultural Resources Act (Act No. 43 of 1983), *Opuntia ficus-indica* (L.) Mill.

was declared as a category 1 weed, which implies that no plants are to be planted, established, maintained, propagated, sold or acquired. It is therefore important to note that all spineless cactus pear cultivars and selections are exempt from this regulation. The *Opuntia* spp. are regarded as weeds, namely those that were introduced into a country outside their native habitats and became naturalized (Brutsch and Zimmerman, 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 twentieth 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 Zimmerman, 1995; Zimmermann, 2010).

2.3 Cultivation

Cactus pear, as a commercial fruit crop, is cultivated in at least 18 countries on more than 100,000 ha globally. These figures do not include cultivations for domestic use, small-scale farming or naturalized stands (e.g. as is found in the Eastern Cape Province). In SA, approximately 3000 ha have been planted exclusively for fruit, which support both domestic and export markets (Claassens and Wessels, 1997). More than 900 local farms devote a total of about 4500 ha to cactus pear production, including 1500 ha for fruit harvesting and 3000 ha for fodder production (de Waal et al., 2007). Cactus pear production is very labour-intensive especially during fruit harvesting. A farm needs about five people per hectare to harvest the fruit while during out-of-season, one worker per hectare is required to maintain the orchard. A hectare planted with cactus pear can yield between 20 and 30 tonnes of fruit per year. Assuming an average fruit yield of 20 tonnes per hectare, the value of the cactus pear fruit production harvested from 1500 ha at a price of R13333 per tonne could be worth at least R400 million (Brown, 2020).

3 Cactus Pear for Animal Feed

Water resources in South Africa are limited and above that, 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 (AgriOrbit, 2019). Increasing demands on already scarce water resources in South Africa require alternative sources of animal feed. One alternative with the potential for widespread production is spineless cactus pear. It is 1.14 times more efficient in its water use than Old man saltbush, 2.8 times more efficient than wheat, 3.75 times more efficient than lucerne and 7.5 times more efficient than rangeland vegetation. Until recently, research has focused extensively on the use of cactus pear as drought fodder. However, this is now beginning to shift, with growing interest in the intensive production of spineless cactus pear for other types of animal feed.

Studies on the use of sun-dried cactus pear cladodes suggest that it has the potential to provide some 25% of the basic feed resources required by South Africa's commercial ruminant feed manufacturing sector (de Waal et al., 2015). Another example is the cactus pear fruit, produced seasonal, yielding large quantities of fruit in a relatively short period of a few months in summer. The fruit cannot be stored for a long period unless kept in cold storage. A procedure was therefore developed to combine large volumes of mashed cactus pear fruit pulp with dry hay and straw to preserve it for longer periods as high moisture livestock feed, called kuilmoes—a high water content livestock feed similar to silage (de Waal et al., 2015).

Production of high quality spineless cactus pear fruit is stimulated by pruning and this 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 thus 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 2 months in summer, namely from about January to March (De Waal et al. 2015). Not all the fruit is suitable for human consumption, thus creating an opportunity to utilise another component of spineless cactus pear as livestock feed. Sun-dried cladodes and mashed fruit preserved on straw and hay can be used by ruminants, provided it can compete with conventional feeds.

Cactus pear, specifically the spineless form, is under-utilized as a multi-purpose crop in South Africa and this situation needs to be addressed urgently. Ruminant livestock utilizes veld (natural pasture or rangeland) as well as 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, such as domesticated cattle, sheep and goats, as well as indigenous wildlife. It is also utilised by other herbivore species such as domesticated equines. 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 AFMA, 11,380,587 tons of animal feed was produced in 2013/2014, including 2,057,788 tons for dairy cattle and 3,297,788 tons for beef cattle and sheep (AFMA, 2014). Most manufactured feeds are used to finish large numbers of cattle and sheep in feedlots but some of the feeds for beef cattle and sheep are used to supplement ruminants on veld and planted pastures. Cattle and sheep consume a variety of diets in feedlots, but in fact 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. Second to that, 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 high growth rates required 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.

Spineless cactus pear 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 under-utilized multi-use crop in South Africa. Spineless cactus pear, mainly *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 the cactus pear fruit. 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). The famous blue-leafed spineless cultivars (Monterey and Robusta) produced disappointingly low yields, but should not be discarded as they are Cochineal resistant. In the past, the selection programmes mainly focused on fruit production and therefore the two cultivars had a low priority (Fouché et al., 2020).

As versatile as the plant is in terms of its fruit, the cladodes are just as valuable. Several options for utilizing the plant exist and these opportunities have not yet been fully exploited by the livestock industry in South Africa. Much can be learned from Brazilians and Mexicans, who have been using the crop for centuries, and where, in many cases, it is the only source of fodder. The main reasons why cactus pear is an ideal forage crop includes its: drought-resistance and production when other forage crops fail; wide adaptability to various climates and soils; production of higher yields than most pasture crops because of its high water-use efficiency; ability to be used and processed in various forms of feed; ease to establish and low establishment costs; suitability to use by small farmers and macro businesses alike; high quality feed yield; tastiness; and high digestibility (Fouché et al., 2020).

The plants are pruned to stimulate fruit quality and yield and in return, yield cladodes that can be utilised by livestock. Unfortunately, the high water content of cladodes restricts its use by livestock to the close proximity of orchards. Dry cladodes however, makes it is easier to process, transport and store material for longer periods. The University of the Free State is promoting sun-dried spineless cactus pear (*Opuntia ficus-indica* and *O. robusta*) cladodes (De Waal et al., 2015) and fruit (De Waal et al., 2015) as major ruminant feed sources. Despite the widespread use of cladodes as drought feed in South Africa, relatively little is known about the use in livestock production diets. In 2005 and 2008, increasing supplementation levels (0%, 12%, 24% and 36%) of sun-dried and coarsely ground cactus pear cladodes were included in balanced diets and was used to partially replace lucerne (*Medicago sativa*) hay in diets for young Dorper wethers. At the highest inclusion of sun-dried cactus pear (360 g/kg diet), there were no adverse effects on feed intake, digestibility, rumen variables, growth, animal performance and carcass quality. In fact, higher levels of dried cladodes in diets improved digestibility. The study further showed that the mucilage in cladodes is responsible for the occurrence of wet manure. Mucilage does not break down the digestive system and binds the water so that it cannot be absorbed from the intestinal tract (water is retained in the distal gastrointestinal tract (GIT)). Thus, the additional amount of water that sheep drank daily, as a result of the intake of dried cladodes in the diets, was not excreted as expected by the kidneys as urine, but largely excreted in the form of wet manure (de Waal et al., 2015). The condition is sometimes confused with laxative or diarrhoea. 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.

Cactus pears are associated with the semi-arid zones of the world (Sáenz, 2000, 2002). It is tolerant to drought and 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). Luther Burbank, pioneer of spineless cactus pear in the USA (De Waal et al., 2015), 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 as cited in Fouché et al., 2020). *Opuntia* spp. are important livestock feeds in several countries (Felker, 1995; De Kock, 2001; Nefzaoui and Ben Salem, 2001), particularly during droughts and seasons of low feed availability (De Waal et al., 2007). 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 (De Kock, 2001; 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). Cladodes are used in several ways. 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).

It is not easy to enter the market as a viable option unless the feed has a competitive advantage (de Waal et al., 2015). 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. Cactus pear is a good source of energy with a low crude protein content (2–3%), but with fertilization, it is well known that the crude protein content can increase to about 8%. Several studies have shown cactus pears as an important source of maintenance feed. In dry areas, the high water content is of great value, with approximately 90,000 l of water found in the cladodes produced per hectare (100 t DM/ha). On the other hand, this high water content impedes the intake of sufficient nutrients. Drying is hampered by mucilage, a water-soluble pectin-like polysaccharide. The well-known ability of cacti to retain water during adverse climatic conditions such as drought is due, at least in part, to the water-binding capacity of mucilage (Fouché et al., 2020).

3.1 Various Ways to Use Cactus Pear as Feed

3.1.1 High-Density Plantings

Research from particularly Brazil has shown that crop yield can be drastically increased by increasing plant density. Intensive feed production goes along with intensive orchard management and practices. Dense plantings can be considered for feed production in higher rainfall areas or under drip irrigation. The utilization of cladodes can mainly be divided into two groups, namely to use the fresh plant material or dried. Both can then be processed further (Fouché et al., 2020).

Traditionally, fresh cladodes are well utilized by livestock either used whole, or cut into strips or cubes. The cladodes can be cut or shredded and partially dried before animals utilize it. Despite the form in which it is used, the high water content impedes the handling and processing of fresh cactus pear cladodes as well as its intake. Practical methods for shredding and drying cladodes can facilitate further processing. In the dry form, deficiencies in the nutrient composition of cladodes can be corrected during the formulation of balanced diets by adding supplements. Cladodes can also first be dried slightly in order to partially dispose of the high water content. The estimated cladode production of 100 tonnes of wet material per hectare (10 t DM/ha) with a plant density of 666 plants per hectare can be produced when orchards are pruned annually. Yields of up to 400 tonnes of wet cladodes/ha (40 t DM/ha) have been measured when the plants are planted exclusively as livestock feed under intensive conditions (Fouché et al., 2020).

3.1.2 Shredding of Cladodes

Fresh cladodes can be shredded by multi-purpose shredders into thin strips to increase the surface area for drying in the sun. Thinner strips dry faster, although water from the slimy cladode pulp evaporates very slowly (nutrients are present in the juice) and the result is that the released mucilage solidifies on the surface and thus stops evaporation. The shredded strips are dried in direct sunlight on drying floors and on racks slightly raised from the ground to ensure free air circulation. Depending on the thickness of the strips, the weather conditions and further processing of the strips, the drying process can be completed within 4–14 days (Fouché et al., 2020). Thereafter, production diets can be formulated. Due to the interaction between mucilage and water, the role and relationship in the drying process of cladodes and especially in the digestive tract of ruminants are further investigated.

If fruit marketing is not the primary focus, the fruit part of the crop is available for livestock feed production. Results from various sources show that about 25–30 tonnes of fruit/ha are produced, and since some producers are only interested in seed production, the fruit pulp becomes a by-product and would therefore also be available as livestock feed. Ripe fruit contain about 12% of sugars (glucose and fructose), which make it a tasty, high-energy food source. Since the shelf life of the harvested fruit is a few days, it complicates its use as feed, and must therefore be used or preserved as soon as possible. Some of the options are to make either silage or fodder blocks. Ripe fruit (preferably pulped) can be mixed with roughage, e.g. corn stalks or grass. Feed-grade urea and other micro-elements should then be added. The mixture is further ensiled in the standard way. The less air in the mixture, the better the silage quality. However, it is possible to make a good quality silage of the fruit (De Waal, 2015) without any additional molasses. In the agricultural industry, waste or by-products, such as olive cake, grape marc, citrus peels, tomato pulp and cactus pear fruit are obtained at production facilities. These products have a very short shelf life and must be used as soon as possible. A possible use of these waste or by-products is in the making of fodder blocks. This practice originated in North Africa, Arab countries and Iraq. In countries with few resources, this is seen as a major breakthrough in the animal nutrition industry (Nasri et al., 2008). The ratio in which the various elements are mixed is determined by the desired quality of the fodder block. Unused fruit or waste from sorting tables can be used as an energy source in the fodder blocks. Dried fodder blocks can be stored indefinitely and can therefore be used in times of drought. It can even be used as supplemental nutrition during winter and early spring. Silage can also be made from fresh cactus pear cladodes, but it requires a lot of practical experience. The silage is very wet and spoils easily. Furthermore, the quality depends on the sugar content of the roughage. If the cladodes are dried first, better results can be obtained. Shredded cladodes are mixed with dry roughage to reduce the water content.

Farming in South Africa is under increasing socio-economic pressure, often because of small and uneconomical farming units, increasing production costs, droughts and unreliable rainfall during critical periods of the growth season of natural pastures (veld). In the arid regions, South African farmers are predominantly keeping livestock or wildlife. They face seasonal losses during winter and early summer because of feed shortages, and managing risk has become part of their daily lives. South Africa urgently needs new initiatives for sustainable rural development. The scarcity of water resources created a need to find alternative sources of animal feed, specifically crops that use water more efficiently. The spineless cactus pear (*Opuntia ficus-indica*) is such a plant, and well adapted in dry environments, producing large yields of cladode and fruit for humans and animals. It has the potential to improve and stabilize the livelihoods of rural people. An initial group of 26 participants in the Oppermansgronde community have been assisted to plant 2-ha plots of spineless cactus pear under a rain-fed system. Spineless cactus pears have high water-use efficiency (WUE) and are adapted to marginal soils, and therefore do not compete with most cash crops. Cladodes are not a complete animal feed source, but they played a marked role in sustaining cattle and sheep during a number of consecutive very dry summers (2014–2016); the usual animal losses were limited and, on some farms, no losses occurred. Reproduction of sheep and cattle was affected, but less than expected. The data are still being evaluated, but an average household income of about US$550 was generated from the sale of fruit and cladodes. Value adding and product development are also taking place in some households, with produce being delivered to road stalls. This project created a working model for other community-based project (de Wit et al. 2019a, b, c, d).

4 Cactus Pear for Human Consumption

The spineless *Opuntia ficus-induca* and *Opuntia robusta* cactus pear species, imported to be used as fodder, necessitated its valuation for human food. Research on cactus pears for human food uses in SA was almost non-existent. It is a so-called "new crop" with immense potential for use in the food, nutraceutical, pharmaceutical and cosmetic industries. With a growing demand for nutritious food to combat food scarcity, the answer lies in under-utilized crops such as cactus pears. All possible applications of this exceptional drought-resistant CAM plant in human food should be evaluated. Research on cactus pears at the University of the Free State (UFS) is in collaboration with the South African Agricultural Research Council (ARC). Food Science research on cactus pears at the UFS started in 2006 and fruit was obtained from the Waterkloof experimental farm. 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). Climatic data are captured *via* an automatic weather station. The site 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 namely Cradock in the Eastern Cape (hosting 16 cultivars) and Oudtshoorn in the Southern Cape (hosting 14 cultivars) (de Wit et al., 2010).

4.1 Fruit Quality

One of the first research questions to be answered was if the fruit of all 42 cultivars being evaluated were suitable for human consumption, in other words, fruit quality was determined physico-chemically as well as sensorically. Data for Bloemfontein was compared to data from other secondary orchards established by the ARC and the Department of Agriculture at other agro-ecological regions namely Oudtshoorn (16 cultivars) and Cradock (14 cultivars). The influence of season and locality on internal cactus pear fruit quality parameters was established. These included fruit mass, pulp percentage, total soluble solids (TSS), pulp pH, pulp titratable acidity (TA), pulp ascorbic acid, pulp fructose and pulp glucose. Significant variation existed between mean values of the different characteristics (parameters) between localities (except for the pulp glucose values). Genotype X Environmental interactions were noted. It was concluded that Meyers is the most appropriate cultivar for economical purposes in South Africa (de Wit et al., 2010).

In the second study, the aim was to determine the influence of the location, cultivar and season on fruit quality, thus establishing the most stable cultivar for fruit quality characteristics among three agro-ecological localities (Bloemfontein, Cradock and Oudtshoorn). Fruit quality parameters were evaluated for 11 cultivars that were common to all three localities. The evaluation was done over two seasons (2008 and 2009). Parameters analyzed included fruit mass, pulp percentage, acidity, ascorbic acid- and sugar content. Significant differences in mean values among cultivars were found in 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. The interaction between location and cultivar however, contributed to variation in most of the parameters tested. The performance of the cultivars varied between seasons. Meyers was found to be 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 (AMMI) analysis, Meyers proved to be the most stable cultivar at all the locations over two seasons. Meyers also possessed substantial quality parameters compared to the other cultivars. Therefore it could be concluded that 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).

In a third study, the aim was to determine the fruit quality of cactus pear fruit from one locality (Bloemfontein) over two seasons. Physico-chemical quality attributes were evaluated for two agricultural seasons (2007 and 2008). The influence of rainfall and temperature on quality was determined. Highly significant differences were observed in terms of physicochemical composition among the 33 different cactus pear cultivars over the two seasons. This finding indicated that genetic differences among cultivars, as well as seasonal changes, have a significant influence on fruit quality. It was also evident from this study that not only the cultivar and agricultural season, but also the interaction between the cultivar and season had a significant influence on fruit quality (Rothman et al., 2013).

The fourth study provided results regarding the effect of cultivar and season on sensory quality of cactus pear fruit. Sensory quality was evaluated by Free Choice Profiling (FCP) over the two agricultural seasons of 2007 and 2008. The five most frequently-used attributes used by the sensory 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. FCP could successfully distinguish between the two seasons, but not between the majorities of the cactus pear cultivars. The exception was observed in Monterey and Robusta, where FCP was able to differentiate these two cultivars clearly from the rest of the cultivars. In an attempt to determine if sensory quality of cactus pear fruit was influenced by the physicochemical parameters, Pearson correlation analysis was performed between the physicochemical and sensory data. Physicochemical attributes like pulp glucose, pulp fructose and percentage pulp were correlated with sensory attributes like sweet, fruity and prickly pear. Positive correlations included "sweet" with pulp glucose and pulp fructose and "prickly pear" with pulp pH. Negative correlations were found between "prickly pear" and "sweet" as well as between "prickly pear" and % pulp (Rothman et al., 2012).

Consequently, in a fifth study, 12 cultivars with commercial fruit production potential in the Free State were selected from the Waterkloof orchard for the evaluation of fruit eating quality as well as the effect of climate (temperature, heat units and rainfall) thereon. These were evaluated over five production seasons. Rainfall had a significant positive effect on fruit mass, total soluble solids (TSS) content, glucose content, pulp pH and percentage titratable acidity (% TA), while rainfall had a negative effect on percentage pulp and betacyanin (Bc) and betaxanthin (Bx) pigment contents. Fruit mass, TSS, glucose, fructose content and % TA correlated negatively with total heat units, while % pulp, vitamin C content, pulp pH, Bc and Bx correlated positively with total heat units. Maximum temperatures had a similar effect on fruit quality to that observed for heat units, except for pulp pH. From these results, it could be concluded that all climatic factors measured correlated to changes in fruit quality, especially TSS, sugars, acidity and colour (pigments), although the effect of rainfall was most profound (Coetzer et al., 2019).

4.2 Processed Fruits

Processed fruits were also evaluated, e.g. cactus pear fruit juice including the effect of processing conditions (heat treatment, cooling and freezing) as well as further processing into fruit jellies. Cactus pear fruit juice was thermally processed (jelly manufacture included) and sensorially analyzed. Fruit from seven cactus pear cultivars used for human consumption and one, an animal feed cultivar, was peeled and the juice extracted. Three thermal treatments were applied namely freezing (−18 °C), refrigeration (4 °C), and pasteurization (60 °C). Ten semi-naïve panelists compared the taste by 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. It was found that pasteurization had a detrimental effect on the flavor of the juice. Descriptive sensory analysis on cactus pear fruit jellies compared textural attributes such as cloudiness, smoothness, pectin content, runniness and cutting edge. Physical analysis of texture was also carried out in support to the sensory data. Only one significant difference between the seven cultivars for the sensory descriptor of cloudiness was found. Both physical tests (line-spread test and Brookfield viscometer) differed significantly between jellies from the seven cultivars (de Wit et al., 2014).

In a second study, a health drink was developed by combining fruit pulp and different teas. Ingredients such as tea, ginger, cinnamon, lemon juice, stevia sweetener, coconut water, and Ginkgo biloba were used alongside the cactus pear juice as functional ingredients in the development of an ice tea health beverage. The sensory panel consisted of 50 people and a 9-point hedonic scale was used to determine consumer acceptance of the cactus pear ice tea. Analysis of variance (ANOVA) was used to determine the differences between the appearance, aroma, taste, mouthfeel, and aftertaste of the five different health drink formulas. Taste, aftertaste and aroma scored the lowest on the 9-point hedonic scale, while appearance and mouthfeel scored the highest on the hedonic scale. The results indicated that the formulas most liked were the Rooibos tea formula and honey-bush tea formula while the least liked formula was the green tea. The other in-between formulas included chamomile and regular black tea (Louw, 2018).

Alternative food uses of cactus pears: to establish cactus pears as a multi-use crop, other parts of the plant such as the cladodes and waste products should be investigated. These included fresh and processed cladodes as well as seeds and peels. Further exploitation and exploration on all human food applications of cactus pears, especially by-products and waste products of the whole plant should be done. Results obtained will broaden the application of this plant in arid and semi-arid countries where food sustainability is needed. With a growing demand for nutritious food to combat food scarcity, the answer lies in under-utilized, multi-use crops.

4.3 Seed Oils

A comprehensive study was launched into the oil composition and fatty acid analysis of the seeds from the cactus pear fruit. This oil is currently one of the most expensive oils to be used in culinary and cosmetic industries. Seed oils from the 42 cultivars from Bloemfontein (Waterkloof), 16 cultivars from Cradock and 14 cultivars from Oudtshoorn were chemically extracted, evaluated and compared over two seasons. Oil quality and stability was also determined. The total lipid content and fatty acid composition depends on various factors, including cultivar, degree of maturity, climate, harvesting season as well as agricultural practices. The first aim of the study was to conduct a seed oil quality analysis by investigating variation among the 12 common cultivars across the three locations (Bloemfontein, Cradock and Oudtshoorn) over two production seasons (2010 and 2011). Seed oil content and fatty acid content, as well as the ratios thereof, differed among cultivars, seasons and locations. Cultivar X location X season interactions were significant for oil content. Levels of oleic acid (C18:1c9) were significantly influenced by the cultivar X location interaction. Mono-unsaturated fatty acid content was significantly influenced by cultivar X location and location X season interactions. Oil content was significantly correlated with levels of palmitic acid (C16:0), stearic acid (C18:0) and oleic acid. The cultivars Van As, Turpin, Roedtan and Meyers showed good associations with oil content and C18:1c9, while Bloemfontein was the most stable location (Shongwe, 2012; de Wit et al., 2016).

The second aim was to evaluate the 42 cultivars from the Waterkloof orchard (Bloemfontein) over two seasons (2010 and 2011) for seed oil content and fatty acid composition in an attempt to determine the best oil yielding cultivar. Seed oil content varied among cultivars and seasons. The unsaturated fatty acids were the most prominent and consist mainly of linoleic acid, followed by oleic acid the saturated fatty acids palmitic and stearic acid. Cultivar and variation in especially rainfall had a statistically significant effect on cactus pear seed oil content and fatty acid composition. Principal Component Analysis showed that certain cultivars were exclusively associated with specific characteristics. American Giant cultivar had the highest seed oil yield (Shongwe, 2012; de Wit et al., 2018).

The third aim was to evaluate and compare preliminary seven South African cactus pear varieties of *Opuntia ficus indica* and *O. robusta* for chemically extracted seed oil content, fatty acid composition and oil quality. Oil quality parameters included refractive index, iodine value, peroxide value, free fatty acid content, *p*-anisidine value and oxidative stability index. These oils demonstrated a relatively low oxidative stability index. Oxidative stability showed significant correlations with the oil content, oleic acid, stearic acid and monounsaturated fatty acid contents as well as with physiochemical properties such as the peroxide value and the *p*-anisidine value (Shongwe, 2012; de Wit et al., 2017).

Consequently, a fourth study investigated cold-pressed seed oil from 12 commercially produced cactus pear cultivars from the Waterkloof experimental farm (Free State) by comparing oil yield, fatty acid composition, physicochemical properties, quality and stability. Large differences in oil content, fatty acid composition as well as physicochemical properties (IV, PV, RI, tocopherols, ORAC, %FFA, OSI and induction time) was observed. Highest oil content was found in American Giant. The important fatty acids detected were C16:0, C18:0, C18;1c9 and C18:2c9,12, with C18:2c9,12 being the dominating fatty acid. Quality parameters of the oils were strongly influenced by the oil content, fatty acid composition and physicochemical properties. Oil content, PV, %FFA, RI, IV, tocopherols, ORAC and *p*-anisidine value correlated negatively with the oxidative stability index (OSI). American Giant was identified as the important cultivar with good quality traits (oil content and oxidative stability) (de Wit et al., 2021).

In a fifth study, the effect of oxidation on the quality and shelf-life of cactus pear seed oil, obtained by cold-pressing, was studied. Chemical and physical methods were employed to determine changes or analyse oxidative stability at both 25 and 30 °C at different stages throughout a 12 month storage period. Tests used included peroxide value (PV), *p*-Anisidine value (*p*-AV), refraction index (RI), free fatty acids (FFA) and oxidative stability index (OSI). Predictions of the shelf-life of the oils to be stored at 25 and 30 °C were made. This predicted shelf-life was found to be less than the actual shelf-life as determined by the comprehensive 1 year shelf-life evaluation. Both oils were very stable and it was concluded that storage time had a more pronounced effect on oil quality than storage temperature (de Wit et al., 2020a, b).

Further investigation into seed oils is being done. As part of an initiative to promote cactus pears as a multi-functional crop, dual-purpose cultivars should be identified and its production increased. This study is aimed to increase the yield and quality of the seed oil of *Opuntia ficus-indica* cultivar Morado produced for its commercially viable green-coloured fruit in South Africa. The project encompasses a trial using nitrogen (N) fertilization from three N sources (LAN, Ammonium

Sulphate and Urea) and four N application rates (0, 60, 120 and 240 kg/ha). It was found that fruit production significantly increased with both N source and application rate, however, the N source did not influence fruit quality, but high N application rates influenced fruit quality parameters negatively. Oil content significantly increased with increased N fertilization rates. The main fatty acids composition (oleic, palmitic, *cis*-vaccenic and stearic acid) were also significantly influenced, the highest content fatty acid, linoleic acid however, was not significantly influenced. It can therefore be concluded that N fertilization promoted an increased oil content, but was detrimental to the linoleic acid content. This study therefore provided important information on cultivation practices aimed at increased oil production (Nkoi et al., 2019).

4.4 Functional Ingredients

Functional ingredients in cactus pears include the powerful antioxidant colourants betalains, vitamin C as well as the soluble fibre mucilage.

4.4.1 Mucilage

Mucilage is a hydrocolloid with interesting functional properties. A patent was registered in 2011 by the UFS (Du Toit and De Wit, 2011) on the extraction of mucilage from cactus pear cladodes. This patented procedure included slicing, microwave cooking, macerating, centrifuging at 8000 rpm for 15 min, and freeze-drying at −60 °C for 72 h. An extensive study into the extraction, characterization and application of mucilage in food products as functional ingredient was completed. Further characterization and application of mucilage as native liquid and dried powder in functional foods was also undertaken.

In the first study, 42 cultivars (*Opuntia ficus-indica* and *Opuntia robusta*) were evaluated in terms of cladode morphology (size, weight, volume, width, length, diameter, and surface area), cladode moisture and solid contents, mucilage yield and mucilage viscosity. Cultivars were categorized into five groups in terms of mucilage viscosity, namely low, medium-low, medium, medium-high and high. Correlations between cladode size and weight, mucilage yield and viscosity as well as cladode moisture content and mucilage viscosity were determined for each cultivar. No correlation was found between size and weight of cladodes and mucilage yield. Positive correlations were found between cladode moisture content and mucilage yield and mucilage viscosity, while the highest positive correlation was observed between the mucilage yield and mucilage viscosity. Cladode dimensions and properties were linked with mucilage yield in order to select cultivars for further analysis in food applications (de Wit et al., 2019a, b, c, d).

In a second study, the unique flow behavior of mucilage was determined. The flow behaviour should be fully understood in order to predict its behavior during processing, packaging, preparation and consumption. Extraction by the patented procedure and drying of mucilage from mature cladodes from four cultivars, harvested in winter (July 2014) was done. The four cultivars had viscosities between 26.0 and 29.8 cm (not significantly different) using the line-spread test and 150 and 328 cP using the viscometer. In the controlled-rate and time-interval tests, mucilage showed non-Newtonian, pseudoplastic tendencies but no rheopectic or thixotropic behaviour. Mucilage exhibited dynamic yield, indicating the force needed for it to start moving. Viscosity increased at lower temperatures and decreased at higher temperatures. In alkaline regions (pH > 11 to 8), viscosities of native mucilage increased, while they decreased in acidic (pH 6 to 1) regions. Monovalent ions had little, divalent more, and trivalent the most influence on native mucilage viscosity (du Toit et al., 2019a, b, c, d).

In a third study, the investigation of the functional properties of extracted freeze-dried powders was determined to predict the potential of South African cultivars as healthy ingredients. Freeze-dried powders of four cultivars (*Opuntia ficus-indica* Algerian, Morado, Gymno-Carpo, and *Opuntia robusta* Robusta) were dissolved in water or oil. The solubility-, swelling power, water and oil holding- and absorption capacity as well as emulsification capacity of the mucilage powders were determined. Freeze-dried mucilage powders had a very high solubility index, water- and oil absorption as well as water- and oil holding capacities. It displayed high emulsification capacity and stability. The protein content for the three *O. ficus-indica* cultivars was not significantly different, but significantly higher in *O. robusta*. None of the cultivars possessed significantly better functional properties. Native mucilage was applied in fat-, dairy and egg-replacement products. Mucilage showed promise as emulsifier and fat-replacer in mayonnaise products and was described as creamy with a highly acceptable mouthfeel. It showed strong potential as a functional ingredient (du Toit et al., 2019a, b, c, d).

During a fourth study on mucilage, it was speculated on the variation in physicochemical and technological properties of powders, when cultivar and harvest month of cladodes differ. This, in turn, could lead to differentiation in the application of mucilage powders. Three *Opuntia ficus-indica* (Algerian, Morado and Gymno-Carpo) cultivars and one *Opuntia robusta* (Robusta) cultivar were harvested over a 6 month period (February to August) and evaluated. February mucilage powders were the most porous with highest oil absorption and oil holding capacity, lowest water holding and swelling capacity, and lowest ability to increase viscosity. August mucilage powders had the smallest impermeable particles, highest water holding and hydrophobic properties, as well as the best emulsifying capacity, stability and ability to increase viscosity. *Opuntia robusta* produced brighter, darker green, more viscous mucilage while *Opuntia ficus-indica* powders were dull, light yellow-green with a lower viscosity and emulsifying capacity. Robusta mucilage was successfully applied in mayonnaise products as emulsifier and fat replacer (mimic) to replace up to 50% egg yolk and 30% oil (du Toit et al., 2019a, b, c, d).

The cultivar with the most optimal nutrient content and the preferred harvest times was still unknown. For that reason, in a fifth study, mucilage from three *Opuntia ficus-indica* (Algerian, Morado and Gymno-Carpo) and one *Opuntia* *robusta* (Robusta) cultivar were investigated to determine their nutrient content over 6 months (February to August). Nutrients that contribute energy were low. The mineral (ash) content was high, particularly calcium and phosphorous. Low insoluble acid-detergent fibre and neutral-detergent fibre values indicated that mucilage was mostly soluble fibre. Calcium oxalate crystals were not detected in dried mucilage. *Opuntia robusta* powders had higher protein, extractable fat and potassium content, while *Opuntia ficus-indica* mucilage powders had higher polyunsaturated (linoleic and α-linolenic acid) fat content. *O. robusta* Robusta mucilage, harvested after the fruit harvest (February) had the lowest energy content and the highest mineral and protein content (du Toit et al., 2018).

During a sixth project, mucilage as gellant in marshmallows was investigated. The objective of the study was to replace gelatin in marshmallows with different concentrations of fluid (native) mucilage, combined with different concentrations of powdered hydrocolloids. Nine different formulations were prepared with combinations of mucilage, xanthan gum, guar gum and agar-agar. Consistency, texture, tenderness of gel and shear measurements were determined, along with color (L* values, as well as C* and H° values) and a_w. Significant differences between the different samples for all measurements were found. The best formulation for gelatin replacement was found to be the 75% mucilage +12.5% xanthan +12.5% agar combination, as it only differed significantly from the control (100% gelatin) sample in regard to shear. It was significantly less tender and resembled the shear of commercially available marshmallows in South Africa. All samples had a light, greyish yellow color (du Toit et al., 2016a). In the subsequent part of this study, the aim was to compare consumer liking of flavored and unflavored marshmallows made with native liquid mucilage, to that of a flavored and unflavored control sample (with 100% gelatin), as well as a flavored and unflavored commercial brand (Manhattan). Consumer liking was tested for taste, aftertaste, texture, as well as an overall acceptability of liking by a panel of 92 consumers. The white mucilage marshmallows had the lowest ranking for taste, aftertaste, texture and overall acceptability, and differed significantly from all the other samples. However, the pink mucilage marshmallow did not differ from the pink commercial one (which had the highest rankings for taste, aftertaste, texture, and overall acceptability) and pink control marshmallow. It could be concluded that flavoring successfully masked the distinctive aroma of the mucilage in the marshmallows, thereby also increasing scores for texture and overall acceptability (du Toit et al., 2016b).

Inclusion of Mucilage as Functional Ingredient in Food Products

Functional food products are not medical food (specific formulations used for specific disorders or diseases used under medical supervision), nor are they dietary supplements. They are products that already form part of normal dietary patterns but address special dietary requirements. Mucilage in its native and freeze-dried form is an ideal candidate for such innovative functional food products, as it has been proven to enhance the nutritional content of food, while replacing undesired and unhealthy ingredients. The aim of the first application study was to evaluate the sensory acceptability of firstly using mucilage as stabilizer and fat-mimic in ice-cream and sorbet, as well as to evaluate the effect of cold processing and frozen storage on the functionality of mucilage, while secondly to use mucilage in the manufacture of yoghurt, to increase soluble fiber content as well as its contribution to water-holding capacity and stability. Native liquid mucilage was used in altered formulas in order to make dairy-free sorbet as well as fat-free ice-cream using skimmed milk. Freeze-dried mucilage was added in different concentrations to plain, unflavored yoghurt. A naïve consumer panel of 50 people was used to for sensory analysis using preference ranking tests to indicate the acceptability and preference of the products using 9-point hedonic scale tests. Mucilage had an adverse effect on the ability of the ice-cream and sorbet to freeze. Large ice crystals were observed in the mucilage replacement products. All the attributes of the replacement products were significantly lower than the control ice-cream and sorbet. The increased addition of mucilage improved the consistency as well as the sensory properties (attributes) of the yoghurt. Therefore mucilage addition had an adverse effect on crystallization of ice-cream and sorbet, but could be used as fiber additive in yoghurt (de Wit et al., 2019a, b, c, d).

The second application study attempted to apply mucilage as gelling and emulsifying agent in edible films and spherification (edible beads). Since mucilage is a hydrocolloid, a gelatinous slimy substance that contains polysaccharides and proteins, and its ability to absorb huge amounts of water which result in modified viscosity, it can be used as a food additive in the food industry as a hydrocolloid to modify food texture. It is used as emulsifier, to form gels and edible coatings. It is a good alternative to the current hydrocolloids and synthetic coatings because of its availability, chemical free production, low calories and cost. Mucilage was extracted by the patented method from four cultivars, namely *Opuntia ficus-indica* and Robusta (*Opuntia robusta*). It was then dried in two ways, freeze-drying and hot-air dehydration. Emulsifying capacity and gelling capacity was tested. Edible coatings were made by mixing mucilage, water and glycerol. For spherification, mucilage was used to replace the usual gelling agents. Mucilage showed good ability to form stable emulsions. During gelling ability tests, mucilage from Robusta showed greater ability to gel, compared to the other three cultivars, but it was concluded that mucilage does not form true gels on its own, but rather improve gel formation with other hydrocolloids. It can form edible coatings which slow down colour, weight and firmness loss in vegetable and fruits. It also acts as an anti-browning agent in potato chips, reduces oil absorption during frying and enhances colour during frying. When mucilage is used on its own to replace sodium alginate in spherification, it does not gellate nor formed the spheres, but it formed a gel membrane when incorporated with xanthan and agar. Mucilage can be a replacement to food hydrocolloids. It has the ability to stabilize emulsions and form edible coatings. Although it cannot form a true gel, when incorporated with xanthan and agar it forms a strong gel (Mushanganyisi et al., 2019).

Mucilage Protein Fraction Characterization

The protein fraction of the mucilage, being responsible for its emulsification and stabilization properties, must especially be characterized. In 1982, Trachtenberg and Mayer found low molecular weight substances in their extracted mucilage, but mistake it for contamination debris. Majdoub et al. (2001) found 2.2% proteins to exist in mucilage by ultra-filtration techniques. In 2012, Gebresamuel and Gebre-Mariam found protein content to be 6.82%. Du Toit et al. (2018) found 2.52–5.74% protein in mucilage. The aim of this study was firstly to determine and compare the protein fraction content of the mucilage extracted by the patented method from 40 *O. ficus-indica* and two *O. robusta* cactus pear cultivars from the UFS west campus collection. The second aim was to determine its foaming capacity and stability in foam food systems. The third aim was to quantify and characterize the proteins and their amino acids from mucilage to understand their effectiveness in reducing surface tension in foams in comparison to that of well-known and used foaming agents in the food industry. The LECO thermal combustion N and protein determination delivered a higher protein concentration in all the cultivars compared to the Bradford method's results. Protein concentration of crude mucilage was also significantly lower than that of Albumin and Sodium caseinate. Five cultivars namely Robusta, Malta, Gymno Carpo and Algerian, with the highest foaming capacity and stability were selected for further fractionation and characterization. SDS-PAGE showed that Robusta was the only cultivar that showed no bands and had a low protein content, although it showed foam stability properties. This could be due to the sugar content. The common sugar in all cultivars was glucuronic acid. Gymno-Carpo contained only glucuronic acid and xylose (Miya et al., 2019).

Mucilage from Fruit Peels

An attempt was made to extract and characterize the saccharides from cactus pear peels. Six cultivars were used, namely Nudosa, Turpin, Ficus Indice, Muscatel, Skinners Court and Vryheid—all from the *O. ficus-indica* spp. These were selected based on earlier fruit quality and genetic analysis (Mashope, 2009; De Wit et al., 2010). The extraction and fractionation method of Habibi et al. (2004a, b) was used. The fat and wax to cell wall material (CWM) ratio was more or less the same for the cultivars. The mucilage content varied between the cultivars with Ficus Indice having the highest percentage of mucilage (~2%). The water soluble pectin (WSP) content was found to be constant among cultivars, while the chelating soluble pectin (CSP) varied considerably. Mono-, di- and polisachharides were analysed by 1H-NMR analysis. All the cultivars had very similar results. The mucilage structure of the cultivars was very similar to each other. A comparison between the mucilage structure and pectin structure indicated two distinguished polysaccharides (results not published).

4.4.2 Cladode Flour

Baked Products

The influence of cladode flour addition to different baked products was investigated. This was done to increase fibre content and replace wheat flour (gluten). Cactus pear (*Opuntia ficus-indica* and *O. robusta*) cladode flour was used to prepare and evaluate three types of baked products. In a health bread, whole wheat flour was replaced with cactus pear flour in percentages of 2%, 4%, 6%, 8%, 10%, 12%, and 17% replacement. The volume decreased and the texture became more solid and firm. The brown colour darkened when the percentage replacement of the flour increased, although it was still acceptable for the consumer. Oats crunchy biscuits were made with increasing replacement levels (0%, 5%, 10%, 20%, and 50%) of wheat flour with cactus cladode flour from three different cultivars, *Opuntia ficus-indica* (Skinners Court and Morado) as well as *Opuntia robusta* (Monterey). Cultivar had a significant effect on colour, taste and texture, but not on appearance. Increasing inclusion levels of cactus pear flour had a significant effect on all the evaluated sensory attributes. The taste most liked by the panel was that of the Morado 10% inclusion level sample. Cladode flours affected quality parameters of texture, colour and taste of the biscuits. With the increase in the level of cladode flour in the formulation of a popular South African carrot cake, the sensory scores for the organoleptic characteristics of the cakes decreased. From the overall acceptability rating, it was concluded that cladodes flour could be incorporated up to 25% level in the formulation of cakes (Van den Berg, 2012; de Wit et al., 2015).

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 main fermenting agent involved in both products was maize meal. In the case of the beer, King Korn (sorghum/millet) was the key ingredient. Mageu is a traditional fermented drink made from cooked maize meal, that is left to sour over a period of 5 days. The pH of all samples tested had a lower pH after 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. As the levels of cactus meal inclusions increased, the colour of the samples got darker in comparison to the control. The best sample contained 20% cactus meal inclusion. The sample showed all the characteristics associated with the control sample of the mageu. Sensory analyses of the control and 20% inclusion were done. Analyses found that the panel of consumers did indeed notice a difference between the two samples. The panel had favored the control mageu over the cactus mageu (Van der Bijl, 2013).

A traditional, indigenous beer, locally also known as "platpit" beer was made from fermented maize meal and sorghum. The fermenting process normally takes up to 5 days. The sorghum (King Korn in this study) is the fermenting agent. What was evident through this study is the relationship between pH, yeast, lactic acid bacteria and alcohol formation. As was the case with the mageu, the pH levels of all beer samples were more acidic after fermentation. The sample with a 25% cactus meal inclusion was the best. This sample had all the characteristics that were found in the control beer. A sensory analysis was also conducted on the beer, and two samples were used, namely the control and the 25% inclusion. The panel had favoured the cactus beer over the control beer. It was clear 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).

4.4.3 Antioxidants

Antioxidant content and potential of cactus pear fruit (pulp, peel and seeds) and cladodes from fresh and processed products were evaluated. In the first study, the fresh fruit (pulp), peel, seeds and cladodes of each cultivar were compared. Analysis included betalains, ascorbic acid, phenolics and carotenoids. The activity of the antioxidants was determined by using the DPPḤ method and by measuring the chelating activity of ferrous ions. When % DPPḤ was tested, peel and cladodes were consistently the highest, while in the % chelating activity tests, fruit pulp and seeds were the best tissue types. Cladodes contained more phenolics and carotenes than fruit regardless of the cultivar. For pulp and peel, the cultivar that contained the highest antioxidant content and potential was Robusta (purple) with its high content of betalains followed by Gymno-Carpo and Ofer (both orange) with high ascorbic acid levels. The study proves that the fruit (pulp), peel and seeds from different cultivars contain specific antioxidants relating to the colour of the fruit, but the cladodes of any cultivar contain similar and highly effective antioxidants (du Toit, 2013; de Wit et al., 2019a, b, c, d).

The aim of the second study was therefore to explore the processing of cladodes into different preserved food products and to study the processed products' antioxidant content and capacity compared to the fresh cladodes. All cultivars demonstrated high antioxidant capacities and therefore, the cladodes of any cultivar could be considered as suitable for processing or preserved to produce healthy products. Processing had a greater influence on the antioxidant content of cactus cladode products than the cultivar. Dried products were the best in terms of antioxidant content and capacity (du Toit et al., 2018b).

During the third study, cactus pear fruit pulp was investigated. The aim of the study was to determine the relationship of fruit processing method and colour with antioxidant content and activity in fresh and processed cactus pear fruit. Antioxidant components (ascorbic acid, phenolic com-pounds, carotenes and betalains) and antioxidant activity (radical scavenging activity towards DPPḤ and Fe-chelating capacity) were determined in fresh and processed (juiced, dried, preserved and chutney) fruits from four different colored cultivars (purple, green, orange and pink). The highest antioxidant content and potential was found in purple (*O. robusta* cv Robusta) fruit products, attributed to the highest levels of betalains (1140.4 mg kg^{-1}). Orange fruit (*O. ficus-indica*) products had the second highest levels, attributed to ascorbic acid and phenolics. Betalains were highly retained in all processed products, while ascorbic acid was mostly retained in the processed products that involved minimal heat treatment. Carotene and phenolic compounds became more available for extraction during processing and showed higher levels after processing. Principal component analysis makes it possible to identify fruit colours of fresh and processed products, which were mostly associated with a specific antioxidant. PCA indicated that fresh purple fruit was correlated with chelating activity and betalains, while orange fruit was correlated with phenolics, ascorbic acid, carotene and DPPḤ For the processed fruit products, most were clustered together with chelating activity, DPPḤ and the antioxidants. Orange and pink dried products had high ascorbic acid, phenolics, carotene and DPPḤ values, while dried and fresh purple fruit had high betalain content and chelating activity (du Toit et al., 2018a).

In a fourth study the antioxidant content and antioxidant potential of fresh and processed (juiced, dried, preserved and chutney) cactus pear fruit peels from different fruit-colored cactus pear cultivars were investigated. Cactus pear peels contained high levels of antioxidants and demonstrated high antioxidant activity. The highest contents were found in dried peels, while the preserves had the lowest contents. PCA analysis indicated that products, rather than cultivars, seem to cluster together. Robusta and its products cluster together, as well as with betalains. The % DPPḤ, carotenoids and phenolics are grouped together, with % chelating activity closely correlated with ascorbic acid. Dried products from all cultivars correlated closely with % DPPḤ, carotenoids and phenolics, especially dried peel from Gymno-Carpo (orange), Ofer (orange), Meyers (red) and Nepgen (green). Purple fruit peel products had the highest % DPPḤ, % chelating activity, betalains, phenolic compounds and carotenes. Ascorbic acid dominated in orange and red fruit peels. Purple and orange were the colours of cactus pear fruit cultivars that might be the best choice in terms of antioxidant content. The cultivar that presented the best fruit peel from an antioxidant point of view for preservation was Robusta. Cactus pear fruit peels should be included in processed products such as juice, dried fruit and chutneys (de Wit et al., 2020a, b).

4.4.4 Colorants

A study was done on the extraction, characterization and application of betalains from different colored cactus pear fruit compared to that of beetroot and purple amaranth leaves. A natural and stable powdered colorant was extracted, dried and applied in food products. The shelf-life of these colored products was determined. Natural colorants promote health safety and are often preferred by consumers. As such, the use of betalains, which are naturally derived pigments with nutritional benefits such as vitamin C and antioxidants that are vital to the end-user was explored. To ensure maximum betalain extraction at low cost, different extraction methods were investigated. Colorants were extracted from red beetroot, amaranth and eight cactus pear cultivars from the following colours: green, orange, red/pink and purple. The cultivars included: American Giant, Morado (both green), Ficus Indice, Gymno Carpo (both orange), Algerian, Meyers (both pink-red) and Monterey, Robusta (both purple and from the *O. robusta* spp.). Results showed that the best extraction solvent in the study was distilled water. Green cactus pear cultivars contained the lowest amount of betalain, while the highest concentration was found in the purple cultivars. The best extraction temperature was 25 °C, and most betalains remained stable until 80 °C (Sigwela et al., 2018). Natural colorant guidelines from the European Commission further revealed that the food definitive safety patterns followed during the extraction phase of these colorants allow them to be labelled as Colouring Food. They are labelled as fruit or vegetable juice with inherent coloring abilities and acceptable for use in countries around the globe. Betalains transmitted color and subsequently remained stable under various production methods. They successfully colored various products including baked, pan-fried, emulsified-cooked meats, jellies, candies and dairy products (Sigwela, 2020).

4.4.5 Seed Proteins

Studies have been done on the extraction and characterization of seed proteins from the cactus pear seeds. The aim of the first investigation was to determine the content and to 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).

In a second investigation, three cultivars namely Morado, Meyers (both from *O. ficus-indica* spp.) and Robusta (from *O. robusta* spp.) from three locations (Bloemfontein, Oudtshoorn and Cradock) were compared over two seasons (2010 and 2011). Proteins were extracted with a step-wise ammonium sulfate (AS) precipitation procedure using different concentrations, namely 40%, 60% and 90%. A step-wise AS precipitation method, that increases the AS concentration, is better to use than just one extraction concentration. A de-fatted fraction was also included in all the analysis. The various cultivars differ from one another for each of the locations as well as the seasons. These differences included the colour of the fruit, the season and location, as well as the determined protein content and composition. De-fattening caused the fat-soluble proteins to be removed. De-fattening could also distort protein characterization, because proteins are selectively extracted. The protein concentration of the supernatants (both methods) for the 2010 season was marginally higher compared to the 2011 season. Both seasons showed expected decreases in supernatant concentrations with increasing AS precipitation concentrations. The SDS gels showed similar results for the cultivars and locations and seasons, although different bands were observed for the different AS concentrations. The only distinct bands (except that of below 10 kDA) were from the 40% AS precipitation. Only 60% and 90% AS showed distinct bands below 10 kDa. A range of different sized bands between 23 and 100 kDa were analysed by MS. A variety of different proteins was found, from metabolic-type proteins to structural-type of proteins. The enzymes, for example Aspartate amino transferase and Putative aspartic protease, are metabolic proteins. The structural proteins included Caleosin. Caleosins are proteins involved in storage lipid mobilization during seed germination (Daffue, 2014).

4.4.6 Cladodes (Nopalitos)

Nopalitos have been considered a valuable food source and enjoyed in cultural cuisines. The nopalito production has been thriving and sustaining people in most countries for many years. According to studies, it is identified as a vegetable with nutritious benefits and can be used for medicinal purposes.

The aim of the first project was to determine the morphological and physicochemical quality characteristics of nopalitos harvested from 20 cactus pear cultivars from 2 seasons (2018 and 2019) from the UFS west campus collection. Nopalitos from 20 cultivars were harvested and morphological and physicochemical tests were conducted including weight, moisture content, solids, sugar content, acidity, color, mucilage content and viscosity thereof, and pH which are some of the main factors which affect the palatability and overall functionality of the plant. Interesting trends were noticed between the two seasons with the 2018 harvest scoring lower than the 2019 harvest in all attributes. The acidity, pH and sugar content of the samples were generally higher in 2019 than in 2018. These attributes affect taste, keeping qualities and overall acceptability of the samples. Overall, 2019 season was better than 2018 with the best cultivars having been Meyers, Malta, Nudosa, Fusicaulis, Fresno and Morado. The reported work has shown acceptable quality of the nopalitos as a vegetable source (Makhalemele et al., 2019).

In the second project, nutritional analysis was conducted for the six nopalito cultivars which were deemed to be the overall best, following the morphological and physicochemical analysis of 20 South African cactus pear cultivars (Makhalemele, 2020).

In a third project, the sensory profile, as well as the consumer acceptability of nopalitos from 20 South African cactus pear cultivars, as well as cucumber and green pepper (vegetable controls) were determined. Sixty-one consumers ranked the overall liking of the samples on a 9-point hedonic scale. The same panelists selected sensory characteristics, which they best associated with certain attributes, by using the Check-all-that-apply (CATA) question. The CATA contained 32 attributes, divided into six categories, namely color (green), appearance (fresh, thin, thick, slimy), taste (sweet, sour, salty, bitter, savory/umami), texture (stalky, chewy, fibrous, slimy, hard, spongy, crisp, soft), aftertaste (sweet, sour, bitter, savory/umami, metallic, none) and flavor (grassy, cucumber, green pepper, green bean, fresh, mild, bland, herbal). No significant differences were noted between the hedonic scaling for the nopalito cultivars. There were significant differences observed for 25 of the CATA attributes, between the 20 cactus pear cultivars and two control vegetables. Among the 20 nopalito cultivars, Skinners court, Turpin, Fusicaulis and R1251 were 'neither liked nor disliked' by the consumers, as they were all ranked higher than the other cultivars. The remaining 16 nopalito cultivars were 'disliked slightly' by the consumers, with the least liked cultivar being Robusta (Makhalemele, 2020, see p. 32).

In the fourth project, two selected cultivars (Morado and Fusicaulis) were evaluated for the influence of harvest size (9, 12, 15, 18, 21, 24 cm), harvest season (post-fruit harvest; March and spring growth; September) and cultivar on the eating quality. A comparison to well-known vegetables (baby marrow, carrot, celery, cucumber, green beans, green pepper, onion, tomato) was undertaken. The preparation techniques and cooking methods were determined, and several recipes were developed. The recipes were evaluated by consumer panels consisting of ten members using 9-point hedonic scale tests. The panelists completed a questionnaire to reflect their attitudes as consumers. This study evaluated the quality characteristics in terms of morphology, colour, texture, turgidity, sliminess and gustatory properties of nopalitos. The quality characteristics observed in this study provided information on mostly consumed known vegetables comparable to *Opuntia* nopalitos. The two nopalito cultivars (Fusicaulis and Morado) showed good quality characteristics in terms of consumer preferences (Mpemba et al., 2019; du Toit et al., 2019a, b, c, d).

The use of fresh cladodes in a vegetable juice manufacture is also being evaluated. A consumer acceptance study was done to evaluate the acceptability of cactus cladode juice blends by consumers. The results obtained from this study indicated that the cladode juice blend was considerably well accepted. The guava juice blend had the highest scores of liking for attributes aroma, taste, mouthfeel and overall liking. A fruit juice/cladode blend, rather than a vegetable juice/cladode blend, should be considered, i.e. a guava/cladode juice blend, followed by a kiwi & pear/cladode juice blend (Muller, 2013).

5 Industrial Applications

5.1 Economic Benefits

The processing of cactus pear in South Africa is relatively limited. This implies that there are many opportunities to develop an agro-industry. In many plants suitable for human and animal consumption, only a few parts of the plant are utilized. On the other hand, cactus pear is a crop of which the fruit, cladodes and even the flowers are useful. South African cactus pears, especially the red fruit varieties, are very popular in the European market, where it is sold as a delicacy. Less common uses of cactus pear include flower and cladode arrangements, jam and even soap. Even the cochineal insects can be used in the cosmetic industry in the manufacturing of lipstick and other make-up products. In many countries including South Africa, some countries in South America, as well as the Mediterranean (Mediterranean), only the fruit is eaten. In Mexico, the tender young leaves (nopalitos) are also eaten. However, both fruit and nopalitos are perishable and processing technology is needed to extend shelf life. Furthermore, both the fruit and cladodes contain many bioactive ingredients that must be preserved during processing. Cactus pear is a versatile fruit and a wide range of products and by-products can be obtained from it. The same goes for the cladodes. Research suggested that the economic benefits of cactus pear production could be important. A recent study demonstrated that young plants pruned to stimulate fruit quality yielded 8000 kg of cladode dry matter per hectare after only 4 years (Brown, 2020).

5.1.1 Developing Cactus Pear Agro-Businesses

Although cactus pear is well-known to many South Africans, misconceptions about its potential persist. Efforts are therefore under-way to revitalise interest in the plant's production, promoting a renewed awareness of its versatility and multiple applications (Brown, 2020).

Currently fresh fruit is commercially produced and sold mainly in the Highveld area in South Africa. A main disadvantage is that the fruit's production and harvesting coincides with the production (mid-season) of many popular summer-produced fruits. This leads to many fruit being used as animal feed. This situation can be mitigated by production in colder areas in South Africa to produce fruit later in the summer season and at a higher price (Boraign, 2020; personal communication).

Most cactus pear producers are using the cladodes for animal feed. New interest to use cladodes for biogas is however emerging. There is currently approximately 300 ha under high-density plantations of cladodes for this application, with a predicted 1000 ha high-density plantations envisioned for the next year. Furthermore, cactus pear plants are used to rehabilitate mine soils, which in turn, can be applied in the biogas industry (Barren Energy, 2020; personal communication).

Increased interest in the food uses of cladodes are also noticed. This interest has led to the development and publication of a recipe book by the UFS in collaboration with the ARC and would soon be published on the UFS' website (www.ufs.ac.za). Research collaboration between the UFS and the ARC has also led to the development of a cellphone application (App) called CactiGrow providing information on South African cactus pear cultivars and its cultivation.

Various restaurants, boutique hotels, guesthouses and road stalls are producing and selling unique cactus pear processed products. Some of these are internationally renowned, e.g. Babylonstoren in Stellenbosch, Western Cape. There is also a new tendency for some of the farmers in some wine-producing areas to replace their vineyards with cactus plantations (Fouché, 2020; personal communication).

Another recently established industry is the seed oils (Cactus Goods Co.; personal communication). These are used in mostly skin-care products (Barnes, 2020; Personal communication).

6 Conclusion

In South Africa the outdated perception of cactus pears as thorny, alien invaders, is rapidly disappearing. Instead, farmers now recognize that cactus pear can play a vital role as a high yielding, water-efficient, multi-use crop.

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