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ORIGINAL PAPER

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THE EFFECT OF FUNGAL ACTIVITY ON PHOTOSYNTHETIC PARAMETERS OF DIFFERENT CANNA CULTIVARS UNDER FIELD CONDITIONS

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ABSTRACT

Three-year studies (2014–2016) were conducted in Lublin in the south-east Poland. The objects of research were the plants of ten canna cultivars: 'Aida', 'America', 'Botanica', 'Cherry Red', 'La Boheme', 'Lucifer', 'Picasso', 'Robert Kemp', 'President' and 'Wyoming'. Observations were carried out each year in October. Plants with symptoms of stem and root rot, leaves yellowing and wilt were noticed on the investigated plantations. The plants were studied with regard to photosynthetic activity and also by disease index for all cultivars and statistical analysis was carried out upon them. The effect of disease index on photosynthetic intensity and transpiration was determined after the calculation of Pearson's correlation coefficient. Infected plants were collected for mycological analysis. The results of mycological analysis showed that canna plants were colonized by *Fusarium* spp., *Sclerotinia* spp. and *Alternaria* spp. *Alternaria alternata*, *Fusarium oxysporum, Fusarium avenaceum* and *Sclerotinia sclerotiorum* predominated among pathogenic species. The best health status and the lowest number of colonies were noticed for plants of cv. 'Botanica'. The infection of canna leaves by pathogenic fungi has negatively affected the intensity of photosynthesis, transpiration, stomatal conductance and sub-stomatal CO_2 concentration and it was largely related to the degree of infestation of specified varieties of canna. The photosynthesis process was limited especially in 'La Boheme', 'Picasso', 'Cherry Red' and 'President' cultivars, which were infected most frequently by pathogenic fungi. It was confirmed by negative Pearson's coefficient.

Key words: diseases, fungi, gas exchange, Indian shot, photosynthesis, transpiration

INTRODUCTION

Canna (family *Cannaceae*) is globally important for its ornamental as well as agricultural importance [Maas-van de Kamer and Maas 2008]. The beauty of cannas is spoiled by many soil-borne and air-borne pathogens. Necrotic lesions on roots, stems and leaves and wilt are the most common symptoms of the diseases. The most important factors responsible for these symptoms are fungal diseases like grey mold and fusariosis. Among the diseases, *Alternaria* leaf blight caused by *Alternaria alternata* is one of the most destructive disease, commonly prevailing in all cannas [Roopa et al. 2014]. Recommended fungicides are often effective but not allowed in urban area. The severity of pathogens does not always manifest itself

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in the form of necrosis or wilting, especially at early stages of plant growth, but can affect the process of photosynthesis [Pospieszny and Struszczyk 2003].

The photosynthesis process is closely linked to plant species or even cultivar, and is modified in considerable degree by environmental conditions, such as temperature, precipitation and its distribution during the growing season, and many other factors [Olszewska et al. 2010]. Simultaneously, photosynthesis is the major physiological plant process, which often suffers from plant pathogens, especially those infecting the leaves [Rios et al. 2017]. It is known that leaf diseases may have destructive effect on the photosynthesis and gas exchange and may dramatically decrease the photosynthesis in various crop plants [Polanco et al. 2014]. Pathogens cause morphological, physiological and biochemical changes, as well as significant decrease in the amount of photosynthetic pigments, and therefore limit the photosynthesis rate, which resulted in reducing the capacity of assimilation apparatus [Lobato et al. 2009, 2010, Alves et al. 2011, Rios et al. 2017]. As a result of plant tissues infestation, many pathogens may impair photosynthesis, even in the initial stage of infection, when no symptoms are visible [Berger et al. 2007, Alves et al. 2011].

The aim of investigations was the estimation of relationship between the infection of selected varieties of canna by pathogenic fungi and intensity of photosynthesis and gas exchange.

MATERIALS AND METHODS

Experimental design. The experiment was conducted in a randomized complete blocks design with four replicates, where block was the random effect. The canna plants were planted in the field in mid-May at 60 × 60 cm spacing. The experimental combination consisted of 12 plants of each cultivar (3 plants in 4 replicates). The observations were conducted in 2014–2016 in the Botanical Garden in Lublin region, Poland (Latitude 51°16'N, Longitude 22°30'E). The objects of study was ten cultivars of canna plants: 'Aida', 'America', 'Botanica', 'Cherry Red', 'La Boheme', 'Lucifer', 'Picasso', 'Robert Kemp', 'President' and 'Wyoming'. Mineral fertilization was used in accordance to recommendations for canna plants. The plants were planted into the pots in March and placed in the soil in May.

Weather parameters. Weather parameters (monthly temperature and rainfall from May to September 2014–2016), were measured at Meteorological Station at Plac Litewski Lublin.

Plant health assessment. The evaluation for the degree of infection was carried out in the first decade of September for the degree of infection, using 5-grade scale: 0 – no symptoms, 1 – yellowing of bottom leaves, 2 – yellow or necrotic spots on all leaves, 3 – wilting, 4 – death. The data were processed by the McKinney's formula [Parafiniuk and Kopacki 2012], which generates a numeric disease index (DI) of the severity of attack: $DI = (\Sigma vn)/(NV) \times 100$, where v represents the numeric value of the class, n is the number of plants assigned to the class, N is the total number of plants in the replication and V is the numeric value of the highest class. The plant health assessment was performed two times in every year, i.e. 10.06.2015 and 10.09.2015, and also on 10.06.2016 and 09.09.2016; however plants have not indicated the disease symptoms in June (3 weeks after the transplanting in target location) and due to that, the disease index was not calculated. The data were analyzed by the analysis of variance (Tukey's test) at 5% significance level using the SAS statistical system (SAS Version 9.1, SAS Inst., Cary, N.C., USA).

Mycological analysis of canna plant. At the first decade of October, selected infected plants were sampled from the field. The plants (leaves and stems) were analyzed in laboratory at University of Life Sciences in Lublin. Plant material was pre-cleaned, rinsed with running water for 20 min and then surface disinfected with 50% ethyl alcohol and 0.1% sublimate for 1 min. Disinfected plant material was rinsed 3 times in distilled water. Next, 3-mm fragments were placed on mineral medium in Petri dishes as described by Kopacki and Wagner [2006]. For each diseased plant, 30 dishes with plant material (10 plant fragments of leaves and stems per each dish) were prepared and incubated in the thermostat at 20–22°C for 7 days in darkness. The obtained fungal colonies were transferred to potato dextrose medium (PDA, Difco) and identified to the species with the available monographs.

Measurement of gas exchange parameters. The measurements of photosynthetic activity of plants were performed in two growing seasons. In every season, the measurements were carried out twice, i.e. at the beginning of July, i.e. 10.06.2015 and 10.06.2016 and at the beginning of September, i.e. 10.09.2015 and 09.09.2016. Ten plants of every cultivars were selected. The measurements of plants were performed on the third completely developed leaf counting from the base of plant, and during the whole season, the same leaves were used, and three measurements were performed on every plant. Following parameters of gas exchange were measured: intensity of photosynthesis (Pn) (μmol $CO_2 \cdot m^{-2} \cdot s^{-1}$), transpiration (E) (mmol $H_2O \cdot m^{-2} \cdot s^{-1}$), stomatal conductance (Gs) (mmol $H_2O \cdot m^{-2} \cdot s^{-1}$) and sub-stomatal CO_2 concentration (Ci) (μmol $CO_2 \cdot m^{-2} \cdot s^{-1}$). They were performed using portable infrared gas exchange analyzer, type CIRAS-2 Portable Photosynthesis System (Hitchin, Herts., UK).

Statistical analysis. The analyzer cuvette conditions were set to external source of carbon dioxide, humidity and temperature equal to ambient and daylight. Obtained results were subjected to statistical analysis using ANOVA and Tukey's confidence intervals at the 5% of significance level ($\alpha = 0.05$). Pearson's correlation coefficient was determined between the photosynthesis, transpiration and disease index in 2015 and 2016.

RESULTS AND DISCUSSION

Weather conditions. Average precipitation per month from May to the end of September in 2014–2016 was analyzed. On the studied area, the temperature and precipitation levels were different from the long-term averages (Tab. 1). Temperatures were higher than the long-term average recorded in May, June, July, August and September. Precipitation exceeded the long-term average (especially in May 2014 and 2015 and July 2016), while the remaining months were much lower than the average for many years [Index Seminum 2015, 2017]. Weather conditions in those months were very favorable for the development of pathogenic fungi. It should be noted that cannas were transferred from greenhouse to field conditions and during rainy weather, it had surely effected the infestation by fungi such as *Sclerotinia sclerotiorum*, *Botrytis cinerea* and *Fusarium* sp. in the following season.

Analysis of the degree of plant infection and fungal biodiversity. The Disease Index measurements of plants conducted in the vegetation period showed index values depending on the study year, weather conditions and variety of cannas. However, no significant statistical differences were noticed. The highest DI were in 2014 (cv. 'Aida') and the lowest in 2016 (cv. 'Botanica', 'Lucifer' and 'President') (Tab. 2).

The results of three-year investigation showed that the weather conditions had effect on the populations of cannas pathogens. We found also differences between monitored cultivars. On the monitored field, all plants had disease symptoms. Yellow, brown or black spots were observed on infected plants, especially on leaves (Figs. 1, 2).

In 2014–2016, as the result of mycological analysis, 4306 fungal colonies were isolated from roots. The predominating species were *Alternaria alternata* and *Fusarium* spp. From stems, 2000 fungal colonies belonging to 18 species were isolated (Tab. 3), while

Table 1. Average monthly temperature (°C) and rainfall in months (mm)

Year	Average monthly temperature (°C)					Sum of rainfall in months (mm)				
	V	VI	VII	VIII	IX	V	VI	VII	VIII	IX
2014	14.6	17.0	21.5	18.8	14.9	175.7	62.7	50.0	78.0	20.9
2015	13.7	18.5	20.9	23.2	15.4	101.7	16.3	21.9	4.7	80.8
2016	15.8	19.9	20.3	19.2	16.4	22.5	35.2	115.9	50.7	14.3
Multiannual mean for 1951–2005	13.0	16.2	17.8	17.7	12.6	57.7	65.7	83.5	79.2	51.6

from leaves – 2306 fungal colonies belonging to 17 species were isolated (Tab. 4).

A. alternata, *Fusarium* spp. and *S. sclerotiorum* predominated among fungi, which are regarded as pathogenic. *F. culmorum* was isolated frequently from all plants, especially from cv. 'America', 'Robert Kemp' and 'La Boheme'. Numerous colonies of *F. avenaceum* were obtained every year, especially from stems of canna cv. 'America', 'Botanica' and 'Lucifer'. *A. alternata* occurred on all plants, but more frequently on stems and leaves, especially in 2016 on cv. 'Picasso'. *S. sclerotiorum* colonized frequently leaves and stems. Also three other fungi: *Cylindrocarpon obtusisporum*, *Thanatheporus cucumeris* and *B. cinerea* were isolated frequently. *C. destructans, Truncatella truncata* and *Phoma exigua* colonised the plants very rarely.

During the time of experiment, statistically significant differences were not observed despite rather low disease index. Probably, with stronger infection pressure, it would be possible to observe the greater differences between the cultivars of canna.

Table 2. Disease Index of canna cultivars growing in 2014–2016

Cultivars	Years of investigations			Average
	2014	2015	2016	
'Aida'	31.500a	20.850a	21.000a	24.45a
'America'	26.250a	16.650a	16.500a	19.80a
'Botanica'	22.500a	15.270a	15.250a	17.67a
'Cherry Red'	25.250a	17.350a	17.250a	19.95a
'La Boheme'	23.750a	17.350a	17.250a	19.45a
'Lucifer'	24.750a	18.750a	15.250a	19.58a
'Picasso'	24.500a	18.720a	18.500a	20.57a
'President'	22.500a	15.270a	15.250a	17.67a
'Robert Kemp'	23.750a	16.650a	21.000a	20.47a
'Wyoming'	26.250a	20.850a	16.500a	21.20a
$NIR_{0.05}$	19.505	11.720	11.458	11.42

Values designated with the same letter in columns do not significantly differ at α = 0,05

Fig. 1. Yellowing and spots on leaves of canna cv. 'Botanic'

Fig. 2. Necrotic spots on leaves of canna cv. 'Cherry Red'

Table 3. Fungi colonizing stems of canna

Year	Fungus species	Cultivars										Total (%)
		Ai	Am	Bo	Ch	LB	Lu	Pi	Pr	RK	Wy	
2014	*Alternaria alternata* (Fr.) Keiss.	13	14	6	23	14	8	4	9		15	106(17)
	Botrytis cinerea Pers. ex Fries.							5				5(1)
	Chaetomium cochlioides							2				2(0)
	Epicoccum nigrum Link						19				4	23(4)
	Fusarium avenaceum (Corda ex Fries) Sacc.	16	2	20	12	4	4	14	16	12		100(16)
	Fusarium culmorum (Smith) Sacc.	26	43	10	15	30	22	24	42	46	47	305(48)
	Fusarium oxysporum Schlecht.	2	7	4	7	2	13	1	2	6	4	48(7)
	Gliocladium catenulatum Gill. et Abb.			5								5(1)
	Penicillium expansum Link ex S.F. Gray			2					2			4(1)
	Truncalella truncata (Lev.) Steyaert							5				5(1)
	Rhizopus stolonifer (Ehrenb.) Vuill.					4						4(1)
	Trichoderma harzianum Rifai					20						20(3)
	Trichoderma koningii Oud.							2				2(0)
	Total	57	66	47	57	74	66	57	71	64	70	629
2015	*Alternaria alternata* (Fr.) Keiss.	7	14	18	26	2	2	18	25	6	13	131(18)
	Botrytis cinerea Pers. ex Fries.		20									20(3)
	Chaetomium cochlioides		2	3							2	7(1)
	Cylindrocarpon destructans (Cooke & Hark.)					2					2	4(1)
	Epicoccum nigrum Link	4					6					10(1)
	Fusarium avenaceum (Corda ex Fries) Sacc.			2	10		21	11		12	9	65(9)
	Fusarium culmorum (Smith) Sacc.	36	4	41	26	42	11	4	30	40	16	250(35)
	Fusarium equiseti (Corda) Sacc.	9	2			13					2	26(4)
	Fusarium oxysporum Schlecht.	5	21			27	7	11	13	7	9	100(14)
	Fusarium solani (Mart.) Sacc.									2		2(0)
	Penicillium expansum Link ex S.F. Gray	3		4		5		2			3	17(2)
	Thanatheporus cucumeris Kühn						4			9	2	15(2)
	Trichoderma koningii Oud.	3	3	18	11			20	8	5		68(10)
	Total	67	66	86	73	78	64	66	78	79	58	715
2016	*Alternaria alternata* (Fr.) Keiss.	19	15	6		10	28	15	19	15	2	129(20)
	Botrytis cinerea Pers. ex Fries.						19	4	2			25(4)
	Chaetomium cochlioides		2	2								4(0)
	Epicoccum nigrum Link		2			8		2	3	2		17(3)
	Fusarium avenaceum (Corda ex Fries) Sacc.		18			10						28(4)
	Fusarium culmorum (Smith) Sacc.		24	17	21	12	3	3	2	19	12	113(17)
	Fusarium equiseti (Corda) Sacc.					2	1	4	17			24(4)
	Fusarium oxysporum Schlecht.		14	32	26	17	27	23	15	37	38	229(34)
	Penicillium notatum Westl.			9		11			2	2		24(4)
	Truncalella truncata (Lev.) Steyaert								11			11(2)
	Phoma exigua Desm.										14	14(2)
	Sclerotinia slerotiorum (Lib.) de By										6	6(1)
	Trichoderma koningii Oud.					20		27			3	32(5)
	Total	19	75	66	43	59	86	87	71	75	75	656

Ai – 'Aida', Am – 'America', Bo – 'Botanica', Ch – 'Cherry Red', LB – 'La Boheme', Lu – 'Lucifer', Pi – 'Picasso', Pr – 'President', RK – 'Robert Kemp', Wy – 'Wyoming'

Table 4. Fungi colonizing leaves of canna

Year	Fungus species	Cultivars										Total (%)
		Ai	Am	Bo	Ch	LB	Lu	Pi	Pr	RK	Wy	
2014	*Alternaria alternata* (Fr.) Keiss.	14	21	11	15	20	20	17	11	9	11	149(23)
	Cylindrocarpon obtusisporum							4				4(1)
	Epicoccum nigrum Link						16					16(2)
	Fusarium avenaceum (Corda ex Fries) Sacc.	10	2	16	11	7	8	23	13	10	2	102(15)
	Fusarium culmorum (Smith) Sacc.	9	43	23	19	35	15	23	29	47	42	285(43)
	Fusarium equiseti (Corda) Sacc.		2									2(0)
	Fusarium oxysporum Schlecht.	3	4	2	12	11	15		2	10	8	67(10)
	Geotrichum candidum Link.	17										17(3)
	Gliocladium catenulatum Gill. et Abb.			6					2			8(1)
	Penicillium expansum Link ex S.F.Gray		2		2							4(1)
	Trichoderma harzianum Rifai					2		4				6(1)
	Total	53	74	58	59	75	74	71	57	76	63	660
2015	*Alternaria alternata* (Fr.) Keiss.	16	18	39	36	27	34	23	35	36	21	285(37)
	Botrytis cinerea Pers. ex Fries.								4			4(1)
	Chaetomium cochlioides	5		17	2					2		26(3)
	Epicoccum nigrum Link	3	21	15		20	9	9	13	15	15	120(16)
	Fusarium avenaceum (Corda ex Fries) Sacc.				2							2(0)
	Fusarium culmorum (Smith) Sacc.	13	11	7	29	5	16	20	19	16	2	138(18)
	Fusarium equiseti (Corda) Sacc.					17		2				19(3)
	Fusarium oxysporum Schlecht.	9	10	2	2	6		2		4		42(6)
	Fusarium solani (Mart.) Sacc.							2				2(0)
	Penicillium expansum Link ex S.F. Gray	2						11	3		10	26(3)
	Sclerotinia slerotiorum (Lib.) de By					4						4(1)
	Trichoderma harzianum Rifai										2	2(0)
	Trichoderma koningii Oud.	6			3		10	14	10	12	14	69(9)
	Total	55	62	80	82	81	76	85	87	84	75	764
2016	*Alternaria alternata* (Fr.) Keiss.	8	66	82	40	71	83	89	86	62	83	670(76)
	Botrytis cinerea Pers. ex Fries.			1			11			13		25(3)
	Epicoccum nigrum Link			1		13		4	4			22(2)
	Fusarium avenaceum (Corda ex Fries) Sacc.			13		6				12	6	37(4)
	Fusarium culmorum (Smith) Sacc.		18		6	4	8	6	4	2	4	52(6)
	Fusarium equiseti (Corda) Sacc.		4	3		2			2	6		17(2)
	Fusarium oxysporum Schlecht.		6		6	3	4		8	13	2	42(5)
	Penicillium nigricans (Bain.) Thom.			4				4				8(1)
	Trichoderma koningii Oud.						5	4				9(1)
	Total	8	94	104	52	99	111	107	104	108	95	882

Ai – 'Aida', Am – 'America', Bo – 'Botanica', Ch – 'Cherry Red', LB – 'La Boheme', Lu – 'Lucifer', Pi – 'Picasso', Pr – 'President', RK – 'Robert Kemp', Wy – 'Wyoming'

Table 5. Values of photosynthesis intensity and gas exchange parameters

Cultivars	Year 2015							
	I term				II term			
	Pn	E	Gs	Ci	Pn	E	Gs	Ci
'Aida'	10.46b–f	1.46g	85.00lm	340.33c–k	10.65a–f	2.05efg	104.00g–m	269.00h–k
'America'	11.06a–f	3.10a–d	153.00a–f	425.00a–h	11.05a–f	3.25abc	152.00a–g	359.50c–k
'Botanica'	15.13a	2.06efg	136.00a–j	549.00a	13.10abc	1.95fg	103.00g–m	456.00a–d
'Cherry Red'	9.93b–g	2.50b–f	89.00j–m	442.33a–g	7.90d–h	2.25d–g	91.00i–m	345.00c–k
'La Boheme'	10.56b–f	2.10efg	96.00h–m	295.00d–k	12.05a–e	2.30d–g	116.50e–m	372.50c–k
'Lucifer'	13.97ab	2.06efg	117.00d–m	479.67abc	10.50b–f	2.30d–g	110.00f–m	432.50a–g
'Picasso'	5.46gh	2.13efg	109.33f–m	438.00a–j	5.75gh	2.05efg	98.00h–m	290.50e–k
'President'	10.56b–f	2.36c–g	130.00a–l	409.00a–j	9.00c–g	3.30ab	78.50m	415.50a–i
'Robert Kemp'	13.43abc	2.43b–f	134.00a–k	537.66ab	11.20a–f	2.40b–f	112.50e–m	478.50abc
'Wyoming'	13.10abc	1.83fg	92.67i–m	343.33c–k	11.05a–f	2.30d–g	99.50h–m	332.00c–k
Mean	11.37a	2.21c	114.23b	425.93a	10.23ab	2.42bc	106,50b	375.10b
	Year 2016							
'Aida'	11.06a–f	2.46b–f	125.67b–m	279.67f–k	7.80d–h	2.56b–f	165.00a–d	331.67c–k
'America'	7.67e–h	3.60a	175.67a	362.67c–k	7.86d–h	2.50b–f	126.67b–m	358.6c–k
'Botanica'	12.26a–d	2.70a–f	170.67ab	460.67abc	14.17ab	2.56b–f	159.00a–e	419.67a–i
'Cherry Red'	12.16a–e	3.10a–d	143.00a–h	319.33c–k	9.10c–g	2.96a–e	142.67a–h	400.67a–i
'La Boheme'	3.86h	2.56b–f	119.00c–m	236.67jk	10.46b–f	2.70a–f	140.00a–i	273.67g–k
'Lucifer'	11.30a–f	2.36c–g	110.67e–m	334.00c–k	11.06a–f	2.30d–g	114.67e–m	377.67b–k
'Picasso'	8.10d–h	2.66b–f	127.67a–l	286.00e–k	5.80gh	2.46b–f	116.50e–m	388.00a–j
'President'	9.00c–g	2.66b–f	129.00a–l	335.66c–k	9.70b–g	2.66b–f	137.67a–i	348.33c–k
'Robert Kemp'	10.40b–f	2.56b–f	125.67b–m	432.33a–g	6.85fgh	3.10a–d	167.00abc	452.6a–d
'Wyoming'	13.70ab	2.36c–g	110.00f–m	218.67k	7.45fgh	2.15efg	85.00lm	263.00ijk
Mean	9.95ab	2.71a	133.70a	326.57c	9.03b	2.60ab	135.50a	361.40bc

Pn – photosynthesis (μmol $CO_2 \cdot m^{-2} \cdot s^{-1}$), E – transpiration rate (mmol $H_2O \cdot m^{-2} \cdot s^{-1}$), Gs – stomatal conductance (mmol $H_2O \cdot m^{-2} \cdot s^{-1}$), Ci – substomatal carbon dioxide concentration (μmol $CO_2 \cdot m^{-2} \cdot s^{-1}$)
Values marked with the same letter do not differ significantly at $\alpha = 0.05$

The results proved that *Alternaria alternata* and *Fusarium* spp. were most probably the cause of diseases of cannas grown in the field conditions. The populations of these fungi differed between years and seasons, which was probably due to weather conditions as the high humidity of soil favors the development of these species [Kopacki and Wagner 2004]. *F. oxysporum* is known as the pathogen of canna in many countries [Turukmane Kunal et al. 2018]. Also *F. culmorum* is regarded as the cause of stem and root rot, as well as flower blight. *Thanatephorus cucumeris*, isolated mostly from stems, was observed also in other countries on ornamental plants as the cause of stem rot and leaf spot [Sharma and Chandel 2013]. *S. sclerotiorum* causes stem rot of many crops under conditions of high humidity [Kessler 2007]. *A. alternata* is regarded very often as a weak pathogen, but its importance for health status of many ornamental crops is increasing recently [Hagan 2001]. In Poland, this species was not connected with

canna diseases, while in tropical countries, it caused considerable losses in canna production [Roopa et al. 2014]. Numerous populations of *A. alternata* obtained in our investigations suggest further studies on its pathogenicity to canna. Very frequent in tropical countries on cannas pathogen *Puccinia thaliae* was not observed [Padamsee and McKenzie 2012]

Frequently isolated antagonistic fungi, like *Trichoderma* sp. or *Chaetomium* sp. and *Epicoccum nigrum*, have a great influence on healthiness of canna plants due to the reduction of pathogenic fungi number, especially in the soil [Ogórek and Pląskowska 2011].

Analysis of obtained results showed significant differentiation of photosynthesis intensity and gas exchange in canna cultivars infected by pathogenic fungi. In performed studies, the lowest photosynthetic intensity was noticed in the second year at 'La Boheme' cultivar, and in the first term amounting only to 3.86 µmol $CO_2 \cdot m^{-2} \cdot s^{-1}$ (Tab. 5). The low level of photosynthesis was measured at cultivars: 'Picasso' in all terms and it was in the range of 5.46–8.10 µmol $CO_2 \cdot m^{-2} \cdot s^{-1}$, 'Cherry Red', 'President' – in all combinations except the first term, and 'America' in the second year of studies and the use of photosynthesis in the range of 7.67–7.86 µmol $CO_2 \cdot m^{-2} \cdot s^{-1}$ (Tab. 5). However, the highest values of photosynthesis intensity were recorded in 'Botanica' and 'Wyoming' cultivars and were in the upper range of values in all terms during two years of studies. Slightly lower values were noticed at 'Lucifer' and 'Robert Kemp' cultivars (Tab. 5).

It has been demonstrated that in 2015, correlation coefficient between photosynthesis (Pn) and disease index (DI) equaled to r = 0.15719 and between the transpiration (E) and disease index (DI), it reached r = 0.44195, which proves a weak and moderate correlation according to Guilford's classification, respectively. The negative signs in both cases reflect the decrease of photosynthesis and transpiration level, which accompany the increase of infestation of plants. In 2016, the Pearson's correlation coefficient between Pn and DI equaled to r = 0.39025, which demonstrates moderate correlation according to J. Guilford. Negative sing determinated in the increase of DI is associated with the decrease of photosynthetic capacity. In the case of comparison, the transpiration coefficient E with disease index DI revealed the correlation coefficient reaching to r = +0.45685 and it demonstrates the moderate correlation. In this regard, the increase of infestation was followed by the increase of transpiration level. The high levels of correlation coefficient in subsequent years may suggest the significant effect of infestation of assimilative system of cannas by disease fungi on transpiration level.

The obtained results confirmed reports of other authors that various cultivars of individual plant species may to a different degree react on infestation by plant pathogens and physiological processes caused by them [Alves et al. 2011, Bispo et al. 2016]. In most diseases, the photosynthesis intensity can decrease from the beginning of infection. In the fact, many pathogens may impair photosynthesis in asymptomatic tissues colonized by pathogens [Berger et al. 2007, Alves et al. 2011]. Low values of photosynthesis corresponded to high air temperatures during vegetable season and small amount and unevenly distributed precipitations. The photosynthesis process is particularly subject to unfavorable climatic conditions, owing to the sensitivity of photosynthetic apparatus in assimilation organs in plants. Reduction in photosynthetic intensity due to water deficiency is related with the decreasing of stomatal conductance and thus the limiting of carbon dioxide availability [Olszewska et al. 2010].

The investigated cultivars differed also in transpiration rate (E). The 'America' and 'Cherry Red' cultivars emitted much water from leaf area unit, in the range 3.60–2.50 mmol $H_2O \cdot m^{-2} \cdot s^{-1}$ and 3.10–2.25 mmol $H_2O \cdot m^{-2} \cdot s^{-1}$, respectively. However, the lowest transpiration was observed in 'Wyoming' cultivar in all terms, (1.83–2.36 mmol $H_2O \cdot m^{-2} \cdot s^{-1}$), and 'Botanica' in the first year of studies, (1.95–2.06 mmol $H_2O \cdot m^{-2} \cdot s^{-1}$) (Tab. 5). Lobato et al. [2010] proved that transpiration rate is correlated with plant infestation degree.

The lowest stomatal conductance (Gs) showed in 'Cherry Red', which falls within the range of 89.00–91.00 mmol $H_2O \cdot m^{-2} \cdot s^{-1}$ in the first year of studies, 'Wyoming' in all terms (85.00–110.00), 'Aida' in the first term (85.00) and 'President' in the second term (78.50). The highest transpiration during performed studies was noticed in 'Botanica' cultivar (Tab. 5).

Bispo et al. [2016] proved that isolates of *Ceratocystis fimbriata* caused the reduction of stomatal conductance, independently of mango cultivar, and

hence the decrease of CO_2 assimilation by limitation of its diffusion. It was confirmed that lower Gs is the one of main restriction of photosynthesis in infected plants by limiting the CO_2 flux into the leaf area [Alves et al. 2011]. Similar to our studies, Riberio et al. [2004] demonstrated on the seedlings of orange that factors of CO_2 assimilation and stomatal conductivity (Gs) were higher in healthy plants than in those infected by *Xylella fastidiosa*. Also Polanco et al. [2014] showed similar relationship in bean plants infected by *Colletotrichum lindemuthianum.*

The lowest concentration of sub-stomatal carbon dioxide (Ci) was noticed in 'Picasso' and 'La Boheme' in comparison to other cultivars in first year of studies (290.50 and 295.00 µmol $CO_2 \cdot m^{-2} \cdot s^{-1}$) and 'Wyoming' in the second year (110.00 µmol $CO_2 \cdot m^{-2} \cdot s^{-1}$). On the other hand, the highest values were observed in 'Botanica' and was in the range 419.67–549.00 µmol $CO_2 \cdot m^{-2} \cdot s^{-1}$ (Tab. 5).

Mikiciuk et al. [2015] demonstrated in their studies that Ci may indicate the significant variability dependent on developmental and physiological stage of plant and is lower at the end of growing period than at the beginning. This trend is also confirmed in our investigations, especially in the first year of studies, when in the first term, a sub-stomatal carbon dioxide concentration reached 425.93 µmol $CO_2 \cdot m^{-2} \cdot s^{-1}$ and differed significantly from values measured in the second term, 375.10 µmol $CO_2 \cdot m^{-2} \cdot s^{-1}$.

CONCLUSIONS

Canna plants were colonized by pathogenic fungi, especially *Fusarium* spp., *Sclerotinia sclerotiorum* and *Alternaria alternata* and frequently antagonistic fungi like *Trichoderma* sp., *Chaetomium* sp. and *Epicoccum nigrum*. The best health status and the lowest number of colonies were noticed for plants of cv. 'Botanica'.

The conducted studies indicate negative effect of pathogens infecting canna on photosynthesis intensity and gas exchange. 'La Boheme', 'Picasso', 'Cherry Red' and 'President' cultivars, more infected by pathogens, conducted photosynthesis and gas exchange on significantly lower level than less infested cultivars like 'Botanica' and 'Wyoming'.

Damage to the photosystem was more severe than external disease symptoms indicated, suggesting that intensity and gas exchange measurements might be helpful in early evaluation of diseases severity.

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