Essential oils from buds and leaves of two hazelnut (*Corylus L.*) cultivars with different resistance to filbert big bud mite (*Phytoptus avellanae* Nal.) and filbert aphid (*Myzocallis coryli* Goetze)

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Abstract The aim of this study was to identify the allelopathic effect of the components of a mixture of essential oils (EO) contained in the buds and leaves of hazel (*Corylus L.*) on herbivores. We examined the effect of these compounds on the choice of plants of two different hazel cultivars by *Phytoptus avellanae* Nal. (filbert big bud mite) and *Myzocallis coryli* Goetze (filbert aphid), which are the most important pests of hazel in Poland and throughout the world. Our results show that plants of cv. ‘Mogulus’ were more resistant than those of cv. ‘Barra’ to the feeding of mites and aphids in all study years. Using gas chromatography (GC) and GC/mass spectrometry methodology, we determined the qualitative and quantitative composition of EO in the buds and leaves of plants of these two hazel cultivars. The EO obtained from the analysed materials was a mixture of mono- and sesquiterpenes. The emission of volatile organic compounds from plants is known to repel or attract pests. The mixture of EO present in the hazel buds of cv. ‘Mogulus’, which is resistant to

filbert big bud mite, was characterized by a high content of nerol, α -campholenol, methyl salicylate, spatulenol, β -caryophyllene and δ -cadinene. In contrast, the leaves of this cultivar, colonized by filbert aphid but to a relatively small extent, contained greater quantities of nerol, α -campholenol, p-cymene, α -terpineol and germacrene D, than the leaves of cv. ‘Barra’, which is more accepted by aphids. However, the leaves of cv. ‘Barra’ were characterized by a considerably high content of menthol, limonene, isomenthone, methyl salicylate and L-menthone.

Keywords Hazel · Essential oils (EO) · Monoterpenes · GC/MS analysis · Big bud mite · Filbert aphid · Plant–insect interactions

Introduction

A number of factors, both in the course of initial acceptance by the pest and after colonization of the plant, determine the plant’s resistance to pests. This resistance is influenced by both the features of the plant’s morphological structure and the chemical composition of the penetrated plant tissues. Secondary plant metabolites, which act both as the plant’s choice of resistance and during the physiological relationship between pest and plant, are considered to be the most important source of cultivar resistance to pathogenic factors and pests. These factors regulate the behaviour of herbivores and affect the phenomenon of natural resistance (Harborne 1997; Gatehouse 2002; Van Den Boom et al. 2004). Essential oils (EO) are an important group of secondary metabolites which have an allelopathic influence on phytophagous species (Chamberlain et al. 2000; Holopainen 2004; Ibrahim et al. 2001). They occur commonly in the plant world where they

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perform a significant function in the interaction between plants and herbivores. Mono- and sesquiterpenes are aromatic stimuli that can be detected by insects even at considerable distances from the host plants. One of these, limonene, a hydrocarbon oil released by conifers, is largely considered to function as an attractant for herbivorous insects of conifers (Ibrahim et al. 2001). Chapman et al. (1981) showed that the monoterpene carvone is an attractant for the aphid *Cavariella aegopodii* which feeds on parsnip, whereas limonene and α -pinen attract the beetle *Ips pini* (Wallin and Raffa 2000). Certain monoterpenes are known as strong toxins against beetles feeding in the wood of coniferous trees (Cook and Hain 1988) and as deterrents of feeding and egg-laying (Leal et al. 1997). Sesquiterpenes are mainly deterrents of insect feeding, especially feeding by butterfly species (Qiu et al. 1998). Some of these are toxic; for example, zingiberen exudated by *Lycopersicon hirsutum* is toxic for the larvae of the Colorado potato beetle (Carter et al. 1989).

The aim of our study was to determine the effect of the aromatic components of EO occurring in the buds and leaves of two cultivars of hazel (*Corylus* L.) on the degree of acceptance during the initial choice by *Phytoptus avellanae* Nal., an acarine gall-mite species (filbert big bud mite), and *Myzocallis coryli* Goetze, commonly known as the filbert aphid.

Materials and methods

Plant and insect material

Determination of the degree of colonization of leaf buds by *P. avellanae* and of leaves by *M. coryli* was conducted between 2004 and 2006 under field conditions on a production plantation (chemically protected against *Monilia coryli* Schellenb. and *Curculio nucum* L.) located in Końskowola (eastern Poland, 51°40' N, 22°06' E). An additional field location for the filbert aphid was the experimental plantation in Motycz near Lublin (eastern Poland, 51° 14' N 22° 34' E), which was not chemically protected. The studies were conducted on five shrubs of two hazel cultivars, 'Barra' and 'Mogulus', characterized by their different resistance to those two pests.

The degree to which the cultivars were injured by the filbert big bud mite was directly established in the field through determining the percentage of buds with clear signs of deformation. These observations were made in the no-leaf period of the plants. The assessment consisted of determining the percentage of infected buds on ten branches of each shrub, together with the ramifications. In addition, the eggs, larvae and adult forms of Eriophyoidea were counted under a microscope: 20 injured and 20

uninjured buds from each selected shrub of each cultivar were analysed, and the final number of overwintering stages was determined, converted to a value per 10 ml of water, according to the method used by Maziarz (1984). In the case of the filbert aphid, the population of the pest was monitored from early spring until the occurrence of the first larvae on hazel leaves in 10-day intervals. The method used was to count the aphids on 100 leaves of each plant (Wilkaniec 1994). The aphid population was checked at 10-day intervals until it had completely disappeared. The number of larvae and winged females as well as the number of colonized leaves were noted. The level of the pest population on the tested cultivars was expressed as a cumulative aphid index (the sum of aphids on 100 leaves), and the mean percentage of colonized leaves was established.

Laboratory studies

The material for studies were the buds and leaves of two hazel cultivars: 'Barra' and 'Mogulus'. The buds (undamaged by mites) were collected from the plants of these cultivars in April, while the plant was still in the no-leaf period, whereas the leaves (previously covered, undamaged by aphids) were collected in June, which is when the aphid can be found at peak concentrations on hazel (Gantner 2007). The plant material was sampled before noon, on sunny and dry days. Directly after harvesting, the study material was dried at temperatures of up to 35 °C in the shade and under air flow conditions.

Essential oils

Essential oils were obtained using the distillation method with water vapour with the addition of meta-xylene in 20 g of dry air. The EO were analysed using gas chromatography (GC) and GC/mass spectrometry (MS) methodology (Polish Pharmacopoeia VI 2002).

GC and GC/MS determinations

The GC/MS system consisted of an ITMS Varian 4,000 GC-MS/MS instrument (Varian, Palo Alto, CA) equipped with a CP-8410 auto-injector and a 30 m $\times$ 0.25-mm VF-5 ms column (Varian); film thickness was 0.25 μ m, the carrier gas and flow rate was He at 0.5 ml/min, the injector and detector temperatures were 220 and 200 °C, respectively, the split ratio was 1:20 and the inject volume was 1 μ l. A temperature gradient was applied (60 °C for 0.5 min, then increments of 3 °C/min up to 246 °C, then holding at 246 °C for 10 min). The mass ranged from 40 to 1,000 Da, the GC system consisted of a Varian 3800 Series instrument (Varian) equipped with a JW Scientific DB-5

column (Agilent Technologies, Santa Clara, CA) operated under the same conditions as the GC/MS (flame ionization detector 256 °C; split ratio 1:50). The qualitative analysis was carried out on the basis of MS spectra which were compared with the spectra of the NIST library (NIST/EPA/NIH 2002) and from data available in the literature (Joulain and König 1998; Adams 2004). The identification of volatiles was verified with authentic standards purchased from commercial sources (Sigma-Aldrich, St. Louis, MO) that had the same GC retention times and mass spectra. The identify of compounds was confirmed by their retention indices taken from the literature and own data (Joulain and König 1998; Adams 2004). The quantitative composition of oils was determined by GC (flame ionization detector), by assuming the total of all the different oils to be 100 %.

Statistical analysis

For all statistical laboratory experiments and analysis of the results, we used the software package Statistica 9.1 (StatSoft, Tulsa, OK). Analysis of variance with the Tukey simultaneous test was applied, with significance set at $p \leq 0.05$. The average results on the figures were determined with standard deviation. Correlation coefficients between the total aphid population and the number of colonized leaves were calculated. All determinations were performed with five replicates (field experiments) and in triplicate (laboratory experiments).

Results

Field observations showed that the plants of the studied hazel cultivars are characterized by varying resistance to colonization by the filbert big bud mite. The percentage of infected buds of cv. 'Barra' varied during the study years, ranging from 5.4 % in 2004 to 8.4 % in 2005 and up to 13.2 % in 2006. In contrast, the infection index for cv. 'Mogulus', based on visual estimation, remained at the zero level during the same period. Winter analyses of buds deformed by the filbert big bud mite and those without any external signs of its feeding indicated the occurrence of all developmental stages during the winter. Eggs, larvae and adult forms of Eriophyoidea were present a high numbers, ranging from 786.6 in 2004 to 1,533.8 in 2006, with, on average, 1,293.8 individuals. In both cultivars, signs of feeding by the filbert big bud mite were found in buds showing no external signs of feeding, with the population of the wintering stages being more than eightfold higher in the buds of cv. 'Barra' (Table 1).

Parallel field studies on the resistance of the selected hazel cultivars to filbert aphid showed, similar to our observations on the filbert big bud mite, that cv. 'Barra'

was more susceptible to the occurrence of aphids than cv. Mogulus. This pest was more numerous on the chemically protected plantation, and it clearly preferred the leaves of cv. 'Barra' to those of cv. 'Mogulus'. This is reflected both by the higher value of the cumulative aphid index and by the higher percentage of colonized leaves on the plants of cv. 'Barra' (Table 2). We also observed a directly proportional relationship between the total aphid population and the number of colonized leaves, both in the protected plantation ($r = 0.93$) and in the plantation that was not chemically protected ($r = 0.95$). The degree of colonization of the cultivars growing in a protected and unprotected orchard was highly convergent ($r = 0.70$).

Analysis of the results of the laboratory analyses revealed that the content of EO in the study material ranged from 0.32 to 0.46 % in buds and from 0.75 to 0.95 % in leaves. Comparing the studied cultivars, we observed that both the buds and leaves of cv. 'Mogulus' contained more EO than those of cv. 'Barra'. Irrespective of the cultivar, the leaves contained more than twice as many EO than the buds.

The analysis of EO by GC and GC/MS showed the presence of 45 compounds of various chemical groups in the raw materials examined. The chemical composition of the EO changed depending on the kind of raw material, the cultivar and the date of harvest.

Monoterpenes represented >70 % of the EO and therefore constituted the dominating fraction of compounds identified in hazel buds (Fig. 1). The second highest fraction of EO consisted of sesquiterpenes, whose quantity—depending on the cultivar—ranged from 0.3 % (cv. 'Barra') to 2.6 % (cv. 'Mogulus'). The EO obtained from hazel leaves was also a mixture of mono- and sesquiterpenes, whose percentage is graphically presented in Fig. 2.

Our analyses revealed that monoterpene hydrocarbons constituted the main group among the monoterpenes present in the hazel buds of cvs. 'Barra' (42.0 %) and 'Mogulus' (41.4 %). In comparison, in the EO obtained from the leaves of these cultivars, monoterpene hydrocarbons and monoterpenes soluble in water constituted 16.2 and 24.2 % (cv. 'Barra') and 23.9 and 19.9 % (cv. 'Mogulus') of the EO (Figs. 3, 4).

The mixture of EO present in the buds of cv. 'Mogulus', which is resistant to the filbert big bud mite, was characterized by a high content of such compounds as nerol, α -campholenol, methyl salicylate, spathulenol, β -caryophyllene, δ -cadinene (Fig. 5). In comparison, the mixture of EO present in the leaves of this cultivar, which were colonized by the filbert aphid to only a small extent, contained greater quantities of nerol, α -campholenol, p-cymene, α -terpineol and germacrene D than those of cv. 'Barra', which showed a higher acceptance by aphids (Fig. 6). In turn, the leaves of cv. 'Barra' were characterized by a considerably high content of menthol, limonene, isomenthone, methyl salicylate and L-menthone (Fig. 7).

Table 1 The average number of *Phytoptus avellanae* development stages in damaged and undamaged buds during the study period of 2004–2006

Cultivar	Damaged				Undamaged			
	2004 ($\pm$ SD)	2005 ($\pm$ SD)	2006 ($\pm$ SD)	$\bar{x}$	2004 ($\pm$ SD)	2005 ($\pm$ SD)	2006 ($\pm$ SD)	$\bar{x}$
Barra	786.6 $\pm$ 104.4	1,561.0 $\pm$ 191.0	1,533.8 $\pm$ 211.2	1,293.8	35.4 $\pm$ 16.50 a	92.8 $\pm$ 105.03 a	115.2 $\pm$ 116.97 a	81.1
Mogulnus	–	–	–	–	12.2 $\pm$ 11.7 b	5.8 $\pm$ 4.9 b	10.8 b $\pm$ 5.1	9.6

–, No damaged buds; SD, standard deviation

Means followed by the same lower-case letter do not differ significantly at $p < 0.05$ (Tukey test)

Table 2 Total mean number of *Myzocallis coryli* individuals on 100 leaves and mean number of colonized leaves of two hazelnut cultivars under field conditions during the study period of 2003–2006

Cultivar	Protected plantation		Unprotected plantation	
	Mean number of aphids $\bar{x}$ ($\pm$ SD)	Mean number of leaves settled by aphids $\bar{x}$ ($\pm$ SD)	Mean number of aphids $\bar{x}$ ($\pm$ SD)	Mean number of leaves settled by aphids $\bar{x}$ ($\pm$ SD)
Barra	943.4 $\pm$ 591.2 a	249.1 $\pm$ 150.6 a	759.1 $\pm$ 42.6 a	244.1 $\pm$ 56.3 a
Mogulnus	421.0 $\pm$ 377.4 b	132.7 $\pm$ 107.0 b	347.1 $\pm$ 151.1 b	119.6 $\pm$ 36.2 b

Means followed by the same lower-case letter do not differ significantly at $p < 0.05$ (Tukey test)

Fig. 1 Percentage of identified fractions present in the mixture of essential oils (EO) isolated from the buds of two hazelnut (*Corylus* L.) cultivars 'Barra' and 'Mogulus'. For each fraction, different lower-case letters above bars indicate a significant difference at $p \leq 0.05$ (Tukey test) between cultivars **Fig. 2** Percentage of identified fractions present in the mixture of EO isolated from the leaves of two hazelnut (*Corylus* L.) cultivars 'Barra' and 'Mogulus'. For each fraction, different lower-case letters above bars indicate a significant difference at $p \leq 0.05$ (Tukey test) between cultivars

Discussion

Among the many possibilities provided by contemporary methods aimed at reducing the population of agrophagous species, alternative methods taking cultivar resistance of the species into account are finding an increasingly greater application in integrated programmes of plant protection (Chamberlain et al. 2000; Dudareva et al. 2004; Holopainen 2004; Zhao et al. 2005). The cultivation of less susceptible cultivars or those which are more resistant is an important element of plant protection methods (Kogan

2000). The relationship between plants and insects or mites is one of the frontier topics in chemoeology, and a clear understanding of the selectivity of mites for the host plant is important for developing control measures (Xugen and Luqin 2006). Secondary metabolites are considered to be the most important source of a plant's resistance to pests (Gatehouse 2002). Some of the secondary metabolites consist of constitutively expressed volatile organic compounds (VOCs), which can be quantitatively or qualitatively induced after herbivory (Dicke et al. 2009; Turlings and Ton 2006; Van Den Boom et al. 2004). However,

Fig. 3 Percentage of identified groups of monoterpenes present in the mixture of EO isolated from the buds of two hazelnut cultivars. For each type of monoterpene, different lower-case letters above bars indicate a significant difference at $p \leq 0.05$ (Tukey test) between cultivars. *moh* Monoterpene hydrocarbons, *akmo* aldehydes and ketones monoterpenes, *mow* monoterpenes soluble in water, *amo* alcohol monoterpenes

Fig. 4 Percentage of identified groups of monoterpenes present in the mixture of EO isolated from the leaves of two hazelnut cultivars. For each type of monoterpene, different lower-case letters above bars indicate a significant difference at $p \leq 0.05$ (Tukey test) between cultivars

many terpene VOCs, such as indole and methyl salicylate, are commonly produced as a result of injury to the plant following insect herbivory (De Moraes et al. 2001). VOCs are formed and released even by healthy plants or undamaged parts of the plant. For example, Röse and Tumlinson (2005) observed that herbivorous cotton plants which were attacked released VOCs even from those leaves which did not suffer injuries. VOCs are directly involved in plant defense system. The same compounds may attract natural enemies of insects and carnivorous

Fig. 5 Average percentage of repellent components in the mixture of EO isolated from the buds of two hazelnut cultivars. For each repellent compound, different lower-case letters above bars indicate a significant difference at $p \leq 0.05$ (Tukey test) between cultivars

Fig. 6 Percentage of EO components found to be a repellent for aphids isolated from the leaves of two hazelnut cultivars. For each repellent compound, different lower-case letters above bars indicate a significant difference at $p \leq 0.05$ (Tukey test) between cultivars

Fig. 7 Percentage of EO components found to be an attractants for aphids isolated from the leaves of two hazelnut cultivars. For each attractant, different lower-case letters above bars indicate a significant difference at $p \leq 0.05$ (Tukey test) between cultivars

insects as well as parasitoids (Arimura et al. 2005; Leither et al. 2005).

Our results suggest that the degree of resistance to *P. avellanae* is a fairly stable cultivar property. This notion is

confirmed by the results in the successive years of studies, when the buds of plants of cv. 'Mogulus' did not show any external signs of feeding by the filbert big bud mite. In comparison, infestation of cv. 'Barra' plants showed an increasing trend, and the buds of this cultivar were colonized to a considerable degree by mites. Bud infestation by the filbert big bud mite in the regions of hazel cultivation ranged from 18 to 70 % and is first of all related to the cultivar and the manner of its cultivation (Özman and Toros 1996; Stamenković et al. 1997; Viggiani and Bianco 1973). This problem appears to be different in comparison to the infection of black currant by filbert big bud mite (*Cecidophyopsis ribis*), which—according to Gajek et al. (1996)—is mainly dependent on the environment.

In our experiment, we confirmed that resistance of hazel cultivars to filbert aphid is a stable feature, independent of the year and intensity of the applied chemical protection. Filbert aphid is a serious pest of hazel plantations throughout the world and represents both a direct and indirect threat to the cultivated plants. By the 1980s it had become the most dangerous pest of hazel in the USA and Canada as it was resistant to most insecticides (AliNiazee 1997; Katundu and AliNiazee 1990). It was only after applying an integrated programme of controlling this aphid, based on establishing the threshold of harmfulness and introducing a parasitic hymenoptera *Trioxys pallidus*, was it possible to control their occurrence (Olsen, 2000). Controlling *M. coryli* on commercial hazel plantations is difficult because changes in the intensity of its occurrence are related to weather conditions (Gantner 2000).

The available literature lacks data on the content of EO occurring in hazel buds. Based on previous research (Najda and Gantner 2012) we conclude that nerol, myrthenol, α -campholenol and p-cymene were the predominant constituents of EO in hazel buds, with their contents ranging up to 20.6, 19.5, 4.7 and 3.7 %, respectively. The main constituents of the EO of hazel leaves were nerol (13.0 %), myrthenol (9.4 %), α -campholenol (9.0 %), menthol (6.7 %), geraniol (4.8 %) and limonene (3.9 %). The organic compounds constituting the EO are secondary metabolites of plants that show multi-directional pharmacological action towards humans and animals. It is currently recognized that monoterpenes play many roles in plant–insect interactions (Piesik et al. 2013b).

The chemical composition of EO can determine the acceptance of the host plant, or its lack, by herbivores. EO perform an important function as different types of aromatic stimuli: attractants, repellents and toxins. In the case of the filbert big bud mite, which moves in a passive manner, EO affect the olfactory receptors of the pest at the moment of its direct contact with the plant (Johnson and Schaal 1957). Therefore, it would appear that compounds of a repellent nature will be of decisive importance in the

resistance of a cultivar to Eriophyoidea. As was shown in our study, the EO present in the buds of cv. 'Mogulus' is characterized by a greater content of nerol, α -campholenol, methyl salicylate, spathulenol and β -caryophyllene. Hence, these compounds can be designated as substances which deter mites from feeding, or which make it impossible for them to feed. Of note is the high content of methyl salicylate in the buds of cv. 'Mogulus', which results from the indirect induction of the plant's resistance in a response to the feeding of mites. As reported by Dicke et al. (1990) and Bouwmeester et al. (1999), the level of this substance increased following feeding of *Tetranychus urticae* on *Phaseolus lunatus* plants, which increased the attractiveness of the plants to the species of predatory spider mite *Phytoseiulus persimilis*. Gajek et al. (1996) showed that the increased content of 3-carene and α -caryophyllene in plants of a black currant cultivar resistant to the mite *Cecidophyopsis ribis* had a repellent effect and caused signs of vigour loss in the mite. A similar phenomenon in which specific concentrations of selected components of EO had a repellent effect on spider mites feeding on strawberry plants was also observed by Dąbrowski and Rodriguez (1972). According to Herr (1988), the negative effect of factors on the olfactory organs affecting cultivar resistance to the filbert big bud mite can be overcome by the latter. This is reflected in the results obtained by the author since individuals of *P. avellanae* were also observed on the buds of all studied cultivars without any external signs of deformation.

EO content can also be decisive in determining the acceptance (or its lack thereof) of the host plant by aphids colonizing new plants in an active manner. Our study demonstrated that the leaves of cv. 'Mogulus' plants, a cultivar that is colonized to only a minor extent by the filbert aphid, contains greater quantities of nerol, α -campholenol, p-cymene, geraniol, α -terpineol, germacrene D, n-nonanol and α -copaene than those of cv. 'Barra', a cultivar with a higher acceptance by aphids and which contains a considerably higher content of menthol, limonene, isomenthol and methyl salicylate. Hence, these latter compounds can be included within the category of attractants which help the aphid to localize the host plant. In contrast the compounds of the EO whose presence was significantly higher in the leaves of cv. 'Mogulus' than in those of cv. 'Barra' can be considered to affect the winged individuals of the filbert aphid as anti-nutritional compounds. According to Francis et al. (2005), aphids, especially two-host species, use VOCs to localize the host plant, and the fact that they make spiral circles of a decreasing radius around the plant testifies to their using the aromatic stimuli to localize the host (Chapman et al. 1981; Kennedy 1974). According to Cheng et al. (2007) and Piesik et al. (2011a, b, 2013a, b), plant terpenoids take

part in the direct and indirect responses of the plant to injuries, and the majority of mono- and sesquiterpenes are produced by plants after an attack by plant herbivores with the aim of attracting parasitoids. In a study by Ozawa et al. (2000), plants of *Lotus japonicus* attacked by spider mites *Tetranychus urticae* produced VOCs that attracted the predator *Phytoseiulus persimilis*. Scots pine has been shown to produce a volatile bouquet that attracts egg parasitoids in response to oviposition of the herbivorous sawfly *Diprion pini* (Mumm and Hilker 2005).

These results indicate that aromatic VOCs play a major role in plant–pest interactions. Future studies should determine the exact concentrations of selected compounds of the EO and their application as defensive substances against harmful insects and mites.

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References

- Adams RP (2004) Identification of essential oil compounds by gas chromatography/quadrupole mass spectroscopy. Carol Stream, Allured Business Media
- Aliniaze MT (1997) Integrated pest management of hazelnut pests: a worldwide perspective. *Acta Hort* 445:469–476
- Arimura G, Kost C, Boland W (2005) Herbivore-induced, indirect plant defences. *Biochim Biophys Acta* 1734:91–111
- Bouwmeester HJ, Verstappen FWA, Posthumus MA, Dicke M (1999) Spider-mite induced (3S)-(E)-nerolidol synthase in cucumber and lima bean. The first dedicated step in acyclic C₁₁-homoterpene biosynthesis. *Plant Physiol* 121:173–180
- Carter CD, Sacalis JN, Gianfagna TJ (1989) Zingiberene and resistance to Colorado potato beetle in *Lycopersicon hirsutum* F. *hirsutum*. *J Agric Food Chem* 37:206–210
- Chamberlain K, Pickett JA, Woodcock CM (2000) Plant signaling and induced defense in insects attack. *Mol Plant Pathol* 1:67–72
- Chapman RF, Bernays EA, Simpson SJ (1981) Attraction and repulsion of the aphid *Cavariella aegopodi* by plant odors. *J Chem Ecol* 7:881–888
- Cheng A, Lou YG, Mao YB, Li S, Wang LJ, Chen XY (2007) Plant terpenoids: biosynthesis and ecological functions. *J Integr Plant Biol* 49:179–186
- Cook SP, Hain FP (1988) Toxicity of host monoterpenes to *Dendroctonus frontalis* and *Ips calligraphus* (Coleoptera: Scolytidae). *J Entomol Sci* 23:287–292
- Dąbrowski ZT, Rodriguez JG (1972) Gustatory responses of *Tetranychus urticae* Koch. to phenolic compounds of strawberry foliage. *Zesz Probl Post Nauk Roln* 129:70–75
- De Moraes CM, Mescher MC, Tumlinson JH (2001) Caterpillar-induced nocturnal plant volatiles repel nonspecific females. *Nature* 410:577–800
- Dicke M, Beek TA, van Posthumus MA, Ben Dom N, van Bokhoven H, Groot AEDE (1990) Isolation and identification of volatile kairomone that affects acarine predator–prey interactions. Involvement of host plant in its production. *J Chem Ecol* 16:381–396
- Dicke M, van Loop JJA, Soler R (2009) Chemical complexity of volatiles from plants induced by multiple attack. *Nat Chem Biol* 5:317–324
- Dudareva N, Pichersky E, Gershenzon J (2004) Biochemistry of plant volatiles. *Plant Physiol* 135:1893–1902
- Francis F, Vandermoten S, Verheggen F, Lognay G, Haubruge E (2005) Is the (E)- β -farnesene only volatile terpenoid in aphids?. Blackwell Verlag, Berlin, pp 6–11
- Gajek D, Nowacki J, Boczek J (1996) Black currant cultivars resistant to the gall mite (*Cecidophyopsis ribis* Westw.) as an element of integrated pest management. *IOBC/WPRS Bull* 19(4):349–350
- Gantner M (2000) Aphidofauna of hazel bushes (*Corylus* L.) on a protected plantation, an unprotected plantation and in a forest. *Annales UMCS, s. EEE* 8:155–167
- Gantner M (2007) Źródła odporności wybranych odmian leszczyny wielkoowocowej (*Corylus* L.) na wielkopakowca leszczynowego (*Phytoptus avellanae* Nal.) I zdobniczkę leszczynową (*Myzocallis coryli* Goetze). [The sources of resistance of chosen hazelnut (*Corylus* L.) cultivars to the filbert big bud mite (*Phytoptus avellanae* Nal.) and filbert aphid (*Myzocallis coryli* Goetze)]. University of Life Science in Lublin vol 324 (in Polish)
- Gatehouse JA (2002) Plant resistance towards insect herbivores: a dynamic interaction. *New Phytol* 156:145–169
- Harborne JB (1997) Ekologia biochemiczna. [Introduction to Ecological Biochemistry]. PWN, Warsaw (in Polish)
- Holopainen JK (2004) Multiple functions of inducible plant volatiles. *Trends Plant Sci* 9:529–533
- Ibrahim MA, Kainulainen P, Aflatuni A, Tiilikkala K, Holopainen JK (2001) Insecticidal, repellent, antimicrobial activity and phytotoxicity of essential oils: with special reference to limonene and its suitability for control of insect pests. *Agric Food Sci Finland* 10(3):243–259
- Johnson G, Schaal LA (1957) Accumulation of phenolic substances and ascorbic acid in potato tuber tissue injury and their possible role in increase resistance. *Am Potato J* 34:200–209
- Joulain D, König WA (1998) The atlas of spectral data of sesquiterpene hydrocarbons. EB-Verlag, Hamburg
- Katundu JM, Aliniaze MT (1990) Variable resistance of Filbert aphid (Homoptera: Aphididae) to insecticides in the Willamette Valley. Oregon. *J Econom Entomol* 83(1):41–47
- Kennedy JS (1974) Changes in responsiveness in the patterning of behavioral sequences. In: Brown BL (ed) Experimental analysis of insect behavior. Springer, New York, 1–6
- Kogan M (2000) Sustainable development and integrated pest management. In: Abstr 21 Intl Congr Entomol. Foz do Iguassu, pp 28–32
- Leal I, White EE, Sahota TS, Manville JF (1997) Differential expression of vitellogenin gene in the spruce terminal weevil feeding on resistant versus susceptible host trees. *Insect Biochem Mol Biol* 27:569–575
- Leither M, Boland W, Mithofer A (2005) Direct and indirect defences induced by piercing-sucking and chewing herbivores in *Medicago truncatula*. *New Phytol* 167:597–606
- Maziarz B (1984) Opanowannie leszczyny przez wielkopakowca leszczynowego—*Phytoptus avellanae* (Nal.) (Acarina, Phytophagidae). [Degree of infestation of hazel by nut gall mite: *phytoptus avellanae* (Nal.) (Acarina, Phytophagidae)]. *Polskie Pismo Entomol.* 53:649–655 (in Polish)
- Mumm R, Hilker M (2005) The significance of background odour for an egg parasitoid to detect plants with host eggs. *Chem Senses* 30:337–343
- Najda A, Gantner M (2012) Chemical composition of essential oils from the buds and leaves of cultivated hazelnut. *Acta Sci Pol Hortorum Cultus* 11:91–100

- NIST/EPA/NIH (2002) NIST/EPA/NIH mass spectral library. Distributed by Agilent Technologies, Santa Clara
- Olsen J (2000) Nut growers handbook. In: Proc and Memb Rost 85th Annu Meet. Portland, pp 18–27
- Ozawa R, Arimura G, Takabayashi J, Shimoda T, Nishioka T (2000) Involvement of jasmonate and salicylate-related path-ways for productions of specific herbivore-induced volatiles in plants. *Plant Cell Physiol* 41:391–398
- Özman SK, Toros S (1996) Distribution in big bud mite (*Phytoptus avellanae* Nal. and *Cecidophyopsis vermiformis* Nal. Acarina: Eriophyoidea) in the Black Sea Region. In: Proc 3rd Turkish Nat Congr Entomol. pp 328–336
- Piesik D, Lemańczyk G, Skoczek A, Lamparski R, Bocianowski J, Kotwica K, Delaney KJ (2011a) Fusarium infection in maize: volatile induction of infected and neighboring uninfected plants has the potential to attract a pest cereal leaf beetle, *Oulema melanopus*. *J Plant Physiol* 168:1534–1542
- Piesik D, Pańka D, Delaney KJ, Skoczek A, Lamparski R, Weaver DK (2011b) Cereal crop volatile organic compound induction after mechanical injury, beetle herbivory (*Oulema* spp.), or fungal infection (*Fusarium* spp.). *J Plant Physiol* 168:878–886
- Piesik D, Pańka D, Jeske M, Wenda-Piesik A, Delaney KJ, Weaver DK (2013a) Volatile induction of infected and neighboring uninfected plants potentially influence attraction/repellence of a cereal herbivore. *J Appl Entomol* 137:296–309
- Piesik D, Rochat D, Delaney KJ, Marion-Poll F (2013b) Orientation of European corn borer first instar larvae to synthetic green leaf volatiles. *J Appl Entomol* 137:234–240
- Polish Pharmacopoeia VI (2002) Wyd. PTFarm, Warsaw
- Qiu YT, Loon JJA, Roessingh P (1998) Chemoreception of oviposition inhibiting terpenoids in the diamondback moth *Plutella xylostella*. *Entomol Exp Appl* 87:143–155
- Röse USR, Tumlinson JH (2005) Systemic induction of volatile release in cotton: how specific is the signal to herbivory? *Planta* 222:327–335
- Stamenković S, Milenković S, Pešić M, Mitrović M (1997) Population dynamics, harmfulness and control of *Phytoptus avellanae* (Nalepa) in Western Serbia. *Acta Hort* 445:521–526
- Turlings TCJ, Ton J (2006) Exploiting scents of distress: the prospect of manipulating herbivore-induced plant odours to enhance the control of agricultural pests. *Curr Opin Plant Biol* 9:421–427
- Van Den Boom CEM, Van Beek TA, Posthumus MA, De Groot A, Dicke M (2004) Qualitative and quantitative variation among volatile profiles induced by *Tetranychus urticae* feeding on plants from various families. *J Chem Ecol* 3:69–89
- Viggiani G, Bianco M (1973) Osservazioni biologiche sul *Phytoptus avellanae* Nalepa in Campania e relative prove di lotta chimica. *Atti Giornate Fitopatol* (Bologna) (1973):79–83
- von Herr R (1988) Investigations of the resistance mechanism of the genus *Ribes* against the currant gall mite *Cecidophyopsis ribis* (Westw.) (Acar, Eriophyidae). *J Appl Entomol* 112:181–193
- Wallin KF, Raffa KF (2000) Influences of host chemicals and internal physiology on the multiple steps of postlanding host acceptance behavior of *Ips pini* (Coleoptera: Scolytidae). *Environ Entomol* 29:422–453
- Wilkaniec B (1994) Aphidofauna of selected tree species in the urban area of Poznań. Aphids and other homopterous insects. PAS, Skierniewice
- Xugen S, Luqin Q (2006) Effect of volatiles from plants on the selectivity of *Tetranychus viennensis* for different host plants. *Frontiers For China* 1:105–108
- Zhao J, Davis LC, Verpoorte R (2005) Elicitor signal transduction leading to production of plant secondary metabolites. *Biotech Adv* 23:283–333