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ACCLIMATIZATION OF MONKEY PUZZLE TREE [*ARAUCARIA ARAUCANA* (MOLINA) K. KOCH] IN CLIMATIC CONDITIONS OF SZCZECIN

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ABSTRACT

Monkey puzzle tree [*Araucaria araucana* (Molina) K. Koch] is an endemic coniferous plant. Its natural locations are on the slopes of dormant volcanoes in Cordillera Mountains in the Andes and insular locations are in Patagonia. According to some authors cultivation of that species in Poland in open ground is impossible because of too low temperature in winter. The aim of the research was to evaluate the hardiness of monkey puzzle tree grown in open ground in Szczecin and to determine the possibilities of its cultivation in climatic conditions of the city. Field research was conducted in the years 1998–2012. In the years of the research every time after winter (in the second half of May) degree of frost damages was determined according to the scale commonly used in the research centers. Was also studied the vitality of needles and determined the color of the upper surface of the needles. Selected weather factors: absolute minimal and maximal temperature, average year temperature and average minimal and maximal temperature and also precipitation and average air humidity were analyzed. In the years of the research thirteen cultivation places of monkey puzzle tree of height of over 1.5 m were found. In most cases those are specimens planted in the years 1998–2005, currently of height in the range from 2.5 to 4.2 m, with 6–11 whorls of sprouts. The greatest monkey puzzle tree growing in the garden in Tarnobrzeska street from the year 1990 was characterized by height of 6 m, trunk circumference of 59 cm at the height of 1.3 m above ground level and 14 whorls of sprouts. Trees growing in Szczecin have not initiated generative phase yet. The greatest damages of needles, frozen sprouts and even totally frozen plants were observed after winters of 2005/2006, 2009/2010 and 2011/2012 with temperature decrease over -20°C.

Key words: *Araucaria araucana*, monkey puzzle tree, cultivation, Szczecin, Poland.

INTRODUCTION

Monkey puzzle tree [*Araucaria araucana* (Molina) K. Koch] is an endemic coniferous plant. Its natural locations are on the slopes of dormant volcanoes in Cordillera Mountains in the Andes and insular locations are in Patagonia at the height of 400–800 m above sea level, maximally to 1700–1800 m above sea level [21, 24, 25]. Examined species was discovered about 1780 and brought to England by Archibald Menzies in 1795 [2, 8]. Currently monkey puzzle trees are grown often in Western Europe, in Crimea and in Scandinavian countries, e.g. Norway and Sweden [2, 21]. First specimens in Poland were planted in the arboretum in Niedźwiedź near Kraków before 1833 and in the Kórnik Arboretum in 1845 [19].

According to some authors cultivation of that species in Poland in open ground is impossible because of too low temperature in winter [14, 19]. However, many attempts of monkey puzzle tree cultivation are made, especially in northern-western Poland that – according to different classifications of climatic zones – is characterized by the calmest conditions for trees cultivation [22, 24]. It is affected mainly by the exotic appearance and original conformation of the tree.

The aim of the research was to evaluate the hardiness of monkey puzzle tree grown in open ground in Szczecin and to determine the possibilities of its cultivation in climatic conditions of the city.

METHODS

Field research was conducted in the years 2004–2012 as a continuation of observations carried out in the years 1998–2003 [9]. In 2012, dendrometric measurements and observations of the examined trees were conducted: height, trunk circumference at the height of 1.3 m above ground level, annual growth of the length of shoots and the number of whorls were measured. Vitality was also determined the basis of admittance and the surface color of needles was analyzed.

Measurements of growth trees were made after the end of the growing season. Annual growth of shoots and tree height were measured with a measuring tape with an accuracy of – respectively – to 1 mm and 1 cm. The paper included the average growth of side shoots, calculated from 10 randomly selected measurements of each of the shoots of plants.

On the basis of data on the age of 13 trees interval / time of shoot whorls growth was set.

In the years of the research every time after winter (in the second half of May) degree of frost damages was determined according to the scale commonly used in the research centers [12, 17] and those results are given in Table 2.

Scale of damages of evergreen plants:

- 0 – undamaged plants but with slightly anthocyanin overcoloured leaves,
- a – partly frozen needles or leaves,
- b – totally frozen needles or leaves,
- c – frozen leaves, needles and flower and leaf buds, usually undamaged sprouts,
- d – frozen tops of the one-year-old sprouts,
- e – frozen one-year-old sprouts,
- f – totally frozen one-year-old sprouts and partly frozen older sprouts,
- g – plant frozen to the surface of snow (ground) but new sprouts are growing from undamaged parts of plant,
- h – totally frozen plant without possibilities of regeneration,
- i – trunk breaks.

Needle vitality was determined during full vegetation - at the turn of June and July, basing on the measurement of the coefficient of plant admittance using a CX -741 meter [13, 15, 16, 23]. The measurements were performed on the needles by placing the electrode in the central part. The feature was characterized on the basis of the average of 10 measurements taken on the needles of this year (A), one-year intact or damaged to by frost varying degrees (B, C, D). Figures, after logarithmic transformation, were statistically analyzed using Tuckey test and the Statistica 10 computer program. The color of the upper surface of the needles was analyzed at the same needles as vitality, in transmitted light, using a CM-700d spectrophotometer. Measurements were carried out in the CIE Lab, where L* is white (100) and black (0) color, and a* determines green (-100) and red (+100), b* determines blue (-100) and yellow (+100). The used type of observer was 10° and D65 illuminant, and the diameter of the measuring aperture was 3 mm [18].

Selected weather factors: absolute minimal and maximal temperature, average year temperature and average minimal and maximal temperature (Fig. 1) and also precipitation and average air humidity were analyzed.

Climatic conditions

Extreme winter temperature and especially fluctuations of temperature in vegetative period affecting disturbances of growth and development and even serious damages of plants are the most important factors reducing possibilities of cultivation of trees and shrubs introduced from warmer regions of the world [1, 22]. According to the map of Heinze and Schreiber [3] of arborescent plants potential resistance to frost in Middle Europe Szczecin is situated in sub-zone 7a with average minimal temperature of the years in the range from -17.7 to -15.0°C. Border of "the warmest" in Poland sub-zone 7b with average minimal temperature in range from -14.9 to -12.3°C proceeds slightly north from Szczecin [3]. Indicatory plants of zone 7, i.e. atlas cedar [*Cedrus libani* subsp. *atlantica* (Endl.) Batt. et Trab.], common holly (*Ilex aquifolium* L.) and cherry laurel (*Prunus laurocerasus* L.) are successfully cultivated in Szczecin with the exception of very frosty periods (so-called "winters of the century").

Average year temperature of years 1961–2000 in Szczecin Dąbie comes to 8.6°C and in the years of the research, i.e. 1998–2012 it oscillated in the range from 7.3°C in the year 2010 to 10.0°C in the year 2000. In the region of Szczecin in a period from November to March on the average from 28 to 30 frosty days are noted. On the average only one of them is numbered among very frosty days. In the years 1961–2000 absolute year minimum of air temperature -33.0°C (at the height of 2 m above ground level) was noted in January of the year 1987 and in the years 1998–2012 – years of observations of monkey puzzle tree growth – absolute year minimum of temperature came to below -20.0°C three times: in the year 2006 -26.0°C, in the year 2012 -25.0°C and in the year 2010 -22.8°C (Fig. 1). In those years also the greatest ranges of year extreme temperature were noted and they came to, respectively: 61.0, 58.8 and 57.6°C (Fig. 1). Those were definitely greater differences of extreme temperatures amplitude than in the years 1956–1990 when in January, February and March they came to from 40.0 to 46.0°C and in the other months they ranged from about 30.0 to 38.0°C [6].

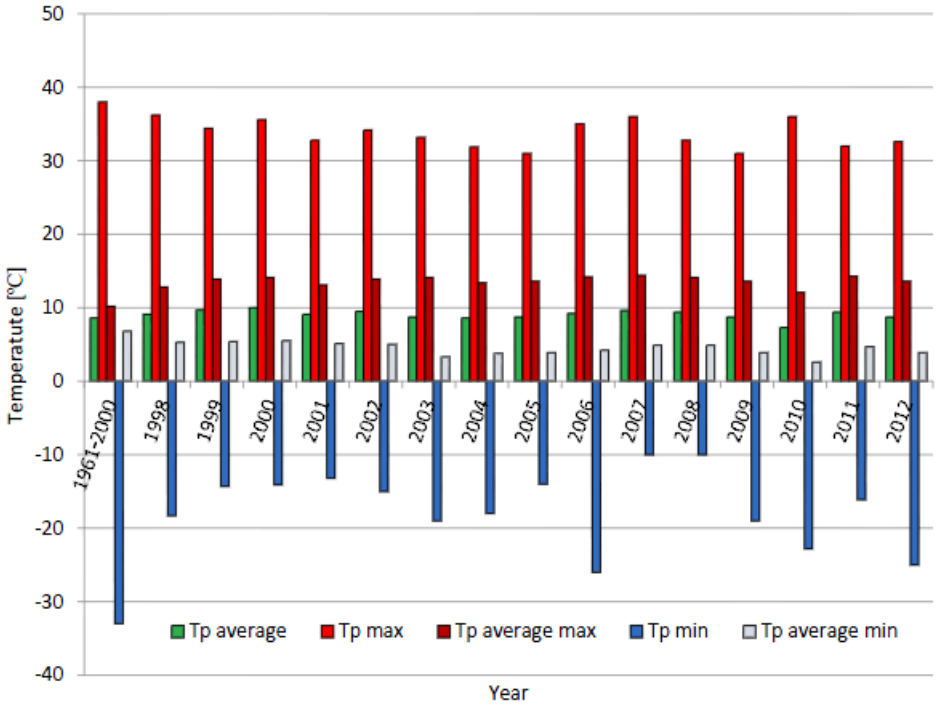

Fig. 1. Average year air temperature, average year minimal air temperature and average year maximal air temperature and its absolute minimum and maximum in the years 1961–2000 and in the years 1998–2012 for the meteorological station of Institute of Meteorology and Water Management Szczecin-Dąbie (Internet 3)

Precipitation in winter and early spring period protects thermophilic plants to a certain degree from low temperature and desiccating wind. Average year precipitation sum in Szczecin Dąbie of the years 1961–2000 comes to 538 mm and in the years of the research 1998–2012 it came to on the average 601.4 mm – from 383.0 mm in extremely dry 2003 year to 788.0 mm in the year 2007. February and March are characterized by the lowest average precipitation (26 and 27 mm, respectively). In the region of Szczecin depth of snow of over 10 cm is rare. Also twenty-four-hour over 20-mm precipitation and droughts lasting over 20 days are unusual [6, 7, 26].

Average relative air humidity of the years 1956–1990 in Szczecin-Dąbie comes to 80%. December is characterized by the highest average relative air humidity (about 90%) however, May and July are characterized by the lowest average relative air humidity [6, 7].

RESULTS AND DISCUSSION

In the years 1998–2012 thirteen cultivation places of monkey puzzle tree of height of over 1.5 m were found in Szczecin [9, 10]. In most cases those are specimens planted in the years 1998–2005, currently of height in the range from 2.5 to 4.2 m, with 6–11 whorls of sprouts (Photo 1–2). The greatest monkey puzzle tree growing in the garden in Tarnobrzeska street from the year 1990 was characterized by height of 6 m, trunk circumference of 59 cm at the height of 1.3 m above ground level and 14 whorls of sprouts (Tab. 1, photo 3). Monkey puzzle tree growing in Szczecin do not annually produce, like most conifers, one whorl of shoots, but on average, the whorl is created approximately every 1.5 years, which is confirmed by many years of observations Søndergaard [20, 21] carried out in western Norway and the Lusk and Carlos [11] results, who report that in South America, the trees make up one whorl at about 2 years. Trees growing in Szczecin have not initiated generative phase yet.

Photo 1. Garden Spiska St.: specimen of height of 3 m (photo K. Wraga, 2012)

Photo 2. Garden Okulickiego St.: specimen of monkey puzzle tree of height of over 4 m (photo M. Kubus, 2012)

Table 1. Localization of cultivation places and characteristics of monkey puzzle tree – trees of height of 1.5 m and more

Ordinal number	Localization of garden in Szczecin	Tree characteristics			Year of planting	Comments
		Height [m]	Trunk circumference [cm]	Number of whorls		
1	Jesionowa St.	2.5	–	7	1995	loss – 2010
2	Kielecka St.	3.5	28	5	1997	–
3	Kłosowa St.	4.6	35	11	1996	regular conformation, whorls from trunk base
4	J. Kochanowskiego St.	2.5	25	7	2003	–
5	W. Korfantego St.	1.8	19	6	1999	loss – 2007
6	Priest J. K. Kluka St.	1.6	12	5	2001	loss – 2012
7	Mierzyńska St.	5.0	44	6	1994	from two specimens one remained
8	L. Okulickiego St.	4.2	36	11	2000	treetop diameter of 3 m; also two young plants of height to 1 m growing
9	Ornitologów St.	2.7	25	7	2005	–
10	P. Gojawiczyńskiej St.	1.8	14	3	2007	–
11	Spiska St.	3.6	30	10	1997	–
12	Tarnobrzeska St.	6.0	59	14	1990	–
13	Wojska Polskiego St.	1.9	15	5	2003	regular conformation, whorls from trunk base

Photo 3. Garden Tarnobrzeska St.: the greatest monkey puzzle tree in Szczecin (photo M. Kubus, 2011)

According to Marosz [14] and Seneta [19] monkey puzzle trees do not winter in Poland in open ground and they should be cultivated in pots (and taken under covers in winter period) or in the greenhouses. Tests of monkey puzzle tree cultivation in Szczecin in open ground have been conducted from the beginning of nineties of twentieth century.

In climatic conditions of Szczecin plants of examined species are characterized by different growth and degree of winter frost resistance depending on place. In periods of frosty winters and those of considerable fluctuations of temperature, e.g. winter of 2005/2006, (absolute minimum of temperature -26.0°C), 2009/2010 (absolute minimum of temperature -22.8°C) and 2011/2012 (absolute minimum of temperature -26.0°C) monkey puzzle trees are nipped by the frost and their youngest sprouts and low parts of treetop turn brown (the lowest sprouts sometimes fade away) – photo 4. Two of monkey puzzle trees noted in the years 1998–2003 [9] were totally frozen and the other from the observed trees in the following vegetation seasons regenerated however, growth of the most of specimens slowed down definitely. In the following years of the research observed plants were also totally or partially frozen (Tab. 2). Older trees were characterized by damaged needles and frozen sprouts in the low part of the treetops but not in the parts of the treetops of over 2 m height (photo 1 and 2).

Photo 4. Frost damages of needles and sprouts and new sprouts increases after winter of 2011/2012 (photo M. Kubus, 2012)

Table 2. Degree of monkey puzzle tree damages in the years 1998–2012

Location*	Year														
	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
1	a	b	b	a	a	b	c	a	h	–	–	–	–	–	–
2	a	b	a	b	a	c	c	a	f	c	0	0	b	a	0
3	–	–	–	–	–	a	a	0	0	0	0	0	0	0	0
4	–	–	–	–	–	–	a	a	0	0	0	b	0	a	0
5	–	–	b	a	a	b	c	a	c	h	–	–	–	–	–
6	–	–	–	–	b	c	e	b	e	f	a	b	e	e	h
7	a	c	b	b	a	b	c	a	f	e	0	0	a	a	0
8	–	–	–	a	a	0	b	0	b	f	0	0	c	e	e
9	–	–	–	–	–	–	–	–	c	e	a	0	a	a	c
10	–	–	–	–	–	–	–	–	–	–	e	e	f	e	f
11	a	b	b	a	a	b	c	a	f	c	0	0	a	a	0
12	a	0	0	0	0	a	b	0	b	f	0	0	c	c	c
13	–	–	–	–	–	–	a	0	0	b	0	0	c	a	a

*1–13 – location conformable with Table 1
0–i – signatures as in chapter Methods

Needle vitality in the studied plants, determined on the basis of the measurement of the coefficient of admittance, did not significantly differ in the case of needles coming out of this year's growth, of the last year's growth with the typical color of needles and of the last year's growth with anthocyanin discoloration, at the significance level 0.05, being an "a" homogeneous group (Tab. 3, Fig. 2). It proves that the needles with frost-caused anthocyanin and brown discoloration, lost their aesthetic value, but still retained vitality. Dark brown needles showed no vitality and admittance values differed significantly in their case, creating a separate homogeneous group "b" (Tab. 3).

Table 2. Degree of monkey puzzle tree damages in the years 1998–2012

Needle age	The average level of the coefficient of admittance [$\mu S \cdot cm^{-1}$] / homogeneous group	The color of the surface of needles		
		L*	a*	b*
this year's needles – A	53.04 a	57.9	-12.9	42.8
one-year needles – B	53.78 a	42.3	-4.9	19.1
one-year needles – C	54.07 a	44.3	6.9	20.7
one-year needles – D	1.49 b	39.1	9.5	18.2

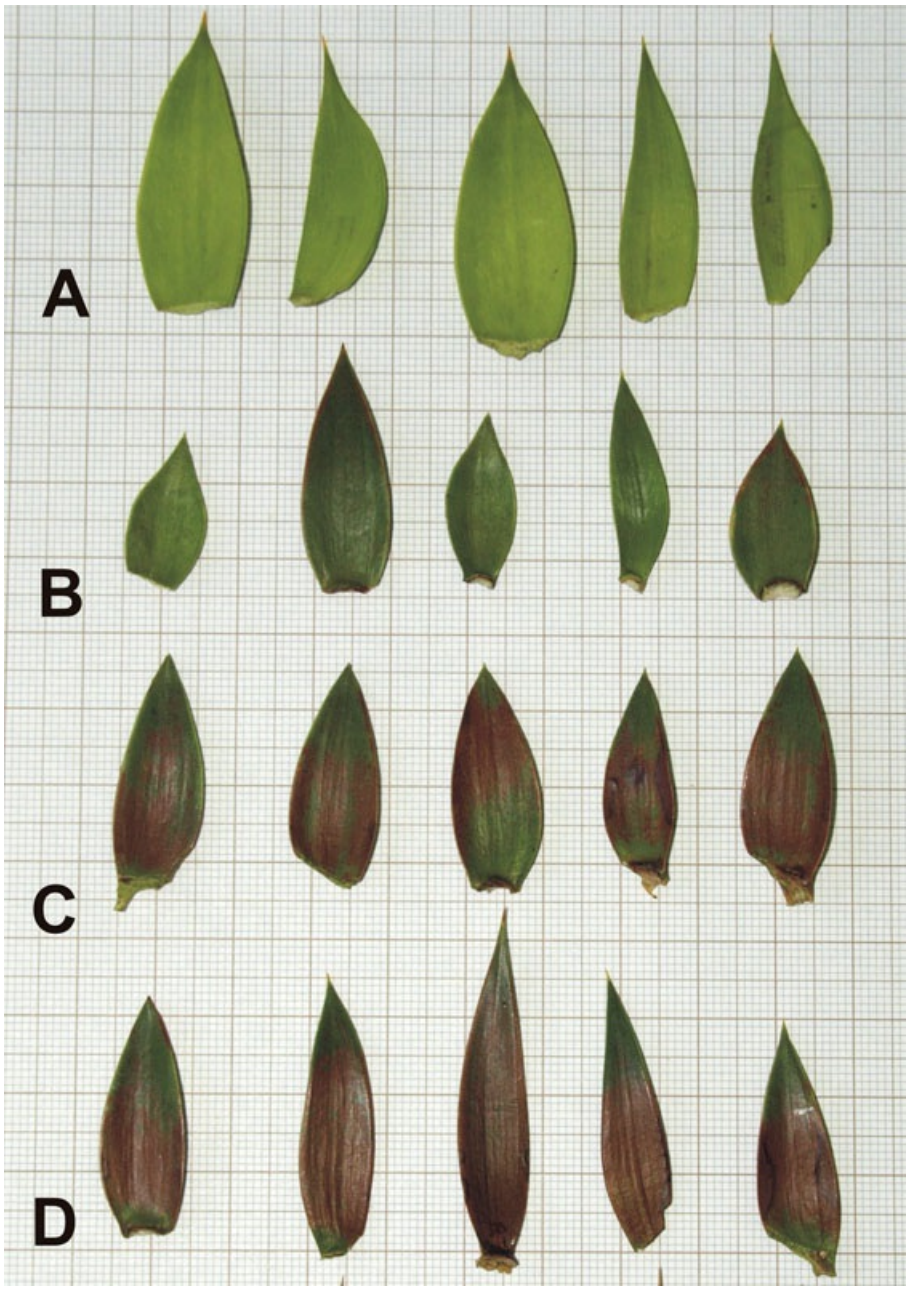

Fig. 2. Color of the surface of needles (A–D, as described in the Methods chapter)

Monkey puzzle tree is characterized by dark green coloration of typical needles, as confirmed by parameter a* (Tab. 3). These measurements showed large differences in the levels of various parameters, depending on the physiological condition of the needles. The highest differences – in excess of 27 units – are in the case of parameter b*. In the case of parameters a* and L*, differences were, respectively, 22.4 and 18.8. The highest amount of green dye was found in the youngest needles – one-year, they were also the brightest, as confirmed by parameter L* and a large amount of yellow dye – parameter b*. In the other leaves, parameter b* was at a similar level. In one-year needles and dark green two-year needles parameter a* showed negative values, which indicates the presence of green dye, at the remaining needles parameter a* was positive (Fig. 3).

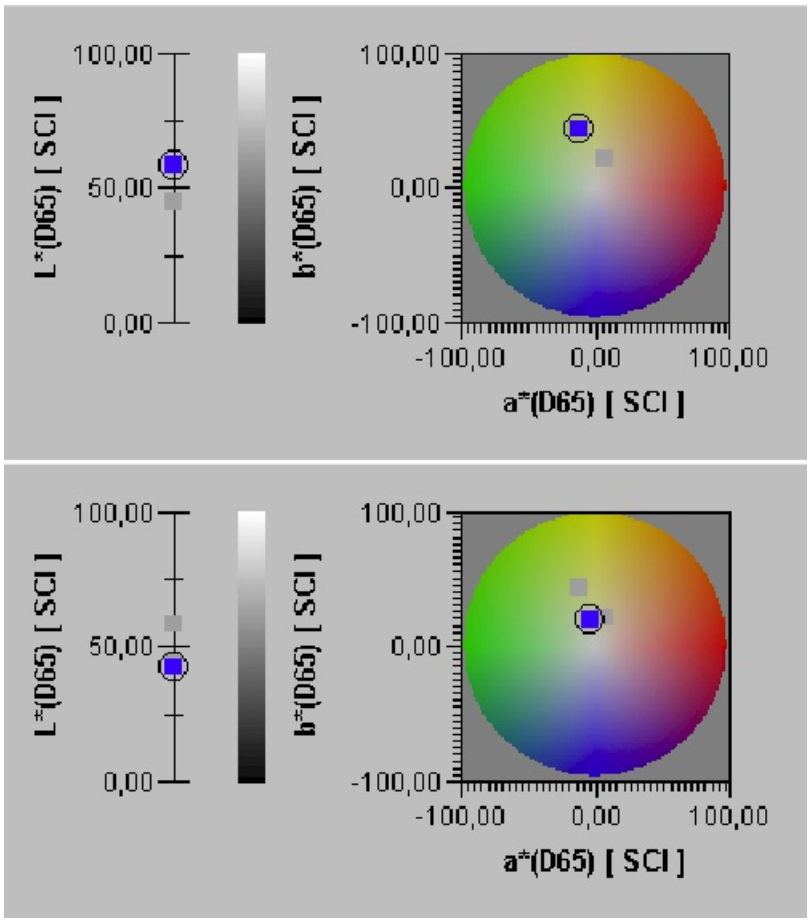

Fig. 3. Brightness of the coniferous needle of *Araucaria araucana* – top side

The average annual growth of Monkey puzzle tree shoots growing in Szczecin in 2012 ranged from 8 to 31 cm. The longest annual growth was generated by trees growing in the gardens at Tarnobrzeska and Okulickiego streets (Tab. 1).

Monkey puzzle trees cultivated in Szczecin grow in the gardens and the most specimens (almost 40% of examined trees) were found in the district Gumieńce. Microclimate of the place of cultivation and plants protection from frost in the first years after planting are also important for success of monkey puzzle tree cultivation in open ground in Szczecin. Origin of plants is also significant. Natural locations are on the slopes of Cordillera Mountains in the Andes. On the western side of Cordillera Mountains very high sums of precipitation (about 2000–4000 mm annually) are noted and temperature in winter ranges from -5 to -10°C and in summer is about 30°C. However, on the eastern side climate is more severe, sum of precipitation comes to about 600 mm and temperature in winter falls even to -20°C.

Plants cultivated in Europe are probably obtained from seeds collected from trees growing on the western slopes of the Andes and that is why they are sometimes less resistant to low temperature [24]. Johnson and More [5] are of the opinion that trees growing in European collections are more genetically diverse than those growing in natural locations and it probably also affects the increase of frost resistance of plants. After winter of 2006 (Tab. 2) when minimal temperature -26°C was noted most of observed trees were characterized by the greatest frost damages. During that winter in Szczecin and in the Glinna Arboretum many evergreen trees were frozen, e.g. cherry laurel (*Prunus laurocerasus* L.), common holly (*Ilex aquifolium* L.), scarlet firethorn (*Pyracantha coccinea* M. Roem.), privet honeysuckle (*Lonicera pileata* Oliv.) and bearberry cotoneaster (*Cotoneaster dammeri* C. K. Schneid.) – Nowakowska and Baran [17].

According to Krüssmann [8] first frost damages are observed when air temperature comes to -10°C. Hrynkiewicz-Sudnik et al. [4] show that monkey puzzle tree is characterized by 4 degree of acclimatization what means that every year or almost every year it is partially or totally frozen and is able to grow in the ground on condition that ecological conditions are favourable or every year plant is protected from winter. This information is partially consistent with results of field research conducted in the years 2004–2012. In the left-bank part of Szczecin totally over 50 locations of young monkey puzzle trees of height of 0.5–1.5 m were catalogued and those specimens were not taken into account in this article because of frequent losses of plants caused by the fact that they were totally frozen in young age. It was found that covering, especially in the first years after planting, affects the decrease of results of low winter temperature. In the treetops of most of young trees of height of over 2 m no considerable damages of sprouts and needles were observed however, sometimes needles were slightly anthocyanin overcoloured.

With regard for attractive and exotic appearance of trees and success of cultivation of some of them study above will be continued and it would be useful to extend the range of the study and to conduct physiological and genetic research.

CONCLUSION

1. In the years 1998–2012 thirteen locations of cultivation of monkey puzzle tree of height of over 1.5 m were found in Szczecin. The oldest of the monkey puzzle trees cultivated since 1990 was characterized by the height of 6 m, trunk circumference of 59 cm at the height of 1.3 m over ground level and 14 whorls of sprouts.
2. The greatest damages of needles, frozen sprouts and even totally frozen plants were observed after winters of 2005/2006, 2009/2010 and 2011/2012 with temperature decrease over -20°C.
3. The observed anthocyanin discoloration and browning of needles does not indicate any loss of viability, but decreases the decorative value of trees.
4. In the araucaria growing in Szczecin (zone 7a) different effects of frost damage, including total freezing of young plants can be seen, even despite the use of aboveground shields.
5. As a species at high risk of growing in the climatic conditions of Szczecin, Monkey puzzle tree can only be recommended for use in amateur cultivation.

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