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WINTER HARDINESS OF CACTI IN HUNGARY

Thesis of Ph.D. Dissertation

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I. PRELIMINARIES AND GOALS OF THE SCIENTIFIC WORK

The winter hardy species of the family *Cactaceae* are plants with a diverse morphology and a broad ecological amplitude. Those cacti which can be kept outside even during the wintertime have a more and more significant role in the broadening of the Hungarian ornamental plant market. They can be successfully used in rock-gardens, on green-roofs, and at special public domains. Due to their characteristics (drought-, radiation- and frost resistance), cacti are the typically aimed plant specialties of extensive green roofs.

Their trade is neither negligible, as the total yearly cacti production is 50 million in the USA, and more than 18 million plants were produced for the European market by the Dutch growers at the end of the 1980's (FULLER and FITZGERALD, 1987). According to the publication of Bloemisterij (2006) 145 000 plants only from the genus *Opuntia* were sold in 2005 in Holland. Regarding the number of sold plants, it is a 4,5 % decline compared to the year 2004, but with the rise of the prices, it meant a 11,5 % higher income.

Since many species are endangered at their original habitat, it can be expected that the possibility of import will partly or totally come to an end (OLDFIELD, 1987). Because of this the reservation of winter hardy cacti collections in Hungary is especially important. In these collections it is of high importance that we keep the species at their correct names, as a potential gene bank for the future, which also offers several possibility to make observations and to research.

The Department of Floriculture and Dendrology of the Faculty of Horticultural Sciences, Corvinus University of Budapest (University of Horticultural- and Food Sciences before) collects and evaluates different winter hardy *Opuntia* taxa since 1994. The rooted joints were first kept in containers, later they were planted on the extensive green roof of building "K" at the Campus. I joined this project in 1997 after having specified the focus of my PhD thesis. I set up experiments to test and work out the most effective way of propagation and the best propagation medium and substrate; and to get to know the changes of peroxidase enzyme activity in the plants due to frost stress. I also found it important to gather and list the species, subspecies and varieties found in Hungarian collections, so buyers and landscapers could choose the right ones. It might sound strange today, but due to the climatic changes, the global warming and as a result of more research, winter hardy cacti could become the future fruit-bearing or forage crop of Hungary.

GOALS

1. Observation of the winter hardy *Opuntia* collection planted on the extensive green roof and selection of species most capable for planting outside. Observation of changes in size due to the influence of weather by examining spines and cladodes of 25 *Opuntia* taxa.
2. Charting other collections in the country by surveying the most often occurring species, circumstances of the planting and the quality of the plants.
3. Biochemical examinations. The change of the winter hardiness related peroxidase enzyme activity due to frost stress and titanium-ascorbate treatment. Determination of phenol content in the case of certain winter hardy and frost sensitive taxa.
4. Examination of the vegetative reproduction and rooting of *Opuntia* species (demonstrated on the species *Opuntia tortispina*), selection of the optimal propagation medium for rooting, and the incidental negative consequences of their quick reproduction.

5. Comparison of the sterile and traditional sowing methods of winter hardy cacti. Comparison of substrates containing Titavit against the abnormal growth (vitrification) appearing at sterile sowing.

II. MATERIAL AND METHOD

1. Frost tolerance and morphological examinations outside

I evaluated cacti planted on the green roof in the Buda Arboretum between 1998 and 2001. I examined the growth of the joints (cladodes), their fruit bearing, their state of health and their typical wrinkling. In 1999 and 2000 I observed the morphological changes due to the different weather at the selected 25 *Opuntia* taxa on the roof.

Evaluation of the winter hardy *Opuntia* collection planted on the extensive green roof

The collection of cacti was finally planted on top of building "K" on the extensive green roof, which means a convenient protection against illegal gatherers, and offers an excellent possibility for observation and maintenance.

Many of the plants donated to the Department of Floriculture and Dendrology came from the "Szutorisz collection" in the form of (rooted) joints (cladodes) collected in North-America (by Debreczy and Rácz), other plants came from other Hungarian collectors.

The number of examined *Opuntia* taxa is 271. The medium where cacti were planted is 15-20 cm thick and consists of 30% red dross, 35% sand (with 4% humus content), 20% peat (NOVOBALT), 10% perlite and 5% rice shell. This medium was laid on a drain system of a 2 mm thick poli-propylene felt (geo-textile) and 1x2 m sized undulatory plastic panels as it was written by HIDY et al. (1995).

Measured parameters in the experiments were as they follow:

- yearly growth of the cladodes
- description of the plants' quality – grading their condition with numbers between 0-5
  - 0 dead (destructed plants),
  - 1 unsatisfactory condition, close (>90%) to death,
  - 2 sufficient condition in bad health, most parts of the organism (>50%) are damaged,
  - 3 average quality, the damage is obviously between 20-50%,
  - 4 good condition, damages less than 25% on the plant,
  - 5 excellent condition, organism without any damage.
- number and morphological description of fruits
- number of dead plants
- extent of wrinkling at autumn.

Examinations comprised two objective and two subjective variables between 1998 and 2000. Objective variables were the number of cladodes (cl) and fruits (f), the subjective variables were the condition (co) and wrinkling (w) of the plants.

Changes in the spines' and joints' size due to weather conditions

The measurements were made on 25 *Opuntia* taxa. In the years of the measurements, in 1999 and 2000 in the case of sprouts I measured the first cladodes from the node until the apex. I took 3 data per each plant then took their average. That is how I

got the values typical of the examined taxon. Data of the average spine growth was measured the same way. Sampling happened from the upper third of the cladodes. I measured the 5 largest spines in both years, and similar to the data of the cladodes, I took the average.

As a statistical analysis of the data of cladode and spine size changes, I used the two-sided t-test in case of equal variances, and the Welch-test in case of unequal variances, with the program Ministat 3.3.

2. Survey of the winter hardy cacti collections of Hungary

Smaller and larger collections can be found at different points of the country which can be characterized with varying number of species and taxa, in diverse medium and under differing circumstances. The survey was done with the help of a data sheet which was posted to 400 addresses between 2003 and 2006. In the period between 1997 and 2006 I also visited collections four-five times per year and collected data personally.

During the investigation 169 winter hardy taxa were described with the maintenance circumstances. Number of taxa of the kept species, age and other characteristics (flowering, fruit-bearing, condition) of the plants were also written down.

3. Biochemical examinations
Change of the peroxidase enzyme activity

Examinations took place in the Zoo and Botanical Garden of Budapest and in the laboratory of the Department of Applied Chemistry, Corvinus University of Budapest in 2005 and 2006.

I used samples taken from the stem succulent *Escobaria vivipara* (V)*, Escobaria vivipara* var. *neomexicana* (N)*, Echinocereus reichenbachii* ssp. *baileyi* (B) and the leaf succulent *Agave parryi* (A) for the examinations. I used titanium-ascorbate called TITAVIT for treating the samples.

Taking the samples first I cleaned all contaminations from the plants. I cut the spines from the areoles found on the warts in case of *Escobaria* species, or on the ribs in case of *Echinocereus* species. The plant part from which the sample was taken was the wart at *Escobaria*, rib cross-section at *Echinocereus*, and a piece of the leaf in case of *Agave*.
Samples were taken four times::
1. 28th November, 2005. before vaporization with titanium-ascorbate (**origination**)
2. 20th January, 2006. treated and control samples (**placement outside**)
3. 29th January, 2006. after a frost colder than -10 °C, treated and control samples (**-10°C**)
4. 13th February, 2006. following the melting of the snow, treated and control samples (**recovery**).

I took 3 (treated and control) samples from *Escobaria vivipara,* (N)*, Echinocereus reichenbachii* ssp. *baileyi*, and *Agave parryi*, and one treated and one control sample from *Escobaria vivipara* var. *neomexicana* because of its size.

The vaporization with titanium-ascorbate took place only two days later following samplings so the cut surfaces could have dried up. I sprayed the control plants with tap-water so they would be placed outside in the cold in the same humid condition, as the treated ones. I sprayed the plants, but both the titanium-ascorbate and tap-water made the soil wet as well. Four days after the vaporization the plants were placed outside from the green-

house onto a sunny area. After taking them I kept the samples at a temperature of -22 °C until they were processed.

To measure the activity of peroxidase enzyme the given quantity of homogenized plant samples were separated with a MSE Micro Centaur tabletop centrifuge, the analysis was made from the upper layer following the separation. We measured the activity of the peroxidase enzyme in a 0,1 M Na-acetate buffer (pH=5,0), with the help of H_2O_2 substrate and ortodianisidine chromogene reagent (ε=11,3), in a spectrophotometrical way (λ=460nm) with the method of SHANNON (1966), with a Varian DSM 100 UV-Visible set. Results of the enzyme activity are given in U/ml, as a result of three parallel measurements.

Measuring the total phenolic content

Examinations took place in the laboratory of the Department of Applied Chemistry, CUB in November, 2006. Samplings happened from *Escobaria vivipara,* which was also used in the experiments with POD enzyme activity, from *Escobaria vivipara* treated with titanium-ascorbate, and from the frost-sensible *Mammillaria prolifera*.

We prepared an extract with water and with alcohol from the fresh samples to characterize the lipid-soluble flavonoids. We measured the total phenolic content with the method of SINGLETON and ROSSI (1965) with a spectrophotometer (λ = 760 nm) with Folin-Ciocalteu reagent. The phenolic content concerning gallic acid was given in mg/ml or mg phenol/g fresh weight.

4. Propagation examinations
Rooting of *Opuntia tortispina* joints

I used the joints (cladodes) of *Opuntia tortispina* from the Zoo and Botanical Garden of Budapest's winter hardy cacti collection rocky garden established in 2004.

To set the experiment I picked 5 portion (10 pieces per portion) joints from the stock plants in the period of intensive growth (second week of June, 2006.). Four portion was picked at the nodes, and in case of the fifth portion of cladodes I made irregular cuttings on them imitating injuries caused by a lawnmower. Then I kept the stem segments on a place where rain could not fall on them so the cut surfaces could dry up. Tested mediums were peat, mixture of soil and gravel (1/1 ratio) and perlite. I put a portion of cladodes in each medium so that one third part of the cladodes were in the soil, I put ten cladodes in the tray without any medium, and I put the cut pieces in the mixture of soil and gravel.

I placed the trays outside on a sunny place. I examined the formation and development of the roots every 5 days following planting, for a period of one month. There was one exception when I missed the measurements after 5 days, when the mediums did not dry adequately after a big rainfall, and taking out the cladodes would have injured the roots.

My observations comprised of two parts. I was checking when did adventitious root formation occur on the cladodes in the different mediums, and I also measured the number and the length of the roots.

Traditional and sterile seed propagation of winter hardy cacti

I used the seeds of *Escobaria missouriensis, E. vivipara* var. *arizonica, E. vivipara* var. *bisbeeana, E. vivipara* var. *neomexicana, E. vivipara* var. *missouriensis* and a mixture of *E. vivipara* varieties for the experiments. I sowed the seeds from the fruits of the previous

year (2005), but before sowing I formed portions of 15 seeds. So altogether I sowed 45 seeds per taxa. Seeds which were going to be sowed onto the sterile substrate were sterilized with two kinds of methods. One portion of seeds (15 pieces) of each taxa was soaked for 15 minutes in a mixture of 1/3 bleach and 2/3 water, then rinsed with distilled water. Another portion of seeds was disinfected with bleach-powder (chloride of lime). I made the sterile sowing in a sterile laminar box. Utensils used for the sterile sowing were washed with 98% alcohol then flamed. The MKC substrate was used for sowing. The seeds sterilized by the two different methods were placed with tweezers on top of the substrate by three or five (per glass) then opening of the glass was closed by a transparent foil. Sterile sowing was placed at a temperature of 22-24 ºC.

In case of the traditional sowing I used a 1‰ suspension of Orthocid 50 WP, freshly sowed seeds were treated with it first. The medium comprised of 50 % garden soil and 50 % gravel and it was disinfected in the micro-wave oven before sowing. Control sowing was made into 8 cm diameter plastic pots. Seeds were covered with a few mm thick layer of soil then a flat glass was placed on top of the pots. In case of the traditional sowing no fertilization was applied. This control sowing was placed in the green house where there was no supplemental light or heat, temperature was fluctuating between 10 and 30 ºC in the following days after sowing.

I processed the values resulting from the examinations with the One-way Analysis of Variance (ANOVA) with Randomized Block Design (GAÁL, 2004).

Substrates used for sowing of winter hardy cacti

To avoid vitrification which I discovered among the sterile seedlings I tested different substrates for sowing seeds of winter hardy cacti in December, 2006 at the Department of Floriculture and Dendrology, CUB. Titavit containing titanium was added in the substrates in different concentrations. As control I used MKC substrate and I also tested a substrate with a high percentage of salt- and sugar content: MS with full salt content and with 60 g/l sugar.

I sowed portions of 20 seeds collected from *Escobaria vivipara* var. *arizonica*, var. *aggregata*, and var. *bisbeeana* species. The process of fertilization was the same in case of each portion of seeds. The seeds were soaked for 2x5 minutes in a mixture of thirty per cent solution bleach and Tween 80, then were rinsed three times with distilled water. Sterile sowing of the seeds and placement of the seedlings happened at the same place and under the same circumstances as it was written above.

Analyzing data got from the experiment I used the program SPSS for Windows 14.0 (GAÁL, 2004).

III. SUMMARY OF THE RESULTS

1. Frost tolerance and morphological examinations outside
Evaluation of the winter hardy *Opuntia* collection planted on the extensive green roof

It was not possible to draw tangible conclusions from the change in the number of the cladodes. Species growing small joints like *Opuntia fragilis* can be characterized by a large number of cladodes and so a bigger number of cladodes enables a further increase in the number of joints. However, during this period of four years (1998-2000) it was a species

with bigger cladodes, namely the *Opuntia phaeacantha* var. *pallida* which produced the most joints.
Taxa producing the most joints in the year given:
In 1999 **1**. *Opuntia arkansana* (44 cladodes), **2**. *O.* sp.(36), **3**. *O. fragilis* (33)
In 2000 **1**. *O. rutila* (43), **2**. *O. rhodantha* (35), **3**. *O. fragilis* (28)
In 2001 **1**. *O. phaeacantha* var. *pallida* (47), **2**. *O. polyacantha* (38), **3**. *O. compressa* var. *microsperma* (33).

The bearing of fruits that refers to both the health and the age of the plants as well as their market value increased significantly after a decrease in 1999 concerning both the number of productive taxa and the number of fruits.
Concerning the condition of the plants a correlation can be seen between the tendencies of conditions given 2nd grade and the number of dying plants in the following year. Plants which can be used best outside were given the grade 4 and 5 regarding their conditions, they constituted the majority of the examined taxa (271). (In 1998: 83,4%; in 1999: 74,2%; in 2000: 62%; in 2001: 69%)

The subjective variable defining the market value is the wrinkling of the plants, which is more or less characteristic of the species and it is derived from the plants loosing humidity, preparing for the unfavorable winter month. The wrinkling grades concerning the species only varied one grade in the years of the examination. For instance *Opuntia engelmannii* with a wrinkling grade of 0 has occasionally reached grade one throughout the four years, however, no bigger alterations could have been experienced.

Changes in the spines' and joints' size due to weather conditions

The bigger size of the spines and joints growing from the areoles can significantly increase the ornamental or market value of the plants. However, the size of the joints and spines can be influenced by the weather conditions to a great extent.
For the ideal developing of cacti two important conditions need to exist:

1. for the cladodes to start their growth – the sufficient amount of rainfall at spring,
2. for the cladodes' "ripening" and for the growth of the spines – a warm and dry summer.

As a result of the year 2000 *Opuntia engelmannii* var. *discata* (being the winter hardy *Opuntia* species growing the biggest joints) has reached a further growth of 77% compared to the year 1999 concerning the final size of the cladodes.

Changes in the sizes of the spines were positive in case of all 25 *Opuntia* taxa, the spines' length increased between 2 and 80 % in average.

Depending on the uniformity of the variances in the given years significant differences were proven with the two-sided t-test and the Welch-test which can be seen on **Figure 1.** and **2**. quite clearly.

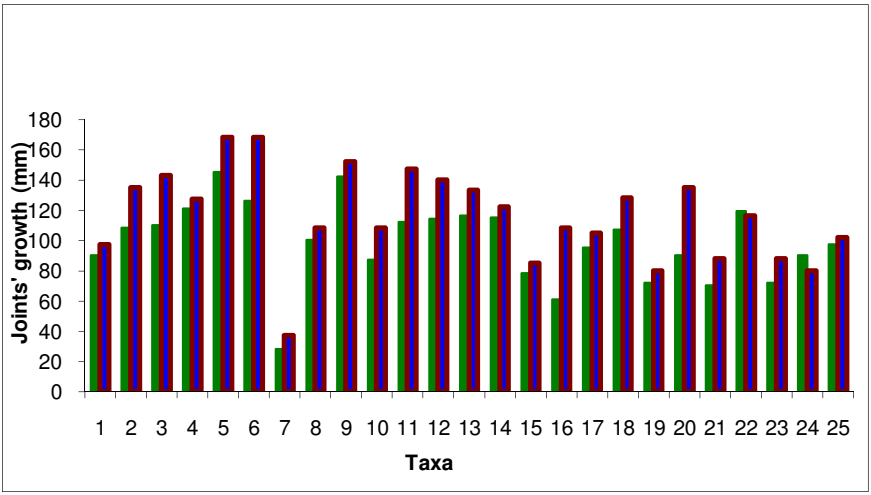

Figure 1. The average of the joints' growth of the examined winter hardy cacti planted on the extensive green roof in the Buda Arboretum in 1999 ■ and in 2000 ■.

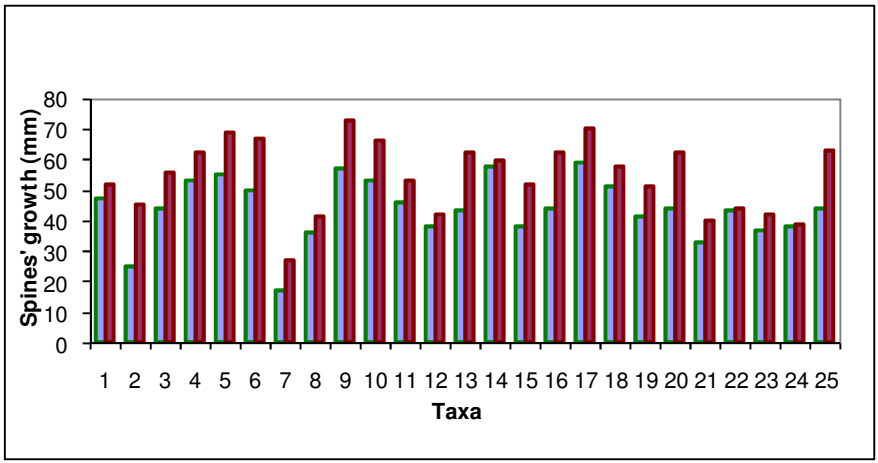

Figure 2.: The average of the spines' growth of the examined cacti planted on the extensive green roof in the Buda Arboretum in 1999 ■ and in 2000■.

Names of taxa showed on Figure 1. and 2.: **1.** *O. arkansana*, **2.** *O. camanchica*, **3.** *O. camanchica* var. *rubra*, **4.** *O. engelmannii*, **5.** *O. engelmannii* var. *discata*, **6.** *O. engelmanni-phaeac.*f., **7.** *O. fragilis,* **8.** *O. juniperina,* **9.** *O. macrocentra*, **10.** *O. macrorhiza*, **11.** *O. phaeacantha*, **12.** *O. p.* var. *camanchica*, **13.** *O. p.* var. *longispina*, **14.** *O. phaeacantha* var. *major*, **15.** *O. phaeacantha* var. *minor*, **16.** *O. p.* var. *piercei,* **7.** *O. p.-macrocentra* f., **18.** *O. polyacantha,* **19.** *O. rhodantha*, **20.** *O. rubrifolia,* **21.** *O. schweriniana*, **22.** *O. tortispina*, **23.** *O. t.* var. *cymochila*, **24.** *O. t.* var. *luteo-straminea*, **25.** *O. t.* var. *stenochila*

2. Survey of the winter hardy cacti collections of Hungary

Visiting the collections I noticed that winter hardy cacti are quite popular amongst cacti collectors, some *Opuntia* and *Cylindropuntia* species can be found in several collections in the country. However, there are only a few winter hardy cacti collections consisting of more species. During my survey I managed to record the names of 169 taxa (species, subspecies, varieties, forms) which number decreases to 64 if we compare it to the taxonomy work of HUNT.

Thanks to visiting collections since 1997 and processing data from the data sheets sent back to me the outline of the distribution of winter hardy cacti species, subspecies and varieties in Hungary seems to get laid.

The plant most often found in the collections is *Cylindropuntia imbricata*.

3. Biochemical examinations

Change of the peroxidase enzyme activity

Regarding the changes in the activities of the peroxidase enzyme I made examinations throughout 4 samplings (origination, placement outside, -10 °C, recovery) concerning plants altering both in age (2-5 years) and in habits (stem succulent, leaf succulent). In the examination I compared the control samples to the samples taken from plants sprayed with Titavit (titanium-ascorbate).

Irrespectively of any treatments I found the least proportional POD activity at *Echinocereus reichenbachii* ssp. *baileyi* marked "B" which is a stem succulent species with columnar habit. Following this come *Escobaria vivipara* var. *neomexicana* marked "N" and *Escobaria vivipara* marked "V" which are globe shaped stem succulent species (**Figure 3.**).

Findings of this experiment can be summarized as follows.

– Lesser peroxidase enzyme activity can be experienced initially by *Echinocereus reichenbachii* ssp. *baileyi* than by other species involved in the experiment. Following from the placement outside and the treatment with titanium-ascorbate the POD enzyme activity grew by a bigger scale in the treated plants than in case of the control plants. Taking samples from the species *Echinocereus reichenbachii* ssp. *baileyi* already means quite a great stress for the plants since those parts from which the samples were taken could have been cut out by such a drastic intervention. So it is not surprising that the results of the recovery samplings became rather extreme.

– Differences in the POD enzyme activities could have already been observed initially by 2 species of the *Escorbaria* genera. Young plants (*Escobaria vivipara* var. *neomexicana*) had continuously higher POD enzyme activity throughout the samplings and this tendency remained so. At the fourth sampling the values of the POD enzyme activity decreased confirming the general tendencies.

– In the experiments I also included the leaf succulent *Agave parryi*. The reasons behind this decision are to be found in the close relation between the habitat of *Agave* species and cacti and in their similar use in designs. *Agave* species can perfectly be used as an additional ornamental species in Hungarian rocky gardens and on green roofs. Amongst the agaves, even though the *Agavaceae* family consists of several species, there are only a small number of taxa (7 species) that can stand the climate of Hungary, and survive the winter staying outside without any covering. Values of their POD enzyme activity can be differentiated from those of the stem succulent cacti. Throughout the examination the peroxidase enzyme activity showed various values. In contrast with the general tendency during the recovery

phase (4th sampling) values of the POD enzyme activities did not drop, more over, they increased, which may refer to the plant trying to survive the cold, the temperature which is too low for it.

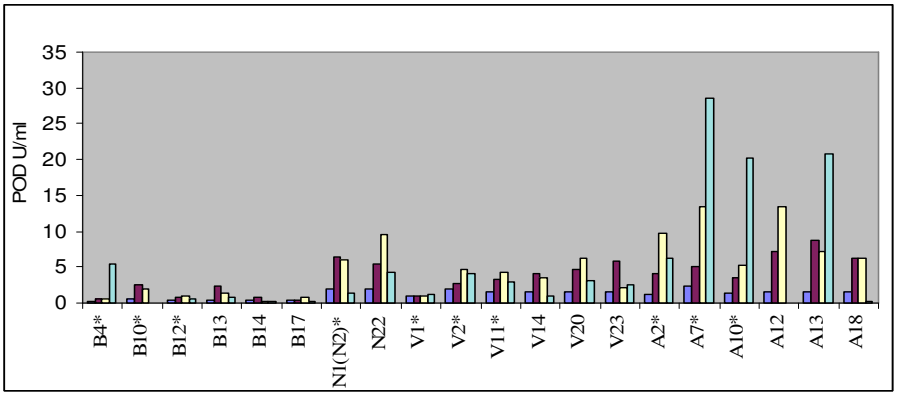

Figure 3. Changes of the peroxidase enzyme activity (U/ml) in the examined plants (B, N, V, A) due to frost stress, in the plants treated with Titavit (*) and in the control plants, at the time of **origination** (11/28/2005) , **placement outside** (01/20/2006) , **-10 ºC** (01/29/2006) , and the **recovery** (02/13/2006) . (B – *Echinocereus reichenbachii* ssp. *baileyi,* N – *Escobaria vivipara* var. *neomexicana,* V – *Escobaria vivipara,* A – *Agave parryi*)

Although the treatment with Titavit influenced the enzyme activity variously depending on the different species and varieties, it can be stated on the whole that it had a positive effect which is also shown in the bigger number of surviving plants (**Figure 4.**)

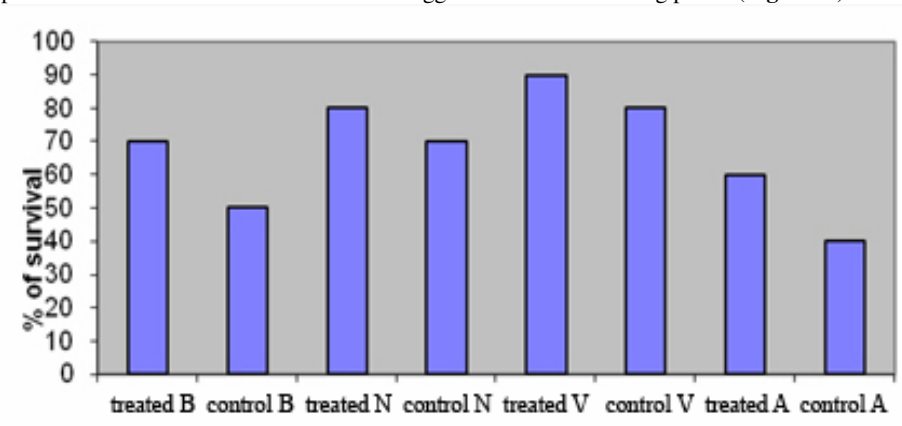

Figure 4. Control and treated specimens of *Echinocereus reichenbachii* ssp. *baileyi* (B), *Escobaria vivipara* var. *neomexicana* (N), *Escobaria vivipara* (V), and *Agave parryi* (A), which survived the winter of 2005/2006 (% of survival).

Measuring the total phenolic content

The phenolic content of the plants could be correlated with stress processes similarly to peroxidase enzymes. The total phenolic content of samples collected from the frost resistant *Mammillaria prolifera* showed a multiple value of that of the winter hardy *Escobaria vivipara*, regardless of whether the plant was treated with titanium-ascorbate or not. This high value of the phenolic content in case of the frost resistant plants could be explained by the increase of flavonoids that are produced for defense functions.

4. Propagation examinations
Rooting of the *Opuntia tortispina* joints

Rooting media had lesser influence on the adventitious root formation of cladodes, however, it had a bigger effect concerning the duration of rooting. Throughout the three-month observation there were three joints (cladodes) which did not produce adventitious roots, however, root development was not hindered by any destruction or other harmful events. They were most likely able to catch up with their rooting within a few weeks. The best results were observed in perlite and in the mixture of soil/sand regarding both the number of roots developed and the speed of the root formation.

Traditional and sterile seed propagation of winter hardy cacti

49.6% of all seeds did not germinate, most probably due to outer circumstances having a destructive effect on traditional sowing. The difficulty of sterile sowing is in sterilization, and still, supported by our experiment, sterile sowing can be applied with higher efficiency. Results of the examination became rather extreme due to the unsatisfactory traditional sowing. Seeds sowed in the traditional way, having no additional equipments (e.g. supplemental heating or light) are much more exposed to the possible effects of their environments, however, traditional seedlings might just get their hardiness right this way – the hardiness that is exactly what sterile seedlings do miss.

On **Figure 5.** I summarize the successfulness of sowing regarding the different methods and parameters. In case of the infected seedlings all taxa reacts the same way, and there is neither a significant difference between the sowing methods. Comparing the effects of treatments with the Games-Howell test, the sowing method indicated with “B” (disinfection with bleach-powder (chloride of lime)) proved to be significantly more effective than the method “C” (control/traditional method of sowing the seeds) regarding the number of seeds not germinated and the number of healthy seedlings.

Substrates used for sowing of winter hardy cacti

During the sterile sowing experiment in order to eliminate the vitrification and to raise the germination percentage the substrate marked T0,5 containing 0.5 mg/l Titavit proved to be the optimal substrate among the used media based on the examined factors (**Figure 6.**). The vitrification was 3,3 % on both substrates marked T0,1 and T1. Though there was no vitrificated nor infected specimen among the seedlings on the MS substrate, the germination process seemed to be very unfavorable, since 88,3 % of the seeds have not germinated.

On the basis of the winter-hardy *Escobaria vivipara* varieties' sowing experiments' results we can establish that the substrates containing different concentrations of Titavit and the control MKC substrate had no significant effect on the vitrification and germination percentage. On the other hand the MS substrate with a high salt and sugar content seriously deteriorated the germination rate.

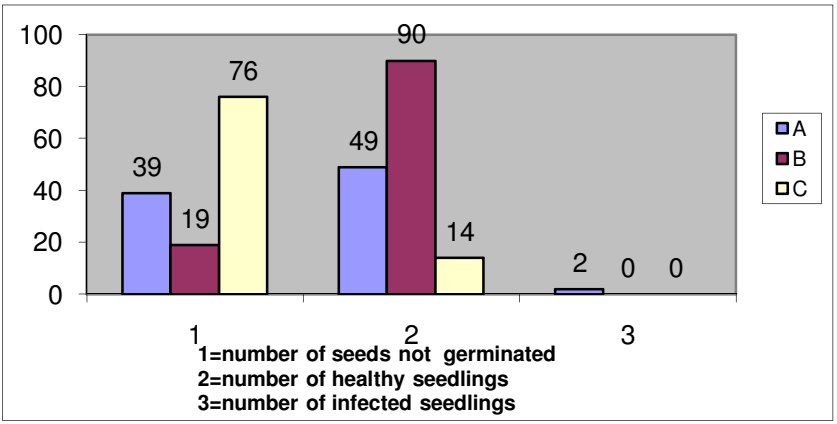

Figure 5. Summary of the sowing methods' results based on the examined variables. A – disinfection with bleach; B – disinfection with bleach-powder (chloride of lime); C – control (traditional sowing method)

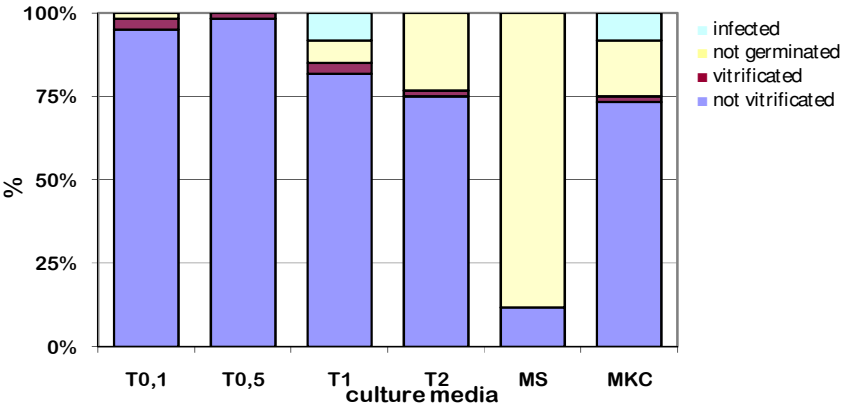

Figure 6. The number of seeds/seedlings of different states occurring on the given substrates in case of *Escobaria vivipara* varieties in 2007 at the Department of Floriculture and Dendrology, CUB.

IV. NEW SCIENTIFIC RESULTS

1. I introduced into the Hungarian terminology a term very typical to the evolution of cacti, called wide-band tracheida.
2. I ascertained that weather conditions (temperature, precipitation) throughout the vegetation period have an influence on the size of the cladodes and spines.
3. I drew the conclusion that destruction of the plants due to unsatisfactory weather conditions appears one year later.
4. I defined the peroxidase enzyme activity of the plants and I pointed out the correlation between the plants' frost resistance and the changes of peroxidase enzyme activity.
5. I found a difference between the total phenolic content of winter hardy and frost sensible cacti.

Results that can directly be applied in practice

1. Throughout the propagation experiments – through the example of *Opuntia tortispina* – I selected the medium that was most favorable for the root formation and also had an influence on both the quantitative and qualitative development of the cladodes.
2. I contrasted the effectiveness of traditional and sterile sowing of winter hardy cacti and I selected the substrate most suitable for the initial development of the cacti seedlings.
3. I have found no significant effect of the substrates containing Titavit used for sterile sowing on the vitrification or the germination percentage.
4. I have established that the substrate with high salt and sugar content decreases strongly the germination rate of cacti.
5. I prepared the synonym table of winter hardy cacti.
6. I summed up the botanical material of the most well-known winter hardy cacti collections of Hungary.

V. CATALOGUE OF PUBLICATIONS WRITTEN FROM THE THESIS' SUBJECT MATTER

1. Publications in journals

SZABÓ, K., MÉSZÁROS, Z. (1999): Observations of winter hardy cacti in two open-ground collections in Hungary. KÉE Közleményei (Publ. Uni. Ind. Alim.) Budapest. 99: 122-128.

SCHMIDT, G., SZABÓ, K. MÁTYUS, SZ., FODOR, A., SZENDRÁK, E., (1999): Prelimitary observations on the winter-winter hardy Opuntias in Buda Arboretum. KÉE. Közleményei (Publ. of the Uni. of Hort. Food Indust.) Budapest. 98: 105-112.

MOHÁCSINÉ SZABÓ, K. (2002): Pediocactus knowltonii. Debreceni Pozsgástár (Rec. Succ. Deb.) Debrecen. 5 (4): 217-224.

MOHÁCSINÉ SZABÓ, K. (2003): Néhány kaktuszfaj megjelenése a Cactaceae család elterjedésének északi határán. Kaktusz-Világ (Succ. Hung.) Budapest 27 (2): 40-45.

MOHÁCSI, G., MOHÁCSINÉ SZABÓ K. (2005): Agave fajok hazai adaptációs lehetőségei. Kaktusz-Világ (Succ. Hung.) Budapest 30 (4): 138-145.

MOHÁCSINÉ SZABÓ, K., TILLYNÉ MÁNDY, A. (2006): Az *Escobaria* nemzetség (Cactaceae) Magyarországon is télálló fajainak magvetése steril és hagyományos körülmények között. Kaktusz-Világ (Succ. Hung.) Budapest 30 (6): 239-245.

MOHÁCSINÉ SZABÓ, K., MÉSZÁROS, Z. (2006): A szélsőséges időjárás hatása a télálló kaktuszok morfológiájára. Kertgazdaság (Horticulture) 38 (3): 42-46.

MOHÁCSINÉ SZABÓ, K., CSÁRÁDI, K. (2007): A télálló *Opuntia tortispina* Engelmann& J.M. Bigelow (Cactaceae) szártagok járulékos gyökérképződésének és fejlődésének vizsgálata különböző közegekben. Kertgazdaság (Horticulture) 39 (1): 41-47.

2. Publications in conference proceedings

MOHÁCSI, G., MOHÁCSINÉ SZABÓ K. (2005): Télálló agavék hazai adaptációs lehetőségei. A *Lippay János - Ormos Imre – Vas Károly Tudományos Ülésszak Előadásainak és Posztereinek Összefoglalói*. Budapesti Corvinus Egyetem Dísznövénytermesztési és Dendrológiai Szekció (2005. október 19-21.), Budapest, pp 17.

SZABÓ, K., TILLYNÉ MÁNDY, A.: (2007): Télálló kaktuszok magvetése titán-aszkorbát tartalmú táptalajokra. A *Lippay János - Ormos Imre – Vas Károly Tudományos Ülésszak Előadásainak és Posztereinek Összefoglalói*. Budapesti Corvinus Egyetem Dísznövénytermesztési és Dendrológiai Szekció (2007. november 7-8.), Budapest, 20-21.

SZABÓ, K., TILLYNÉ MÁNDY, A., STEFANOVITSNÉ BÁNYAI, É. (2007): A peroxidáz enzim aktivitásainak változásai télálló szukkulens növényekben. A *Lippay János - Ormos Imre – Vas Károly Tudományos Ülésszak Előadásainak és Posztereinek Összefoglalói*. Budapesti Corvinus Egyetem Dísznövénytermesztési és Dendrológiai Szekció (2007. november 7-8.), Budapest, 34-35.