Long-Lasting Changes in the Species Spectrum of Cucurbit Powdery Mildew in the Czech Republic – Influence of Air Temperature Changes or Random Effect?

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Abstract: Two ectoparasite powdery mildew species *Golovinomyces cichoracearum* (*Gc*) and *Podosphaera xanthii* (*Px*) occurring on cucurbits differ, besides other characteristics, by specific ecologic requirements. While *Px* is common in subtropical and tropical areas and greenhouse crops, *Gc* occurs more frequently in temperate and cooler areas under field conditions. Their presence on cucurbit field crops (*Cucurbita pepo*, *C. maxima*, *Cucumis sativus*) was monitored in the Czechoslovakia (1979–1980) and in the Czech Republic (1995–2007). Their identification was carried out by microscopic observation of the morphological characteristics of the dry conidia on 1527 leaf samples. Data on air temperature in 1979–2007 were provided by the Czech Hydrometeorological Institute. In 1979–1980 *Gc* was identified in 86.0% of samples, *Px* in 14.0% samples, there was no mixed infection; prevalence of *Px* was recorded in South Slovakia and South Moravia, and on crops under cover. Since 1995 species *Px* was recorded each year on field crops in different locations of Bohemia and Moravia, usually in mixed infection with *Gc.* The average year temperature of 8.1°C for period 1992–2007 was higher than corresponding value of 7.4°C in 1979–1983. Similarly, average temperature in vegetation season of 16.2°C in 1992–2007 was higher than corresponding value of 15.7°C in 1979–1983. The higher air temperature can positively influence spreading of *Px* in the Czech Republic. Climate variability and effect of their changes are discussed in relationship to the geographic distribution and geographic patterns of cucurbit powdery mildews.

Keywords: *Golovinomyces cichoracearum*; *Podosphaera xanthii*; Cucurbitaceae; epidemiology; air temperature; geographic distribution

Powdery mildew is a serious disease of field and greenhouse cucurbit crops worldwide (Sitterly 1978; McGrath & Thomas 1997). Three species are known to cause cucurbit powdery mildew (CPM) (Braun 1995). While the endoparasitic species *Leveillula taurica* (Lev.) Arnaud has only a limited economic importance, the ectoparasitic species *Golovinomyces cichoracearum* (DC.) V.P. Gelyuta (*Gc*) (Vakalounakis & Klironomou 2001), and *Podosphaera xanthii* (Castag.) U. Braun & N. Shish. (*Px*) (Shishkoff 2000) are considered most important (Braun 1995; Pitrat *et al.* 1998).

Besides differences in host range (Braun 1995), response to certain fungicides (McGrath 1996; Hollomon & Wheeler 2002; Sedláková & Lebeda 2004), and pathogenicity (Bardin *et al.* 1997, 1999; Lebeda & Sedláková 2004, 2006; McCreight 2006; Lebeda *et al.* 2008), ectoparasitic species differ also in ecological requirements (Sitterly 1978).

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Powdery mildews differ from most other fungi in their superficial hyphae, their xerophytic existence, and the high water content of their wind-disseminated conidia (Aust & Hoyningen-Huene 1986). They are generally favoured by relatively dry atmospheric conditions, moderate temperature, reduced light, and luxurious plant growth (Yarwood 1957). The combination of climatic factors, i.e. air temperature, humidity, sun light (radiation), wind and rainfall influence dissemination and germination of conidia, mycelial growth and sporulation.

Zlochová (1990) defined the temperature range of 15–25°C as optimum for germination of conidia *G. cichoracearum* (*Gc*) as established by laboratory experiments, and 25–30°C for *P. xanthii*. Experiments carried out by Nagy (1976) revealed that the conidial germination of *P. xanthii* (*Px*) was observed in temperature of 20–30°C with optimum of 22°C; the optimum temperature for *Gc* was 25°C, and this species had larger interval of 15–30°C for conidial germination. Relative humidity has strong effect on conidia germination. Species *Px* is more sensitive to moisture than *Gc*. Turgid conidia of *Px* can persist for 24 h only in saturated atmosphere of 100% R.H., and requires 100% R.H. for conidia germination; viable conidia *Gc* can be found also in 94% R.H. and such humidity is sufficient for their germination (Nagy 1976).

Dry conditions favoured process of colonisation, sporulation and dispersal, of both *Px* and *Gc*, but *Px* tolerates higher moisture content during the infection (Reuveni & Rotem 1974; Nagy 1976). Species *Px* expressed highest infection potential under 15°C and 65% R.H. (Bashi & Aust 1980).

Measured differences in ecological requirements of both species match well their reported distribution under natural conditions. *P. xanthii* is common in subtropical and tropical areas and on greenhouse crops in temperate areas, while *G. cichoracearum* occurs more frequently in temperate and cooler areas (Křístková *et al.* 2009). Both species occur on cucurbits under climatic conditions of the Central Europe. Since the 1960s, *P. xanthii* has been reported as frequent or even predominant as the causal agent of cucurbit powdery mildew in many parts of the world (Jahn *et al.* 2002), as a single species or in mixed infections with *G. cichoracearum* (Wichura 2007; Křístková *et al.* 2009). At the end of the 1970s, *P. xanthii* was not detected on field cucurbit crops of Bohemia and Moravia, i.e. in the recent Czech Republic (Lebeda 1983). Since 1995, *Px* was recorded each year on field crops in many locations of Bohemia and Moravia, usually in mixed infection with *Gc* (Křístková *et al.* 2009).

The main aim of this study was to compare the distribution of cucurbit powdery mildew species in the Czech Republic to air temperature in a period of 1979–2007.

MATERIAL AND METHODS

Collecting and origin of cucurbit powdery mildew samples. The presence of CPMs on cucurbit field crops and their species spectra were monitored in Czechoslovakia (1979–1980) and in the Czech Republic (1995–2007). Altogether 1527 leaf samples of cucurbitaceous vegetable crops (mostly *Cucurbita pepo*, *C. maxima*, *Cucumis sativus*) with symptoms of CPM infection were collected, mainly in the most important growing areas of cucurbits in the Czech Republic, though some marginal areas for cucurbit growing were visited too.

Sampling of leaves followed the assessment of infection degree on plants and CPM distribution within the location: one sample was represented by one to three leaves of different age collected randomly from plants in each location. If several host plant species grown on the field/location, separate samples were collected and analysed. Several locations were visited during one growing period and leaf samples were collected there; some selected locations were visited subsequently of each year.

Microscopic examination of samples and species determination. Leaf samples were dried under laboratory conditions and stored as herbarium specimens. Microscopical preparations were prepared from several places on both sides of leaves. Identification of both CPM species was carried-out by microscopic observation of the morphological characters (shape, presence of fibrosin bodies, character of germ tubes) of the dry conidia in 3% KOH solution (Lebeda 1983). The species structure of CPMs populations was expressed by frequencies of occurrence of single species infections, and/or of mixed infections (for details see Křístková *et al.* 2009).

Methods of processing of temperature data. Data on air temperature (measured 2 m above ground level) were processed from temperature time series provided by the Czech Hydrometeorological Institute (CHMI 2009). These time series can be considered as homogenous. Input

Table 1. Average air temperatures (°C) in the Czech Republic in 1979–2007

Period	Average air temperature (°C)					
	year	June	July	August	September	June–September
1979–1983	7.4	16.1	16.8	16.5	13.3	15.7
1984–1987	6.8	14.2	16.6	16.0	12.5	14.8
1988–1991	8.0	14.8	17.6	17.2	12.8	15.6
1992–1995	8.3	15.9	19.0	18.2	12.7	16.4
1996–1999	7.6	16.1	17.0	17.1	12.7	15.7
2000–2003	8.5	17.1	17.6	18.8	12.2	16.4
2004–2007	8.2	16.6	18.7	16.7	13.4	16.4
1979–2007	7.8	15.8	17.6	17.2	12.8	15.8

Calculated by authors on the base of original data provided by CHMI, Prague, Czech Republic

values, e.g. annual and monthly air temperature were computed at CHMI by use GIS (methods CLIDATA-DEM – linear regression between meteorological station level above sea and digital elevation model) (CHMI 2009).

These time series served for calculation of yearly average air temperatures (1979–2007), average temperatures of individual months representing the main vegetation season for cucurbits (June, July, August and September), and average temperatures of the main vegetation season (June–September). The average air temperatures for years, months and vegetation seasons were calculated for selected groups of years (1979–1983, 1984–1987, 1988–1991, 1992–1995, 1996–1999, 2000–2003, and 2004–2007).

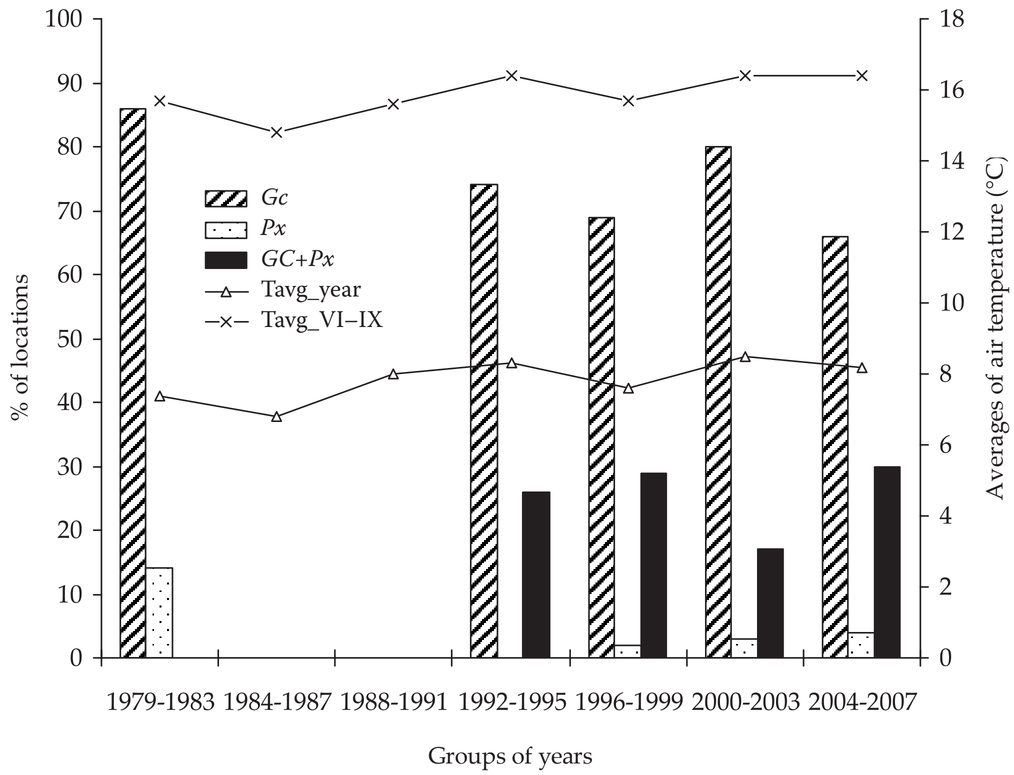
RESULTS

General overview of air temperature in the period 1979–2007, or for selected groups of years, is given in Table 1 and Figure 1. Average year air temperature in the Czech Republic for the period 1979–2007 was 7.8°C, average air temperature of the main vegetation season (for cucurbits) of June–September for the same period was 15.8°C. Average year air temperature in the Czech Republic

Table 2. Occurrence of cucurbit powdery mildew species on cucurbitaceous crops in Czechoslovakia in 1979–1980 (Lebeda 1983) and in the Czech Republic in 1995–2007 (modified according to Křístková *et al.* 2009)

Powdery mildew species	Number of locations						
	1979–1980*	1995	1996	1997	1998	1999	2000
Gc	32	28	48	42	21	27	10
Px	5	0	1	2	0	0	0
Gc+Px	0	10	17	24	14	3	3
Total	37	38	66	68	35	30	13
	2001	2002	2003	2004	2005	2006	2007
Gc	53	78	43	64	43	42	39
Px	2	1	5	1	5	3	1
Gc+Px	4	10	21	7	17	26	36
Total	59	89	69	72	65	71	76

Gc – Golovinomyces cichoracearum; Px – Podosphaera xanthii; Gc+Px – mixed-infection
*Data from Czechoslovakia



Gc – *Golovinomyces cichoracearum; Px* – *Podosphaera xanthii; Gc+Px* – mixed-infection
Tavg_year – average of annual air temperature (°C); Tavg_VI–IX – average of air temperature (°C) in vegetation season (June–September)

Figure 1. Occurrence of cucurbit powdery mildew species in Czechoslovakia in 1979–1980 and in the Czech Republic in 1995–2007 and average air temperatures (°C) in the periods of four-five years

for 20th century was 7.5°C, average air temperature of the main vegetation season (for cucurbits) of June–September for the same period was 15.5°C (Tolasz R. personal communication 2009).

Last decade of the 20th century (1990–2000) was the warmest in the past 100 years (Tolasz *et al.* 2007). This phenomenon was most evident in June, and during vegetation season. This trend is continuing also in the first decade of 21st century (Table 1).

In the studied period, there were substantial temporal and spatial changes in the frequency of both CPM species recorded. In 1979–1980 *Gc* was identified in 86.0% of samples, *Px* in 14.0% samples and there was no mixed infection. Samples with *Px* were recorded in South Slovakia and sporadically in South Moravia, and on crops under cover. Since 1995, when powdery mildews on cucurbitaceous crops were systematically monitored, species *Px* was recorded each year on field crops in multiple locations of Bohemia and Moravia, usually in mixed infection with *Gc* (Křístková *et al.* 2009).

During the period of 1995–2007, there were substantial fluctuations in frequency of occurrence of both powdery midews recorded among the years (Table 2, Figure 1). Frequency of occurrence of *Gc* varied from 51.0% to 90.0% of all locations surveyed in respective year; frequency of *Px* varied from 0% to 8%, and frequency of mixed infections from 8.0% to 48.0%.

The average year temperatures (8.3°C, 7.6°C, 8.5°C and 8.2°C) for four-year periods in 1992–2007 were higher than corresponding value of 7.4°C in 1979–1983. Similarly, average temperatures in vegetation seasons in 1992–2007 were equal or higher than corresponding value in 1979–1983 (Table 1). Average year temperature for 1979–1983 was 7.4°C, for 1992–2007 was 8.1°C; average temperature of vegetation season for 1979–1983 was 15.7°C, and for 1992–2007 was 16.2°C (Figure 1).

DISCUSSION

Climate variability and their changes are one of the many limiting factors for disease ecology and epidemiology. Nevertheless, research in the effects of climate change on plant disease continues to be limited, especially on population and ecosystem levels (Garrett *et al.* 2006). Bio-geographical studies reveal that an unequal distribution of organisms based on endogenic and exogenic factors, is the rule rather than the exception. Transport and spread leads to the colonisation of new habitats. Most organisms, including the powdery mildews, are restricted to specific areas, defined by ecological boundaries and areas of distribution of their respective host plant species (Weltzien 1978). The most complete study on the world wide distribution of powdery mildews was compiled by Hirata (1966), and more generalised study published Weltzien (1978). The most recent study focused on cucurbit powdery mildew geographical distribution (Křístková *et al.* 2009) showed large differences in the occurrence of individual species in Europe and around the world. From this study it is evident that there are some more or less general geographic distribution patterns of CPM. These patterns are probably most enhanced by ecological factors, primarily by temperature (Weltzien 1978). Yarwood (1957) concluded that powdery mildews are more severe in dry weather and are more associated with regions of low rainfall. However, temperature and humidity must be considered together because they are the components of water pressure deficit, a more meaningful parameter than relative humidity in describing water dynamics in host-parasite systems (Jarvis *et al.* 2002).

There are about 118 genera and 825 species of Cucurbitaceae, however only 6 genera and about 12 species are cultivated in larger scale (Lebeda *et al.* 2007) and all these species are hosts of CPMs (Sitterly 1978). CPMs occur throughout the world, however, for individual pathogen species (*L. taurica*, *G. cichoracearum* and *P. xanthii*) have different distribution patterns (Křístková *et al.* 2009). Recently, Ratna Hadi (2005) and Ratna Hadi *et al.* (2005) experimentally confirmed that *P. xanthii* requires for its development higher temperature and lower humidity than *G. cichoracearum*. This is also supported by recent CPMs distribution studies (Křístková *et al.* 2009) and the data about long-lasting temporal dynamics of CPMs summarised in this paper (Figure 1). The question is which factor(s) are the most responsible for these changes. In recent study is considered only temperature, which showed over thirty year period increasing trend. Over the same period there were also recorded changes in the species structure of CPMs. In comparison with the end of 1970s (Lebeda 1983) *P. xanthii* and mixed infections of *G. cichoracearum* and *P. xanthii* are more common. Because of large year to year fluctuations, it is difficult to conclude if *P. xanthii* occupied a new and most northern habitats. Perennation of CPMs, as a biotrophic plant pathogens, is determined largely by their survival between growing seasons. Within a species, the mode of perennation largely depends on the climate (Jarvis *et al.* 2002). In the conditions of the Czech Republic, it is not possible to consider overwintering of CPMs by perennating mycelium. Cleistothecia could be crucial for overwintering, though their role in this process is still controversial (Jarvis *et al.* 2002). Occurrence of cleistothecia of *P. xanthii* in the studied territory is extremely rare (e.g. Křístková *et al.* 2009), so we expect that *P. xanthii* is not permanently present in the Czech Republic. As a primary source of these population changes could be considered long-distance dispersal of conidia by wind (Aust & Hoyningen-Huene 1986) from southern areas of Europe where *P. xanthii* is the most common species, or crops cultivated in greenhouses in certain locations in Bohemia and Moravia (Křístková *et al.* 2009). In the seasonal periodicity of powdery mildews the wind speed is an important factor, as it acts together with temperature and humidity to determine the leaf microclimate and transport patterns (Schnathort 1965). Complex of all these factors will be analyzed in our following studies.

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