Establishing of Agave Americana Industry in South Africa

Boguslavsky, A.*, Barkhuysen F.*, Timme, E.** and Matsane, R.N.***

*) – CSIR Materials Science and Manufacturing, Port Elizabeth, South Africa.
**) – University of Cape Town, Cape Town, South Africa
***) – CSIR BioSciences, Pretoria, South Africa

ABSTRACT

South Africa has high level of unemployment and low standards of living in rural areas. The Eastern Cape Province is particularly impoverished, with unemployment of about 60 % in the Great Karoo region alone. *Agave americana* (AA), the only plant of value in the arid Karoo is currently used for the production of an alcoholic beverage, with the bulk of the plant being not utilized. Research was carried out with a view to the greater utilization of the plant. The research demonstrated the commercial potential of the AA plant for the production of fructans, fibre, textiles and paper products. A long term programme on AA plant beneficiation was therefore launched by a consortium including national and provincial governmental departments, local authorities, funding agencies, industrial partners and research organisations. A comprehensive concept for establishing AA agro-processing complexes in the Great Karoo was developed and is reported here.

1. INTRODUCTION

South Africa has high level of unemployment and low standard of living in rural areas. The Eastern Cape Province is particularly impoverished, with unemployment of 60 % in the Great Karoo alone. Land claims by emerging farmers are currently in progress, but the 5000-hectare farms to be allocated will not be sufficient for economic independence without some crop cultivation. The climate and soil of the Great Karoo are not favourable, however, for the cultivation of commercial crops. The only plant of value which grows in the arid Karoo and that can also grow on eroded soil is the *Agave americana* (AA). This plant is currently used for the production of an alcoholic beverage by fermentation of the heart (pina) of the plant, chiefly for export purposes. The current production of the alcoholic beverage does not meet the demand, resulting in the expansion of AA cultivation in the Great Karoo. Nevetheless, the viability of this industry alone is not high enough since the bulk of the plant is not utilized. The pina waste left after juice extraction is used as compost, and 95% of the leaf waste is left to decompose on the fields.

The Agave genus, comprising around 140 species, occurs, and is cultivated, in arid and semi-arid regions world-wide. This family includes leaf fibre plants, such as *Agave americana, Agave sisalana and Agave tequilana* (AT). Agave plants are native to Mexico and other parts of the Caribbean region. This plant was taken from there to Europe, Africa and the Far East by the Spaniards and Portuguese, where it naturalized rapidly, especially in the high arid regions around the shores of the Mediterranean (Lewin *et al*, 1985). The best known, and most common application of the AT is the production of tequila, an alcoholic beverage, from the sap of the pinas. However, recently research programmes were launched in Mexico and other countries to evaluate the potential of Agave for other applications. According to the Mexican company 'Nekulti', 25% of *Agave's* wet weight is inulin, a

valuable component widely used in the food industry as an additive, sugar substitute and prebiotic agent (NUTRA, 2005, website).

Inulin is a generic term for a polydisperse chain of fructose units having degrees of polymerisation (DP) varying from 2-60, normally with an average of ~12. Fructans are oligo- or polysaccharides which comprise at least two adjacent fructose monomers. They have value in the health and food arenas, and occur in nature in a polydisperse form. The DP has a bearing on the functional behaviour of these fructans and determines their end use. Molecules with a DP of 2-7 are known as oligofructose, whilst the larger molecules are known as inulin.

Fructans function as prebiotics due to the inability of the human gut to digest their specific linkage type, thus making them available in the colon where health benefits arise due to the stimulation of bacteria, such as bifidobacteria, with concomitant production of short chain fatty acids which enhance gastrointestinal functions (Roberfroid *et al*. 1998; Manning and Gibson, 2004). Fructans have also been shown to modulate endocrine and immune functions (Silva *et al*., 2004), promote absorption of calcium and magnesium, reduce cholesterol and stimulate vitamin synthesis (Roberfroid 2005). Long chain or 'gamma' inulin has been successfully tested as a vaccine adjuvant (Cooper, 1995; Petrovsky, 2005) due to the ability to stimulate the 'alternative complement pathway', and has been used in the preparation of 'microspheres' for the controlled release of drugs (Wu & Lee, 2000; Poulain *et al*., 2003), In the food industry, fructans find use as fat substitutes due to their functional properties, as additives to control viscosity and moisture (Silva, 1996) and as low calorie sweeteners (López-Molina *et al*., 2005; Roberfroid, 2005).

In October 2005, Nekulti announced the development of a gentle enzymatic process for the recovery of inulin from the Mexican *Agave* plant. It was found that inulin from *Agave* is more soluble in cold water than inulin derived from chicory, indicating that it can find a much broader range of applications as a food additive. Inulin from *Agave* has the added benefit of being cheaper than that from chicory. The large scale commercial production of inulin from AT was launched in February 2006, with an initial capacity to produce 150 tons of pure, dried inulin a month. Within two years, the capacity may increase to yield as much as 5000 tons per year. Such large scale production will target the worldwide demand for inulin, the main focus being on Europe and Japan.

Utilisation of leaves for the fibre production is another focus area of the AA programme. The AA leaves contain numerous fibres running along their length and these support the cellular tissue and constitute the vascular system of the leaf. Fibres can be extracted mechanically, chemically or by retting in seawater. Recently, a research program, aimed at the evaluation of the potential of AA as a new source of textile fibres, was launched in Tunisia where AA fibres were, for a long time, extracted and used for ropes and twines (Msahli *et al*, 2005).

The above information attracted interest from local researchers, farmers, industrial companies and potential investors. The rapidly growing world market for fructans and plant fibres is considered by all the local main stakeholders as warranting the expansion of AA cultivation in the Great Karoo. An AA Steering Committee was formed for establishing an AA industry in the Great Karoo including governmental departments, local authorities, industrial partners, R&D organisations and other stakeholders.

For this ambitious programme to succeed requires a strong science and technology support in a number of disciplines, including biochemistry, textile technology and paper making. However, little knowledge is available on the agronomy of the AA plant, the influence of environmental parameters on fructan and fibre properties, and optimal conditions for the extraction and processing of these products. The present study focused on fructans and fibres extracted from the AA plants growing in the Great Karoo region in South Africa. The outcomes of this research formed a basis for developing a concept for establishing an AA industry in the Great Karoo.

2. MATERIALS AND METHODS

2.1. Fibre and textiles.

2.1.1. Fibre extraction: Agave Americana leaves were randomly harvested in the Graaff-Reinet area and supplied to the CSIR for evaluation. The leaves were decorticated on a one door decorticator manufactured according to the principle and design of a Brazilian separating machine. This machine, with a manual feeding system, is a very versatile piece of equipment which can be mounted on a stationary or transportable carriage system which permits easy transportation to different growing areas. This unit was designed for fibre extraction from sisal leaves which are much shorter, narrower and thinner than Agave Americana leaves. A disadvantage of this machine is that it becomes blocked by fibres when processing Agave leaves.

The design of the sisal decorticator was therefore modified to make it more suitable for the processing of Agave Americana leaves. Steel side plates were attached to the rotor to prevent the blockage of the machine. The feeding tray and beater bars were modified to accommodate the side plates of the enlarged rotor. For added operator safety, a “tunnel” guard was also added the feeding tray through which the leaves are fed. The size of this was such that the Agave leaf could fit into it but without any space for the hands of the operator. Provisions were also made to vary the rotor speed between 900 revs/min and 1270 revs/min. The modified one-door decorticator is shown in Figure 2.1.

Figure 2.1. Modified decorticator for extraction of Agave fibre

2.1.2. Fibre yield determination: Freshly harvested leaves were weighed and processed on the decorticator. Extracted fibres were collected, dried and conditioned at a relative humidity of 65 ± 2% and a temperature of 20 ± 2ºC for a minimum of 48 hours. The fibre yield was defined as a weight of conditioned fibre expressed as a percentage of the leaf weight before processing.

2.1.3. Fibre testing: Extracted fibre were air dried and processed in a fibre opening machine. The opened fibres were conditioned at a relative humidity of 65 ± 2% and a temperature 20 ± 2ºC for a minimum of 72 hours. The extracted fibres were tested for mechanical properties (linear density, breaking tenacity and elongation at breaking load). The sample preparation for measuring the breaking tenacity, elongation at breaking load and fibre fineness was done according to the ISO 3060 test method. To determine fibre strength, a bundle tensile test was carried out on an Instron Tensile Tester (Model 4411) at 0 mm gauge length, using Pressley clamps with leather facing. Ten bundles were tested per sample, with bundles being carefully assembled to ensure continuous and parallel fibres in the test area. The gravimetric method (i.e. linear density method) was used for fibre fineness evaluation. This method involves the selection of small representative samples and the preparation of bundles of 10 or more fibres, with a length of 100 mm. The bundles were weighed and the average fibre linear density was calculated.

The fibre cross-sectional characteristics were determined by means of an Olympus CX31 image analyzer, using transmitted light. A thin cross-section of a bundle of fibres, embedded in methyl methacrylate resin, was cut with a microtome and a photomicrograph was obtained by means of a light microscope using 100 and 400x magnification. The images were then digitised using a digital image processing system.

2.1.4. Producing Agave fibre based nonwoven fabrics: The opened AA fibres were processed on a Temafa cottonising line, which included a Lomy machine and a Fine Opener (Linstar). The following variables were incorporated in these trials:

i) One passage through the Lomy
ii) Two passages through the Lomy
iii) One passage through the Lomy followed by one passage through the Fine Opener.

A Dilo needle loom (maximum working width 600mm, maximum stroke frequency 1200 str/min, needle density 6000 needles/m) was used for producing the AA fibre based needle-punched nonwoven fabrics. The following conditions were used for the trials:

Feeding speed	0.7 m/min
Infeed apron speed	1.20 m/min
Infeed roller speed	1.25 m/min
Stroke frequency	180 and 220 str/min
Punching density	160 punches/cm^2
Depth of needling	-2, 2 and 5 mm
Needle density	6000/m

A supporting lightweight spunbonded polypropylene material was used for the manufacture of nonwovens.

2.2. Fructans.

2.2.1. Preparation and extraction of fructan material

2.2.1.1. Leaf Sap: Pressed saps were used as such after removal of insoluble matter by filtration or centrifugation at 8000 g and 20°C for 20 min. On average, 300 ml sap were obtained per kg leaf material.

2.2.1.2. Leaf pulp: A 1:2 ratio of pulp:deionised water (w/w) was heated to 80°C, held at that temperature, while stirring, for 25 min, and allowed to cool at ambient temperature (~20°C) until the temperature dropped to 30°C. The soluble portion was then separated, with an initial removal of long fibres by filtration through fine muslin.

2.2.1.3. Leaf base and pina: The epidermis was removed from the leaf base tissue. The leaf parenchyma or pina tissue was diced into blocks of 2-3 mm^3. This material (50 g) was homogenized with 100 ml of deionised water, using 20 second cycles, and continuing until a homogeneous mixture was obtained. Homogenates were preheated in an oven at 60±2°C for 30-90 minutes before extraction of each individual sample at 75±5°C for 20 min with constant agitation. After cooling, soluble matter was separated by centrifugation and filtration. A composite sample, comprising aliquots of 16 leaf base extractions, was purified by anion exchange chromatography and used for the profile confirmation.

2.2.2. Analyses.

2.2.2.1. Analysis of sugar content: The standard phenol sulphuric assay (Harris *et al*., 1995) was used for the analysis of the sugars for yield estimation and for monitoring during the extraction processes. Standard curves, using both fructose and inulin, were prepared for reference. Although the response factor of the inulin polymer (chicory) was different to that of the fructose monomer, all quantitation was based on the monomer standard curve as the relative DP's of the standards and samples were not known. HPLC analysis, to show the polymer /monomer profile, was carried out as described elsewhere (Zuleta and Sambucetti, 2001).

2.2.2.2 Measurement of protein content and ultraviolet (UV) absorbing contaminants: The presence of protein was monitored by UV absorbance at 280 nm using bovine serum albumin as standard and assuming an equivalent absorption co-efficient. A scan of the samples from 190 to 400 nm was used as an indicator for removal of UV absorbing substances.

2.2.2.3 Measurement of colour components: A visible light scan (340 to 500 nm) was conducted to determine the wavelength at which the highest absorption occurred. This wavelength was then used to monitor colour intensity.

2.2.3. Fructan purification.

2.2.3.1. Adsorption on activated charcoal: Activated charcoal was used for removal of contaminants, by modifying the method by Nair according to Kim *et al,* (2002). Activated charcoal was added to the material to a level of 3% (w/w) and hand stirred for 2 min. The mixture was then filtered using Whatman No. 542 paper. The filtrate was analysed for sugar, protein and colour concentrations, and results compared with those obtained prior the treatment.

2.2.3.2. DEAE Sephadex A-25 or DEAE cellulose anion exchanger: The exchange resin was poured into a column, after being prepared according to the manufacturer's instructions. The sample was then passed through the column and collected for analyses. In each case, the amount of fructan or protein added to the resin matrix was compared to the total fructan or protein recovered from the process, and a recovery yield calculated. The colour yield was based on absorption units.

2.2.3.3. Separation of high and low molecular mass portions: Ultrafiltration (UF) was used for separating the polymeric inulin molecules from the free fructose molecules, as the functional properties and end use of fructans depend on their DP. Generally, the lowest desired DP for inulin is around 10, which correspond to a molecule of molecular weight (MW) ~ 2000, whilst free fructose has a MW of 180, and oligofructans, with a DP of 2 to 7 lie in between. The membrane used should therefore be able to retain anything of molecular weight $\geq$ 2000, while those of lesser MW should pass through. A Millipore Stirred Ultra-filtration Cell (Model XFUF 076 01) was used with different membranes for preliminary UF screening, in order to determine which worked best. After UF, the sample was passed through a SEC column to determine the effectiveness of the UF process.

2.2.4. Fructan profile.

The composition of the polymeric material of the AA saccharides was determined by HPAEC-PAD after mild hydrolysis in 0.5 M TFA at 60 ˚C for 1 hr. Identification of the constituent monosaccharides was based on a comparison of retention times with the use of the standards.

Molecular Mass Distribution by Size Exclusion Chromatography (Churms, 1996) was used to determine molecule size. Sephacryl S100HR, with a fractionation range of 100 000 to 1000 Daltons, was used to estimate average molecular size of the extracts and BioGel P2 , with a fractionation range of 1800 to 100 daltons, was used to separate free sugars and oligofructans from the polymers of 10 or more units.

2.3. Agave fibre based paper.

Different types of Agave fibre, namely those after extraction by the decorticator and those processed by means of a fine opener, were used for a comparative paper making investigation. A beater of 150 litre capacity was filled with clean tap water and 2 kg of Agave fibres were placed in the beater for the pulping process which lasted between 3 to 12 hours. 50 litres of pulp were diluted with 100 litres of water in a big container called a vat. A retention aid and gelatine were added to the vat and the mixture was cooked while stirring occasionally. The retention aid bonds the fibres, while the gelatine helps to make the paper smoother, easy to press and to write on.

The tensile strength of the Agave fibre based paper samples was measured on an Instron Tensile Tester (Model 4411) according to the Paper Tensile Test – SI Units specification contained in the Instron's Test methods list. The maximum load to tear a sample was measured and calculated per unit width and for the particular thickness of each sample.

3. RESULTS AND DISCUSSION.

3.1 Fibre extraction.

The modified decorticator was used for extensive trials in processing leaves of different sizes, age and from various localities. The machine performed satisfactorily, without any blockage problems. It was found that AA fibre was easily extractable from the leaves. For optimizing the extraction process, leaves were processed at a rotor speeds of 900 revs/min, 1150 revs/min and 1270 revs/min. It was found that the rotor speed did not affect the breaking tenacity. Increasing the rotor speed to 1270 revs/min, however, yielded coarser fibres. The results obtained indicated that a rotor speed of 900 revs/min was the most suitable for processing the leaves.

The fibre yield varied from 1.7% to 2.7% for different samples, with an average yield of 2.0% for the rotor speed of 900 revs/min.

3.2. Fibre properties and structure

The properties of the AA fibres are given in Table 3.1. It can be seen that the locality of the farm and site on the farm have considerable impact on the fibre yield and strength. The fibre fineness, on average, was not affected in the same way by the location of the plants. No correlation was found between the fibre properties and the age of the plants at the different localities. Fibres from the Samara Nature Reserve had the best overall properties.

Image analysis provides valuable information about the shape and fine structure of fibres which could assist in identifying those factors having an impact on fibre extractability. Figure 3.1 shows the cross-sectional images of the fibres differing in fineness. It appears that the AA fibres have a non- circular cross-section similar to other coarse plant fibres, such as flax and hemp. The fine structure of the fibres is not as distinct as that of flax fibres, although it can be seen that these fibres occur in bundles comprising several ultimate (individual) fibres. The average perimeter and cross-sectional area of the fibres are 621 µ and 20518 μ^2, respectively.

3.3 Nonwoven and paper products.

Two potential applications for Agave fibre based nonwoven materials were considered, namely geo-textiles and composite materials for the automotive industry. Kaymac and Brits Textiles, the leading manufacturers of such materials in South Africa, specified the

Table 3.1. Properties of Agave fibre

No	Farm location	Place	Plant age (years)	Yield (%)	Bundle tenacity (cN/tex)	CV (%)	Linear density (tex)
1	BLOEMHOF FARM	Ostrich Camp	10	1.8	19.7	12.0	27.6
2		Ostrich Camp	10	1.7	20.9	10	25.1
3		Ostrich Camp	12	2.5	21.7	12.3	21.2
4		Bloemhof North West Red Gate	12	1.9	15.0	20.8	28.0
5		Bloemhof North West Red Gate	15	2.3	24.0	16.7	31.7
		Average	-	2.0	20.3	14.4	26.7
6	ROODEBLOEM FARM	Houseland plantation	5	2.1	23.4	16.6	27.8
7		Siding camp	11	1.7	21.5	11.5	27.7
8		Vlaklands plantations	11	1.7	21.1	12.0	32.5
		Average	-	1.8	22.0	13.4	29.3
9	MARA NATURE RESERVE	Old lands	10	1.6	24.7	17.9	25.0
10		Klipfontein House plantation	10	1.9	25.6	16.6	30.6
11		Klipfontein House plantation	10	2.7	24.7	5.8	28.0
12		Paardekraal plantation	11	2.3	28.0	9.4	20.3
13		Paardekraal plantation	11	2.2	26.8	19.4	22.1
14		Lande plantation	10	1.8	22.4	16.2	33.3
		Average	-	2.2	25.5	13.5	26.9

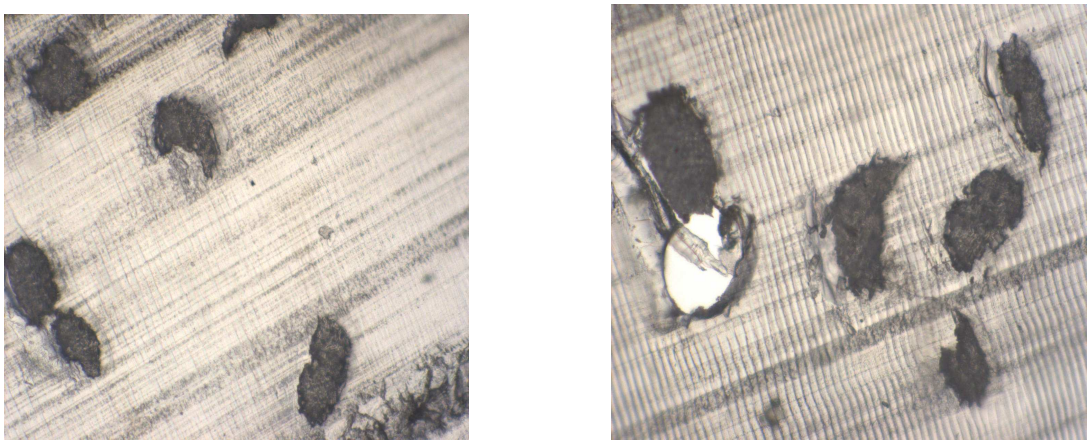

Figure 3.1. Cross-sectional images of Agave Americana fibres

required composition and optimum parameters of the materials. To improve the formation of a web for geo-textile nonwovens, the fibres were blended with polypropylene (PP) fibres in a ratio of 80: 20 (AA : PP) (percentage by mass). A blend ratio of 50 : 50 (AA : PP) (percentage by mass) was used for producing nonwovens for composite materials. The blend composition and processing parameters are given in Table 3.2.

Satisfactory results were obtained when processing AA fibre into nonwovens using blends with PP. The samples of the AA fibre based nonwoven materials were tested at industrial laboratories and positive feedback was obtained on the potential utilising the proposed blends for composite materials and geo-textiles.

The potential of utilizing the AA fibre for paper making was investigated under conditions simulating small scale paper making. Fibre based paper samples were produced from the following three different types of material, in some cases in blends with either flax or bagasse or both:

i) Decorticated fibres
ii) Waste produced on the fine opener (short fibres)
iii) Pina waste generated during tequila production

The properties of the paper samples produced are given in Table 3.3. It can be seen that the paper strength depends on the beating time and composition of the pulp. Utilizing fibres after extraction on the decorticator requires a longer pulping time in order to achieve the desirable paper quality. The addition of binding materials, such as retention aid and gelatine, and increasing the beating time to 12 hours, ensure maximum strength of paper and uniformity of paper sheets (sample No 2). The AA fibre can also be used in combination with other fibres, such as flax, for producing paper materials. The AA waste fibres are much finer than the decorticated fibres which enables stronger paper to be produced at a reduced beating time. Preliminary experiments on pina waste gave promising results, indicating that it can be used as a raw material for paper making (sample 7). More detailed research is required to evaluate its commercial potential and to make specific technological recommendations.

3.4. Fructans.

Extracts showed a wide range of fructan content and varying proportions of polymer to low DP, depending on source and treatment. Composition analysis showed that only fructose and glucose were present. The yield of fructans from the pulp and sap was lower than the yield from pina and leaf base (Table 3.4), probably due to an inability to separate and dissolve all the soluble material during the decortication or pressing processes. Re-extraction of treated material released a further 2-3 g fructan/100g material, whilst preheating the raw leaf parenchyma to 60°C for 60 min resulted in increased yields. These results suggest the need to ensure maximum solubilisation of fructan in the raw material, and efficient separation from the fibrous constituent of the raw material if viable commercial production is to be achieved.

Table 3.2. Fibre composition and processing parameters for nonwoven samples

Sample number	*Fibre composition*	*Potential application*	**Processing parameters**		
			Number of web layers	Depth of needling (mm)	Stroke frequency (str/min)
N1	80 Agave/20 PP	Geotextiles	12	-2	180
N2	80 Agave/20 PP	Geotextiles	12	2	180
N3	80 Agave/20 PP	Geotextiles	12	5	180
N4	80 Agave/20 PP	Geotextiles	16	-2	180
N5	80 Agave/20 PP	Geotextiles	16	2	180
N6	80 Agave/50 PP	Geotextiles	16	5	220
N7	50 Agave/50 PP	Composites	20	5	220
N8	50 Agave/50 PP	Composites	28	5	220
N9	50 Agave/50 PP	Composites	2 x 20 sandwich	5	180
N10	50 Agave/50 PP	Composites	56	-2	180

Table 3.3. Properties of Agave based paper samples.

No	*Fibre composition*	*Beating time (hrs)*	*Pigments*	*Thickness (mm)*	*Area weight (g/sq.m)*	Breaking Load per unit width (N/mm**)**
1	Agave 100%	12	Green	2.5	125	0.80
2	Agave 100%	12	no	2.3	139	3.20
3	Agave 100%	8	no	3.8	169	0.97
4	Agave 50% Flax 50%	12	no	3.3	155	1.07
5	Agave 50% Bogasse 50%	12	Green	3.5	161	1.24
6	Agave 40% Flax 30% Bogasse 30%	12	no	3.8	178	0.90
7	Waste 100%	3	no	1.9	137	4.39

The pulping and sap production procedures resulted in more extraneous soluble material being extracted, specifically coloured products and ultra violet absorbing compounds. These contaminants could be removed by use of activated charcoal or ion-exchange, the latter being more effective in removing protein and/or ultraviolet absorbing material. Reduction to around 20% of the starting levels was obtained by a single batch ion-exchange treatment, but evidence of post harvest changes with rapid darkening of the sap, probably due to phenol oxidase activity and the Maillard reaction was noted. Sugar,

recovered after the clean up process, of the leaf base extract, was 60%. Positive changes, with respect to removal of contaminants and minimum reduction of fructans, occurred after treatment through the first column, with UV material and colour being reduced to 11 and 20%, respectively, of the original material.

The fructan extracts show molecules of lower DP than chicory (Figures 3.2 and 3.3), with the pina material having larger molecules than the leaf extract. The average DP, determined by comparison with standard dextrans, is estimated to be around 16. Literature comparisons show that commercial Agave inulin (Nekutlin™) produced by 'The Colibree Company' have a product profile with 30.4% having a DP lower than 10, 41% with a DP between 10 and 20, and 28.6% with a DP greater than 20.

The membranes used for UF were not effective in fractionating the compounds as shown in Figure 3.4. Both the low and high MW fructans were still present in the UF retentate as compared to the AIR (alchohol insoluble residue) precipitate (used to separate polymers from monomers). Further fractionation trials, to separate monomers or very short chains from the inulin, are required, that will result in two products, namely, fructose syrups and inulin

Table 3.4. Average Content and Yield of Fructans from AA

Material type	Sugar Content (as fructose) g/100 ml sap or g/100 g solids	Yield fructans g/100 g whole material*
Sap (n=14)	7.4 (Range 2.3 - 24.7)	2.2
Pulp (n=3)	4.7 (Range 2.5 – 8.9)	Not recorded
Leaf base (n=16)	14.4 (Range 5.1 – 24.3)	13.0
Pina (n=4)	22.4 (Range 19.2 – 24.3)	22.4

* 300 ml sap per kg leaf material, 100 g epidermis/kg whole leaf material

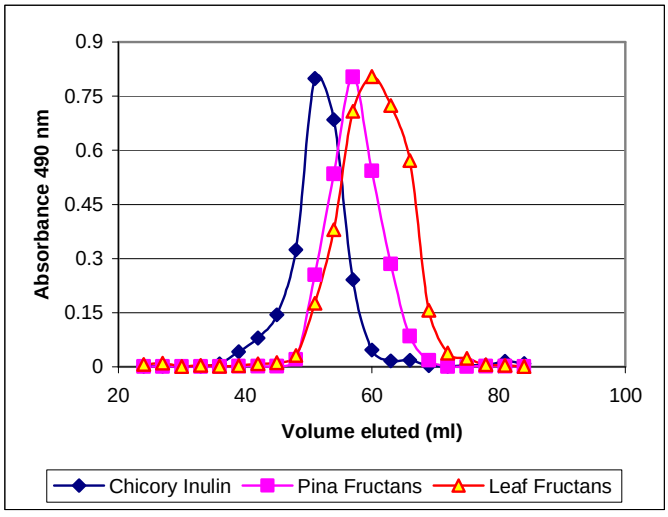

Figure 3.2. Comparison of molecule sizes using Sephacryl S100HR

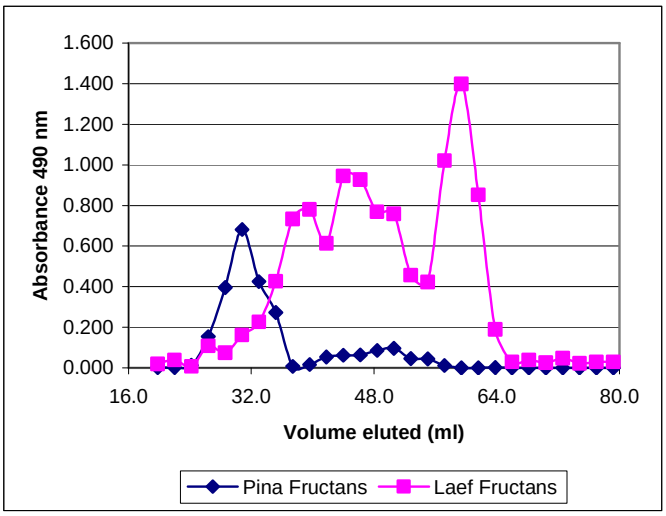

Figure 3.3. Comparison of molecular sizes of pina and leaf fructans using Biogel P2

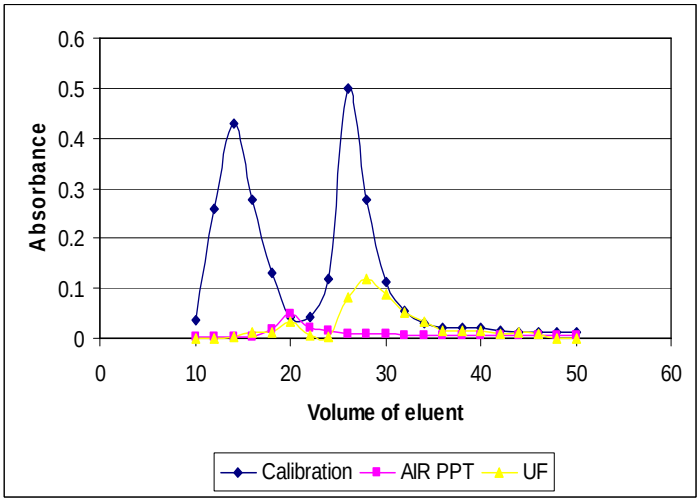

Figure 3.4. Comparison of molecular sizes of UF and AIR sap passed through Sephadex G-25 SEC column

Commercial fructans for incorporation into other products are required to be colourless and free from associated compounds. Costs to achieve cleaned ‘pressed or pulped’ leaves would need to be balanced against product value.

As the pina or leaf base appears to be the preferential material, a process design to enable maximum yield is being based on this source. Of note is that the insoluble portion left after extraction would constitute a dietary fibre with good water binding capacity and residual fructan; and could, after relevant assay to meet specification requirements, be presented as

an extra product or could be channelled into the paper fibre extraction process, thus negating the need for disposal.

3.4. Agave plant utilisation

The research has demonstrated that all parts of the AA plant, namely, pina, leaf base and leaves, can be utilised for various applications. The potential market for AA plant products is presented in Figure 3.2.

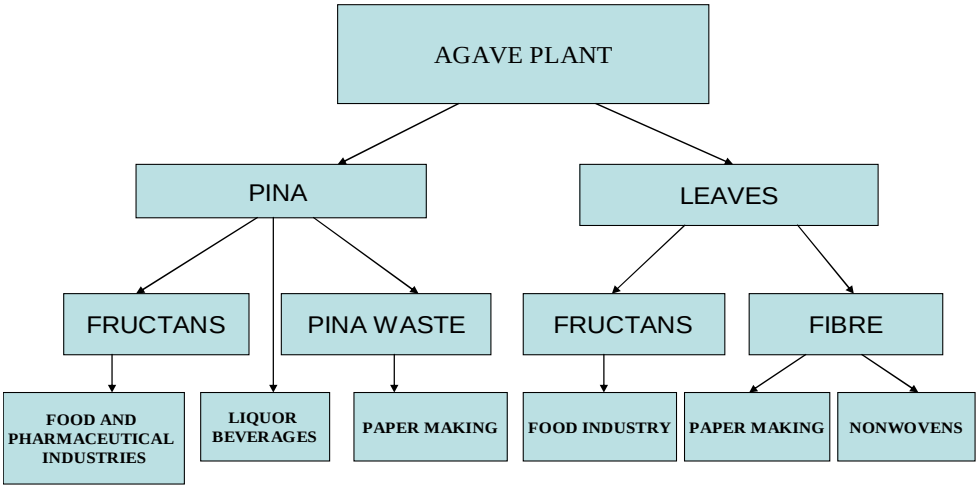

Figure 3.2. Potential market for AA plant products.

The "zero-waste" utilization of the plant would enable its production and processing to be translated into a viable and sustainable industry. The results of this research formed a basis for developing a general concept for commercialising the Agave plant in the rural areas of the Great Karoo. The concept envisages the following phases for establishing an AA industry in this region:

a) **Phase 1. Establishing a pilot AA agro-processing complex in Graaff-Reinet** . This first complex will comprise a large scale fibre extraction business, agricultural and paper making SMEs in Graaff-Reinet. The main objective of an agricultural SME will be planting and cultivating AA to ensure a sustainable supply of raw materials for processing SMEs to produce liquor beverage, inulin, fructans and fibre. The complex will supply AA fibre for small scale paper making businesses to produce paper goods, in particular souvenirs, for outlets in Graaff-Reinet and towns in the Great Karoo. The incubation of technologies and optimization of business operations will take place during this phase. A training centre will be established at the complex to train community members involved in Agave projects in other areas of the Great Karoo. Scheduled completion – end of the first year.

b) **Phase 2. Establishing AA agro-processing complexes in the Great Karoo.** If successful, the pilot project in Graaff-Reinet will be used as a basis for replicating similar AA complexes in other regions of the Great Karoo. Three areas have been identified for establishing such projects, namely, Aberdeen, Pearston and Jansenville. The infrastructure, facilities and expertise gained from the project in Graaff-Reinet will be used for training of staff members and consultancy services for the established SMEs.

   During this phase, the CSIR will transfer technologies developed for the recovery of fructans from pina and leaves to the agro-processing complex in Graaff-Reinet. The AA leaves will be used both for the fibre and sap production, the latter to be utilized for the extraction of fructans. The complex will provide its facilities for the piloting and further commercialising of these technologies to ensure maximum value addition and no-waste utilization of the Agave plant. If successful, a fructan production SME will be established as a part of the agro-processing complex in Graaff-Reinet. Scheduled completion – end of the second year.

c) **Phase 3. Expansion of the scale of AA complexes in the Great Karoo.** During the third phase, the agro-processing complexes established in the abovementioned locations in the Great Karoo will expand their business operation into production of fructans from AA pinas and leaves. The CSIR will provide support for the technology transfer to SMEs producing fructans. Scheduled completion – end of the third year.

The above commercialisation model assumes that land owned by the state (Camdeboo Municipality) will be allocated to the AA project. The proposed commercialisation model includes establishing a Workers Trust which is governed by a Trust Deed. Benefits are channelled to the community and liability is limited to the extent of the assets. This option is attractive to private sector investment partnership because it is easy to form and there is potential for tax exemption.

The Trust will control the business activity of an AA agro-processing complex. The complex will comprise four sections, namely, AA plant cultivation, AA fibre extraction, a paper making and entrepreneurs sub-contracted for manufacturing AA based paper products. The Trust will appoint a manager for the complex who will be responsible for co-ordination of SME activities, marketing and sales. The AA plant cultivation will be carried out on the land specially allocated for this purpose by the Camdeboo Municipality. During the growth and maturing of the cultivated plants (7-10 years), the AA leaves will have to be supplied from commercial farms. The proposed commercialisation model is presented in Figure 3.3.

Since AA is one of few plants which can grow in Great Karoo and which has considerable potential for large scale cultivation and commercialization, this initiative is of national importance. It would result in the transformation of the rural economy and provide jobs for hundreds of subsistence farmers and entrepreneurs in this impoverished region.

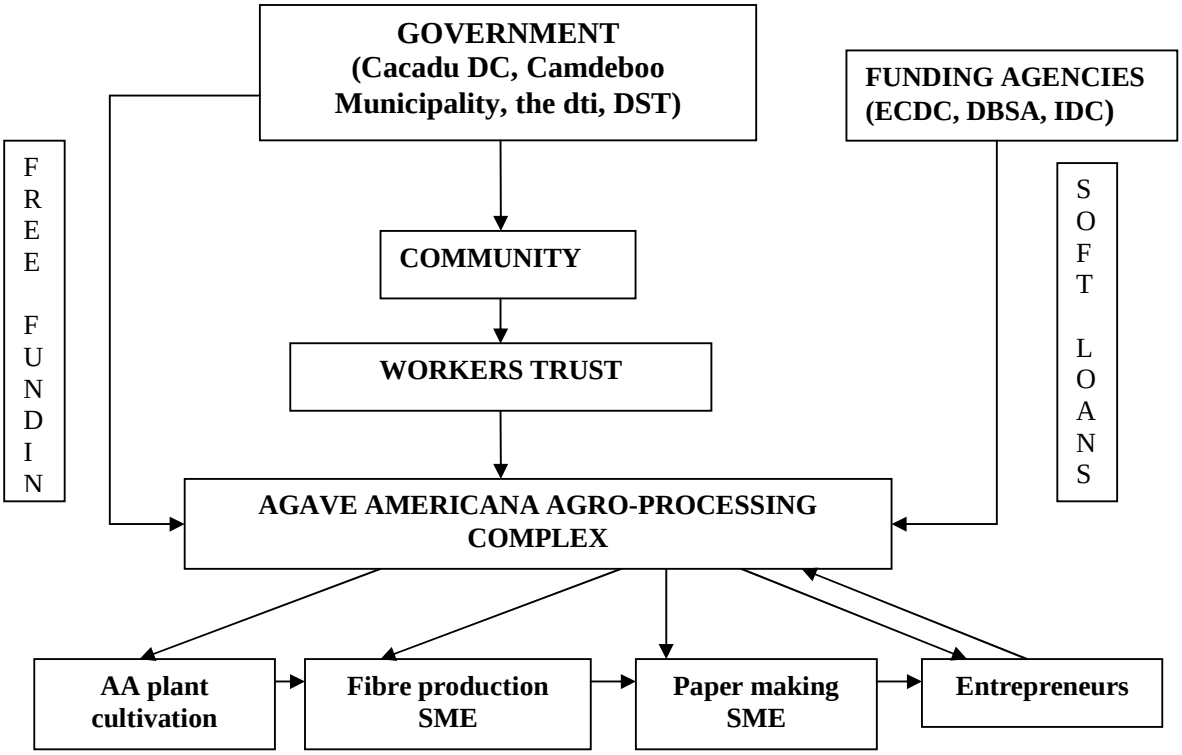

Figure 3.3. Commercialisation model for an AA agro-processing complex.

4. CONCLUSIONS

1. It was found that a modified sisal decorticating units is efficient for the extraction of Agave Americana leaf fibre.
2. Agave Americana fibre can be utilised for the production of nonwovens. Two main applications were identified for the Agave Americana based nonwovens, namely, geo-textiles and composite materials for the automotive industry.
3. Pinas of the Agave Americana plant contain up to 25% of inulin, matching the Mexican plant. The leaf base of the local Agave Americana plant contains up to 16% of fructans. Both the pina and leaf base can be utilised for the commercial production of long chain inulin and fructans which have application as vaccine adjuvants in the pharmaceutical industry and fat substitutes and low calorie sweeteners in the food industry, respectively.
4. Pina waste and short fibre textiles are suitable for small scale and commercial paper making.
5. A general concept for commercialising Agave plant in the rural areas of the Great Karoo has been developed. The “zero-waste” utilization of the plant would enable its production and processing to be translated into a viable and sustainable industry.

5. REFERENCES.

Churms, S. C. (1996). Recent progress in carbohydrate separation by high-performance liquid chromatography based on size exclusion. *Journal of Chromatography A* 720, 151-166.

Cooper, P.D. (1995) Vaccine adjuvants based on gamma inulin. *Pharmaceutical Biotechnol.* 6**,** 559-580

Harris, P., Morrison, A. and Dacombe, C. (1995) A practical approach to polysaccharide analysis. In Food Polysaccharides and their Applications. Ed. A.M. Stephen. Marcel Dekker, Inc. New York.

Herbert, R.M. (1954) *Textile Fibres, Their Physical, Microscopy and Mechanical Properties,* Chapman and Hall, London.

Kim, J.H., Kang, I.S., Choi, H.K. , Hong, S.S. and Lee, H.S. (2002) A novel prepurification of paclitaxel from plant cell cultures. *Process Biochemistry* 37, 679 – 682.

Lewin, M., and Pearce, E.M. (1985) *Handbook of Fiber Sciences and Technology* IV, Fiber Chemistry, NY

López-Molina,D., Navarro-Martíne, M.D., Melgarejo, F.R., Hine, A.N.P., Chazarra, S. and Rodríguez- López, J.N. (2005) Molecular properties and prebiotic effect of inulin obtained from artichoke (*Cynara scolymus* L.). *Phytochemistry* 66, 1476-1484.

Manning, T.S. and Gibson, G.R. (2004) Prebiotics. *Best Practice and Research Clinical Gastroenterology* 18 (2), 287-298.

Msahli, S., Drean, J.Y. and Sakli, F. (2005) Evaluating of Fineness of Agave Americana L. Fibers. *Textile Res. J.* 75 (7), 540 -543.

NUTRA (2005) Inulin answers agave surfeit problem, http://www.foodnavigator-usa.com/news/ng.asp?n=63246&m=1FNUo17&c=maudaalmlqeva (accessed 17 October 2005).

Petrovsky, N. (2005) Novel human polysaccharide adjuvants with dual Th1 and Th2 potentiating activity. *Vaccine,* Apr.12.24, Suppl 2: S2-26-9.

Poulain, N., Dez,I., Lasne, M.C. ,Prud'homme, M.P. and Nakache, E. (2003) Microspheres based on inulin for the controlred release of serine protease inhibitors: preparation, characterization and in vitro release. *Journal of Controlled Release* 92, 27-38.

Roberfroid, M.B., Van Loo, J.A.E. and Gibson, G.R. (1998) The bifidogenic nature of chicory inulin and its hydrolysis products. *The Journal of Nutrition* 128, 11-19.

Roberfroid, M.B. (2005) Introducing inulin-type fructans. *British Journal of Nutrition* 93 (Supplement 1), S13-S25.

Silva, R.F. (1996) Use of inulin as a natural texture modifier. *Cereal Foods World* 41, 792 -794.

Silva, D.G., Cooper, P.D. and Petrovosky, N. (2004) Inulin-derived adjuvants efficiently promote both Th1 and Th2 immune responses. *Immunology and Cell Biology* 82, 611-617.

Wu, X.Y. and Lee, P.I. (2000). Preparation of inulin ester microspheres as drug carriers. *Journal of Applied Polymer Science* 77, 833-840.

Zuleta, A. and Sambucetti, M.E. (2001) Inulin determination for food labelling. *Journal of Agricultural and Food Chemistry* 49, 4570-4572.