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ORIGINAL PAPER

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HEALTH STATUS OF CARROTS *Daucus carota* L. ssp. *sativus* GROWN IN INTEGRATED AND ORGANIC FARMING SYSTEMS

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ABSTRACT

Carrot culrivars 'Bolero', 'Fayette F1', 'Flakke, Koral', 'Nantes', 'Perfekcja' and 'Sukces' were grown in integrated and organic farming systems. The severity of Alternaria leaf blight and root diseases was evaluated at harvest and after five months of storage. Fungi were isolated from carrot roots. Disease severity was affected by the years of the study, farming system and cultivar. The severity of Alternaria leaf blight was lower in the integrated farming system than in the organic system. Carrots of cvs. 'Bolero' and 'Fayette F1' were healthiest. In both production systems, the symptoms of mixed rot (soft rot, *Pectobacterium carotovorum* subsp. *carotovorum* and Sclerotinia rot, *Sclerotinia sclerotiorum*), dry rot (*Fusarium* spp.), common scab (*Streptomyces scabies*), crater rot (*Rhizoctonia carotae*) and black rot (*Alternaria radicina*, *A. dauci*) were encountered sporadically, and their severity was low on carrot roots analyzed at harvest. Disease symptoms became more severe during storage, and they were more frequently observed on carrot roots in the organic farming system. Cultivars exerted varied effects on the severity of the analyzed root diseases. The fungal pathogens isolated from carrot roots confirmed the presence of disease symptoms.

Key words: *Daucus carota*, farming system, cultivars, roots, diseases, pathogens

INTRODUCTION

Some of the main challenges for the global society in the coming decades will be to overcome the constraints in agriculture while minimizing the adverse effects of farming on ecosystems (decrease in biological diversity, soil and water quality) and human health. The growing interest in food safety and quality stimulates the demand for crops produced in integrated and organic farming systems. Bio-based agronomic practices, breeding methods and crop protection techniques, which minimize the use of mineral fertilizers and pesticides, play a very important role in agriculture and horticulture.

The domestic carrot (family: *Apiaceae*) originated in Asia, and it is one of the most popular vegetables around the world. Carrots are abundant in nutrients, including antioxidants (α- and β-carotene, ascorbic acid, phenolic compounds), and they reduce the risk of cardiovascular diseases, hypertension, stroke and cancer [Leja et al. 2013]. Poland is the third largest producer of carrots in the EU after Spain and Italy. In 2018, Poland produced 726 000 tons of carrots which accounted for 14% of total vegetable production (5.271 million tons). The carrot is the third most popular vegetable after cabbage and tomatoes (field- and greenhouse-grown). In Poland, carrots are cultivated on an area of 22 400 ha, and yields are estimated at 324 dt ha^{-1} [Statistics Poland 2019]. The total area under organic farming has decreased from 605 519.61 ha in 2011 to 484 676.15 ha in 2018, whereas the area under organic vegetable production has increased from 7 266 ha in 2011 to 30 049.9 ha in 2018 [IJHARS 2019].

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Carrot yields and quality are considerably affected by disease incidence and severity. During growth and storage, carrot roots are susceptible to infections caused by *Alternaria dauci* (Kühn) Groves & Skolko, *A. radicina* Meier, Drechsler & Eddy, *Botrytis cinerea* Pers., *Cercospora carotae* (Pass.) Kazn. and Siemaszko, *Pectobacterium carotovorum* subsp. *carotovorum* Hauben, *Sclerotinia sclerotiorum* (Lib.) de Bary, *Fusarium* spp., *Rhizoctonia carotae* Rader G.C. and *Thielaviopsis basicola* (Berk. & Broome) Ferraris pathogens [Farrar et al. 2004, Mazur and Nawrocki 2007a, Nuñez and Davis 2016]. Organic and natural fertilizers are applied in organic and integrated carrot production to minimize the use of mineral fertilizers [Karklelienė et al. 2012]. Seaweed extracts are also used as biostimulants to improve the availability of nutrients [Papenfus et al. 2013]. Chemical agents are replaced by agronomic practices (cultivation of cover crops, mulching), which increase the biological activity of soil and suppress root-rot pathogens. They can also be used to protect plants against pests. In the group of cover crops (oat, tansy phacelia, spring vetch), oat induced the greatest increase in the populations of antagonistic *Clonostachys* spp., *Myrothecium* spp., *Penicillium* spp. and *Trichoderma* spp. in soil, which reduced the counts of pathogenic *S. sclerotiorum*, *A. dauci* and *A. radicina* fungi (and, to a smaller extent, *F. oxysporum* and *R. solani* pathogens) relative to conventional carrot farming systems (without cover crops) [Patkowska et al. 2018, Patkowska 2020]. Endophytic microbiota effectively protect crops against biotic stressors. Bacterial and fungal endophytes from organically-grown carrots were more powerful antagonists of *A. dauci*, compared with conventionally produced carrots [Abdelrazek et al. 2020]. *Ascophyllum nodosum* extracts decreased biotic stress [Jayaraman et al. 2011].

The aim of this study was to evaluate the health of the above-ground plant parts and roots of selected carrot cultivars grown in integrated and organic farming systems.

MATERIALS AND METHODS

Field location, soil conditions, agronomic practices, control of plant pathogens, pests and weeds. The health status of seven carrot cultivars grown in the integrated farming system [Journal of Laws of 2004. No. 11, item 94, as amended] and in the organic farming system [Journal of Laws of 2004, No. 93, item 898, as amended] in north-eastern Poland was evaluated in 2010–2012. The following carrot cultivars were analyzed: early cv. 'Bolero' (Nickerson-Zwaan Ltd.), mid-early cv. 'Nantes 3' (PNOS S.A. Ożarów Mazowiecki), and late cvs. 'Fayette F1' (Bejo Zaden), 'Flakke', 'Koral', 'Perfekcja' and 'Sukces' (PNOS S.A. Ożarów Mazowiecki). Figure 1 shows the location of plantations in the integrated and organic farming systems. In the integrated farming system, cultivated fields spanned an area of more than 5 ha each and were located in:

– Królikowo – Abruptic Luvisols, class IVb [IUSS Working Group World Reference Base for Soil Resources 2015]; field patches with 6 rows each at 6 cm spacing,

– Mielno – Abruptic Luvisols, R IVb; ridge cultivation with 2 rows each at 6–8 cm spacing,

– Rywociny – Abruptic Luvisols, R IVb; ridge cultivation with 2 rows each at 6–8 cm spacing (Region of Warmia and Mazury),

– Szpiegowo – Haplic Luvisols, R IIIb; ridge cultivation with 2 rows each at 6–8 cm spacing (Region of Kuyavia and Pomerania). Farmyard manure was applied at 25 t ha^{-1} to the preceding crops. Mineral fertilizers were applied in the fall of the preceding year at 26.2–34.9 kg P ha^{-1} (triple superphosphate) and 125–166.7 kg K ha^{-1} (50% potash salt), and in the spring before sowing at 80–110 kg N ha^{-1} (urea) (as recommended by the Institute of Horticulture in Skierniewice, Poland). Seeds were dressed with Marshal 250 DS (25% carbosulfan) at 70 g kg^{-1} seeds to protect them against the carrot fly (*Psila rosae*). Plants were double-sprayed with Signum 33 WG (6.7% pyraclostrobin, 26.7% boscalid) at 1 kg ha^{-1} and Amistar 250 SC (25% azoxystrobin) at 0.6 dm^3 ha^{-1} to protect them against pathogens. Weeds were controlled with Linurex 500 SC (42.27% linuron) at 1.5–1.8 dm^3 ha^{-1}, mechanically and manually.

In the organic farming system, cultivated fields spanned an area of up to 0.5 ha each and were located in:

– Godki – Abruptic Luvisols and Dystric Brunic Arenosols, R IVa-V; ridge cultivation with 2 rows each at 6–8 cm spacing,

– Tomaszkowo – Abruptic Luvisols, R IVa; ridge cultivation with 2 rows each at 6–8 cm spacing (Region of Warmia and Mazury),

– Taraskowo – Abruptic Luvisols and Dystric Brunic Arenosols, R IVb-V; ridge cultivation with 2 rows each at 6–8 cm spacing (Podlasie Region),

Fig. 3. Location of carrot plantations. Source: Wierzbowska et al. 2017

– Zgniłobłoty – Haplic Luvisols, R IIIa-IIIb; flat cultivation, row spacing of 35 to 40 cm (Region of Kuyavia and Pomerania). Only farmyard manure was applied at 25 t ha^{-1} to the preceding crops. Pathogens were controlled with the biocontrol agent Grevit 200 SL (0.2% grapefruit extract) applied at 1.5 dm^3 ha^{-1}. The Asahi SL growth biostimulant (0.1% solution, sodium o-nitrophenol, sodium p-nitrophenol, sodium 5-nitroguaiacol) was applied at 0.5 dm^3 ha^{-1} under stress conditions. Weeds were controlled mechanically and manually.

In both farming systems, plants of the *Brassicaceae* family, cereals (winter wheat, winter rye, spring triticale, winter triticale, oat), and grass and legume mixtures were the preceding crops. All agronomic practices were consistent with the recommendations of the Institute of Horticulture in Skierniewice. During the three-year experiment, certified carrot seeds were sown at 1.2–2 mln ha^{-1} between 26 April and 10 May. Roots were harvested between 27 September and 8 October.

Foliar disease severity scoring. The severity of *Alternaria* leaf blight (*Alternaria dauci* (Kühn) Groves & Skolko, *A. radicina* Meier, Drechsler & Eddy; including the symptoms of Cercospora leaf spot *Cercospora carotae* (Pass.) Kazn. & Siemaszko because it is difficult to differentiate between the diseases under field conditions) and powdery mildew (*Erysiphe heraclei* DC) was determined twice, from the stage of leaf development to the stage of root expansion, on 25 plants collected at four different sites in the field in each location, with the use of the following scale: 1° – <5% leaves infected, 3° – 5–30% leaves infected, 5° – 30–60% leaves infected, 7° – 60–90% leaves infected, 9° – >90% leaves infected/severe defoliation [Pawelec et al. 2006]. The results were expressed as the infection index (%), according to the formula:

$$\text{Indection index Ip} = \frac{\Sigma\,(a \cdot b)}{N \cdot I} \cdot 100\%$$

where: $(a \cdot b)$ – sum of the products of the number of the analyzed plants (a) and their severity scores (b), N – total number of the analyzed plants, I – highest severity score.

Root disease severity scoring. The roots of seven carrot cultivars were harvested randomly at four different sites in the field in each location. The health status of carrots was evaluated at harvest and after five months of storage in piles layered with sand. The severity of soft rot (*Pectobacterium carotovorum* subsp. *carotovorum* Hauben) and Sclerotinia rot (*Sclerotinia sclerotiorum* (Lib.) de Bary) – combined analysis, and dry rot (*Fusarium* spp.) was estimated on 5 kg root samples collected in each field. The results were expressed by the percentage of infected roots weight. The severity of common scab (*Streptomyces scabies* (Thaxter) Waksman et Henrici), crater rot (*Rhizoctonia carotae* Rader G.C., teleomorph *Athelia arachnoidea* (Berkeley) Jülich) and black rot (*Alternaria radicina*, *A. dauci*) was evaluated on samples of 50 roots. The severity of common scab was estimated on a 9° scale, where 1° – absence of disease symptoms, 9° – more than 50% of infected root area; of crater rot – on 9° scale, where 1° – absence of disease symptoms, 9° – more than 25% of infected root area; of black rot was evaluated on a 4° scale, where 1 – black lesions without root narrowing, 4° – black lesions with root narrowing >50% at discolored sites. The results were expressed as a percentage by calculating the infection index Ii.

Isolation of fungal pathogens. During the growing season, petioles were collected randomly at four different sites in the field in each location (a pooled sample of 30 petioles from the field in each location). Fungi were isolated from petioles and roots in the laboratory (at harvest and after five months of storage). The cubes (0.5 × 0.5 × 0.5 cm) were cut out from roots and were disinfected with 50% ethanol and 0.1% sodium hypochlorite for 30 sec, they were rinsed three times with sterile water, dried on filter paper, and cultured on the potato-dextrose-agar (PDA) medium.

Statistical analysis. The results were processed statistically by three-way analysis of variance (ANOVA) with the following factors: year, farming system and cultivar, where farming system and cultivar were fixed effects, and years and replications were random effects. The calculations were performed using *STATISTICA* 10 (2013) software (StatSoft, Tulsa, Oklahoma, USA). Mean values were compared by Duncan's test at a significance level of 0.05.

Weather conditions during the growing seasons in the analyzed locations. During the three-year experiment, mean temperatures in April–September were higher than the long-term average (Tab. 1). In all locations, mean temperatures were somewhat higher in the growing season of 2011, compared with the remaining years of the study. Temperatures in the summer (June–July) were comparable, ranging from 17.4 to 18.6°C. July and August 2010 were the warmest months during the entire experiment, and May was coldest, with temperatures below the long-term average. In all locations, total precipitation was highest in 2010 and lowest (but above the long-term average, except in Szpiegowo) in 2012. In the summer of 2010, precipitation was unevenly distributed (except in Szpiegowo), with the heaviest rainfall in August. May was cold and wet due to high precipitation levels (3- to 4-fold higher than the long-term average). July 2011 was also wet, with rainfall levels from 2.6-fold (Rywociny) to 3-fold (Taraskowo) higher than the long-term average. In the last growing season, the highest rainfall (approx. 100 mm) was recorded in June in Zgniłobłoty and Rywociny, and in June and July in the locations monitored by the Weather Station in Olsztyn.

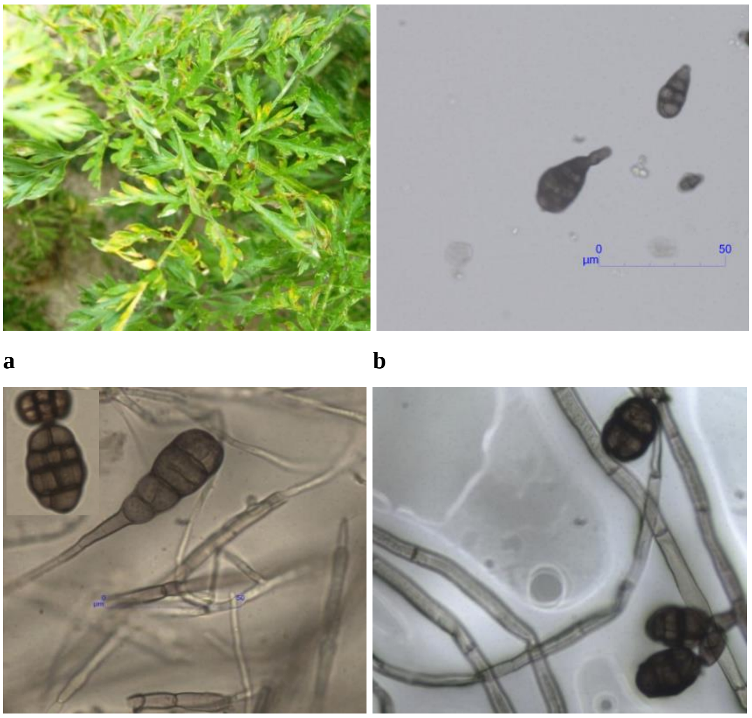
RESULTS AND DISCUSSION

Severity of foliar diseases during the growing season. The symptoms of powdery mildew on carrot plants were observed only sporadically, therefore the results were not presented in the table. Significant differences in the average values of the infection index were noted across the years of the study, which implies that the incidence of *Alternaria* leaf blight (*Alternaria dauci*, *A. radicina*) – Figure 2a was considerably affected by weather conditions. The severity of the disease was lower in the integrated farming system than in the organic system. Carrots of cvs. 'Bolero' and 'Fayette F1' were healthiest (Tabs 2 and 3). In the organic farming system, the highest values of the infection index (approx. 40%) were noted on carrot cvs. 'Flakke', 'Koral' and 'Perfekcja' in 2010, which was very wet and characterized by a hot summer season (significant differences relative to cvs. 'Bolero' and 'Fayette F1'), and on cv. 'Koral' in 2012 (significant differences relative to the remaining cultivars). In the integrated farming system, the highest value of the

Table 1. Weather conditions according to synoptic and climate stations

Year	Month	Zgniłobłoty/ *Lidzbark Działdowski		Szpiegowo/ Płock-Trzepowo		Rywociny/Mława		Mielno, Królikowo, Godki, Tomaszkowo/Olsztyn		Taraskowo/ Myszyniec	
		temp.**	prec.***	temp.	prec.	temp.	prec.	temp.	prec.	temp.	prec.
2010	April	8.0	14.8	9.0	22.0	8.6	14.2	7.9	15.1	7.7	14.0
	May	12.4	101.1	12.8	151.7	12.5	146.7	11.8	149.5	12.8	200.4
	June	16.7	65.2	16.9	108.1	16.4	58.9	16.0	79.4	16.6	84.9
	July	21.2	142.5	21.0	97.3	21.2	56.6	20.9	65.1	20.8	71.9
	August	19.1	121.0	19.2	137.9	19.1	105.2	19.0	130.0	18.7	102.5
	September	10.8	50.1	12.3	51.0	11.8	56.3	12.0	32.1	11.4	43.2
x/∑		14.7	494.7	15.2	546.0	14.9	437.9	14.6	471.2	14.7	516.9
2011	April	9.6	24.8	10.8	17.0	10.3	30.0	9.5	32.2	9.1	45.5
	May	13.4	45.9	14.2	45.3	13.5	64.7	13.2	46.1	13.2	51.3
	June	18.1	37.6	18.3	42.3	17.7	44.5	17.4	61.1	17.6	72.9
	July	17.9	198.3	18.0	200.1	17.8	182.5	18.0	222.2	18.3	215.8
	August	17.6	56.4	18.6	41.6	17.8	58.7	17.7	65.3	17.5	59.0
	September	13.7	24.1	15.0	18.1	14.0	16.0	14.2	20.8	13.4	20.3
x/∑		5.1	387.1	15.8	364.4	15.2	396.4	15.0	447.7	14.9	464.8
2012	April	8.3	49.2	9.3	45.1	8.5	59.9	8.2	73.0	7.8	58.2
	May	14.4	25.1	15.1	27.8	14.4	38.5	13.6	57.3	13.6	51.9
	June	15.4	107.8	16.3	74.1	15.5	105.7	15.1	96.1	15.4	84.3
	July	19.4	82.7	19.8	70.8	19.4	77.3	18.8	104.6	19.5	85.4
	August	18.0	54.2	18.6	47.6	17.9	44.8	17.5	44.3	17.1	54.5
	September	13.4	36.4	14.3	47.9	13.6	29.2	13.6	42.1	12.9	33.9
x/∑		14.8	355.4	15.6	313.3	14.9	355.4	14.5	417.4	14.3	368.2
1985–2004	April	7.3	29.6	8.2	35.3	7.8	38.7	7.3	40.8	7.8	35.4
	May	13.1	51.8	13.6	44.5	13.3	52.1	12.7	57.1	13.6	48.6
	June	15.9	63.8	16.0	64.2	15.8	73.5	15.4	75.0	16.3	68.2
	July	18.0	74.7	18.2	72.3	18.0	70.5	17.7	74.9	18.5	63.5
	August	17.4	49.3	18.0	54.4	17.6	52.8	17.2	61.8	17.6	59.3
	September	12.2	47.9	13.0	50.1	12.5	58.6	12.3	57.9	12.4	63.4
Mean / Total		14.0	317.1	14.5	320.8	14.2	346.2	13.8	367.5	14.4	338.4

* Weather Station located closest to the cultivated field; ** temperature (°C), *** precipitation (mm); x – average temperatures, ∑ – sum of precipitation



a b c d

Fig. 2. a. *Alternaria* leaf blight on carrots; b. Spores of *Alternaria alternata*; c. Spores of *Alternaria dauci*; d. Spores of *Alternaria radicina*

Table 2. Effects of farming system, cultivar and growing conditions on the severity of foliar diseases in carrots

Year			Farming system		Cultivar						
2010	2011	2012	integrated	organic	‘Bolero’	‘Fayette’	‘Flakke’	‘Koral’	‘Nantes’	‘Perfekcja’	‘Sukces’
31.4^{A*}	14.6^{C}	22.7^{B}	19.3^{N}	26.5^{M}	17.7^{Z}	19.1^{Z}	25.0^{Y}	28.0^{X}	22.6^{Y}	24.4^{Y}	23.6^{Y}

* Values followed by the same letters do not differ significantly at $P \leq 0.05$

Table 3. Health status of carrot plants (*Alternaria* spp., *Cercospora carotae*) in 2010–2012 (infection index in %)

Cultivar	Integrated farming system				Organic farming system			
	2010	2011	2012	mean	2010	2011	2012	mean
‘Bolero’	23.6$^{a–e}$*	10.4^{h}	13.5^{gh}	15.8^{b}	27.1$^{c–f}$	13.4^{i}	18.0^{ghi}	19.5^{d}
‘Fayette F1’	23.0$^{a–e}$	9.6^{h}	14.2^{fgh}	15.6^{b}	29.8^{bcd}	15.4^{hi}	22.6$^{d–h}$	22.6^{cd}
‘Flakke’	30.1^{a}	11.6^{gh}	21.4$^{b–f}$	21.0^{a}	39.6^{a}	18.9$^{f–i}$	28.2^{cde}	28.9^{b}
‘Koral’	29.7^{a}	13.3^{gh}	25.3$^{a–d}$	22.8^{a}	38.7^{a}	22.3$^{d–h}$	38.8^{a}	33.3^{a}
‘Nantes’	28.1^{abc}	12.0^{gh}	18.7$^{d–g}$	19.6^{ab}	35.1^{abc}	17.0^{ghi}	24.8$^{d–g}$	25.6^{bc}
‘Perfekcja’	28.8^{ab}	12.7^{gh}	20.8$^{c–f}$	20.8^{a}	39.6^{a}	20.0$^{e–i}$	24.7$^{d–g}$	28.1^{b}
‘Sukces’	29.6^{a}	11.5^{gh}	17.0^{ef}	19.4^{ab}	36.8^{ab}	17.1^{ghi}	29.8^{bcd}	27.9^{b}
Mean	27.6^{a}	11.6^{c}	18.7^{b}	–	35.2^{a}	17.7^{c}	26.7^{b}	–

* Statistical data within farming system; values followed by the same letters do not differ significantly at $P \leq 0.05$

infection index (30.1%) was noted in cv. 'Flakke' in 2010, whereas the lowest values of the infection index were recorded in cvs. 'Bolero' and 'Fayette F1' in 2011 (10.4% and 9.6%, respectively). These cultivars were found to be healthiest in both farming systems, and significant differences were observed relative to the most infected cv. 'Koral' (Tabs 2 and 3). An analysis of infection rates in the years of the study revealed differences among locations (Tab. 4). The values of the infection index were significantly lower in Szpiegowo, compared with the remaining locations, during the last two growing seasons in the integrated farming system, and in Zgniłobłoty during the last growing season in the organic farming system. The above results were confirmed by the mean values for the years of the study in both farming systems.

Alternaria dauci, *A. radicina* and the polyphagous *A. alternata* (Fig. 2b–d) are fungal pathogens of carrots [Pryor and Strandberg 2002, Farrar et al. 2004]. According to Irzykowska et al. [2007], cv. 'Koral' is more susceptible to infections caused by *A. radicina* than other carrot cultivars. Rogers and Stevenson [2010] also noted significant differences in the severity of *Alternaria* leaf blight between carrot cultivars, which were reflected in the total root yield. The aggressiveness of *A. dauci* isolates has been studied extensively in different carrot cultivars and under various environmental conditions [Courtial et al. 2018]. Grapefruit extract was effective in controlling *Alternaria* leaf blight during the growing season [Mazur and Nawrocki 2007b]. Töfoli et al. [2019] demonstrated that fluxapyroxad + pyraclostrobin and pyraclostrobin + metiram were more effective in controlling *Alternaria* leaf blight than boscalid + kresoxim-methyl, copper hydroxide and azoxystrobin.

Severity of carrot root diseases (Fig. 3a–f). In the present experiment, the severity of carrot root diseases was affected by weather conditions, farming system and cultivar (Tab. 5). The severity of disease symptoms evaluated on carrot roots at harvest was low. The symptoms of dry rot, common scab and black rot were less severe in the organic farming system, whereas the symptoms of root diseases after storage were less severe in the integrated farming system. The wet growing season of 2010 promoted the development of soft rot and black rot. The percentage of roots infected by *Pectobacterium carotovorum* subsp. *carotovorum* and *Sclerotinia sclerotiorum* did not exceed 5% on a weight basis in the integrated farming system (cvs. 'Perfekcja' and 'Flakke' in the first two years of the study) and 8% in the organic farming system (cvs. 'Bolero' and 'Fayette F1' during the last two growing seasons) – Tab. 6. In both production systems, the symptoms of mixed rot became more severe during storage. The weight of infected roots was significantly highest in the wettest growing season of 2010, at around 30% in the organic farming system (cvs. 'Koral', 'Nantes' and 'Perfekcja') and 26% in the integrated farming system (cvs. 'Koral' and 'Perfekcja'). After storage, cvs. 'Bolero' and 'Nantes' in the integrated farming system and cv. 'Fayette F1' in the organic farming system were characterized by the healthiest roots (Fig. 4a). The incidence of soft rot of carrots (bacterial soft rot) caused by *P. carotovorum* subsp. *carotovorum*, *P. atrosepticum* and *Dickeya dadantii* reaches epidemic proportions during prolonged spells of hot weather (20–25°C) and high soil moisture content [Nuñez and Davis 2016]. Different defense responses of carrot breeding lines to bacterial soft rot have prompted molecular analyses to investigate mechanisms of resistance to the pathogens. Pusz and Pląskowska [2008] reported that the Asahi SL biostimulant reduced the severity of infection caused by *S. sclerotiorum* in rapeseed stems. In a study by Tokeshi et al. [1998], Effective Microorganisms (EM) suppressed *S. sclerotiorum* in lettuce by reducing the number of soil sclerotia and enhancing antibiosis. A biocontrol method involving the use of *Trichoderma* [Geraldine et al. 2013] and *Coniothyrium minitans* [Bitsadze et al. 2015] isolates was effective in degrading sclerotia of *S. sclerotiorum*. The development of cultivars resistant to *S. sclerotiorum* seems promising but challenging, even with the use of genetic engineering strategies [Andrade et al. 2016]. Wang et al. [2015] found that boskalid, fluazinam, fluxapyroxad, pyraclostrobin, penthiopyrad, pycoxystrobin, prothioconazol, trifloxystrobin, tetraconazole and thiophanate-methyl were effective in controlling *S. sclerotiorum.*

Throughout the experiment, in both production systems, the symptoms of dry rot (*Fusarium* spp.) were absent or present sporadically on carrot roots analyzed at harvest (and after storage in 2010). Dry rot symptoms were observed in only 5.5% of roots in cvs. 'Bolero' and 'Fayette F1' in the integrated farming system

Table 4. Health status of carrot plants (*Alternaria* spp., *Cercospora carotae*) in 2010–2012 (infection index, %)

Location	Bol*	Fay	Fla	Kor	Nan	Per	Suk	2010	2011	2012	Mean
					integrated farming system						
Królikowo	16.3^{a}**	15.0^{a}	23.0^{a}	24.1^{a}	20.2^{a}	21.9^{a}	20.4^{a}	28.0^{a}	12.6^{ab}	19.8^{b}	20.1^{AB}
Mielno	16.4^{a}	15.6^{a}	19.4^{a}	22.7^{a}	21.2^{a}	19.7^{a}	16.8^{a}	27.8^{a}	11.0^{bc}	17.6^{b}	18.8^{B}
Rywociny	16.6^{a}	18.8^{a}	25.2^{a}	26.4^{a}	20.6^{a}	25.2^{a}	23.4^{a}	26.8^{a}	13.5^{a}	26.6^{a}	22.3^{A}
Szpiegowo	14.0^{a}	13.0^{a}	16.6^{a}	17.9^{a}	16.3^{a}	16.3^{a}	16.8^{a}	27.5^{a}	9.2^{c}	10.8^{c}	15.8^{C}
					organic farming system						
Godki	21.9^{a}	22.9^{a}	28.4^{a}	35.6^{a}	27.4^{a}	28.0^{a}	26.0^{a}	34.2^{a}	16.5^{a}	30.9^{a}	27.2^{A}
Taraskowo	21.0^{a}	20.6^{a}	29.0^{a}	37.3^{a}	23.8^{a}	29.6^{a}	30.5^{a}	35.3^{a}	15.9^{a}	30.9^{a}	27.4^{A}
Tomaszkowo	17.1^{a}	27.1^{a}	31.6^{a}	34.1^{a}	29.0^{a}	28.3^{a}	30.3^{a}	38.0^{a}	19.3^{a}	27.4^{a}	28.2^{A}
Zgniłobłoty	18.0^{a}	19.8^{a}	26.5^{a}	26.0^{a}	22.2^{a}	26.3^{a}	24.8^{a}	33.5^{a}	19.1^{a}	17.6^{b}	23.4^{B}

* Bol – 'Bolero', Fay – 'Fayette F1', Fla – 'Flakke', Kor – 'Koral', Nan – 'Nantes', Per – 'Perfekcja', Suk – 'Sukces'; ** means followed by the same letters in columns do not differ significantly at $P \leq 0.05$

Fig. 3. Disease symptoms on carrot roots: a. Common scab; b. Soft rot; c. Sclerotinia rot; d. Crater rot; e. Black rot; f. Dry rot

Table 5. Effects of farming system, cultivar and growing conditions on the severity of root diseases in carrots

Disease	Year			Farming system		Cultivar						
	2010	2011	2012	integrated	organic	Bol*	Fay	Fla	Kor	Nan	Per	Suk
at harvest												
Mixed rot	2.0^{B}**	3.6^{A}	2.0^{B}	2.3^{N}	2.8^{M}	2.3^{X}	2.3^{X}	2.45^{X}	1.8Y	2.9^{W}	3.8^{U}	2.3^{X}
Dry rot	0.5^{B}	3.4^{A}	0.7^{B}	2.1^{M}	1.0^{N}	2.1^{U}	1.7^{UW}	1.5^{WX}	1.1^{XY}	0.9^{Y}	2.1^{U}	1.5^{WX}
Common scab	0.2^{C}	2.2^{B}	4.3^{A}	2.8^{M}	1.7^{N}	1.7^{X}	2.1^{WX}	2.7^{U}	2.5^{UW}	2.0^{WX}	1.9^{WX}	3.0^{U}
Crater rot	0.4^{C}	2.4^{B}	2.8^{A}	1.6^{N}	2.1^{M}	0.9^{Z}	1.9^{WXY}	2.3^{W}	1.6^{XY}	2.9^{U}	2.0^{WX}	1.5^{Y}
Black rot	0.9^{C}	0.7^{A}	0.2^{B}	0.4^{M}	0.3^{N}	0.4^{W}	0.2^{X}	0.2^{X}	0.4^{W}	0.2^{X}	0.4^{W}	0.6^{U}
after storage												
Mixed rot	22.2^{A}	13.2^{B}	13.6^{B}	15.2^{N}	17.4^{M}	14.8^{Y}	15.4^{XY}	16.3^{XY}	18.2^{U}	15.3^{XY}	17.9^{UW}	16.6^{WX}
Dry rot	1.3^{C}	14.8^{B}	17.6^{A}	9.9^{N}	12.6^{M}	9.7^{Y}	9.9^{Y}	12.0^{WX}	13.1^{UW}	9.6^{Y}	10.9^{XY}	13.4^{U}
Common scab	0.7^{C}	3.4^{B}	9.0^{A}	4.3^{M}	4.3^{M}	2.8^{Y}	5.4^{U}	5.6^{U}	4.1^{W}	3.1^{XY}	3.9^{WX}	5.7^{U}
Crater rot	3.6^{B}	4.8^{A}	3.5^{B}	3.4^{N}	4.5^{M}	3.7^{W}	3.6^{W}	4.8^{U}	4.6^{U}	4.1^{UW}	3.6^{W}	3.4^{W}
Black rot	6.7^{A}	6.2^{AB}	5.9^{B}	5.5^{N}	7.1^{M}	7.4^{W}	4.6^{Y}	5.9^{X}	5.6^{XY}	5.5^{XY}	6.4^{WX}	8.7^{U}

* Explanation as in Table 4; ** Explanation as in Table 2

Table 6. Infection of carrot roots by *Pectobacterium carotovorum* subsp. *carotovorum* and *Sclerotinia sclerotiorum* – percentage (%) of infected root weight

Cultivar	Integrated farming system						Organic farming system					
	2010		2011		2012		2010		2011		2012	
	har*	st	har	st	har	st	har	st	har	st	har	st
‘Bolero’	2.9$^{k–p}$**	21.3^{b}	3.0$^{k–o}$	8.7^{ij}	0^{pq}	9.2^{hij}	0.4^{rs}	17.3^{def}	7.0^{mno}	13.9$^{g–k}$	0.3^{s}	18.3^{d}
‘Fayette F1’	2.0$^{l–q}$	13.8^{ef}	3.4$^{k–o}$	20.1^{bc}	0^{pq}	16.1^{de}	0.2^{s}	14.2$^{f–j}$	0.5^{rs}	9.1^{lm}	7.9^{mn}	18.8^{cd}
‘Flakke’	2.2$^{k–q}$	17.9^{cd}	4.8^{kl}	19.1^{bc}	0^{pq}	10.7$^{g–j}$	1.5^{qrs}	21.4^{c}	3.8$^{o–r}$	14.1$^{f–k}$	1.8^{qrs}	14.5$^{e–i}$
‘Koral’	2.1$^{k–q}$	25.8^{a}	4.2^{klm}	12.9^{fg}	0^{pq}	11.2$^{f–i}$	2.2^{qrs}	30.2^{a}	1.1^{rs}	11.2^{jkl}	1.0^{rs}	17.6^{de}
‘Nantes’	1.8$^{m–q}$	16.3^{de}	3.8$^{k–n}$	15.5^{de}	1.1$^{n–q}$	8.4^{j}	0.5^{rs}	28.2^{ab}	4.5^{opq}	10.9^{kl}	5.9^{nop}	12.2$^{i–l}$
‘Perfekcja’	5.0^{k}	25.8^{a}	3.7$^{k–o}$	12.2^{fg}	0.8^{opq}	11.5^{fgh}	1.8^{qrs}	29.9^{a}	5.6^{nop}	11.9$^{i–l}$	5.6^{nop}	16.3$^{d–h}$
‘Sukces’	3.8$^{k–n}$	21.7^{b}	3.0$^{k–o}$	12.2^{fg}	0^{pq}	9.2^{hij}	2.0^{qrs}	26.4^{b}	2.0^{qrs}	13.3$^{h–k}$	2.9$^{p–s}$	16.6$^{d–g}$
Mean	2.8^{D}**	20.4^{A}	3.7^{D}	14.4^{B}	0.3^{E}	10.7^{C}	1.2^{E}	23.9^{A}	3.5^{D}	12.0^{C}	3.6^{D}	16.4 ^{B}

* har – after harvest, st – after storage; ** statistical data within farming system; values followed by the same letters do not differ significantly at $P \leq 0.05$

and in approximately 8% of roots in cv. 'Perfekcja' in the organic farming system in 2011 (Tab. 7). Disease symptoms became more severe during carrot storage in the last two years of the study in both production systems. The weight of infected roots was significantly higher in cv. 'Koral' than in the remaining cultivars in the integrated farming system (17% in 2011 and 22% in 2012). The weight of infected roots was higher in the organic farming system, accounting for 25% in cvs. 'Flakke' and 'Sukces' (2011) and 22% in cv. 'Koral' (2012); significant differences were noted relative to the remaining cultivars. The above results were confirmed by the mean values for cultivars in all years of the study (Fig. 2b). As reported by Zhang et al. [2014], Fusarium dry rot of carrots is widespread in Japan and China, reaching an average incidence of up to 80% in the latter country. The disease has been caused by *F. solani*, *F. avenaceum*, *F. culmorum* and, most recently, *F. caeruleum* [Zhang et al. 2014]. In a study by Cwalina-Ambroziak et al. [2015], the Asahi SL biostimulant (as well as Bio-Algeen S-90 and Kelpak SL growth regulators) reduced the rate of infection caused by *Fusarium* spp. in stored potato tubers, and exerted varied effects on the severity of infections caused by *P. carotovorum*, *Streptomyces scabies* and *Rhizoctonia solani.*

In both production systems, the symptoms of common scab (*S. scabies*) were absent or present sporadically on carrot roots analyzed at harvest and after storage in 2010 (Tab. 8). The values of the infection index were significantly higher in integrated and organic farming systems during the last two growing seasons, particularly in 2012 (both at harvest and after storage). In the integrated farming system, the percentage of infected roots analyzed at harvest was significantly higher in cv. 'Sukces' (9.2%), compared with the remaining cultivars. More severe disease symptoms were observed after storage, and the highest percentage of infected roots was noted in cv. 'Fayette F1' (13.2%) in the integrated farming system and in cv. 'Sukces' (15%) in the organic farming system in 2012. The mean values for cultivars point to significant differences in root infection at harvest and after storage in both farming systems (Fig. 5a). Schoneveld [1994] demonstrated that carrots were most susceptible to infection by *S. scabies* 4 to 5 weeks after spring sowing, and infected skin cells died rapidly during dry weather.

The symptoms of crater rot (*Rhizoctonia carotae*) were absent or present sporadically on carrot roots analyzed at harvest in the integrated farming system in 2010 and 2012, and in the organic farming system during the first two growing seasons. The highest value of the infection index (8%) was noted in cv. 'Nantes' in the organic farming system in 2012 (Tab. 9). Disease symptoms got worse during storage, except in the integrated farming system in 2011 and in the organic farming system in 2012. After harvest, the highest value of the infection index was noted in cv. 'Fayette F1' in the organic farming system in 2011. Differences were observed in the rates of root infection in the analyzed carrot cultivars at harvest and after storage in both production systems (Fig. 5b). *Rhizoctonia carotae* (= *Fibularhizoctonia carotae*, sexual stage *Athelia arachnoidea*), the causative agent of crater rot of carrots, is a soil-borne fungal pathogen. The fungus produces a white mycelium and brown sclerotia on the surface of carrot roots under conditions of high humidity and low temperatures [Punja 2002]. In a study by Dłużniewska [2018], grapefruit extract inhibited mycelial growth and sclerotium germination of *Rhizoctonia solani.* Nasir et al. [2018] demonstrated that a combination of *Bacillus pumilus* INR7 and *Trichoderma harzianum* suppressed *Rhizoctonia* root rot of common beans.

The symptoms of infections caused by *Alternaria* fungi were absent or present sporadically on carrot roots analyzed at harvest in both production systems throughout the experiment. The differences in the infection index between the years of the study were not significant and did not exceed 1% (Tab. 10). Storage contributed to disease progression in both farming systems, but the symptoms were more severe in organically grown carrots. The highest values of the infection index were noted in cv. 'Sukces' (9%) in the integrated farming system and in cvs. 'Bolero' and 'Sukces' (12% and higher) in the organic system in 2010, which was confirmed by the mean values for cultivars across years (Fig. 5c). The severity of disease symptoms on carrot roots during storage were affected by cultivars. The fungus *A. radicina*, responsible for root rot and, in earlier growth stages, for leaf spot, causes substantial economic losses [Farrar et al. 2004]. In a study by Chen and Wu [1999], black rot lesions were considerably reduced when carrots were treated with

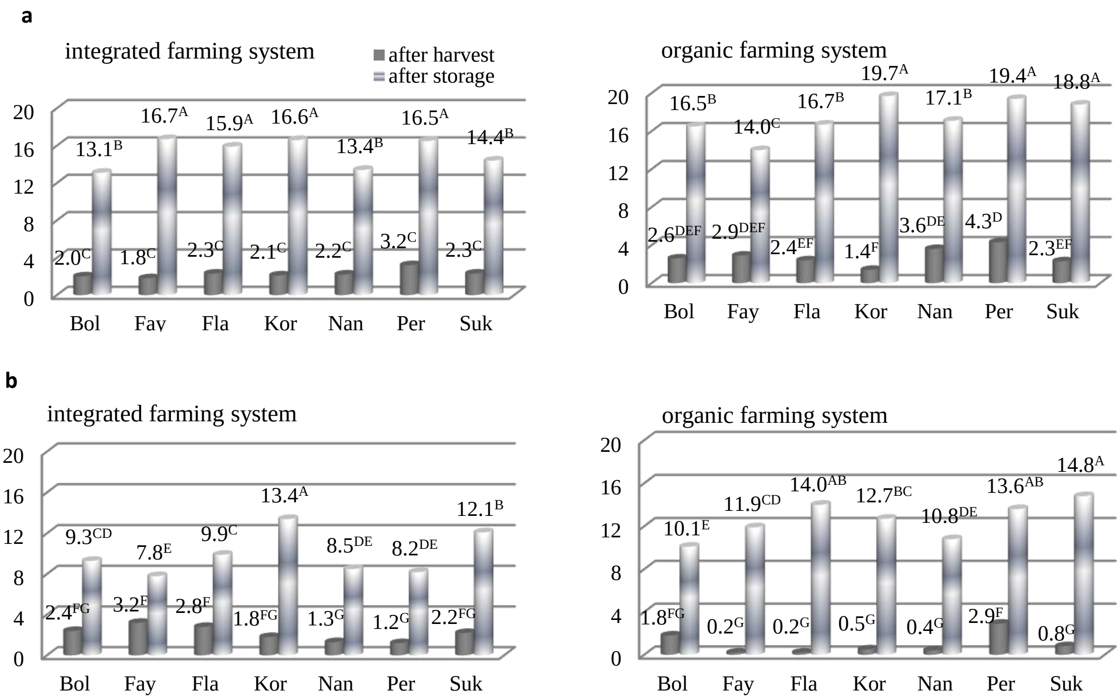


Fig. 4. Infection of carrot roots by pathogens, percentage (%) of infected root weight: a. *Pectobacterium carotovorum* subsp. *carotovorum*, *Sclerotinia sclerotiorum*, b. *Fusarium* spp. Values followed by the same letters do not differ significantly

Table 7. Infection of carrot roots by *Fusarium* spp. – percentage (%) of infected root weight

Cultivar	Integrated farming system						Organic farming system					
	2010		2011		2012		2010		2011		2012	
	har*	st	har	st	har	st	har	st	har	st	har	st
'Bolero'	0^{k}**	2.0^{g-k}	5.5^{f}	9.4^{e}	1.8^{g-k}	16.6^{c}	0^{i}	2.6^{hi}	4.6^{h}	14.5^{e-f}	0.7^{i}	13.2^{f}
'Fayette F1'	1.0^{ijk}	1.0^{ijk}	5.4^{f}	4.0^{fg}	3.1^{f-i}	18.3^{bc}	0^{i}	0^{i}	0.3^{i}	13.9^{e-f}	0.3^{i}	21.7^{b}
'Flakke'	2.4^{g-k}	0^{k}	4.1^{fg}	13.8^{d}	1.8^{g-k}	16.0^{cd}	0^{i}	0^{i}	0.5^{i}	24.7^{a}	0^{i}	17.3^{cde}
'Koral'	1.3^{h-k}	1.8^{g-k}	4.0^{fg}	16.7^{c}	0^{k}	21.7^{a}	0^{i}	0^{i}	0.8^{i}	16.5^{def}	0.6^{i}	21.6^{b}
'Nantes'	0^{k}	0^{k}	3.9^{fgh}	5.6^{f}	0^{k}	19.8^{ab}	0^{i}	0^{i}	0.8^{i}	17.9^{cd}	0.4^{i}	14.5^{ef}
'Perfekcja'	0^{k}	3.4^{f-i}	3.5^{f-i}	10.4^{e}	0.2^{k}	10.8^{e}	0^{i}	2.8^{hi}	7.8^{g}	19.8^{bc}	1.0^{i}	18.3^{cd}
'Sukces'	2.3^{g-k}	2.8^{g-j}	4.3^{fg}	14.2^{d}	0^{k}	19.3^{b}	0^{i}	1.8^{hi}	2.4^{hi}	25.3^{a}	0^{i}	17.2^{cde}
Mean	1.0^{D}**	1.6^{D}	4.4^{C}	10.6^{B}	1.0^{D}	17.5^{A}	0^{E}	1.0^{D}	2.4^{C}	18.8^{A}	0.4^{DE}	17.7^{B}

* har – after harvest, st – after storage; ** explanation as in Table 4

Table 8. Infection of carrot roots by *Streptomyces scabies* – infection index (%)

Cultivar	Integrated farming system						Organic farming system					
	2010		2011		2012		2010		2011		2012	
	har*	st	har	st	har	st	har	st	har	st	har	st
'Bolero'	0^{q}**	0^{q}	3.2^{j-m}	3.2^{j-m}	2.2^{k-q}	7.0^{c-g}	0.6^{j-m}	0.4^{j-m}	1.7^{h-m}	2.5^{g-j}	2.4^{g-k}	3.6^{gh}
'Fayette F1'	0^{q}	0^{q}	1.7^{l-q}	4.3^{h-k}	7.5^{c-f}	13.2^{a}	0^{m}	0^{m}	1.2^{i-m}	5.9^{ef}	2.0^{h-m}	9.0^{cd}
'Flakke'	0.1^{q}	3.5^{i-l}	2.8^{j-o}	3.7^{i-l}	6.6^{efg}	10.1^{b}	0.2^{lmn}	0.7^{j-m}	3.5^{gh}	4.2^{gh}	3.2^{ghi}	11.2^{b}
'Koral'	0.5^{n-q}	0.5^{n-q}	2.8^{j-o}	0.9^{m-q}	7.8^{c-f}	8.7^{b-e}	0^{m}	1.7^{h-m}	1.7^{h-m}	2.4^{g-k}	2.2^{g-l}	10.2^{bc}
'Nantes'	0^{q}	0.4^{n-q}	1.5^{l-q}	1.9^{k-q}	5.1^{g-j}	6.9^{d-g}	0.2^{lmn}	0^{m}	1.7^{h-m}	1.3^{i-m}	3.2^{ghi}	7.8^{d}
'Perfekcja'	0.3^{opq}	0^{q}	2.0^{k-q}	5.6^{f-i}	2.6^{k-p}	6.2^{fgh}	0.7^{j-m}	0.3^{klm}	2.3^{g-l}	3.6^{gh}	3.5^{gh}	7.4^{de}
'Sukces'	0.3^{opq}	2.0^{k-q}	2.3^{k-q}	3.7^{i-l}	9.2^{bcd}	9.3^{bc}	0.5^{j-m}	0^{m}	3.0^{ghi}	4.2^{fg}	2.9^{ghi}	14.9^{a}
Mean	0.2^{E}**	0.9^{E}	2.3^{D}	3.3^{C}	5.9^{B}	8.8^{A}	0.3^{D}	0.4^{D}	2.1^{C}	3.4^{B}	2.8^{C}	9.2^{A}

* har – after harvest, st – after storage; ** explanation as in Table 4

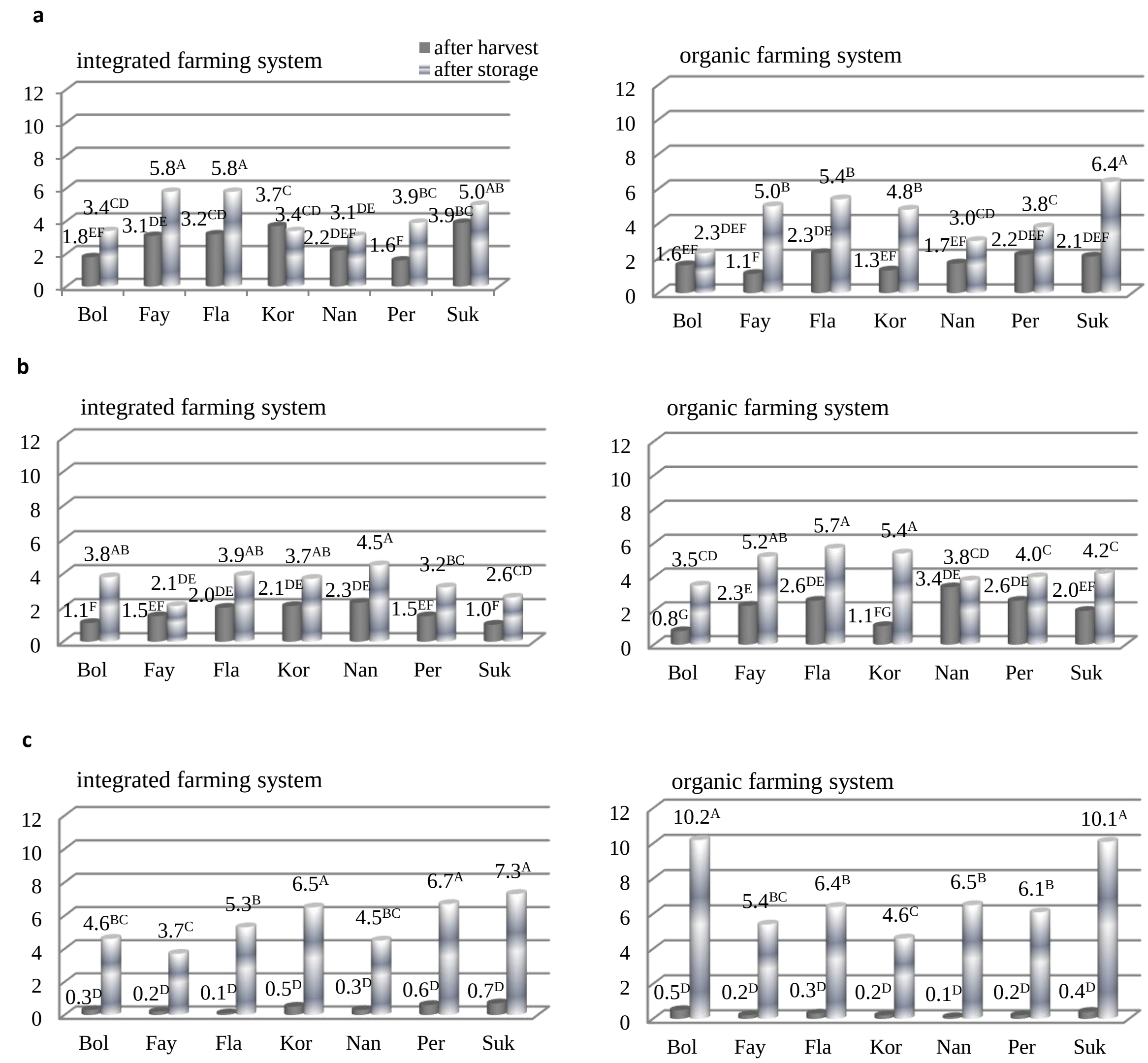


Fig. 5. Infection of carrot roots by pathogens – infection index (%): a. *Streptomyces scabies*, b. *Rhizoctonia carotae*, c. *Alternaria* spp. Values followed by the same letters do not differ significantly

Table 9. Infection of carrot roots by *Rhizoctonia carotae* – infection index (%)

Cultivar	Integrated farming system						Organic farming system					
	2010		2011		2012		2010		2011		2012	
	har*	st	har	st	har	st	har	st	har	st	har	st
‘Bolero’	0^{m}**	5.5^{bc}	2.9^{e-k}	3.6^{d-k}	0.3^{l-m}	2.4^{h-k}	0^{u}	3.3^{i-o}	0.8^{q-u}	5.1^{d-i}	1.6^{p-u}	2.1^{l-s}
‘Fayette F1’	0^{m}	0^{m}	4.4^{c-f}	2.9^{e-k}	0.2^{lm}	3.3^{d-j}	0^{u}	1.8^{n-u}	1.0^{p-u}	10.2^{a}	5.8^{d-k}	3.5^{i-o}
‘Flakke’	0.8^{lm}	6.4^{ab}	3.5^{d-k}	2.5^{h-k}	1.6^{klm}	2.8^{f-k}	0^{u}	4.6^{e-k}	1.3^{p-u}	5.9^{d-g}	6.5^{b-e}	6.7^{bcd}
‘Koral’	2.7^{g-k}	4.4^{c-f}	3.5^{d-k}	3.4^{d-i}	0^{m}	3.3^{d-j}	0^{u}	4.0^{g-l}	0.8^{q-u}	8.3^{b}	2.6^{k-q}	3.9^{h-m}
‘Nantes’	0.7^{lm}	7.3^{a}	4.5^{cde}	3.4^{d-i}	1.7^{jkl}	2.7^{g-k}	0.2^{stu}	4.4^{f-k}	2.2^{l-r}	3.3^{i-o}	7.9^{bc}	3.6^{i-k}
‘Perfekcja’	0.8^{lm}	2.9^{e-k}	3.0^{d-k}	4.2^{c-g}	0.7^{lm}	2.6^{g-k}	0.3^{r-u}	3.8^{i-m}	2.9^{j-p}	4.8^{d-j}	4.5^{f-k}	3.4^{i-o}
‘Sukces’	0.4^{lm}	0.4^{lm}	1.8^{i-l}	2.9^{e-k}	0.8^{lm}	4.6^{bcd}	0.3^{r-u}	2.0^{m-t}	0.8^{q-u}	6.3^{c-f}	4.9^{d-j}	4.4^{f-k}
Mean	0.8^{C}**	3.8^{A}	3.4^{AB}	3.2^{B}	0.8^{C}	3.1^{B}	0.1^{E}	3.4^{C}	1.4^{D}	6.3^{A}	4.8^{B}	3.9^{C}

* har – after harvest, st – after storage; ** explanation as in Table 4

Table 10. Infection of carrot roots by *Alternaria* spp. – infection index (%)

Cultivar	Integrated farming system						Organic farming system					
	2010		2011		2012		2010		2011		2012	
	har*	st	har	st	har	st	har	st	har	st	har	st
'Bolero'	0^{j}**	6.1^{b-e}	0.4^{j}	2.7^{gh}	0.4^{j}	4.9^{c-f}	0^{i}	11.5^{ab}	1.6^{h-i}	11.6^{ab}	0^{i}	7.6^{c}
'Fayette F1'	0^{j}	1.4^{hij}	0.6^{j}	4.7^{def}	0^{j}	4.9^{c-f}	0^{i}	3.3^{gh}	0.6^{i}	5.5^{c-f}	0^{i}	7.5^{c}
'Flakke'	0^{j}	5.2^{c-f}	0.4^{j}	3.7^{fg}	0^{j}	6.9^{b-c}	0^{i}	7.3^{cd}	0.8^{i}	6.9^{cde}	0^{i}	5.1^{efg}
'Koral'	0.3^{j}	7.9^{ab}	1.1^{hij}	6.8^{bcd}	0^{j}	4.8^{c-f}	0.1^{i}	1.0^{i}	0.6^{i}	6.3^{c-f}	0^{i}	6.5^{c-f}
'Nantes'	0^{j}	6.3^{b-e}	0.4^{j}	2.6^{ghi}	0.4^{j}	4.5^{efg}	0^{i}	7.5^{c}	0.3^{i}	7.4^{c}	0^{i}	4.7^{fg}
'Perfekcja'	0.2^{j}	7.4^{b}	1.5^{hij}	7.4^{b}	0^{j}	5.3^{c-f}	0^{i}	6.6^{c-f}	0.5^{i}	5.2^{d-g}	0^{i}	6.5^{c-f}
'Sukces'	0.3^{j}	9.4^{a}	0.5^{j}	6.4^{b-e}	1.3^{hij}	6.0^{b-e}	0.3^{i}	12.8^{a}	0.5^{i}	9.8^{b}	0.4^{i}	7.7^{c}
Mean	0.1^{C}**	6.2^{A}	0.7^{C}	4.9^{B}	0.3^{C}	4.9^{B}	0.1^{C}	7.1^{AB}	0.7^{C}	7.5^{A}	0.1^{C}	6.5^{B}

* har – after harvest, st – after storage; ** explanation as in Table 4

Table 11. Results of the analysis of variance for the severity of carrot diseases

Diseases	Years of the study (Y)	Farming system (FS)	Cultivar (C)	Y × FS	Y × C	FS × C	Y × FS × C
			foliar diseases				
Alternaria leaf blight	**	**	**	ns	ns	ns	ns
			of carrot root at harvest				
Soft rot, Sclerotinia rot	**	**	**	**	**	**	**
Dry rot	**	**	**	**	**	**	**
Common scab	**	**	**	**	**	**	**
Crater rot	**	**	**	**	**	**	**
Black rot	**	**	**	**	**	**	**
			root diseases after storage				
Soft rot, Sclerotinia rot	**	**	**	**	**	**	**
Dry rot	**	**	**	**	**	**	**
Common scab	**	ns	**	ns	**	*	**
Crater rot	**	**	**	***	**	**	**
Black rot	ns	**	**	*	**	**	**

* Significantly at $P < 0.05$; ** significantly at $P < 0.01$; ns – not significant

Table 12. Pathogenic fungi isolated from carrot petioles (%) in 2010–2012

Species	Cultivar						
	Bol*	Fay	Fla	Kor	Nan	Per	Suk
	integrated farming system						
Alternaria alternata (Fr.) Keissler	30.7	23.9	27.4	33.1	26.2	29.8	34.7
Alternaria dauci (J.G. Kühn) J.W. Groves & Skolko	9.3	3.2	6.2	9.3	5.5	9.3	9.1
Alternaria radicina Meier, Drechsler & E.D. Eddy	0.5	4.5	3.5	5.4	2.5	4.6	5.3
Cercospora carotae (Pass.) Kazn. & Siemaszko	2.3	4.2	1.1	0.6	1.1	1.0	0.5
Total (number of isolates)	397	380	372	354	362	409	395
	organic farming system						
Alternaria alternata (Fr.) Keissler	39.4	38.8	37.9	47.4	41.3	34.6	39.9
Alternaria dauci (J.G. Kühn) J.W. Groves & Skolko	7.5	9.8	6.8	10.3	7.8	6.6	5.1
Alternaria radicina Meier, Drechsler & E.D. Eddy	5.7	3.5	6.5	4.7	4.7	6.6	7.6
Cercospora carotae (Pass.) Kazn. & Siemaszko	0.5	0	1.4	1.5	0	0.8	0
Total (number of isolates)	401	317	367	340	344	364	353

***** Explanation as in Table 4

Bacillus cepacia or *B. amyloliquefaciens*. Karklelienė et al. [2012] observed differences in the susceptibility of carrot cultivars to infections caused by *A. radicina* and *S. sclerotiorum*. Cwalina-Ambroziak et al. [2014] found that cv. 'Koral' was more susceptible to infection caused by *A. radicina* than cv. 'Bolero'.

Results of the analysis of variance. Significant differences in the severity of *Alternaria* leaf blight were determined by the main effects: year, farming system and cultivar, but not by interaction effects (Tab. 11). The experimental factors and their interactions significantly influenced the severity of root diseases at harvest and after storage, except for the farming system and the farming system x year interaction for common scab, and year for black rot.

Isolation of fungi from carrot petioles and roots. Species of the genus *Alternaria*, i.e. the most common *A. alternata*, followed by *A. dauci* and *A. radicina*, predominated in the fungal community isolated from carrot petioles. They had a higher share of the fungal community in the organic farming system than in the integrated system, and colonized 62.4% and 47.8% of petioles in cv. 'Koral', respectively (Tab. 12), which is consistent with the results of field analyses of the severity of *Alternaria* leaf blight. Species of the genus *Alternaria* (*A. radicina* followed by *A. dauci*)

Table 13. Pathogenic fungi isolated from carrot roots (%) in 2010–2012

	After harvest							After storage						
	Bol*	Fay	Fla	Kor	Nan	Per	Suk	Bol	Fay	Fla	Kor	Nan	Per	Suk
	integrated farming system													
Alternaria alternata (Fr.) Keissler	19.4	12.1	25.0	13.9	20.0	24.1	21.3	13.9	10.4	17.7	15.0	11.3	18.7	8.8
Alternaria dauci (J.G. Kühn) J.W. Groves & Skolko	0.3	2.2	0.7	2.0	0	0.3	0	0	0	2.4	0	0.3	0	0
Alternaria radicina Meier, Drechsler & E.D. Eddy	1.4	9.6	1.1	17.5	4.3	13.7	13.1	1.5	7.1	5.4	6.7	3.6	5.6	5.4
Fusarium spp.	7.8	9.6	13.8	20.1	15.1	23.8	16.1	8.8	5.4	9.7	16.6	11.8	15.8	25.1
Rhizoctonia carotae Rader, *Botrytis cinerea* Pers., *Sclerotinia sclerotiorum* (Lib.) de Bary	1.4	0.6	5.2	3.3	0.6	0.6	0.9	0	0.5	4.2	0.7	1.3	0	0.9
Total number of isolates	345	322	268	303	345	336	329	339	367	424	433	391	450	331
	organic farming system													
Alternaria alternata (Fr.) Keissler	20.7	16.2	22.1	13.9	22.9	20.1	31.9	2.8	9.9	17.3	12.7	6.3	9.7	12.8
Alternaria dauci (J.G. Kühn) J.W. Groves & Skolko	1.2	3.6	5.3	3.8	1.7	8.5	0	0.2	0	0.2	0.8	0.2	3.0	0
Alternaria radicina Meier, Drechsler & E.D. Eddy	12.5	11.2	17.6	26.0	8.7	17.5	16.5	10.4	9.2	10.9	5.5	6.9	2.8	11.0
Fusarium spp.	12.2	12.3	20.3	15.3	9.3	16.4	21.1	5.2	7.8	10.0	14.6	8.4	7.3	10.2
Rhizoctonia carotae Rader, *Botrytis cinerea* Pers., *Sclerotinia sclerotiorum* (Lib.) de Bary	5.2	2.9	5.3	2.9	7.2	1.1	1.6	0	0.9	0	0.4	0	0.2	0
Total number of isolates	328	277	340	339	345	354	285	424	425	421	529	462	466	509

***** Explanation as in Table 4

were also isolated most frequently from carrot roots at harvest and after storage in both production systems. Most *Alternaria* fungi were isolated at harvest from cv. 'Sukces' in the organic farming system (more than 48%) and from cv. 'Perfekcja' in the integrated farming system (38%) – Table 13. After storage, the above pathogens more frequently colonized cv. 'Flakke' than the remaining cultivars, and organically grown carrots than carrots grown in the integrated system (more than 28% and 25%, respectively). The causative agents of dry rot were less prevalent; they had an over 20% share of the fungal community isolated at harvest (cv. 'Perfekcja' in the integrated farming system and cv. 'Sukces' in the organic farming system) and after storage (cv. 'Sukces' in the integrated farming system). The least prevalent fungal pathogens were the causative agents of crater rot, *Sclerotinia* rot and gray mold rot. In a study by Lima et al. [2016], *A. dauci* and *A. alternata* were isolated during emergence of carrot seedlings.

CONCLUSIONS

1. The health status of carrots was determined by the farming system, cultivar and weather conditions during the growing season. Throughout the experiment, the severity of *Alternaria* leaf blight was lower in the integrated farming system than in the organic system. Carrots of cvs. 'Bolero' and 'Fayette F1' were healthiest, and cv. 'Koral' was most infected. In both production systems, the wet and warm growing season of 2010 promoted the development of *Alternaria* leaf blight.

2. Disease severity was low on carrot roots analyzed at harvest. The symptoms of infections caused by *Fusarium* spp., *S. scabies*, *Alternaria radicina* and *A. dauci* were less severe in the organic farming system. The symptoms of root diseases, mostly soft rot and *Sclerotinia* rot, got worse during storage. The symptoms of infections caused by pathogens were less severe in the integrated farming system.

3. In both farming systems, significant differences were found between cultivars in the severity of root diseases caused by *S. scabies*, *R. carotae* and *Fusarium* spp. at harvest and after storage, and by *P. carotovorum*, *S. sclerotiorum* and *Alternaria* spp. after storage.

4. The isolated *Alternaria* species had a 50% and higher share of the fungal community colonizing carrot petioles, and they were responsible for Alternaria leaf blight. The above pathogens predominated also on carrot roots, potentially pathogenic *Fusarium* species were isolated less frequently, and the causative agents of the remaining root diseases were least prevalent.

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