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RESPONSE OF CELERY AND CELERIAC CULTIVARS TO INFECTION BY *CERCOSPORA APII*[1]

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Abstract

Early blight is one of the most destructive diseases of celery, celeriac and smalage as well. In 2006–2008 18 celeriac and five celery cultivars were tested in field experiment for reaction to *Cercospora apii*. All the cultivars tested were found susceptible to infection (basing on applied disease severity scale). Moreover, the disease displayed substantial influence on fresh weight of leaves and roots. Mass reduction was variable, depending on year and cultivar, and reached the value up to 90% and 94% for leaves and roots respectively.

Key words: early blight, celery, celeriac, *Cercospora*

Introduction

Early blight, also called Cercospora leaf blight, is considered one of the most important fungal diseases of *Apium graveolens*. It has been reported on celery, celeriac and smalage as well. The causal factor blight is *Cercospora apii*. Despite the fact that it was described as early as 1863 by Fresenius, mycological status of the fungus is still unclear. Chupp (1954) suggested that *Cercospora* is a host specific genus and the range of plants infected by *C. apii* is limited to *A. graveolens*. On the contrary, Crous and Brawn (2003) considered *C. apii* a taxon in which the process of speciation is not yet finished and included to this species 281 morphologically indistinguishable entities previously treated as different *Cercospora* taxons. According to their concept *C. apii* sensu lato is a polyphagous and biologically complex species. Etiology of early blight is additionally complicated by the fact that most recently a new species *C. apicola* occurring on celery was recognized (Groenewald et

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al. 2006). Its role, spread and significance as celery pathogen is so far poorly documented. Early blight is a typical polycyclic disease. The sources of primary infection can be seeds and most often plant debris, where the fungus can survive for over two years. During cultivation period the pathogen is dispersed by conidia, abundantly developed on diseased tissue and easy wind-borne transmitted. Several secondary cycles can be completed at that time (Davis and Raid 2002).

In Poland the occurrence of *C. apii* was confirmed at the beginning of XX century during documentation surveys by Garbowski and Juraszkówna (1933). Most recently epidemic outbreaks of the fungus on celeriac were reported by Nowicki and Zamorski (2004) who stated very high susceptibility of tested cultivars to early blight in their preliminary studies.

The present paper summarizes the results of three years field experiment in which plants response to infection by *C. apii* of two botanical varieties *A. graveolens* var. *dulce* and *A. graveolens* var. *rapaceum* was evaluated and reciprocally compared.

Materials and methods

The studies were performed in 2006–2008 in experimental field of the Department of Plant Pathology, the Warsaw University of Life Sciences.

Plant material

Seeds of currently produced commercial celery and celeriac cultivars were sown into peat substratum in seed trays. After germination seedlings were transplanted to 3 cm pots in the glasshouse. Plant were watered and fed with "Azofoska" as required and planted out to the field at the end of April at three to four leaf stage. The field experiment was arranged in one factor design with three replications for each cultivar. Experimental unit consisted of a plot with celery/celeriac planted in three rows with 50 cm spacing between them. Annually the set of the same 18 cultivars of *A. graveolens* var. *rapaceum* and five cultivars of *A. graveolens* var. *dulce* were included into the experiment.

Inoculation of plants

Plants were inoculated four weeks after transplantation to the field. The source of inoculum was ground dry celery/celeriac leaf tissue, overgrown with *C. apii* mycelium, deriving from plants diseased in previous cropping season. The inoculum was spread over the tested plants at the rate of 100 g dry weight per 1 m^2 of plot. To maintain high relative humidity necessary for conidia production on debris and to create suitable conditions for infection, plants were watered daily by sprinkling with calibrated system providing approximately 0.1 cm water per 1 h. The control plots were kept free of disease throughout growing season by applying chlorotalonil.

Characterization of symptoms

Symptoms associated with early blight on celery and celeriac were characterized on annual plants. Infected plant organs were examined for the occurrence and character of disease changes, i.e. their shape, size, pigmentation and presence of etiological signs.

Assessment methods of disease severity

Three parameters were used for assessing disease severity in each cultivar: percentage of leaves with disease symptoms, percentage of infected petioles and infection degree of leaves, expressed in six-degree scale (**0** – no disease, **1** – discrete spots on 1–10% of leaf area, **2** – single spots on 11–25% of leaf area, **3** – coalescing spots covering 25–50%, **4** – 50–70% of blighted area, **5** – completely damaged leaves with spots on 70% and more of leaf surface). Evaluation of disease parameters was performed on 15 randomly selected plants per plot, six weeks after inoculum introduction.

Leaf and root yield loss

Each year at the middle of September plants were harvested by hand, carefully cleaned from debris and soil and subsequently leaves and roots of 15 plants per plot were individually weighted. Leaf and root indices (%) for data analysis were calculated as weight ratio of infected plants' leaves and roots to healthy plants' leaves and roots.

Data analysis

The occurrence of significant differences in reaction of celeriac and celery cultivars to infection by *C. apii* was verified with one-way ANOVA analysis of variance. Statistical similarity of the mean values for particular cultivars was compared using Fisher's test. Disease intensity – leaf and root index relationships were determined by regression analyses for each year of experiments, separately for *A. graveolens* var. *dulce* and *A. graveolens* var. *rapaceum*. Independent and dependent variables included in statistics represented an average value for particular cultivar plots, which were treated as repetition. Analysis was performed using Statgraphics plus for Windows 4.1 program. All tested hypotheses were verified at $p = 0.05$.

Results

All the above ground plant parts can be infected at different stages of growth. The most characteristic symptoms occur on leaf blades. They appeared on both blade sides approximately 14 days after inoculum introduction. Initially, during early stages of disease small irregular in shape and size chlorotic lesions developed,

without clear border between healthy and diseased tissue. The changes enlarged with disease progress, coalesced, turning into large necrotic area. On the damaged surface of both blade sides etiological symptoms aroused, which were easy recognizable under low magnification. They consisted of stromata, conidiophores and conidia which allowed unequivocal diagnostic of celery blight. At the same time symptoms developed also on petioles. They were dark necrotic spots, usually with slightly sunken tissue.

All the tested cultivars of both botanical varieties, *A. graveolens* var. *dulce* and *A. graveolens* var. *rapaceum*, were susceptible to *C. apii*. In all years analysis of variance revealed that parameters applied for evaluation of disease severity, i.e. percentage of infected leaves, petioles and blades as well as infection degree, differed significantly among 18 celeriac and five celery cultivars (Tables 1, 2).

Table 1

Reaction of celeriac cultivars to infection by *Cercospora apii*

Cultivar	Infected leaves (%)	Infected petioles (%)	Infection degree*	Leaf index** (%)	Root index*** (%)
1	2	3	4	5	6
2006					
'Albin'	60.00 **d**	59.26 **ab**	2.33 **eg**	19.35 **gh**	13.14 **bc**
'Brilant'	46.67 **bc**	55.56 **ab**	2.33 **eg**	22.06 **i**	20.76 **g**
'Cezar'	50.00 **c**	55.56 **ab**	1.83 **bd**	10.48 **de**	14.45 **d**
'Cisko'	40.00 **a**	40.74 **ab**	2.33 **eg**	10.88 **e**	15.98 **e**
'Diamant'	70.00 **e**	62.96 **b**	1.83 **bd**	8.29 **bd**	11.06 **a**
'Edward'	41.67 **ab**	48.15 **ab**	2.00 **ce**	26.37 **j**	17.80 **f**
'Feniks'	66.42 **e**	51.85 **ab**	3.33 **i**	6.11 **a**	10.99 **a**
'Gol'	50.00 **c**	50.00 **ab**	1.39 **ab**	37.95 **k**	25.15 **h**
'Ilona'	71.62 **e**	44.44 **ab**	2.17 **df**	12.10 **e**	19.91 **g**
'Luna'	46.67 **bc**	48.15 **ab**	3.00 **hi**	9.96 **de**	12.34 **b**
'Makar'	60.42 **d**	62.50 **b**	1.63 **ac**	24.47 **j**	29.54 **i**
'Mentor'	46.67 **bc**	33.33 **a**	2.67 **gh**	24.83 **j**	19.97 **g**
'Monarch'	90.78 **f**	51.85 **ab**	2.67 **gh**	10.32 **de**	13.62 **cd**
'Odrzanski'	56.67 **d**	33.33 **a**	2.00 **ce**	26.02 **j**	18.00 **f**
'President'	70.00 **e**	55.56 **ab**	2.67 **gh**	17.60 **fg**	17.94 **f**
'Prinz'	46.67 **bc**	51.85 **ab**	1.33 **a**	20.99 **hi**	17.11 **ef**
'Rex'	40.00 **a**	44.44 **ab**	1.83 **bd**	7.66 **b**	14.03 **cd**
'Talar'	57.14 **d**	0.52 **ab**	2.57 **fh**	16.67 **f**	16.39 **e**
2007					
'Albin'	64.27 **eh**	100.00 **f**	3.82 **fh**	36.08 **c**	63.89 **i**
'Brilant'	57.15 **ab**	90.91 **ef**	3.89 **fh**	30.39 **b**	53.72 **df**

Table 1 – cont.

1	2	3	4	5	6
'Cezar'	54.17 **a**	7.14 **a**	2.82 **ac**	53.18 **f**	58.03 **fg**
'Cisko'	61.88 **df**	100.00 **f**	4.13 **gi**	20.31 **a**	35.28 **a**
'Diamant'	62.41 **eg**	28.57 **ab**	3.07 **bd**	22.00 **a**	44.06 **b**
'Edward'	62.22 **eg**	60.00 **cd**	2.60 **a**	57.59 **g**	93.11 **k**
'Feniks'	62.85 **eh**	93.33 **ef**	2.93 **ac**	62.91 **h**	87.66 **j**
'Gol'	57.63 **ad**	92.86 **ef**	2.69 **ab**	38.37 **cd**	51.89 **de**
'Ilona'	61.78 **df**	92.86 **ef**	4.68 **j**	30.36 **b**	46.04 **bc**
'Luna'	67.08 **h**	100.00 **f**	4.15 **gi**	23.64 **a**	46.33 **bd**
'Makar'	66.28 **gh**	92.86 **ef**	3.07 **bd**	47.43 **e**	59.65 **gh**
'Mentor'	61.22 **be**	78.57 **df**	3.79 **eg**	41.01 **d**	61.48 **hi**
'Monarch'	66.89 **h**	73.33 **ce**	4.13 **gi**	28.95 **b**	48.87 **cd**
'Odrzanski'	61.67 **bf**	50.00 **bc**	3.69 **ef**	27.70 **b**	44.10 **b**
'President'	64.94 **eh**	92.86 **ef**	4.43 **ij**	28.60 **b**	57.59 **fg**
'Prinz'	62.98 **eh**	93.33 **ef**	3.40 **de**	23.51 **a**	48.75 **cd**
'Rex'	57.27 **ac**	78.57 **df**	3.10 **cd**	29.15 **b**	55.98 **ef**
'Talar'	65.75 **fh**	80.00 **df**	4.20 **hi**	34.87 **c**	50.71 **cd**
2008					
'Albin'	61.64 **ce**	85.71 **ce**	2.79 **ce**	35.60 **g**	86.82 **j**
'Brilant'	60.36 **be**	61.54 **ce**	3.00 **eg**	13.75 **a**	19.33 **a**
'Cezar'	60.85 **be**	42.86 **bc**	2.18 **a**	37.14 **g**	32.53 **cd**
'Cisko'	61.52 **be**	14.29 **ab**	3.07 **eg**	17.50 **bc**	22.65 **ab**
'Diamant'	61.49 **be**	40.00 **ac**	2.87 **df**	19.96 **cd**	44.07 **e**
'Edward'	57.05 **ab**	50.00 **c**	2.54 **bd**	39.69 **h**	61.77 **gh**
'Feniks'	61.68 **ce**	60.00 **cd**	3.47 **hi**	29.67 **f**	47.23 **e**
'Gol'	61.30 **be**	35.71 **ac**	2.29 **ab**	49.74 **i**	68.43 **i**
'Ilona'	63.05 **df**	85.71 **ce**	3.54 **ij**	16.92 **b**	28.12 **c**
'Luna'	64.20 **ef**	46.67 **bc**	3.47 **hi**	26.41 **e**	63.41 **hi**
'Makar'	75.61 **h**	42.86 **bc**	2.51 **ac**	35.96 **g**	53.80 **f**
'Mentor'	59.74 **bd**	35.71 **ac**	3.18 **fh**	28.54 **ef**	57.20 **fg**
'Monarch'	62.99 **cf**	85.71 **ce**	3.79 **j**	21.78 **d**	32.26 **cd**
'Odrzanski'	66.25 **fg**	53.33 **cd**	3.00 **eg**	25.96 **e**	46.52 **e**
'President'	53.30 **a**	100.00 **e**	2.93 **eg**	21.60 **d**	25.52 **b**
'Prinz'	58.72 **bc**	92.86 **de**	3.21 **gi**	19.41 **bd**	25.72 **b**
'Rex'	67.45 **g**	35.71 **ac**	3.21 **gi**	17.31 **bc**	41.61 **e**
'Talar'	60.92 **be**	7.69 **a**	3.08 **eg**	28.62 **ef**	35.49 **d**

*Based on 0–5 disease severity scale.
**Calculated as weight ratio of leaves from infected plants to healthy ones.
***Calculated as weight ratio of roots from infected plants to healthy ones.
Numbers followed by the same letter are not significantly different at p = 0.05.

Table 2

Reaction of celery cultivars to infection by *Cercospora apii*

Cultivar	Infected leaves (%)	Infected petioles (%)	Infection degree*	Leaf index** (%)
2006				
'Claret'	43.33 **a**	55.56 **b**	2.67 **c**	12.13 **a**
'Helios'	49.99 **b**	54.29 **b**	1.89 **ab**	36.81 **c**
'Pascal'	40.00 **a**	66.67 **b**	1.67 **a**	39.07 **c**
'Tango'	68.60 **c**	50.00 **b**	2.19 **b**	17.05 **a**
'Zefir'	43.33 **a**	11.11 **a**	2.81 **c**	23.24 **b**
2007				
'Claret'	71.07 **c**	60.00 **a**	4.03 **bc**	23.16 **a**
'Helios'	73.16 **c**	100.00 **b**	4.20 **c**	49.84 **cd**
'Pascal'	52.27 **a**	93.33 **b**	2.53 **a**	51.87 **d**
'Tango'	64.14 **b**	100.00 **b**	3.73 **b**	29.09 **b**
'Zefir'	63.47 **b**	100.00 **b**	3.77 **b**	47.28 **c**
2008				
'Claret'	71.07 **c**	60.00 **bc**	3.00 **c**	23.14 **a**
'Helios'	66.98 **bc**	78.57 **c**	3.68 **d**	46.03 **c**
'Pascal'	63.07 **ab**	38.46 **a**	0.96 **a**	50.00 **c**
'Tango'	61.69 **a**	53.85 **ab**	2.58 **b**	19.16 **a**
'Zefir'	62.20 **a**	69.23 **bc**	2.42 **b**	28.24 **b**

*Based on 0–5 disease severity scale.
**Calculated as weight ratio of leaves from infected plants to healthy ones.
Numbers followed by the same letter are not significantly different at p = 0.05.

Percentage of infected leaves

The highest variability in percentage of infected leaves was stated in 2006. Among the *A. graveolens* var. *rapaceum* cultivars the parameter differed more than twice: from 40% for 'Cisko' and 'Rex' to over 90% for 'Monarch'. In the next years variance of this characteristic was significantly lower: the percentage of infected leaves ranged from 54% for 'Cezar' to 67% for 'Luna' (in 2007) and from 51% to 75% for 'Albin' and 'Makar' (in 2008). Similar results were obtained for *A. graveolens* var. *dulce*. The five tested cultivars displayed the greatest differences in percentage of infected leaves in 2006: 40% and 68% for 'Pascal' and 'Tango', respectively.

Percentage of infected petioles

Petiole infection was noticed in all tested celery and celeriac, however, the value of the parameter differed greatly depending on cultivar and year. The highest percentage of infected petioles of both celery and celeriac was noticed in 2007. Symptoms on at least 80% petioles were exhibited by 10 out of 18 celeriac and four out

of five celery cultivars. In 2008 such infection level was noticed only in five celeriac cultivars, while any of the cultivar exhibited symptoms on petiole at that level (at least 80% of infected petioles) in 2006.

Infection degree of celery and celeriac

Significant differences in reaction between *A. graveolens* var. *rapaceum* and *A. graveolens* var. *dulce* to *C. apii* was proved only in 2008: the mean value of infection degree for celeriac and celery plants was 3.01 and 2.55, respectively. Particular celeriac and celery cultivars differed greatly in their reaction to infection. Among the tested celery cultivars, significantly lowest infection degree over three years exhibited 'Pascal', while celeriac cultivars infected to the lowest degree were 'Gol', 'Edward' and 'Cezar'.

Leaf and root yield loss

Fresh leaf and root weight of infected plants of all tested cultivars of both botanical varieties (*A. graveolens* var. *rapaceum* and *A. graveolens* var. *dulce*) were significantly lower ($p = 0.05$) than those of control plants. In the case of celery cultivars the highest leaf index, calculated as ratio of healthy to damaged leaves, expressed in percentage, was found for 'Pascal'. In 2006, 2007 and 2008 the obtained yield of fresh leaf per plant of 'Pascal' amounted 39, 51 and 50% of non infected, control plants of this cultivar. Over the period mentioned the highest reduction of leaf mass per plant and the lowest leaf index was noticed for 'Claret' and 'Tango'. In the case of 'Claret' particularly strong leaf yield loss per plant due to early blight occurred in 2006. An average plant produced only 12% leaf mass of a healthy (control) plant. In 2007 and 2008 the coefficients were slightly better but the yield of fresh leaf per single 'Claret' plant was still low and constituted in both years only 23%, as compared to the control.

The disease incidence had also significant impact on celeriac yield parameters. The strongest cultivar reaction, similarly to reaction of celery, was recorded in 2006. Among the 18 tested cultivars the highest loss of leaf mass exhibited 'Feniks', which produced on average, per single plant, only 6% of control plant leaf mass. Considerable leaf mass reduction occurred also in cultivars 'Cezar', 'Cisko', 'Diamant', 'Luna', 'Monarch' and 'Rex', which at harvest time had up to 10% leaf mass of control plants. Five of the cultivars mentioned ('Cisko', 'Diamant', 'Luna', 'Monarch' and 'Rex') exhibited stable reaction during the next two study years (2007 and 2008) and belonged to the group of cultivars whose leaf yield loss per plant was the highest.

Celery infection by *C. apii* resulted in significant root weight reduction of all 18 cultivars over three years of studies. In 2006 the lowest index calculated as ratio of healthy root mass to damaged root mass (in %) was noticed for cultivars 'Diamant', 'Feniks', 'Luna' and 'Monarch'. An average plant of these cultivars produced respectively 11, 10, 12 and 13% of control plant roots.

Relationships between infection degree and leaf and root index

The regression analysis proved statistically significant relationship between infection degree and the leaf and root index for both celeriac and celery in each year of the studies (Table 3). For celery the correlation coefficients between infection degree and leaf index ranged from –0.67 to –0.78 and in the consecutive years they were higher than the coefficients for celeriac. Significant and strong relationship between leaf and root index underline obvious dependence between the mass of leaves and roots and explain the influence of leaf damage on root development.

Table 3

Regression analysis between infection degree and leaf and root indices

Year	Evaluated parameter	Celeriac			Celery
		leaf index (y)	root index (y)	root index (y)	leaf index (y)
		Dependent variable			
		infection degree (c)	infection degree (e)	leaf index (h)	infection degree (d)
2008	y	72.96 – 15.21·c	115.32 – 23.11·e	3.80 + 1.54·h	61.94 – 16.19·d
	Correlation coefficient	–0.6627	–0.5138	0.7881	–0.7115
	R^2	43.92	26.39	62.1	50.63
	Standard error	7.3863	16.58	11.89	8.23
	Significance	**	**	**	**
2007	y	89.21 – 14.41·c	112.61 – 15.09·e	19.71 + 1.03·h	68.77 – 7.81·d
	Correlation coefficient	–0.7214	–0.6347	0.87	–0.3937
	R^2	52.05	40.29	74.97	15.51
	Standard error	8.81	11.71	7.58	11.79
	Significance	**	**	**	**
2006	y	29.71 – 5.74·c	25.45 – 3.72·e	8.77 + 0.48·h	43.52 – 4.05·d
	Correlation coefficient	–0.3741	0.4158	0.7889	–0.29
	R^2	14	17.29	62.24	8.52
	Standard error	7.84	4.48	3.24	12.88
	Significance	**	**	**	**

**Significant at p = 0.01.

Discussion

Celery and celeriac requirements during vegetation, i.e. cool temperature, humid and long growing season with ample and uniform supply of moisture (Bouzo et al. 2007) are also favourable for early blight. That is why the disease is present wherever celery is grown intensively and *C. apii* is considered one of its most important pathogens. Paradoxically, literature regarding early blight is scarce, probably due to generally minor market importance and popularity of this vegetable

(Rożek 2007). On average, plant infection by the fungus resulted in losses evaluated at the level 20–25% (Sherf and MacNab 1986). In the performed studies the occurrence of early blight in celery and celeriac crops had substantial influence on all estimated traits: percentage of infected leaves and petioles, infection degree and mass reduction of leaves and roots. Significant relationship between the disease severity and leaf yield loss was proved for both *A. graveolens* var. *dulce* and *A. graveolens* var. *rapaceum*. The association between the parameters mentioned was variable in particular years. The highest value of r^2 was obtained in 2007 for celeriac – 0.40 and celery – 0.61. Regression analysis indicated that plant infection increased by one point (in the applied six-degree scale) resulted in the loss of 20 to 58 g of celeriac fresh leaf weight, depending on year. A stronger reaction was exhibited by celery cultivars: an average increase of infection by one degree caused a loss up to 610 g of fresh leaf weight per plant.

Moreover, the infection of celeriac leaves by *C. apii* had significant influence on the development of root system. The decrease of leaf fresh mass by 1 g due to early blight resulted in the loss of 0.9–1.39 g of root tissue. The negative effect of leaf infection on root system in the simplest way could be explained by compensatory growth of new leaves instead of damaged ones. Usually such compensation process is associated with increased photosynthetic rates, mobilization and retranslocation of stored resources (Boge 2005).

However, biomass of the produced leaves correlated negatively with the infection degree, except for one case: severe infection associated with relatively high yield was observed in 'Helios'. Such exception, with plant ability to reduce the effect of disease, is defined as tolerance. It is a worth noticing phenomenon, which is an often overlooked plant resistance mechanism that may provide alternate solution for reducing crop loss (Kover and Schaal 2002).

In conclusion, results of these studies indicated that commercially produced celery and celeriac were susceptible to early blight. Infection of plants resulted in substantial mass loss of leaves and roots. However, cultivars differed greatly in their reaction.

Streszczenie

REAKCJA ODMIAN SELERA KORZENIOWEGO I SELERA LIŚCIOWEGO NA PORAŻENIE PRZEZ *CERCOSPORA APII*

Badano podatność 18 odmian selera korzeniowego i pięciu odmian selera liściowego na porażenie przez *Cercospora apii*. Stwierdzono, że infekcji mogą ulegać wszystkie nadziemne części roślin. W warunkach prowokowanej epifitozy porażeniu ulegały wszystkie badane odmiany selera. Z punktu widzenia produkcji szczególne znaczenie ma towarzyszące chorobie zniszczenie liści i przedwczesne ich zamieranie, czego konsekwencją są bardzo istotne straty związane z przyrostem bryły korzeniowej.

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