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The Influence of Aphid Infestation during the Hop Growing Season on the Quality of Harvested Cones

The influence of aphid infestation on the quality of harvested hop cones was researched during four years from 2008 to 2011. The cone infestation of altogether 60 hop gardens (2011: 16 gardens) and five cultivars – Hallertauer Magnum, Hallertauer Tradition, Herkules, Spalter Select (2008-2010) and Perle (2011) – was assessed in three plots, respectively (untreated control, one insecticide application, practice), during the growing season by the use of modified Berlese funnels. In three gardens of each cv. an experimental harvest was conducted annually, determining yield, cone infestation, and other quality parameters. The registered infestations ranged from nil to a maximum of 50.5 aphids per cone. High aphid infestation was able to cause a significant loss of yield and alpha acids in several cases in 2009 and 2011, whereas in 2008 even severe infestations did not have according similar impact. During 2010, almost no aphid infestation was detected at all. However, investigated quality parameters other than the bitter acids – cohumulone, colupulone, xanthohumol and hop oils or their constituents (e.g. linalool, humulene, myrcene) – were never affected by high cone infestation. It is concluded that these quality parameters are unlikely to be impaired by aphid infestation of the hop plant.

Descriptors: hop entomology, damson-hop aphid, hop quality, alpha-acid content

1 Introduction

The damson-hop aphid *Phorodon humuli* (Schrank) is a notorious pest of hops in the northern hemisphere. It is an obligate heteroecious species with sloe *Prunus spinosa*, plum *P. domestica* and a few other closely related *Prunus* trees and shrubs serving as primary winter hosts, and the hop *Humulus lupulus* L. as its sole secondary host during summer [1]. The aphid can cause serious losses of yield up to the complete destruction of a crop, and even light infestations of the harvested cones can reduce their economic value [2]. Farmers usually control *P. humuli* with the prophylactic use of insecticides. This has stimulated the development of resistant aphid genotypes within the hop-growing regions, where hops are usually concentrated in a comparatively small area [3]. Aphid resistance to chemical control agents has become an ongoing problem in hop growing, often including new active ingredients already within a few years. Moreover, due to an increasing environmental consciousness by the public, the hop industry is obliged to reduce the use of pesticides generally to a necessary minimum level. Therefore an integrated approach to pest management in hops is needed badly in order to break this cycle of insecticide resistance in the future, and to ensure that efficient insecticides are used only when absolutely inevitable.

Almost the entire European hop growing area is treated regularly at least once a year with insecticides. When the efficacy of registered insecticides is generally low or decreases due to the selection of

Fig. 1 Modified Berlese funnel device to expel arthropods by light and heat from green hop cones

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Table 1 Detailed results of three experimental harvests conducted 2008 in cv. 'Hallertauer Magnum'. For quality assessment classes (G1-G5) see text. Values followed by the same character (a, b, c) are not significantly different (ANOVA; df = 3, $p < 0.05$)

experimental site code	BCH08/HM			EBM08/HM			ILM08/HM		
cultivar	HM			HM			HM		
harvest date	08 ix 2008			09 ix 2008			08 ix 2008		
plot	P0	P1	P2	P0	P1	P2	P0	P1	P2
insecticide 1		pymetrozine	pymetrozine		imidacloprid	imidacloprid		imidacloprid	imidacloprid
insecticide 2			flonicamid			flonicamid			flonicamid
insecticide 3			abamectin			abamectin			abamectin
leaf infestation [aphids/leaf] (abloom)	44.6	0.8	0.8	113.3	7.0	7.0	0.2	0.3	0.0
green cone infestation [aphids/100 cones] (harvest)	5,047	3,094	494	652	1,402	12	32	123	12
dried cone infestation [%]	99.5	97.9	46.7	81.7	85.0	7.0	4.0	10.8	3.4
"weighted average"	3.681	3.319	1.830	2.352	2.392	1.081	1.042	1.112	1.034
quality assessment	G-5	G-5	G-3	G-5	G-5	G-2	G-2	G-2	G-2
yield [dt/ha]	22.43 a	25.98 a	23.85 a	22.95 a	21.63 a	24.69 a	28.18 a	28.81 a	28.84 a
alpha [%] (EBC 7.4)	15.71 a	15.28 a	15.29 a	15.30 a	14.64 a	15.52 a	15.70 a	15.19 a	15.08 a
alpha/ha [kg]	352.5 a	397.2 a	364.3 a	351.0 a	316.4 a	383.2 a	442.2 a	437.9 a	434.9 a
alpha [%] (EBC 7.7)	13.75	14.85	14.47	13.68	13.24	14.37	15.00	13.83	14.32
beta [%]	6.89	6.96	7.39	6.05	6.25	6.94	7.37	7.26	7.43
beta/alpha	0.50	0.47	0.51	0.44	0.47	0.48	0.49	0.53	0.52
cohumulone [%]	26.70	26.66	26.15	25.24	25.45	25.43	26.77	25.93	27.52
colupulone [%]	46.26	46.41	45.15	45.00	46.30	46.16	45.97	44.53	44.99
xanthohumol [%]	0.49	0.50	0.47	0.4	0.42	0.43	0.48	0.48	0.47
2-methylbutylisobutyrate [1]	143	165	175	127	113	124	158	163	149
linalool [1]	9	9	9	10	9	8	8	9	9
humulene [1]	275	281	279	280	283	282	285	283	287
myrcene [1]	8,538	8,871	8,624	8,660	8,002	7,582	7,655	9,746	9,042
farnesene [1]	0	0	0	0	0	0	0	0	0
aromadendrene [1]	0	2	2	2	2	2	2	3	3
α-selinene [1]	2	1	1	1	1	1	1	1	1
β-selinene [1]	2	2	2	2	2	2	2	2	2
selinadiene [1]	0	0	0	0	0	0	0	0	0

[1] relative value to β-caryophyllene (= 100)

resistant aphid strains, second or third applications have often been necessary in the past. Growers' decisions to spray are personal and based on their previous experience with the pest. Therefore, the development of a dynamic threshold model for the control of *P. humuli* would provide them with a tool that would enable them to decide on an objective basis whether a prophylactic use of insecticides is necessary or not. The most important module within a control threshold system is the economic injury threshold: how many aphids are actually tolerable on hop plants at the end of the growing season without loss of yield or quality of the harvested cones? Therefore, the principal aim of the present study was to evaluate the damage caused by *P. humuli* to hops at harvest in each of four years, and to use that information to establish an empirically-derived economic injury threshold. As differences in the varietal susceptibility to aphids have been demonstrated previously [e.g., 4, 5, 6, 7], we also tried to consider differences between hop cultivars with distinct aphid susceptibility, with moderate susceptibility and with aphid tolerance or resistance.

2 Materials and Methods

2.1 Study area

The Hallertau is the world's largest contiguous hop-growing region and accounted for 15,387 ha of hops grown in 2010, thus representing ca 30 % of the world's acreage under hops cultivation [8, 9]. The Hallertau is situated south of the river Danube in the central part of Bavaria, Germany, and has a total area of approximately 1,500 km².

Table 2 Detailed results of three experimental harvests conducted 2009 in cv. 'Hallertauer Tradition'. For quality assessment classes (G1-G5) see text. Values followed by the same character (a, b, c) are not significantly different (ANOVA; df = 3, $p < 0.05$)

experimental site code	LAN09/HT			WOL09/HT			UEB09/HT		
cultivar	HT			HT			HT		
harvest date	31 viii 2009			31 viii 2009			27 viii 2009		
plot	P0	P1	P2	P0	P1	P2	P0	P1	P2
insecticide 1		flonicamid	flonicamid		flonicamid	flonicamid		flonicamid	flonicamid
insecticide 2			flonicamid			abamectin			abamectin
insecticide 3			abamectin						
leaf infestation [aphids/leaf] (abloom)	334.6	0.0	0.0	403.4	0.4	0.0	41.3	0.0	0.0
green cone infestation [aphids/100 cones] (harvest)	272	3	80	105	16	8	228	0	10
dried cone infestation [%]	76.1	4.4	1.6	31.9	2.7	0.9	10.6	0.1	0.1
"weighted average"	2.102	1.046	1.016	1.354	1.027	1.009	1.111	1.001	1.001
quality assessment	G-4	G-2	G-2	G-3	G-2	G-1	G-2	G-1	G-1
yield [dt/ha]	15.21 a	22.05 b	19.20 b	11.19 a	19.07 b	19.04 b	20.91 a	20.58 a	19.61 a
alpha [%] (NIR)	6.25 a	6.62 a	6.52 a	6.45 a	7.89 b	7.60 b	7.99 a	7.59 a	7.97 a
alpha/ha [kg]	95.1 a	146.4 b	125.2 b	72.3 a	150.0 b	144.8 b	167.2 a	156.2 a	156.1 a
alpha [%] (EBC 7.7)	5.68	7.47	6.48	6.82	8.25	7.74	7.86	7.49	7.34
beta [%]	5.74	5.88	5.28	6.54	5.94	6.08	6.69	6.21	6.03
beta/alpha	1.01	0.79	0.81	0.96	0.72	0.79	0.85	0.83	0.82
cohumulone [%]	26.04	23.57	25.05	24.56	24.39	23.80	22.57	23.49	23.34
colupulone [%]	46.94	47.17	48.14	46.75	47.61	46.79	45.55	46.42	45.98
xanthohumol [%]	0.36	0.36	0.30	0.41	0.35	0.35	0.42	0.38	0.37

2.2 Experimental layout

The damage caused by *P. humuli* was assessed by harvesting hop plants with known levels of infestation during the vegetation period until the day of the harvest from insecticide-untreated plots, and comparing that with nearby insecticide-treated plants in the same garden. The latter plants were either uninfested, or with lower infestations than the untreated plants. In almost all cases the grower could market the hops from treated plots without financial loss according to hop market standards. Neighbouring treated and untreated plants were chosen in order to minimise other factors, mainly soil-borne, that could potentially influence yield or quality.

The hop gardens chosen for this study were a sub-set from a large monitoring program for *P. humuli*, which was run from 2008 to 2012 in either 60 (2008-2010) or 16 (2011) gardens distributed evenly over the Hallertau growing region. All of these gardens had been regularly treated with insecticides in former years. Three plots of ca 126 hop plants (six rows with 21 plants each; ca 450 m^2, representing average conditions of the field) had been laid out in each garden at the beginning of the monitoring and were retained for the entire duration of the project. The first plot from the field margin was the insecticide-untreated control (P0). The second plot that followed P0 immediately in the same rows was in all cases treated only once with an insecticide per year (P1); the timing of the application was left to the grower's decision. The third plot that followed P1 immediately in the same rows was the plot identical with the grower's routine in the rest of the field and comprised ideally two insecticide applications (P2). The use of the acaricide 'abamectin' was regarded as an insecticide application during this study, because it causes a significant control effect also on aphids, with an efficiency factor >90 %. Moreover, in 2010 and 2011 many farmers had used the systemic soil insecticide 'thiamethoxam' early in the vegetation period to control soil pests like wireworms (*Elateridae*) and Alfalfa snout weevil *Otiorhynchus ligustici*. Likewise, this application had a significant side-effect on the colonisation of the hop plant with aphids and therefore was also considered during this study. Other pests and diseases were controlled in the plots using the respective grower's routine programme.

The aphid leaf infestation was assessed in each plot of each garden annually seven or eight times in 14 days' intervals, from late May to late August, on 50 leaves per plot and monitoring day. Moreover, the final monitoring after cone formation also comprised the aphid infestation of 100 green hop cones per plot. Those cones were picked manually directly in the plots into plastic bags, cooled and transferred to the laboratory. There, each sample of 100 cones was filled in a specially constructed, modified Berlese funnel, where aphids and other arthropods hidden in the cones were expelled by light and heat (provided by a 60 W light bulb, exposure time 18-60 hrs), fell into a small PE bottle with ethanol for preservation, and later were exactly counted (Fig. 1 and 2).

Thus, the aphid population development in each plot was well-

Table 3 Detailed results of three experimental harvests conducted 2010 in cv. 'Herkules'. For quality assessment classes (G1-G5) see text. Values followed by the same character (a, b, c) are not significantly different (ANOVA; df = 3, $p < 0.05$)

experimental site code	TEG10/HS			HLL10/HS			BCH10/HS		
cultivar	HS			HS			HS		
harvest date	17 ix 2010			17 ix 2010			20 ix 2010		
plot	P0	P1	P2	P0	P1	P2	P0	P1	P2
insecticide 1		flonicamid	thiametho-xam		flonicamid	thiametho-xam		abamectin	thiametho-xam
insecticide 2			flonicamid			flonicamid			flonicamid
insecticide 3						abamectin			abamectin
leaf infestation [aphids/leaf] (abloom)	320.5	428.2	174.9	10.2	0.0	0.0	106.1	37.4	0.1
green cone infestation [aphids/100 cones] (harvest)	1,369	247	236	375	5	251	367	433	74
dried cone infestation [%]	35.0	3.5	3.0	10.0	4.2	2.7	17.9	21.7	5.5
"weighted average"	1.410	1.036	1.033	1.110	1.046	1.029	1.222	1.297	1.066
quality assessment	G-3	G-2	G-2	G-2	G-2	G-2	G-2	G-2	G-2
yield [dt/ha]	29.76 a	27.12 a	26.02 a	32.39 a	35.14 a	33.97 a	24.46 a	28.08 a	28.25 a
alpha [%] (EBC 7.4)	16.58 a	16.37 a	15.96 a	16.72 a	14.27 a	15.58 a	13.26 a	14.45 a	14.93 a
alpha/ha [kg]	494.2 a	443.5 a	415.1 a	541.4 a	501.6 a	529.3 a	324.3 a	405.6 a	422.6 a
alpha [%] (EBC 7.7)	16.37	16.78	15.24	16.53	12.50	15.55	13.66	14.76	15.37
beta [%]	5.80	6.16	5.70	5.83	4.87	5.70	5.10	5.33	5.53
beta/alpha	0.35	0.37	0.37	0.35	0.39	0.37	0.37	0.36	0.36
cohumulone [%]	40.37	41.42	41.97	39.85	40.25	41.42	41.99	41.28	40.89
colupulone [%]	58.60	57.49	58.57	56.32	56.00	57.45	58.05	57.01	56.71
xanthohumol [%]	1.06	1.11	1.00	1.01	0.85	1.03	0.83	0.83	0.86

known. Twelve of these gardens with a desired infestation level in the plots were chosen annually for experimental harvests and underwent a final aphid monitoring on the day of the harvest in late August or September.

2.3 Experimental harvests

In four field seasons from 2008 to 2012, twelve experimental harvests were conducted annually; thereby creating 48 data sets altogether. Three harvests were made from each of four cvs, viz the high alpha cvs Hallertauer Magnum (HM) and Herkules (HS), and the aroma cvs Hallertauer Tradition (HT) and Spalter Select (SE); in the fourth project year 2012, SE was substituted by Perle (PE). Four replicate samples of 10 untreated bines were compared with a similar number of insecticide-treated bines in each garden. Four rows of 10 bines each were marked for harvesting in the centre of the untreated control plot, leaving a gap of usually seven plants to the border of the treated plot (approx. 9-11 m), where 10 treated bines were marked in each of the same four rows. All bines were first checked visually for normal growth; those with non-aphid induced injuries or abnormalities were excluded from harvesting.

Field harvesting was conducted manually or using the grower's own equipment. In both procedures, the bines were cut just above ground level and their tops were pulled from the upper wires of the trellis system to fall on a trailer. Each harvested group of 10 bines was immediately separated on the trailer from the following replicate with a sheet of plastic film. The harvested bines were taken without delay to the stationary picking machine at the farmstead to separate cones from stems, leaves and other debris. The cones from each 10 bine sample were picked separately and bagged, and their fresh weights were recorded. A sub-sample of ca 3 kg fresh weight was taken from each replicate for further processing.

2.4 Analytical work

The sub-samples were immediately taken to the laboratory, weighed on an analytic scale, then dried overnight in an experimental kiln to a moisture content of ca 10-12 %, and the exact dry weight was recorded once the sample had cooled. A further sub-sample of approximately 100 g of dried cones was taken from each sub-sample. The exact moisture content was determined, and the percentage of α-acids of the two high alpha cvs was measured by conductimetric analysis according to EBC 7.4 [10], and that of the three aroma cvs by near infra-red spectroscopy (NIR).

For a second analytical round, a pooled sample of approximately 100 g was taken from the four replications of each plot. From that

Table 4 Detailed results of three experimental harvests conducted 2011 in cv. 'Hallertauer Magnum'. For quality assessment classes (G1-G5) see text. Values followed by the same character (a, b, c) are not significantly different (ANOVA; df = 3, $p < 0.05$)

experimental site code	OEB11/HM			GBG11/HM			HLL11/HM		
cultivar	HM			HM			HM		
harvest date	06 ix 2011			12 ix 2011			05 ix 2011		
plot	P0	P1	P2	P0	P1	P2	P0	P1	P2
insecticide 1		flonicamid	thiamethoxam		flonicamid	thiametho-xam		flonicamid	thiamethoxam
insecticide 2			flonicamid			flonicamid			flonicamid
insecticide 3			abamectin			abamectin			abamectin
leaf infestation [aphids/leaf] (abloom)	257.4	0.2	0.0	486.6	0.8	0.1	773.3	41.5	2.0
green cone infestation [aphids/100 cones] (harvest)	315	152	0	1,548	963	17	820	970	44
dried cone infestation [%]	37.3	72.1	10.2	80.1	56.7	3.6	88.3	78.2	16.5
"weighted average"	1.413	2.063	1.109	2.163	1.671	1.039	2.299	1.977	1.174
quality assessment	G-3	G-4	G-2	G-4	G-3	G-2	G-5	G-4	G-2
yield [dt/ha]	7.35 a	13.87 b	21.63 c	15.24 a	20.16 b	23.97 c	15.54 a	16.20 a	20.70 b
alpha [%] (EBC 7.4)	11.88 a	14.84 b	16.73 c	14.52 a	16.44 b	16.48 b	15.11 a	14.67 a	15.11 a
alpha/ha [kg]	87.5 a	206.2 b	361.5 c	222.2 a	331.6 b	395.3 c	234.9 a	237.7 a	312.8 b
alpha [%] (EBC 7.7)	12.74	16.22	17.29	12.83	15.25	15.91	15.79	14.41	14.73
beta [%]	5.99	6.32	6.60	6.72	6.71	7.05	7.59	7.15	6.34
beta/alpha	0.47	0.39	0.38	0.52	0.44	0.44	0.48	0.50	0.43
cohumulone [%]	24.8	23.9	23.1	27.1	26.7	26.3	26.7	26.9	25.3
colupulone [%]	48.0	48.5	47.6	49.1	49.6	48.6	47.0	46.7	49.4

pooled sample, the α-acids, the β-acids, the β/α ratio, cohumulone, colupulone and xanthohumol were determined by HPLC according to EBC 7.7 [10]. However, instead of a conventional HPLC-system an ultra HPLC-system was applied. The column EC 125/4 NUCLEODUR 100-3 C18 (Macherey-Nagel) was used for the accelerated separation of bitter substances.

A third analytical round to determine the essential oil compounds by headspace gas chromatography (GC) was performed only in the first project year 2008, with another pooled sample of approximately 100 g from the four replications of each plot. The GC analysis (with 1 g dried, ground hop cones plus 1 µl of enanthic acid ethyl ester, respectively) was carried out using a Dani 8500 gas chromatograph plus flame ionization detector equipped with a Dani headspace sampler HSS 86.50. The polyethylene glycol fused silica cross-bonded capillary column Permabond (Macherey-Nagel) with 50 m x 0.25 mm ID and 0.23 µm of film thickness was used. The temperature program started at 60 °C for 10 min, increased to 170 °C at 2 °C/min and then to 200 °C at 6 °C/min, held for 20 min. The sample vial was kept at a temperature of 110 °C for 80 min and then 5 ml of the headspace was injected into the column. The injector and detector temperatures were 200 °C and 210 °C, respectively. The carrier gas was helium, at a flow rate of 1.2 ml/min and the split ratio was 1:25. Myrcene, linalool, aromadendrene, humulene, farnesene, α-selinene, β-selinene, selinadiene and β-caryophyllene were identified by commercially available standards. 2-methylbutylisobutyrate was synthesized in our own laboratory.

2.5 Quality assessment

Finally, 500 cones were taken from each sub-sample for the evaluation of aphid infestation. Infestation percentages were evaluated by visual assessment for aphid traces on the cones [11]. This assessment then was graded according to German hop market standards into the five standard categories 'no infestation' (G-1; no penalty), 'slight infestation' (G-2; no penalty), 'middle infestation' (G-3; 2 % penalty), 'strong infestation' (G-4; 5 % penalty), and 'very strong infestation' (G-5; 10 % penalty) [12]. In addition, the "weighted average" of infestation (ranging from 1.000 to 4.000, with 1.000 representing zero infestation) was determined according to the formula: [(number of uninfested cones) + 2 (number of cones with light infestation) + 3 (number of cones with middle infestation) + 4 (number of cones with heavy infestation)] (number of all assessed cones) –1. The latter procedure results in a finer assessment of infestation and is standard in German hop research.

3 Results

During this study 48 experimental harvests were conducted from 2008 to 2011 and analysed. A brief overview of the results in regard to significant differences in yield and α-acids between the untreated control plot and the grower's routine plot is provided in Figure 3. It is visible at first glance that there are extreme differences between the four project years: In 2008 and 2010 no significant damage at all regarding both yield and α-acids content in the control plot was

Table 5 Detailed results of three experimental harvests, conducted 2008 in cvs 'Herkules' and 'Spalter Select', and 2010 in cv. 'Hallertauer Tradition'. For quality assessment classes (G1-G5) see text. Values followed by the same character (a, b, c) are not significantly different (ANOVA; df = 3, *p* < 0.05)

experimental site code	UMK08/SE			OEB08/HS			HHF10/HT		
cultivar	SE			HS			HT		
harvest date	12 ix 2008			18 ix 2008			01 ix 2010		
plot	P0	P1	P2	P0	P1	P2	P0	P1	P2
insecticide 1		imidacloprid	imidacloprid		imidacloprid	imidacloprid		flonicamid	flonicamid
insecticide 2			flonicamid			flonicamid			abamectin
insecticide 3			abamectin			abamectin			
leaf infestation [aphids/leaf] (abloom)	3.3	0.1	0.0	38.4	1.0	0.0	253.6	106.1	382.0
green cone infestation [aphids/100 cones] (harvest)	7	14	7	1,068	32	22	75	68	45
dried cone infestation [%]	0.0	0.0	0.0	47.8	19.1	1.0	1.35	1.25	0.7
"weighted average"	1.000	1.000	1.000	1.666	1.233	1.011	1.014	1.013	1.007
quality assessment	G-1	G-1	G-1	G-3	G-2	G-1	G-2	G-2	G-1
yield [dt/ha]	24.21 a	23.69 a	20.97 b	33.18 a	30.20 a	26.45 b	14.09 a	11.70 a	12.15 a
alpha [%] (EBC 7.4)	5.81 a	6.28 a	5.73 a	17.36 a	17.79 a	17.95 a	6.55 a	6.21 ab	5.92 b
alpha/ha [kg]	140.7 a	148.7 a	120.1 b	576.7 a	536.8 a	474.9 b	92.2 a	72.5 ab	71.8 b
alpha [%] (EBC 7.7)	3.83	4.99	4.77	15.36	17.38	17.77	4.81	5.17	4.63
beta [%]	4.04	5.08	5.60	5.12	5.66	5.97	4.41	5.17	5.16
beta/alpha	1.05	1.02	1.17	0.33	0.33	0.34	0.92	1.00	1.12
cohumulone [%]	21.86	21.12	21.50	38.03	36.14	35.38	22.93	23.39	23.53
colupulone [%]	45.59	43.36	43.08	57.69	55.84	55.51	44.14	43.47	43.32
xanthohumol [%]	0.35	0.41	0.41	0.71	0.80	0.75	0.35	0.39	0.43
2-methylbutylisobutyrate [1]	118	137	81	443	352	347			
linalool [1]	91	110	100	10	8	9			
humulene [1]	172	185	185	280	285	282			
myrcene [1]	9,236	10,368	6,261	10,689	8,566	9,709			
farnesene [1]	87	102	65	0	0	0			
aromadendrene [1]	21	21	19	0	0	0			
α-selinene [1]	29	33	35	1	1	1			
β-selinene [1]	27	32	33	2	3	2			
selinadiene [1]	41	44	48	0	0	0			

[1] relative value to β-caryophyllene (= 100)

noticed (e.g. Tab. 1 and 3). On the other hand, in 2009 and 2011 a significant loss of yield, often accompanied by a loss of α-acids, was detected in more than 50 % of all harvests (e.g. Tab. 2 and 4). Furthermore, there is a conspicuous difference between cultivars in regard to aphid susceptibility: in the two years with scores of aphid damages, in all harvests of the two high alpha cvs HM and HS the control plots were negatively affected. In contrast, the aroma cv. SE was in three project years never negatively affected by uncontrolled aphid infestation, and neither was PE in 2011. The third aroma cv. HT ranged between those extremes (Fig. 3).

Overall, 29 of the 48 experimental harvests produced no significant differences neither in yield nor in α-acids content between uncontrolled plots and plots sprayed according to the grower's routine (Tab. 1 and 3). However, even if yield and α-acids content showed no differences, a high aphid infestation level of the harvested cones sometimes resulted in a negative quality assessment according to hop market standards, grading the cones down to the lowest quality level G-5 (Tab. 1). In 15 harvests, the grower's plot produced a significantly higher yield, accompanied in eight cases by significantly higher α-acids content (Tab. 2 and 4). On the other hand, in two harvests the untreated control plot produced significantly higher yields than the grower's plot, and in other two harvests significantly higher α-acids content (Tab. 5).

4 Discussion

„The selection of hops is not a beauty contest!" – This sentence by *David Grinnell* (The Boston Beer Company) during the EBC Hop Symposium 2010 in Wolnzach, Bavaria, is fully supported by the results of the presented study. It was proven that, with the exception of the bitter acids, all other quality parameters in harvested hop cones obviously are not affected by aphid infestation. This even includes experimental harvests with extremely high infestation levels of up to 50 aphids per single cone in average, which did neither have any negative effect on yield nor hop essential oils, polyphenols or α- and β-acids (Tab. 1), although by visual quality assessment these cones were graded into the lowest category and would have been unsellable on the hop market. The looks of hops do not reflect the actual quality of their substances of content and hence their brewing value, but are mainly an aesthetic issue. A similar conclusion was given by *Gahr* and *Hansen* [13], who compared the potential beer quality impact of aphid-infested and premium quality hops, and found that “neither the hop samples nor their resulting beers showed any apparent difference in the analytical data that could tell them apart” [13]. However, during sensory evaluation of these beers in triangular tastings, the beer produced with premium hops was significantly preferred by the tasters in one of two cases. The effect of the secondary infection of aphid-infested hops with sooty mold fungi, which grow on the excrements of aphids (honeydew) in the cones and can produce mycotoxins, is a probable answer to this organoleptic evaluation preference.

During the four project years this situation – a high aphid infestation level without any influence on yield and quality – was encountered only during 2008. In 2009 and 2011 heavy aphid infestation in more than 50 % did indeed have a negative effect on yield and in some cases also on the α-acids content, whereas in 2010 a very low aphid infestation level had no influence at all. There is obviously not only an extreme difference of the impact of aphid infestation on the crop between cultivars, but also between single years, because climate, soil, water supply, other pests and diseases and their chemical control and many other factors in combination can play a significant role. We could also demonstrate that in those years, where aphid damage did have an effect on the crop, mainly yield was impaired whereas the α-acids content was affected less often (Fig. 3). In a study similar to ours, conducted in a small hop garden (cv. Nugget) of the University of León’s experimental farm in Spain, *Lorenzana* et al. even concluded that the α-acids content of dried hops was not affected by the aphid population on the leaves [14].

However, our data proves that this statement can’t be generalised.

Especially high alpha cultivars like HM and HS are obviously much more susceptible to aphid infestation than aroma cultivars like HT, allowing for both yield and α-acids content (Fig. 3). Moreover, an aphid-tolerant aroma cultivar like SE, on which the population development of *P. humuli* is lower by the factor 10 as compared to cv. HM [7], can obviously be grown without risk each year devoid of an insecticide application for the control of aphids. Aphid tolerance or resistance as an environmentally compatible property of a hop cultivar currently poses one of the major challenges in hop growing. At present, the UK dwarf cv. ‘Boadicea’ worldwide is the only variety with a high aphid resistance [15]; therefore according breeding work is intensified in the Bavarian Hop Research Center Huell.

Fig. 2 Single modified Berlese funnel

At first glance, the fact that in four of 48 experimental harvests conducted during our project the insecticide-untreated control plot even had a significantly higher yield or α-acids content as compared to the grower’s plot (Fig. 3, Tab. 5) seems unlikely and to be an error. However, there is a simple explanation for the difference in yield, especially in the case of one garden of cv. SE in 2008 (Tab. 5). In this case the aphid population level in the entire garden was extremely low without control measures, but neverthe-

cv.	2008			2009			2010			2011		
	site code	yield	alpha	site code	yield	alpha	site code	yield	alpha	site code	yield	alpha
HM	BCH08/HM	=	=	LAN09/HM	*	=	LAN10/HM	=	=	OEB11/HM	*	*
	EBM08/HM	=	=	BCH09/HM	*	=	WOL10/HM	=	=	GBG11/HM	*	*
	ILM08/HM	=	=	WOL09/HM	*	*	HLL10/HM	=	=	HLL11/HM	*	=
HS	PAR08/HS	=	=	PAR09/HS	*	*	BCH10/HS	=	=	OEB11/HS	*	*
	KDF08/HS	=	=	ILM09/HS	*	*	TEG10/HS	=	=	GBG11/HS	*	*
	OEB08/HS	+	=	TEG09/HS	*	=	HLL10/HS	=	=	OUR11/HS	*	=
HT	SBA08/HT	=	=	LAN09/HT	*	=	UEB10/HT	=	=	WOL11/HT	*	=
	EBG08/HT	=	=	WOL09/HT	*	*	SBA10/HT	=	=	EBG11/HT	=	=
	UEB08/HT	=	=	UEB09/HT	=	=	HHF10/HT	=	+	PCH11/HT	=	+
SE	NOT08/SE	=	=	UMK09/SE	=	=	MZL10/SE	=	=			
	RBA08/SE	=	=	KDF09/SE	=	=	RBA10/SE	=	=			
	UMK08/SE	+	=	HLL09/SE	=	=	HLL10/SE	=	=			
PE										OEB11/PE	=	=
										OUR11/PE	=	=
										EBG11/PE	=	=

* significant loss in untreated control plot

= no significant difference

\+ significant loss in farmer's plot (practice)

Fig. 3 Overview on 48 experimental harvests during the four project years, comparing the results in yield and α-acids content from the insecticide-untreated control plot with the farmer‘s practice plot

less the grower had applied two sprayings of pesticide mixtures that prophylactically contained also an insecticide. The second of those applications, called the 'July spraying' in the Hallertau, often contains up to five different active ingredients: two fungicides, one acaricide, one insecticide and one adhesive. Obviously a pesticide cocktail, containing compounds that are applied only by prophylactic means and without need, is sometimes able to slightly damage the hop plant in a way that results in a significant loss of yield – in the discussed case a loss of 10 %. This result should demonstrate growers the disadvantages of unnecessary sprayings. The higher α-acids content found sometimes in the hops of untreated control plots can also be explained easily. As part of the soft resin fraction in hops, the synthesis of bitter acids in the plant is stimulated by small lesions of the plant, as it was already evidenced for injuries caused by slight spider mite infestation [16]. The penetration of hop leaves by aphids is an according case and will sometimes lead to an increased α-acids level of slightly infested plants.

All in all, the results of our study show that aphid infestation of the hop plant may have a negative impact on both hop yield and α-acids content. However, quality parameters other than the bitter acids are obviously never affected by aphids. Furthermore, the impact of aphid colonisation of cultivated hop plants varies extremely between years and makes it therefore impossible to give according valueable prognosis.

Acknowledgements

Expert technical assistance was provided by J. Kneidl, M. Ackstaller, S. Ackstaller, T. Baumgartner, A. Bogenrieder, M. Bauer, O. Ehrenstrasser, K. Grimm, A. Neuhauser, C. Petzina, B. Sperr, S. Weihrauch and B. Wyschkon. Alicia Lorenzana de la Varga, León, Spain, shared with us the initial idea to use Berlese funnels to expel aphids from hop cones. The hop growers Leonhard Berger, Josef Daniel, Helmut Deinhofer, Georg Felber, Josef & Stefan Finkenzeller, Georg Fuchs, Michael Grünwald, Eugen Kirzinger, Manfred König, Christian & Siegmund Königer, Georg Lidl, Georg Loibl, Georg Nutz, Bartholomäus & Ella Obster, Hans & Maria Ostler, Rudi Pfab, Jakob Pichelmeyer, Sepp Rockermeier, Helmut Schmid, Josef Schwarzmeier, Franz Steininger, Johann Thalmair, Georg Weber, Alois Widmann, Franz Wimmer and Josef Wittmann kindly let us misuse their fields for this study. Special thanks to all!

This study was part of the research project "Nachhaltige Optimierung der Bekämpfung von Blattläusen (*Phorodon humuli*) im Hopfen (*Humulus lupulus*) durch Bekämpfungsschwellen und Züchtung Blattlaus-toleranter Hopfensorten", funded by Deutsche Bundesstiftung Umwelt (DBU), Osnabrück, Germany. The support of Dr Holger N. Wurl (DBU) during this project is gratefully acknowledged.

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Received 15 June, 2012, accepted 1 July, 2012