CHAPTER 13

DEVIL'S CLAW (*HARPAGOPHYTUM PROCUMBENS*) FROM SOUTHERN AFRICA

Sustainable use by cultivation combined with controlled harvesting in semi-wild populations

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Abstract. Devil's claw (*Harpagophytum procumbens*), a plant well adapted to the desert conditions of the Kalahari in Southern Africa, has been shown to have anti-inflammatory properties. The herb used is the sliced and dried secondary root tuber developing from the side roots of the succulent main root containing harpagoside as active ingredient. Because the herb is usually collected from the wild the harvesting method used in the past cannot sustain demand on the long term. Experiences of a project for cultivation and sustainable harvest of *Harpagophytum* in the Kalahari of South Africa paralleled by intensive ecological research will be presented.

Methods were established to cultivate the plant and also to transfer gained knowledge to the local communities. The most important step is the training of harvesting methods in the collection of wild-grown tubers and how to avoid adulterants. The cultivation success was achieved by developing an environmentally suitable 'rain-feed system' on vegetation-free stripes and successful propagation methods. The main aim of a parallel Scientific Support Project in Ecology was to find out the optimum ecological conditions of *Harpagophytum* by research in eco-physiology as well as factors influencing yield of tubers and harpagoside contents.

Keywords: *Harpagophytum*; sustainable use; wild-collection; domestication; cultivation; plant ecology; ecophysiology

INTRODUCTION

Devil's claw, *Harpagophytum procumbens* (Burch.) DC. ex Meissn. (Family: Pedaliaceae) (Figure 1; see colour pages elsewhere in this book)**,** a plant well adapted to the desert conditions of the Kalahari in Southern Africa (Ihlenfeldt and Hartmann 1970) has been shown to have anti-inflammatory properties (ESCOP 2003). The sliced and dried secondary root tubers developing as side roots of the succulent main root containing harpagoside as active ingredient are used as

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medicinal herb (PharmEur 2003).

Because of the unique source it is important to have a reliable supply-chain management for sufficient supply of starting material for medicinal products. At the end of the 1990s we decided to start a project for cultivation and sustainable harvest of *Harpagophytum procumbens* in the Kalahari of South Africa (RSA), paralleled by intensive ecological research. Experiences and results of this project will be presented.

STARTING POINT – CITES

In Europe the use of devil's claw tubers has grown rapidly because of an ageing population with an escalating number of cases of arthritis. The global market currently uses between 600 and 700 metric tons of raw material each year and the plant needs to grow for several years before it becomes ready for harvesting (Schneider 1997). Because the herb is usually collected from the wild, the harvesting method used in the past cannot sustain demand on the long term. In 1997 these amounts resulted in the emergence of concerns on the potential over-exploitation. This was the starting point for our project for cultivation and sustainable harvest of *Harpagophytum* in the Kalahari of South Africa, paralleled by intensive ecological research. The plant was proposed to be included in the list of endangered species of CITES (Convention on International Trade in Endangered Species) at the conference in Nairobi, Kenya, 2000 (CITES 2000). But the conference ended with a resulting request for more scientific data on the distribution of the species and monitoring of the market. Following up the recommendation of the conference a monograph was published reviewing extensive data on ecology and utilization of Devil's Claw (Hachfeld 2003).

WILD-COLLECTION AND TRAINING OF HARVESTERS

Usually *Harpagophytum* is harvested from the wild with the risk of over-exploitation by collection combined with damage to habitat due to careless digging work. For the future sustainable harvesting methods must be established (Figures 2 and 3; see colour pages elsewhere in this book).

The first and most important step is the training of all stakeholders in the *Harpagophytum* business. As suitable tools we distributed a handbook for trainers and posters for harvesters (Schneider 2000). The main issue is to teach the best harvesting methods and how to avoid adulterants (Ryser et al. 2001; Schneider et al. 2001).

Sustainability will be established by managing the harvest by the headmen of the communities. Their responsibility is only to allow harvesting in certain areas, observing proper regeneration time, and to supervise the diggers during harvesting and refilling the digging pits.

Additionally, the organization of wild-collection from national nature conservation authorities down to the diggers was to establish and to distribute all training information between the stakeholders.

CULTIVATION PROJECTS

Between 1997 and 2001 the Kalahari *Harpagophytum* project was established to cultivate the plant and also to transfer gained knowledge to the local communities (Von Willert et al. 2002).

Preconditions for successful cultivation are a proper agricultural method and procedures for propagation of the plants. The cultivation success was achieved by developing an environmentally suitable 'rain-feed system' (Olivier et al. 2000). In order to achieve this, agricultural fields were cleared in narrow stripes within the intact grass and tree savannah vegetation and devil's claw planted on the stripes (Figure 4; see colour pages elsewhere in this book). Only rainwater of precipitation was used to irrigate the plants (Von Willert et al. 2002; Sanders et al. 2001a; 2001b).

Different propagation methods with seeds, transplanting primary roots, cuttings and *in vitro* cultivation were also elaborated and tested for their advantages and disadvantages (Table 1).

Transplanting primary roots from other locations where farmers like to eradicate *Harpagophytum* due to damage of the claws to cattle is a good opportunity to establish a fast-growing cultivation with stability against unexpected weather changes.

The disadvantages of seed propagation – the only really sustainable propagation method – are the low natural germination rate (below 1%) and problems with the survival rate of seedlings.

Table 1. *Advantages and disadvantages of different propagation methods for Harpagophytum*

Propagation method	Advantages	Disadvantages
seed	not expensive	low germination rate
	only really sustainable method	low survival rate of seedlings
		genetic diversity
cuttings	propagation of single selected plants	need of irrigation
	clonal material	no primary root
		not economic
in vitro	unlimited propagation of elite plants	no primary root
	clonal material	very expensive
transplanting of wild-grown primary roots	fast-growing plants	not really sustainable
	good yield	
	stability against climatic changes	

The germination rate can be enhanced by mechanical removal of seed hull (Blank 1973) or treatment with sulphuric acid (Schenk et al. 2004). Seedlings grow very slowly in the first 30 days and are therefore threatened by arthropods (e.g.,

'millipeds', *Spirobolus sp.*, Julidae, Myriapoda) feeding on the leaves.

Also an *in vitro* cultivation method was elaborated similar to those described in literature (Shushu 2001; Levieille et al. 2000) to be prepared if an elite plant with an exorbitant content of harpagoside could be selected.

Other cultivation projects rely on propagation by cuttings with the disadvantage of a lack of formation of a primary root (Hannig and Graven 2004). The continuous need of cuttings for drip irrigation with water from deep wells enhances the danger of salt-affected soils under the arid conditions in the Kalahari. The cultivation method with vegetation-free stripes is not suitable for cuttings because of insufficient constancy in water supply.

SCIENTIFIC SUPPORT PROGRAMME IN ECOLOGY

The aim of a parallel scientific support project in ecology was to find out the optimum ecological conditions of *Harpagophytum* by research in eco-physiology as well as factors influencing yield of tubers and harpagoside contents (Von Willert and Sanders 2004). Cultivation was accompanied by monitoring and comparing the performance of the cultivated plants in the strips were vegetation has been removed and wild grown plants in natural condition by measuring their respective carbon and water balance (Sanders 2003).

Methods of eco-physiological research

Soil type

In all research plots soil samples were collected and tested according to pH, conductivity, particle size and contents of C, N, Cl, P, K and organic components (Sanders 2000; 2003). The data were similar to Blank (1973).

Vegetation

Parallel to the eco-physiologic research the vegetation type of the research plots was described and compared to other *Harpagophytum* growing sites (Schneider et al. 2001).

Precipitation and availability of water

The Kalahari is a summer rainfall area, receiving most of the precipitation between November and April (Gellert 1962). Within this area the long-term mean is 150 mm in the southwest to 300 mm in the northern area (Leistner and Werger 1973). Due to the high potential evaporation (2300–3800 mm) this region shows a semi-arid character. For this region availability of water is the most limiting factor to plant growth. Recording of weather and micro-climatic conditions paralleled by measuring the soil water content was established.

By means of TRIME sensors it could be shown that the water availability in the vegetation-free strips was significantly higher and more constant throughout the year than in the vegetation strips (Figure 5). *Harpagophytum procumbens* was planted in the vegetation free strips.

Ecophysiological methods

The investigations run on the Farm 'Avontuur' (26°49'S, 22°44'O), in the southern Kalahari (Northern Cape Province, South Africa). This area receives mainly rain in summer, with a long-term average of 286 mm per annum.

In summer 1997 the cultivation plot was established by removing the natural vegetation in stripes 5 metres wide alternating with vegetated stripes 7 metres wide and every 200 metres perpendicular to the original direction. This pattern should avoid erosion by wind. After each rain the capillary system of the top soil is always destroyed by the use of a tiller.

Since September 1998 meteorological data have been recorded by an automatic weather station (Thies, Germany). The soil water content is continuously monitored by TRIME-TDR sensors (Imko Mikromodultechnik, Germany), which were mounted in 5 different depths in both the vegetated and the vegetation-free stripe.

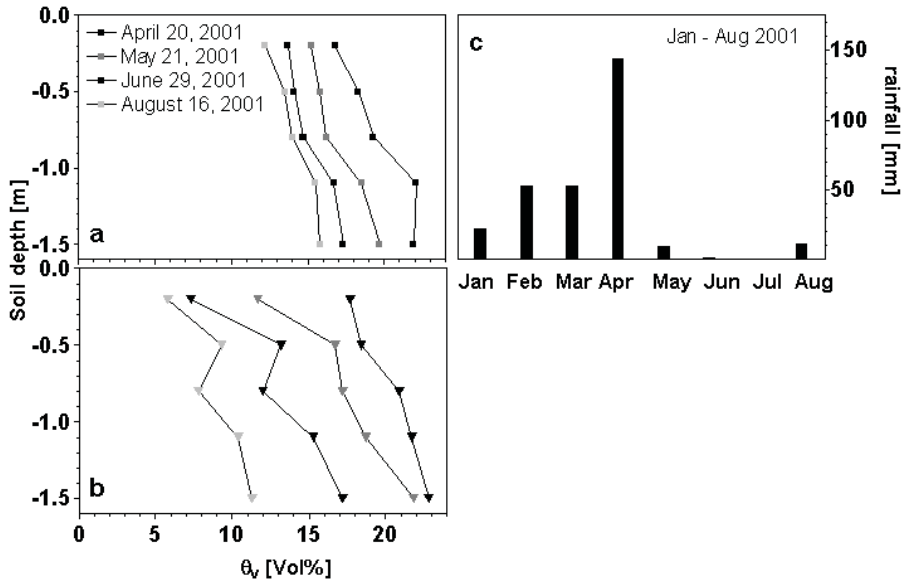

Figure 5. *Soil water content at five different depths in (a) a cultivation strip and (b) a vegetation strip. c: Monthly rainfall sum during that season in 2001. Data sets (a,b) have been selected from the end of the rain season in April to mid-winter (August). The curves from right to left represent data from April, May, June and August, respectively*

The plant water status (leaf water potential) was measured with a Scholander pressure bomb (Soilmoisture Equipment, Santa Barbara, California, USA). Gas exchange and transpiration have been measured with a gas exchange chamber system (Kompakt Miniküvetten System, Walz, Effeltrich, Germany) to ensure a defined water vapour-pressure deficit between the leaf and atmosphere and a defined CO_2 partial pressure in the measuring chamber. The system consists of three

modules: the central unit CMS-400 with integrated infrared gas analyser (BINOS 100 4p, Rosemount Analytical, Hasselroth, Germany), a gas-mixing unit GMA-4 with integrated gas analyser (BINOS 100) and a bypass humidity control CNF-400. When necessary, constant PPFD was supplied by an artificial light source (FI-400, Walz).

For quick steady-state measurements a porometer was used (HCM-100, Walz). To determine the stress-status of PS II and determine the photon yield and ETR under exposure to light different portable fluorometers were used (PAM 2000 and Mini-PAM (Walz). Both systems are equipped with the same leaf clip (2030-B) (Figure 6; see colour pages elsewhere in this book).

For details of the methods used see Von Willert et al. (1992; 1995) and Stacheder (1996).

Short glossary of abbreviations used with the graphs:

c_i:	CO_2 partial pressure between mesophylic cells [ppm]
ETR:	electron transport rate trough [µmol m^{-2} s^{-1}]
F_v/F_m:	maximum photon yield of a dark-adapted leaf trough PS II
g_{H2O}:	leaf conductivity of water vapour [mmol m^{-2} s^{-1}]
J_{CO2}:	CO_2 exchange rate [µmol m^{-2} s^{-1}]
J_{H2O}:	transpiration [mmol m^{-2} s^{-1}]
PPFD:	flow rate of photosynthetic active radiation at leaf surface [µmol m^{-2} s^{-1}]
WUE:	Water Use Efficiency; ratio of net photosynthetic CO_2 uptake and transpiration [µmol $mmol^{-1}$]
$\Delta F/F'_m$:	photon yield of PS II during exposure
θ_v:	volumetric water content of the soil body [Vol.%]
ψ_{Leaf}:	leaf water potential [MPa]

Results

Physiological variation in a natural population

In a natural population group consisting of 51 *Harpagophytum procumbens* plants clear differences could be found in the vitality of the plants during one vegetation period. By means of chlorophyll fluorescence measurements and determination of the leaf water potential, two groups of plants could be defined (Figure 7).

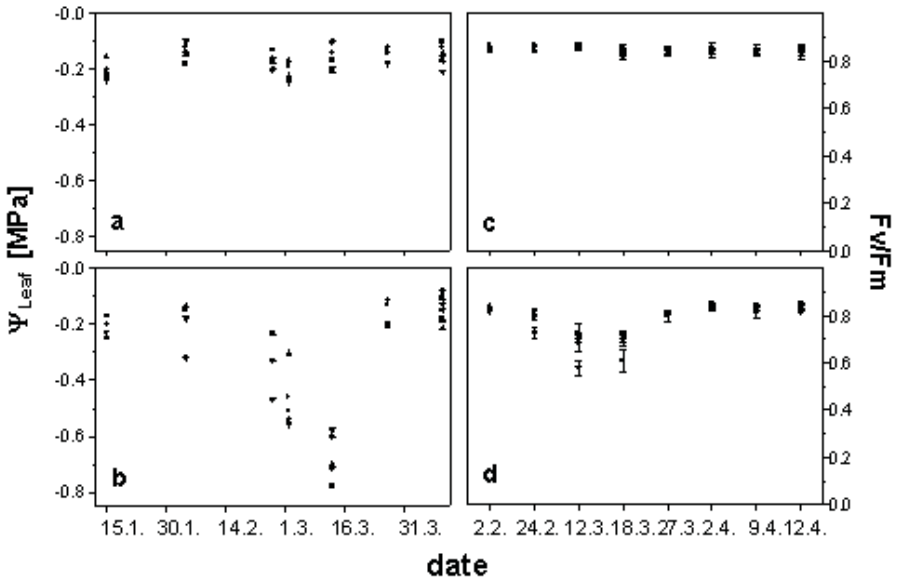

Figure 7. *Predawn determined leaf water potential (a, b) and maximum photon yield (c, d) during summer 1999. Figures a and c show data of high-performer and Figures b and d of low-performer plants. Each data set displays the measurements of five plants; mean and SD are shown*

The first group of plants ('high-performer') is characterized throughout the entire vegetation period by high maximum quantum yields of the PSII, electron transport rates up to 150 µmol m^{-2} s^{-1}, and predawn water potentials never dropped below -0.3 MPa.

In contrast to this the second group ('low-performer') showed gradual decline of maximum quantum yields of the PSII and a clearly lower ETR (<80 µmol m-2 s-1) during a prolonged dry spell. In the same period predawn leaf water potential dropped well below -0,6 MPa. After an abundant rainfall at the end of March 1999 the two plant groups showed no differences in their physiological features (Figure 8).

Artificially watered plants group behaved similar to the 'high-performer', but predawn leaf water potentials were even higher.

These three plant groups showed clear differences in their growth performance; the irrigated plants were substantially larger than the other plants and generated more fruit. The 'high-performance' plants were larger than the 'low-performance' plants, however, they did not form more fruit.

The non-irrigated plants did not differ in the content of harpagoside of their secondary tubers. The irrigated plants, however, showed an extremely significantly lower content of harpagoside in their secondary tubers.

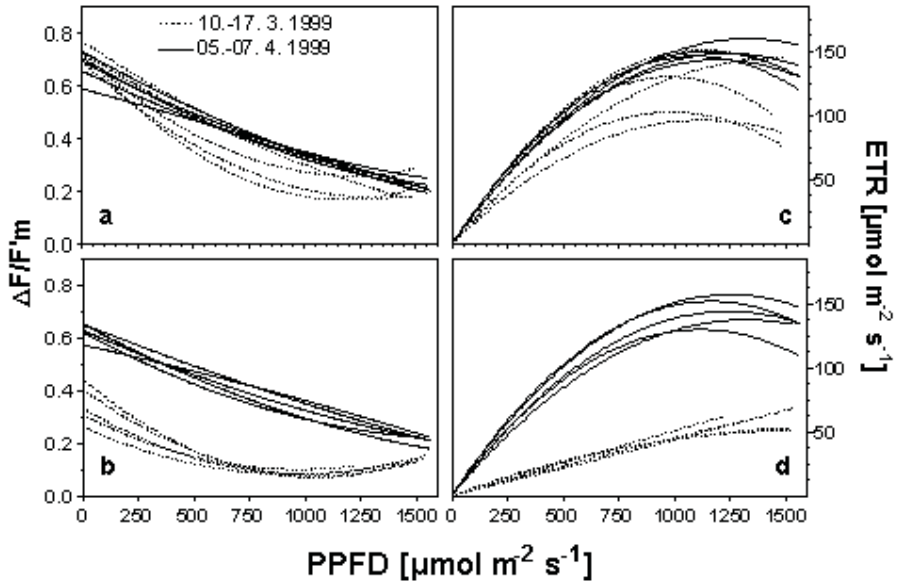

Figure 8*. Photon yield (a, b) and corresponding ETR (c, d) through PS II in dependence of the PPFD at the end of a prolonged dry spell (dashed line) during summer 1999 and after sufficient rainfall (full line). Figures a and c show data of high-performer and Figures b and d of low-performer plants that are more sensitive to dry conditions. Each curve represents a data set of at least 50 single data points*

All plants showed high variations in their respective content of harpagoside, however no common features could be found (Table 2).

Table 2*. Column statistics of harpagoside content of tubers from different plant groups. (Note: non-irrigated plants = high-perf. + low-perf.)*

Data set	High-perf.	Low-perf.	Irrigated	Non-irrigated
Number of values	33	19	43	52
Minimum	0.6300	0.4000	0.3300	0.4000
25% Percentile	1.130	1.205	0.5500	1.140
Median	1.530	1.460	0.7300	1.490
75% Percentile	1.660	1.595	0.9450	1.675
Maximum	2.500	2.340	2.320	2.500

Leaf water potential – differences between wild-growing and cultivated plants

Mainly predawn-determined leaf water potential has been observed for wild-growing and cultivated plants during a vegetation period (Figure 9).

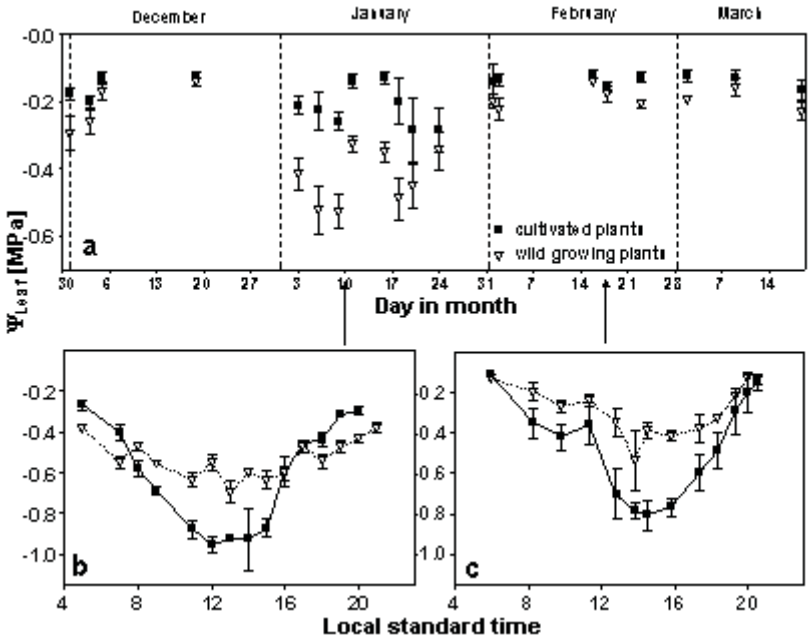

Figure 9*. a: Predawn leaf water potential of cultivated and wild-growing plants during the vegetation period 2001/2002. Mean and SD of 5 to 10 plants are given. b: Daily courses of leaf water potential for cultivated and wild-growing plants at the end of a dry spell (n = 5). c: The same measurement during a period with frequent rain (n = 6). In both graphs the mean and SD are given. Data of cultivated plants are in full rectangles, those of wild-growing plants in open triangles*

Due to sufficient rainfalls during vegetation period 2001/2002 (see also Figure 5) the predawn measured water potential of the wild growing plants was slightly – but not significantly – lower than that of the cultivated plants. This changed significantly during a dry period in January 2002, when the water potential of the wild-growing plants dropped and the water potential of the plants growing in the vegetation-free strips stayed on the same level. Irrespective of the date, daily courses of the leaf water potential of cultivated plants were always lower than those of the wild growing plants (Figure 9b, c), indicating that those plants had a higher ability to buffer the water loss during the day. At or shortly (one hour) after sunset the leaf water potential of all plants reached the predawn level again.

Gas exchange and transpiration

The gas exchange of *Harpagophytum procumbens* shows the typical features of the C3 photosynthetic pathway (Figure 10).

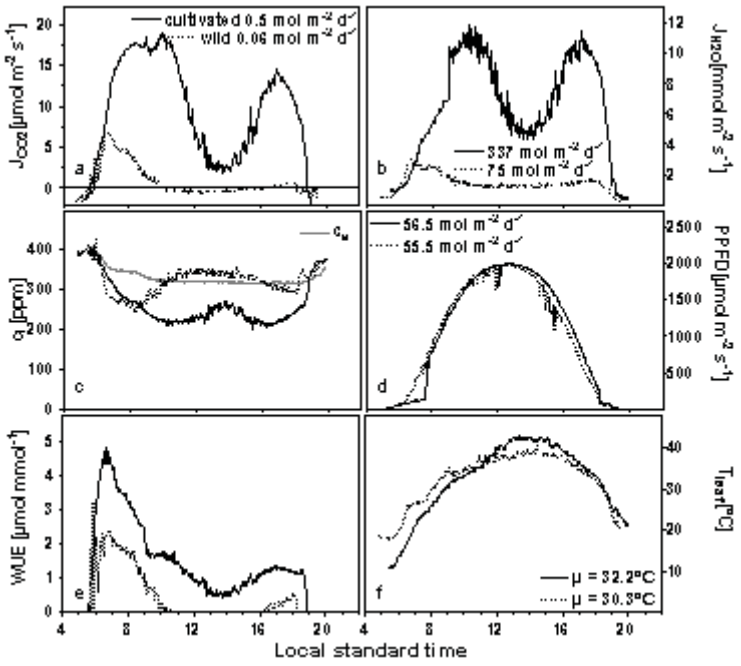

Figure 10*. Daily course of the gas exchange of wild-growing (dashed line) and cultivated plants (full line). a: photosynthesis; b: transpiration; c: CO_2 partial pressure in the mesophyll and ambient air (c_a, less noisy line); d: incident radiation; e: water use efficiency; f: leaf temperature. Measurements have been performed on two consecutive days in December 2001*

Comparison of the maximum rates of photosynthetic carbon dioxide uptake of different grasses known as C_4 plants and geophytes of the typical vegetation known as C_3 type of photosynthesis showed *Harpagophytum* to be a C_3 type (Sanders 2003) (Table 3).

Since *Harpagophytum procumbens* is a pioneer plant, the photosynthetic CO_2 uptake and electron transport rate through PSII were not saturated at the incident irradiation of 1800 µmol $m^{-2}s^{-1}$ (Sanders 2003). *Harpagophytum procumbens* growing in vegetation-free areas featured higher photosynthetic CO_2 uptake and transpiration rates and showed a better water use efficiency (Figure 11).

Table 3. *Maximum rates of photosynthetic CO_2 uptake of six C_4 grasses and four C_3 geophytes growing in the vegetation strips to be compared with Harpagophytum procumbens.*

species	net CO_2 uptake [µmol m^{-2} s^{-1}]
C_4- grasses	
Eragrostis lehmanniana	38.4
Cenchrus ciliaris	35.8
Brachiaria nigropedata	34.8
Schmidtia pappophoroides	34.5
Schmidtia kalihariensis	33.4
Antephora pubescens	32.7
C_3- geophytes	
Harpagophytum procumbens	16.3
Tylosema esculenta	13.5
Senna italica	12.9
Boophane disticha	12.1

It could be shown that even with sufficient water supply photorespiration reduced net photosynthesis by 28%. Stomatal limitation reduced photosynthetic CO_2 uptake by 22% (Sanders 2003).

As the assimilation chamber did not permit gas exchange measurements without influencing the incident irradiation, for most test runs no significant differences between both plant groups could be found with this method (Sanders 2003). Therefore, we decided to use mainly chlorophyll fluorescence as a tool to observe the photosynthetic performance of the plants. This method has very little impact on the incident radiation on the leaf surface.

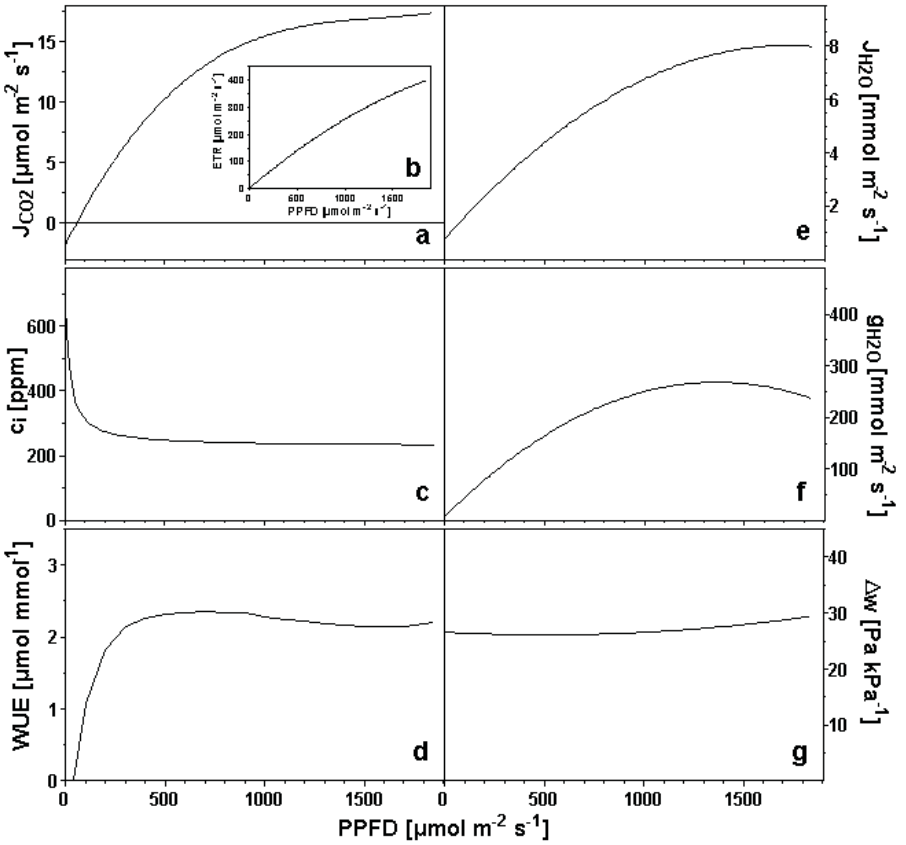

Figure 11. *Dependence of the gas exchange on the incident PPFD. Net photosynthesis (a) and corresponding electron transport rate through PS II (b; ETR vs. PPDF). c: CO_2 partial pressure in the mesophyll. d: water use efficiency. e: transpiration; f and g: the corresponding leaf conductivity for water vapour (f) and water vapour saturation pressure deficit between leaf and air (g)*

Chlorophyll fluorescence

The predawn-determined Fv/Fm ratios were similar for the wild-growing and the cultivated plants, with an exception of January 2001 after a period of prolonged dry spell when the mean of the wild-growing plants dropped below 0.72 and the variability of recorded data increased (Figure 12). For plants growing in the vegetation-free strips only single measurements indicated stress symptoms.

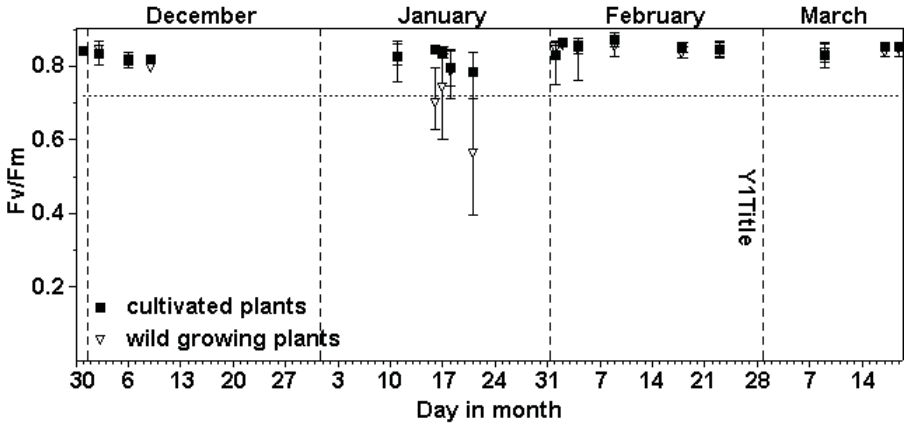

***Figure 12**. Predawn-measured F_v/F_m values of wild-growing and cultivated Harpagophytum procumbens plants from November 2001 to March 2002. Mean and extreme values are given (n = 10). The dotted line indicates stress level (Bolhàr-Nordenkampf and Götzl 1992)*

By means of chlorophyll fluorescence measurements in the course of the day, it could be shown that the incident light amount was much higher for those plants growing in the vegetation-free strips (Figure 13a), while dependency of electron

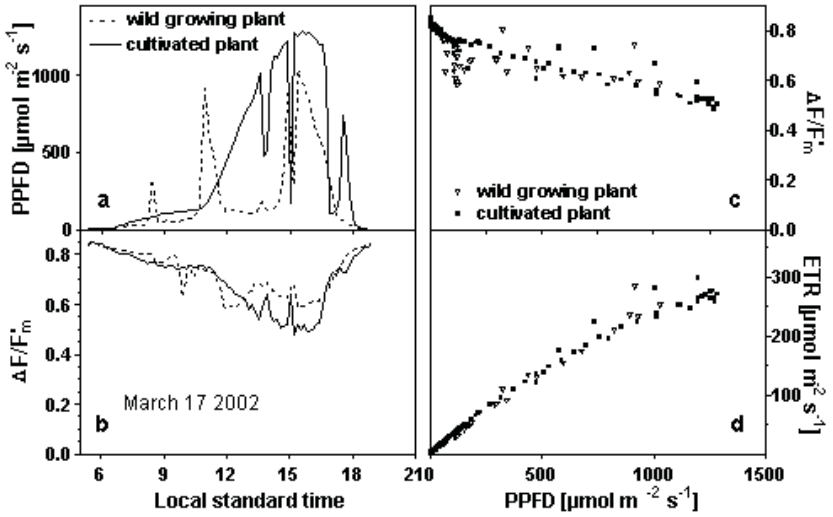

***Figure 13**. Some parameters of a cultivated (full line, full rectangle) and a wild-growing plant (dashed line, open triangle) determined by means of chlorophyll fluorescence. Incident radiation (a) and efficiency of PS II (b) in the course of the day; dependency of PS II (c) and electron transport rate (d) through PS II on incident radiation*

transport through PS II was similar for both plant groups (Figure 13c, d). In this particular situation (good water supply due to sufficient amount of rain) it could be shown that competition for light had a tremendous impact on the plant performance.

This could be shown when the integral of transported electrons through PS II was plotted against the integral of incident PPFD of simultaneous measurements (Figure 14). Less then 10% of the observed wild growing plants received more then 23 mol photosynthetic active radiation while 60% of the screened cultivated plants received 23 mol or even more PAR. Corresponding with this result we found that only one out of 30 measured wild-growing plants transported more than 5 mol electrons m^{-2} d^{-1} while 50% of the cultivated plants exceeded this level.

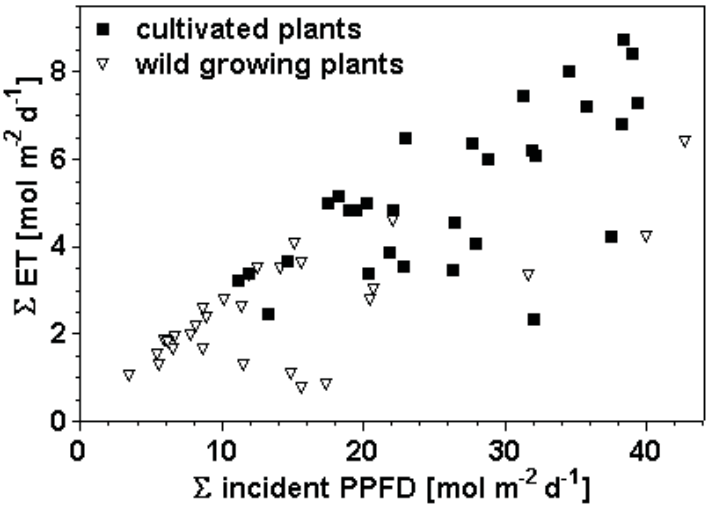

Figure 14*. Relationship between electrons transported through PS II and the corresponding integral of incident PPFD for the period from dawn to dusk. Data of 30 simultaneous measurements of cultivated and wild-growing plants between December 2001 and March 2002 are given*

Biometric data on growth of plants and tubers

At a natural population of *Harpagophytum procumbens* clear differences could be found in the vitality of the plants during one vegetation period (Sanders 2000).

Cultivated plants generally grew much faster and more vigorously than wild-growing plants (Figure 15). The total shoot length of plants after three years of cultivation ranged from 40 to 149 m at the end of the vegetation period in 2002. At the same time the total shoot length of wild growing plants ranged from 0.2 to 2.2 m.

The secondary tuber yield of cultivated plants was almost 0.5 kg dry mass and nearly ten-fold higher then the yield of wild growing plants (Sanders 2003).

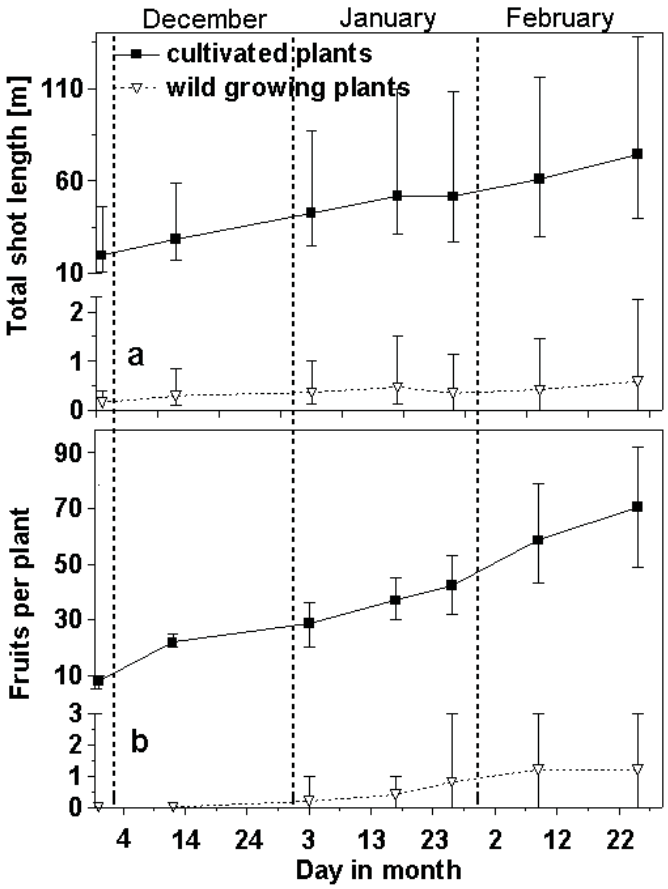

***Figure 15**. Total shoot length (a) and number of fruits (b) of cultivated and wild-growing plants during summer 2001/2002. Each group consisted of 10 individuals. Mean and extreme values are shown*

By the end of the vegetation period in 2002 cultivated plants had formed 70 times more fruits than the wild-growing specimens. If these fruits are used as a supply of plant material it is possible to establish the cultivation of *Harpagophytum procumbens* on a commercial scale without exploiting the wild population (Sanders 2003).

The number of secondary tubers from plants growing in the vegetation free stripes was, after one year of cultivation, significantly higher than the number of tubers formed by wild-growing plants of unknown age (Figure 16a). After the second and third year of cultivation the mean of harvested secondary tubers increased from 12 to 20 and 42, respectively. The total dry mass of the secondary tubers correlated with the number of harvested tubers and was 0.049 kg for the wild-

growing plants, while cultivated plants had generated 0.095 kg after one year and 0.201 kg (0.443 kg) after the second (third) year.

The harpagoside content of secondary tubers was significantly lower for cultivated plants (Figure 16c; median 1.19% to 1.34% dry matter) than for wild-growing plants (median 1.52 % dry matter) – perhaps as a result of better water supply (Sanders 2003).

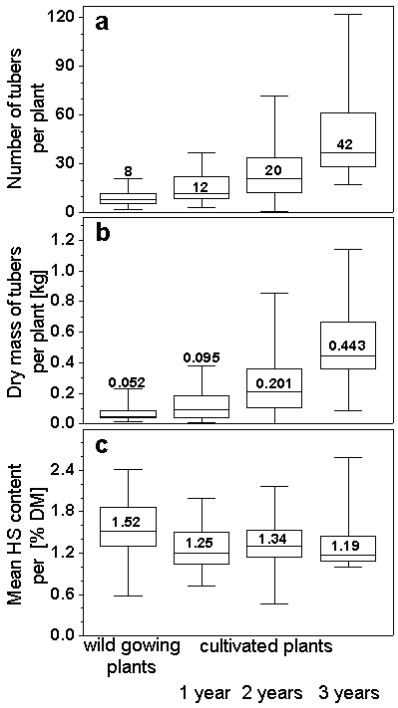

Figure 16*. Number of secondary tubers per plant (a), total dry mass of secondary tubers per plant (b) and mean harpagoside content of the secondary tubers (c), plotted for wild-growing and cultivated plants with different total plant age. Median is given as numerical data; box represents 25% and 75% quartile, while whiskers represent minimum and maximum values. Sample size varies between 25 and 83 plants per set*

Influence on harpagoside contents

All plants showed high variations in their respective contents of harpagoside. However, no common features could be found so far. Tubers of one single plant show up to 7-fold differences in harpagoside contents even in neighbouring tubers.

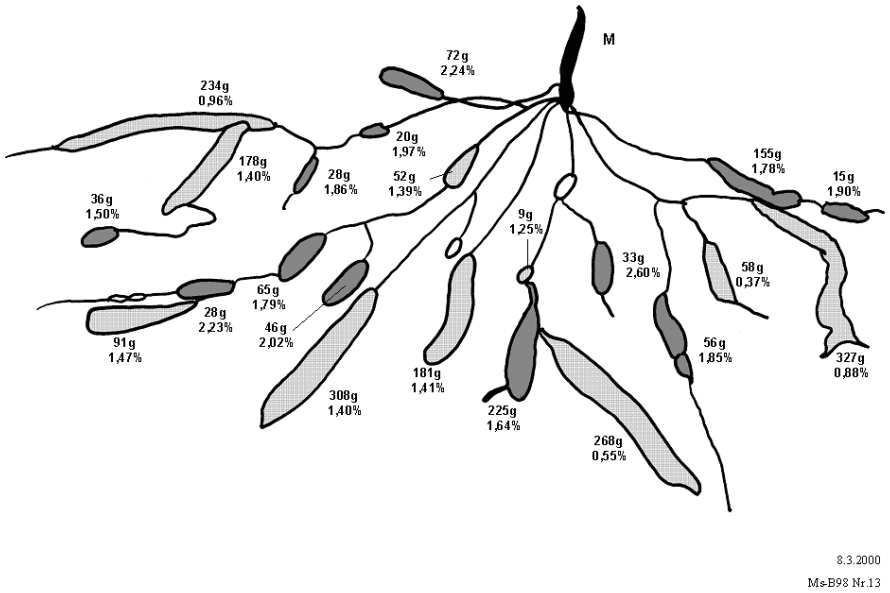

Figure 17*. Construction of the root system from a plant after two years of cultivation. For each tuber the dry mass and harpagoside content is shown; M = primary tuber*

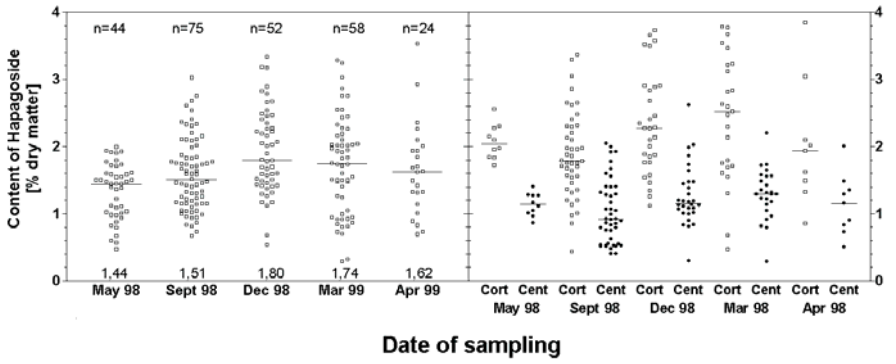

Figure 18*. Comparison of the harpagoside contents in the secondary tubers of plants which where harvested at different seasons. B: Comparison of the harpagoside contents in the cortex and the centre of those excavated tubers*

Contents are higher in cortex of tubers than in the central cylinder. Own data (Sanders 2000) were footed by new data of NIR-FT-Raman spectroscopy (Baranska et al. 2005). In almost all samples the cortex contained approximately twice as much harpagoside as the centre of the tuber; this was not found for irrigated plants. Influence of harvesting seasons showed a slight increase during December but there

was no significant difference due to wide variability of data (Sanders 2000). The content of harpagoside is subject to seasonal oscillations and was highest at the beginning of the vegetation period in December 1998 (Figure 18).

Comparing all collections of data showed similar variability in one plant, in plants of one location and all over Namibia (Von Willert and Schneider 2001). For this reason it was not possible to select a plant with significantly higher harpagoside content.

We tried to show the influence of age of tubers and of plants but there was no significant difference. Young tubers seemed to have a higher content of harpagoside than old tubers.

In the end, the only factor influencing the harpagoside content seems to be water supply. Irrigated plants (Sanders 2000) tend to have lower harpagoside contents, as well as plants from vegetation-free stripes (Sanders 2003). The two non-irrigated plant groups, wild and cultivated respectively, did not differ in the contents of harpagoside in their secondary tubers. The irrigated plants, however, showed an extremely significantly lower content of harpagoside in their secondary tubers. The harpagoside content of secondary tubers was significantly lower for cultivated plants (median 1.19 – 1.34% dry matter) than for wild growing plants (median 1.52% dry matter) perhaps as a result of better water supply in the 'rain-feed' system (Sanders 2003).

Further research needs

Fieldwork with plants should run for a couple of subsequent years to avoid random results. This also applies to the question of whether the content of harpagoside is under control of climatic factors rather than of genetics. For this approach cloned material should be used rather than an existing wild population (Sanders 2000).

There is an urgent need for further scientific research on the eco-physiological influence on biosynthesis of active principles. A new hypothesis emerged from comparing our results with different water supply and climatic conditions other species of the genus *Harpagophytum* are growing in.*H. zeyheri*, since 2003 also possible as starting material in the European Pharmacopoeia (PharmEur 2003), differs from *H. procumbens* by the shape of the fruits and the contents of the secondary metabolites, harpagoside and p-coumaroyl-harpagide. The relative contents of both were calculated as PCHG ratio (Feistel and Gaedcke 2000). Plotting a large amount of PCHG-ratio data into a histogram shows an important difference between the two species. Data from *H. procumbens* nearly fit into a one-peak Gaussian distribution curve, whereas *H. zeyheri* shows no viable standard distribution.

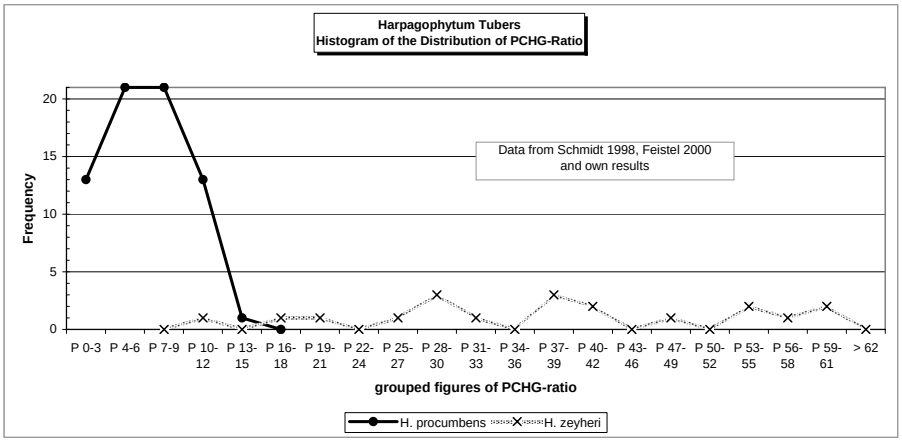

Figure 19. *Histogram of frequency of PCHG ratio comparing the distribution for Harpagophytum procumbens and H. zeyheri*

The current hypothesis is that the biosynthesis of the both metabolites is influenced by water supply (Inouye and Uesato 1986). The difference between both molecules is a single phenolic hydroxy group in the phenylpropane side chain introduced by phenoloxidase reaction depending on water contents. Comparing the distribution of the two species in southern Africa (Ihlenfeldt and Hartmann 1970) with a precipitation map (DWD 1996) shows the range of *H. procumbens* in dryer areas than *H. zeyheri*. Only *in situ* analysis of these secondary metabolites paralleled by registration of environmental factors will help to find any answers.

SPECIES CONSERVATION

From the CITES discussion a question emerged: is *Harpagophytum* really endangered? Recent research work on population dynamics of *Harpagophytum* (Hachfeld 2003) revealed the spatial aspects of *Harpagophytum* ecology and the influence of bush encroachment dynamics (Rhode 1997).

With our methods of ecophysiology we could demonstrate the differences between plants in vegetation-free stripes compared to plants in vegetation influenced by competition between *Harpagophytum* and other plants for water and irradiation. Because the dense vegetation will evaporate most of precipitation, the soil water contents in vegetation-free stripes were approximately 3-fold those of vegetation strips. In parallel there is more irradiation on vegetation-free plots, not shadowed by other plants. More sunshine during morning and evening allows faster onset and a longer period of photosynthesis. Higher leaf surface temperature could also be observed influencing the biochemical reactions.

There is also sufficient soil seed stock for fast regeneration after harvesting. Observations on plots where primary roots were removed for starting cultivation showed intensive re-growth of seedlings in the same density as before harvesting.

Seeds have severe germination problems because of strong but ecologically necessary germination inhibition and the seedlings are endangered during growth.

The result of these observations is that *Harpagophytum* as a species is not really endangered but there are severe problems with sustainable harvest in some areas of the range states. Self-made suppliers are harvesting tubers without any permit and are even stealing roots in areas where communities have installed sustainable harvesting methods (Von Willert pers. comm. 2005).

More scientific research is necessary on spatial patterns in time and space, e.g., by installing long-term surveillance/monitoring plots and using the new methods in spatially explicit modelling (Wiegand et al. 2000).

CONCLUSIONS

We tried to create a social and environmental sustainability of the *Harpagophytum* supply chain and elaborated habitat-friendly methods for cultivation and collection of wild-grown tubers.

In parallel there was an intensive scientific support programme to get more information on the

- advantage of cultivation method
- influence of ecological factors
- variation of contents of active ingredients

with the result that there is an urgent need for more scientific research, especially on the eco-physiological influence on biosynthesis of active principles (pharmaceutical aspect) and population dynamics (aspect of species conservation).

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