Annette Herz

Alternative flowering crops as potential food sources for beneficial arthropods

Blühende Alternativkulturen als potentielle Nahrungsquelle für Nützlinge

Abstract

Various flowering crops (buckwheat, caraway, carrot, faba bean, flax, lupine, milk thistle, mustard, parsnip, phacelia) were evaluated for their suitability in providing nutritional resources for natural enemies and pollinators in small scale field trials. Flower visitors were documented by visual observation during the full blossom period of these plants. In addition, transparent water traps were installed to record the activity of arthropod groups in the flowering plots. Honey bees and bumble bees were the most frequent flower visitors of crop plants with more or less concealed nectaries and specialized flower structure (mustard, phacelia, lupine and milk thistle). Other wild bees could be observed frequently in flax. Ants and parasitic wasps were mainly active in plants with open flower type and exposed nectaries and stamina (parsnip, buckwheat). Also the extrafloral nectaries of faba bean were frequently visited by ants. Syrphids, but also various bee species (e.g. *Apis*, *Bombus*, *Halictus*) were better documented by direct visual observation than by captures in transparent water traps.

Key words: Functional biodiversity, pollinators, conservation biological control, agricultural landscape, crop diversification

Zusammenfassung

Alternativkulturen wie Ölfrüchte, Körnerleguminosen, Pseudocerealien, Heil- und Gewürzpflanzen oder auch Saatgutkulturen erhöhen die Anbauvielfalt in der Agrarlandschaft und könnten insbesondere für bestimmte Bewirtschaftungsformen wie dem ökologischen Landbau eine attraktive Einkommensquelle erschließen. Dabei vermögen Pflanzen, die in ihrer Kultur zur Blüte gelangen, auch das Nektar- und Pollenangebot in einem Agrarökosystem zu erhöhen, wovon viele Organismen, die auf derartige Ressourcen angewiesen sind, profitieren könnten. Eine Auswahl derartiger Alternativkulturen wurde in einem Kleinparzellenversuch über zwei Jahre auf eine mögliche Attraktivität und Nutzung durch Insekten wie Bestäuber und natürliche Gegenspieler von Agrarschädlingen geprüft. Dazu wurde die Präsenz verschiedener Nützlings-Gilden bzw. ihr Blütenbesuch während der Hauptblühzeit erfasst. Hummeln dominierten in Kulturen mit röhrenförmigen Trichter-, Röhren- oder Schmetterlingsblumen (Phazelie, Mariendistel, Süßlupine), die auch von *Apis mellifera* neben Gelbsenf bevorzugt aufgesucht wurden. Öllein wurde vor allem von Wildbienen besucht. Pflanzen mit frei liegenden Nektarien und offenem Nektarangebot (Buchweizen, Pastinak, Möhre, Kümmel) waren attraktiv für parasitische Hymenopteren und Ameisen. Die extrafloralen Nektarien der Ackerbohne wurden hauptsächlich von Ameisen besucht. Durch Integration dieser Alternativkulturen in die Fruchtfolge wäre es möglich, die betreffenden Nützlingsgilden in der Agrarlandschaft gezielt zu fördern.

Stichwörter: Funktionelle Biodiversität, Bestäuber, Nützlingsförderung, Agrarlandschaft, Anbauvielfalt

Institute
Julius Kühn-Institut (JKI) – Federal Research Centre for Cultivated Plants, Institute for Biological Control, Darmstadt

Correspondence
Dr. Annette Herz, Julius Kühn-Institut (JKI), Federal Research Centre for Cultivated Plants, Institute for Biological Control, Heinrichstr. 243, 64287 Darmstadt, Germany, E-Mail: annette.herz@julius-kuehn.de

Accepted
26 October 2016

Introduction

Biodiversity is decreasing in agricultural landscapes (Krebs et al., 1999; Benton et al., 2003; Guerrero et al., 2012). This applies in general, but also regarding elements of functional biodiversity, providing certain ecosystem services in agro-ecosystems (Altieri, 1999; Isaacs et al., 2009; Geiger et al., 2010; Meehan et al., 2011). Invertebrate arthropods like pollinator insects and natural pest antagonists are of fundamental importance for crop production. Effective measures for their conservation and promotion are a central requirement which needs to be considered in the common agricultural policy of the EU ("Greening" of the EU agriculture). Consequently, action plans and agri-environment schemes at national scale of European countries are in duty to offer an attractive framework for European farmers for modification of current land use towards a more biodiversity friendly agricultural management (Aviron et al., 2009); EU-Regulation No 1305/2013; BMEL, 2015; BfN, 2016).

Many insects depend on the occurrence of plant-derived food sources (nectar, pollen, leaf exudates, seeds, indirectly honeydew) in one or all stages of their life cycles. There are numerous studies demonstrating the importance of such resources for pest antagonists to reach their full capacity in host-/prey location, egg laying and survival (detailed summary e.g. Lundgren, 2009). Important pollinators like wild bee species with various pollen preferences depend on provision of suitable flowering plants throughout the season (Pfiffner and Müller, 2014). On the other hand, the agricultural landscape gets increasingly poor from diverse and season-long supply of non-crop flowering plants (Isaacs et al., 2009). Strategies to counteract this trend aim for example on measures for the conservation of agricultural wild herbs (which are inherently valuable elements of biological diversity (Grass et al., 2016), on the establishment of grasslands, field margins, fallows and hedgerows, the targeted sowing of flowering strips and suitable cover crops or intercropping (Holland et al., 2016). Consideration of particular angiosperm crop plants, which have to flower in their cultivation for the agricultural produce and need to be insect-pollinated (Taki et al., 2010), within the farm management may also increase the availability for nectar and pollen resources in the landscape (Holzschuh et al., 2013; Diekotter et al., 2014).

Furthermore, there is evidence that habitat and landscape heterogeneity have a major effect on the level of biodiversity in the agricultural landscape (Benton et al., 2003; Bianchi et al., 2006; Haenke et al., 2009; Carvalheiro et al., 2011; Holzschuh et al., 2012; Jonsson et al., 2015). Increasing plant diversity, e.g. by considering polycultures, may improve pest control (Altieri, 1999; Letourneau et al., 2011; Iverson et al., 2014). Such an increase of diversity in crop growing on arable land is also an objective within the Greening measures, suggested by the CAP ("crop diversification", "ecological focus areas", BMEL (2015); BfN (2016) and supporting agri-environment schemes (EU-Regulation No 1305/2013). Suitable, (partially) insect-pollinated angiosperm crop plants can be found as oilseeds, pseudocereals, seed cultures, medicinal and aromatic plants, cover crops, biofuel and protein crops. Beside oilseed rape, such alternative crops are still a niche in most EU-countries and in many cases the management practice for these cultures may lack modern strategies for cultivation, plant protection or integration into crop rotation systems (Agroscope, 2016). Certain cultures like medicinal and aromatic plants are especially interesting for organic growing. However, farmers need here long-term reliability, in particular with regards to the purchase of their products at acceptable prices (Mielke and Schöber-Butin, 2004: keyword: contract farming).

Crops that come into flourishing during their cultivation can be attractive for flower-visiting insects, thus being of importance for pollinators and natural enemies. Their availability in the agricultural landscape at certain periods could appeal to different species or groups of these beneficial insects. Biological determinants such as flower type, flower structure, reward system or the special need for nectar and pollen are critical to the usability of a particular plant by a certain beneficial insect (Kugler, 1970; Campbell et al., 2012; Wäckers and van Rijn, 2012). The objective of the work presented here was to examine a range of alternative angiosperm crop plants with respect to their attractiveness during flowering to various beneficial arthropod guilds in a small-scale field trial. The results were used to create a visitor profile for the respective cultivars that can serve as a baseline for further assessment of the contribution of these plants for the potential enhancement of agrobiodiversity.

Material and Methods

Study plots

A field choice trial consisting of 2 m × 2 m wide monoculture plots of various plants was established on the experimental field of the Julius Kühn-Institut in South-Hessia (Table 1). The plots were distributed randomly in fourfold repetition over an area of 0.5 ha. Individual plots were separated by 0.7 m-wide strips covered with plastic foil. Annual crops were seeded in spring after mechanical soil tillage whereas two-year crops such as parsnip and carrot were planted as turnip after winter storage. A fertilisation or plant health treatment did not take place. Weeds were removed manually by hacking or digging out until the crops prevailed. The whole field was surrounded by a one meter wide grassy strip where frequent mowing prevented the flowering of naturally occurring weeds. In the year 2013, a second sowing was done for selected plants (yellow mustard, buckwheat) in late summer to represent their growing phase as a green manure plant.

Assessment of flower visitor activity

Visual observation of flower-visiting arthropods was carried out on windless, sunny days at certain times (between 09:00 to 10:00 and 18:00 to 19:00) during the full blos-

Table 1. Flowering characteristics and usage of various crop plants which were included in the present study. Plants are ordered with regards to their flower type and rewarding system. EFN = extrafloral nectaries, PFN = postfloral nectar production

Flower type according to Kugler (1970)	Plant family	Plant species, crop variety	Usage (Mielke and Schöber-Butin, 2002, 2004, 2007)	Reward system according to Kühn and Klotz (2002)	Full blossom period during the study
Disk flowers with nectar open (Type 1.2 a)	Polygonaceae	*Fagopyrum esculentum* Moench, variety "Lileja"	Pseudocereal, medicinal plant, fodder plant, honey production, green manure	Nectar open, plentiful	11.06. – 05.07. 2013 13.06. – 07.07. 2014
Disk flowers with nectar open (Type 1.2a)	Apiaceae	*Daucus carota* L., vegetable	Seed production	Nectar open	28.06. – 22.07.2013
Disk flowers with nectar open (Type 1.2a)	Apiaceae	*Carum carvi* L., annual variety	Medicinal plant, spice plant	Nectar open	13.06. – 10.07.2013
Disk flowers with nectar open (Type 1.2a)	Apiaceae	*Pastinaca sativa* L., vegetable	Seed production, medicinal plant	Nectar open, plentiful, PFN	28.06. – 22.07.2013 01.07. – 24.07.2014
Disk flowers with nectar open (Type 1.2a)	Brassicaceae	*Sinapis alba* L., variety "Serveka"	Green manure, spice plant, oil seed	Nectar open, pollen	11.06. – 05.07.2013 30.05. – 18.06.2014
Disk flowers with nectar ± hidden (Type 1.2bb)	Linaceae	*Linum usitatissimum* L., variety "Ingot"	Oil seed, green manure, some cultivars for fibre	Nectar ± hidden, nectaries at base of stamens, pollen	08.07. – 22.07.2013 13.06. – 07.07.2014
Funnel flowers, small (Type 2.2)	Boraginaceae	*Phacelia tanacetifolia* Benth.	Green manure, honey production, fodder plant	Nectar ± hidden, plentiful, corolla tube long	20.06. – 08.07.2013
Flower heads, only disk flowers (Type 7.2a)	Asteraceae	*Silybum marianum* L.	Medicinal plant, oil seed	Nectar hidden, coralla tube long, pollen	30.06. – 05.07.2014
Flag blossom (Typ 6.1c)	Fabaceae	*Lupinus angustifolius* L., JKI-variety	Protein crop, fodder plant, green manure	Nectar hidden, plentiful, long corolla	19.06. – 26.06.2013
Flag blossom (Type 6.1c)	Fabaceae	*Vicia faba* L., variety "Espresso"	Protein crop, fodder plant, green manure	Nectar hidden, long corolla, EFN	09.05. – 12.06.2014

som period of the respective crop. Plots were observed for up to ten minutes to register the taxonomic category of each flower visitor of 10 visited inflorescences per plot (= positively evaluated inflorescences). This was done for each crop at four different dates during the flowering period (Table 1). Flower visitors were assigned to the following taxonomic units, considered as beneficial functional groups: (1) honey bees (*Apis*), (2) bumble bees (*Bombus*), (3) other wild bees, (4) mainly aphidophagous hoverflies (Syrphinae), (5) hoverflies belonging to the Eristalinae, (6) parasitic Hymenoptera (Ichneumonidae, Braconidae and others), (7) Formicidae, (8) Coccinellidae and (9) all other arthropods. In some cases, the determination to genus or species level was possible (e.g. *Apis mellifera*, *Bombus* sp., *Halictus* sp., *Episyrphus balteatus*, *Eristalis* sp., *Coccinella septempunctata*). These surveys were carried out again during the second phase of late sowing of buckwheat and yellow mustard in the same way.

In addition, the activity of arthropods within the flowering plots was registered using water traps. These consisted of round transparent plastic bowls (diameter 18 cm) with 2 l capacity, which were installed at the level of the florets of each crop. The bowls were filled with saline solution (3% plus a few drops of liquid soap). Water traps were set into the plots at the time of full blossom for 14 days (Table 1). At the same time, similar traps were put in the grass strip around the experimental field and served as control without flowers around. Every two to three days, captured arthropods were removed from the traps and were transferred into ethanol (70%) for further examination in the laboratory. The arthropods were assigned to the same categories as in the visual observation method.

Data evaluation and statistical analysis

Only inflorescences were taken into account when at least one visitor had been observed (= number of positively evaluated inflorescences) within the observation time. The number of flower visits of a particular taxon was summed up across the observation dates per plot and the relative abundance of this taxon was calculated with reference to the total number of positively evaluated inflorescences observed per plot during the observation period. Captures of the water traps were calculated by taking the sum of trapped specimen of a particular taxon for the duration of the total trapping period (14 days) in each plot.

For graphical analysis, the relative abundance of beneficials (i.e. *Apis*, *Bombus*, other wild bees, Syrphidae, parasitic Hymenoptera, Formicidae, Coccinellidae) in relation to the remaining arthropods in the data set of observed flower visitors were presented in bar charts. The relative distribution of these taxa in the late sowing buckwheat/mustard trial was presented in circular diagrams. The appearance of certain beneficial groups in relation to the different flowering crops (termed as "preference") was compared by analysing recorded numbers in appropriate general linear models (GLM) with adequate error distribution (R version 3.2.4). For binomial data (number of flower visitors/positive evaluated inflorescence) binomial or quasibinomial models were used. For count data (number of specimen/water trap), poisson models, quasipoisson models or negative binomial models were chosen. The GLM tested the effect of "crop plant species" on the number or proportion of a particular taxon in water traps and observation data. After determination of significance, multiple comparison between means were performed using the library "multcomp" in order to identify preferences of that taxon for particular crop plants. In some cases, the standard error could not be estimated if only zero values exist for a particular plant – insect combination, which leads to an exclusion of these data from the analysis (indicated by # in Tables 2 to 5).

To estimate the diversity of the visitor profile (only the beneficial taxa) of a particular crop plant, the Berger-Parker-Index *D* (May 1975) was calculated according to $D = N_{(max)}/N$, which is the measure of the proportion of the most abundant taxon in the sample (Wheater et al., 2011).

Results

Observation of flower visitors in the flowering plots

The direct observation method for census of flower visitors in the different blooming crops is certainly biased by the fact that very small arthropods were not detected with a similar probability than arthropods exceeding about 5 mm in size. This should be kept in mind when evaluating the obtained results, especially with respect to the occurrence of e.g. small parasitic wasps, Heteroptera or Coleoptera whose numbers were very probably underestimated.

Considering the suggested beneficial guilds, these contribute to more than 50% of the registered arthropods on most of the crop plants (Fig. 1 and 2). Plants with flowers of the open disk type (Table 1) were visited by nearly all considered beneficial taxa (Fig. 1 and 2), but insects with

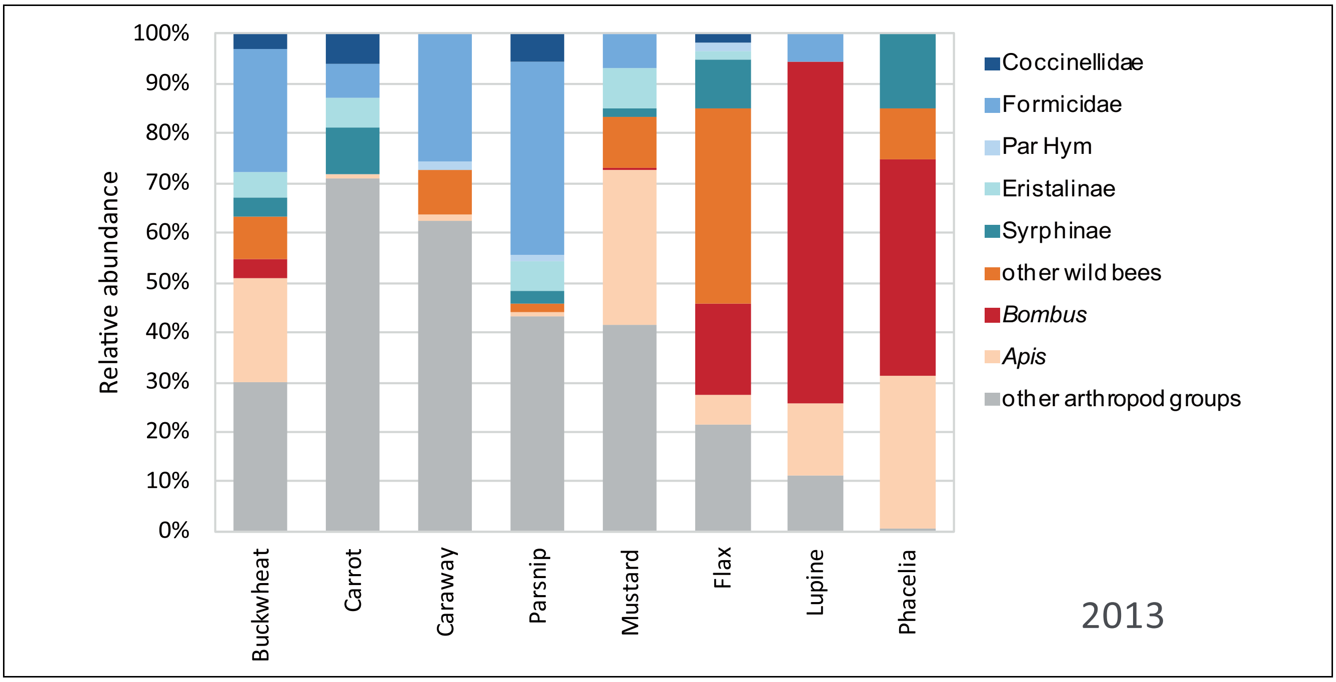

Fig. 1. Relative abundance of different arthropod groups which had been observed visiting flowers of alternative crop plants in a small-scale field trial in 2013.

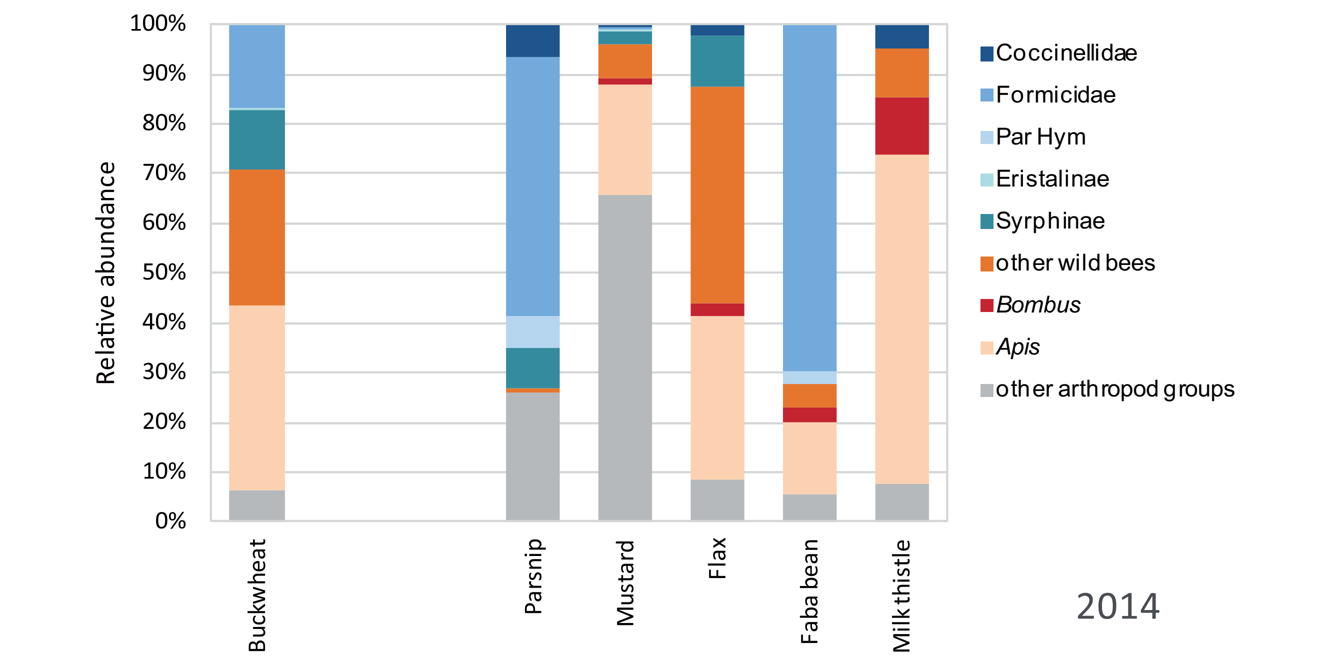

Fig. 2. Relative abundance of different arthropod groups which had been observed visiting flowers and/or extrafloral nectaries of alternative crop plants in a small-scale field trial in 2014.

less specialised mouthparts (Coccinellidae, Formicidae, parasitic Hymenoptera, Syrphinae) were more frequent on these plants than members of the Apoidea. The Apiaceae were also frequently visited by beetles belonging to the family Cantharidae. Buckwheat and mustard were visited by the honeybee and some wild bees (especially *Lasioglossum*, but in the case of mustard also by the rare oligolectic species *Andrena agillisima*) beside ants and other "short tongue" groups. Plants with more concealed nectaries attracted *Apis* and *Bombus* in 2013 (lupine,

Fig. 3. Inflorescence of *Pastinaca sativa* showing developing fruits with droplets of nectar (arrows).

phacelia) as well as in 2014 (faba bean, milk thistle). But ants exploited also the extrafloral nectaries of faba bean located at the stipulae of the leaves. Flax was mainly visited by bee species.

The composition of the flower visitors on buckwheat and mustard at two different blooming periods (June 2013 versus August 2013) did not differ fundamentally. For mustard, the proportion of Apoidea accounted to 40 to 50% of the registered beneficial guilds (Fig. 4 and 5) during both periods. The proportion of Syrphinae was higher during the late summer period, which was probably a consequence of higher abundance of this taxon later in the year (increased 2nd generation of bivoltine species). Buckwheat was always attractive to ants which were frequently observed on the nectar-rich flowers of this plant during early as well as late summer.

Preferences of flower visitors for particular flowering crops

There was some overlapping in the blooming period of the various crop plants during the study (Table 1) and flower visiting arthropods could select between different flower resources. Therefore, observation data were also analyzed for plant preferences of particular functional groups by testing the potential effect of plant species on the occurrence of the beneficial guilds in those plots. This was estimated by the relative number of observed visitors per evaluated inflorescence (observation census) as well as by their general activity, measured by the number of individuals caught in water traps. Only those plant species were considered, where four plots/season had been successfully established (buckwheat, parsnip, mustard, flax, phacelia, faba bean, milk thistle). According to this analysis, the recorded number of a particular beneficial group was significantly influenced by plant species in both years of the investigation (Tables 2 to 5).

The honey bee was observed on all plant species in the year 2013 with a preference for mustard, phacelia and buckwheat (Table 2). In 2014, the milk thistle was most attractive for *A. mellifera* (Table 3). Representatives of *Bombus* sp. preferred phacelia in 2013 and also milk thistle in 2014. Both *Apis* and *Bombus* were rarely caught in the water traps (Table 4 and 5).

Various wild bees occurred in all plots. Members of the genus *Halictus* were regularly observed as dominant group in flax in both years, collecting pollen there (Table 2 and 3, Fig. 6). Higher numbers of wild bees were caught in the water traps installed in buckwheat (Table 4 and 5); these belong to various genera (*Lasioglossum*, *Andrena*, *Hylaeus* and others).

No clear preference for certain flowering plants could be determined for the hoverflies. In the year 2013, many of them were observed in phacelia, but they occurred also in other plots, indicating that they are attracted to many different plants. In general, they were rarely caught in the water traps.

Parasitic Hymenoptera and ants (*Lasius niger*, *Formica* species and others) were highly attracted by inflorescences of parsnip. This plant developed plenty of postfloral nectar droplets on the developing fruits (Fig. 3). Ants were observed on the inflorescences in large numbers (Table 2 and 3) and their prevailing activity was also confirmed by the capture rates in the water traps installed at the height of the inflorescences. Parasitic Hymenoptera were mainly recorded by the water traps and here they were found more frequently in parsnip than in the other crop plots (Table 4 and 5). Parsnip was also the plant most attractive for the Coccinellidae (Table 3).

Visitor profile of the different crop plants

When summarizing the attractiveness of the various crop plants for the beneficial taxa (taking into account obser-

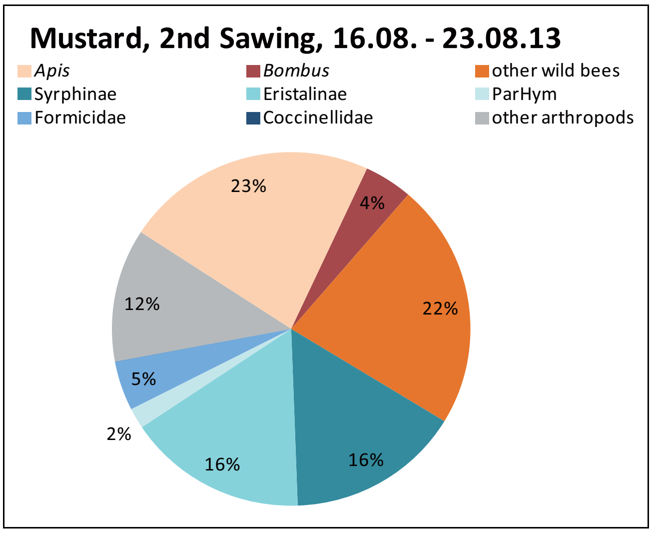

Fig. 4. Relative abundance of different arthropod groups which had been observed visiting flowers of yellow mustard (*Sinapis alba*) blooming in late August 2013.

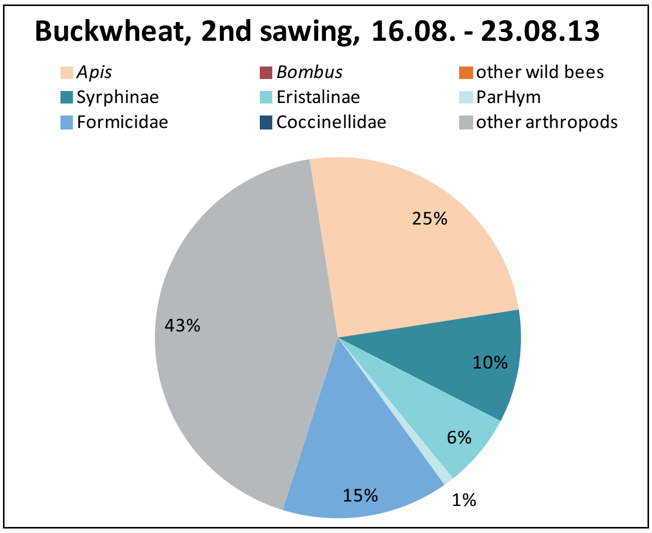

Fig. 5. Relative abundance of different arthropod groups which had been observed visiting flowers of buckwheat (*Fagopyrum esculentum*) blooming in late August 2013.

Table 2. Number of beneficials/positive evaluated inflorescence (mean ± SEM) in plots (n = 4) of flowering crop plants during full blossom in the year 2013. Significance of flower effect on the occurrence of the beneficial taxa was tested using GLM. Different letters indicate significant differences between treatments in post hoc tests (Tukey-Kramer correction, p = 0.05). #: Zero values were excluded from analysis

	Buckwheat	Parsnip	Mustard	Flax	Phacelia	Significance of plant effect
Apis	0.22 ± 0.04a	0.02 ± 0.01b	0.35 ± 0.01a	0.06 ± 0.02b	0.30 ± 0.03a	F (4, 15) = 25.11 P < 0.001
Bombus	0.01 ± 0.01c	0#	0.01 ± 0.01c	0.19 ± 0.07b	0.43 ± 0.04a	CHI2 = 131.47 P < 0.001
Wild bees	0.07 ± 0.02b	0.03 ± 0.01b	0.12 ± 0.01b	0.40 ± 0.14a	0.10 ± 0.04b	F (4,15) = 7.86 P = 0.001
Syrphinae	0.02 ± 0.01b	0.06 ± 0.01ab	0.02 ± 0.01b	0.10 ± 0.05ab	0.15 ± 0.02a	CHI2 = 24.22 P < 0.001
Parasit. Hymenoptera	0#	0.03 ± 0.02a	0#	0.02 ± 0.02a	0#	CHI2 = 0.123 P = 0.72
Formicidae	0.37 ± 0.08b	0.83 ± 0.11a	0.08 ± 0.02c	0#	0#	F (4,15) = 16.22 P < 0.001
Coccinellidae	0#	0.12 ± 0.04a	0#	0.02 ± 0.02a	0#	F (1,7) = 2,66 P = 0.154

Table 3. Number of beneficials/positive evaluated inflorescence (mean ± SEM) in plots (n = 4) of flowering crop plants during full blossom in the year 2014. Significance of flower effect on the occurrence of the beneficial taxa was tested using GLM. Different letters indicate significant differences between treatments in post hoc tests (Tukey-Kramer correction, p = 0.05). #: Zero values were excluded from analysis

	Buckwheat	Parsnip	Mustard	Flax	Faba Bean	Milk Thistle	Significance of plant effect
Apis	0.37 ± 0.06b	0#	0.35 ± 0.07bc	0.34 ± 0.10bc	0.09 ± 0.04c	0.68 ± 0.09a	F (4,15) = 7.27 P = 0.002
Bombus	0#	0#	0.02 ± 0.02ab	0.02 ± 0.02ab	0.02 ± 0.01b	0.12 ± 0.04a	F (3,12) = 4.18 P = 0.03
Wild bees	0.28 ± 0.05ab	0.01 ± 0.01c	0.10 ± 0.03bc	0.45 ± 0.08a	0.03 ± 0.03c	0.10 ± 0.04bc	F (5,17) = 13.9 P < 0.001
Syrphinae	0.12 ± 0.01a	0.14 ± 0.06a	0.04 ± 0.01a	0.11 ± 0.04a	0#	0#	CHI2 = 8.05 P = 0.045
Parasit. Hymenoptera	0#	0.11 ± 0.09a	0#	0#	0.02 ± 0.02a	0#	F (1,6) = 3.05 P = 0.1412
Formicidae	0.17 ± 0.12b	0.86 ± 0.06a	0.01 ± 0.01bc	0.02 ± 0.02bc	0.48 ± 0.20ab	0#	F (4,15) = 10.89 P < 0.001
Coccinellidae	0#	0.11 ± 0.02a	0.01 ± 0.01b	0.02 ± 0.02ab	0#	0.05 ± 0.03ab	F (3,11) = 4.85 P = 0.022

vational census and water trap records), mustard, buckwheat, parsnip and flax sustained all relevant beneficial taxa in this study (Table 6). The Berger-Parker-Index *D* was calculated to prove the evenness in the visitor profile. Thereafter, buckwheat, carrot and flax supported a higher diversity of beneficial taxa, which were attracted to the rich nectar/pollen provision by these plants. The other plants were mainly exploited by one particular beneficial group (*D* > = 0.5) which was dominant (parsnip, caraway, EFN of faba bean: ants; phacelia and lupine: *Bombus*; mustard and milk thistle: honey bees). Except of lupine and milk thistle, all tested crop plants were at least four weeks at blossom and flowered – depending on the seeding time – during early to late summer.

Table 4. Number (mean ± SEM) of captured beneficial taxa in water traps in the year 2013. These were installed in plots (n = 4) of flowering crop plants for 14 days during full blossom period. Significance of flower effect on the occurrence of the beneficial taxa was tested using GLM. Different letters indicate significant differences between treatments in post hoc tests (Tukey-Kramer correction. p = 0.05). #: Zero values were excluded from analysis

	Buckwheat	Parsnip	Mustard	Flax	Phacelia	Control	Significance
Apis	1.5 ± 0.95[a]	0[#]	0.75 ± 0.25[a]	0[#]	0.50 ± 0.29[a]	0[#]	CHI2 = 2.28 P = 0.3196
Bombus	1.0 ± 1.00[a]	0.25 ± 0.25[a]	0.75 ± 0.48[a]	0.25 ± 0.25[a]	0.75 ± 0.48[a]	0[#]	F (4,15) = 0.48 *P* = 0.752
Wild bees	10.0 ± 3.10[a]	9 ± 6.05[a]	6.0 ± 1.68[a]	2.3 ± 0.94[ab]	9.5 ± 3.28[a]	0.25 ± 0.25[b]	CHI2 = 28.9 P < 0.001
Syrphinae	2.3 ± 1.60[a]	0[#]	3.3 ± 1.65[a]	0.25 ± 0.25[a]	0.75 ± 0.25[a]	0.25 ± 0.25[a]	F (4,15) = 13.69 *P* = 0.008
Parasit. Hymenoptera	4.2 ± 0.63[b]	16.7 ± 1.49[a]	5.7 ± 0.85[b]	2.3 ± 0.85[b]	4.5 ± 0.5[b]	0[#]	CHI2 = 66.3 *P* < 0.001
Formicidae	1.5 ± 0.29[b]	18.5 ± 8.5[a]	1.3 ± 0.63[b]	1.5 ± 0.64[b]	0.3 ± 0.25[b]	0.8 ± 0.48[b]	CHI2 = 177.9 P < 0.001

Table 5. Number (mean ± SEM) of captured beneficial taxa in water traps in the year 2014. These were installed in plots (n = 4) of flowering crop plants for 14 days during full blossom period. Significance of flower effect on the occurrence of the beneficial taxa was tested using GLM. Different letters indicate significant differences between treatments in post hoc tests (Tukey-Kramer correction. p = 0.05). #: Zero values were excluded from analysis

	Buckwheat	Mustard	Flax	Control	Significance
Apis	0.25 ± 0.25[a]	3.75 ± 1.18[b]	0.25 ± 0.25[a]	0[#]	CHI2 = 22.26 P < 0.001
Bombus	0[#]	2.0 ± 0.82[#]	0[#]	0[#]	No analysis
Wild bees	14.7 ± 5.20[a]	7.0 ± 0.71[ab]	2.5 ± 0.29[bc]	0.33 ± 0.14[c]	CHI2 = 49.28 P < 0.001
Syrphinae	0.25 ± 0.5[a]	0.5 ± 0.6[a]	0.25 ± 0.50[a]	0[#]	CHI2 = 0.47 P = 0.7901
Parasit. Hymenoptera	6.5 ± 0.65[ab]	11.2 ± 3.71[a]	1.5 ± 0.65[c]	3.9 ± 0.61[bc]	CHI2 = 26.96 P < 0.001
Formicidae	5 ± 2.34[b]	5.8 ± 3.52[a]	0[#]	1.6 ± 0.34[b]	CHI2 = 6.85 P = 0.032

Discussion

The idea of this study was to prove the usefulness of various crop plants for provision of nutrional resources (extra)-floral nectar, pollen) to beneficial insect groups. These crops are currently considered as minor alternative crops, but they may become more attractive for farmers who want to increase their crop diversification. In most cases, the considered plants have multifunctional roles regarding their agricultural usage – ranging from green manure till honey production.

Flower morphology and especially nectar accessibility determines the suitability of a plant to "feed" beneficial insects (CAMPBELL et al., 2012; WÄCKERS and VAN RIJN, 2012; GARIBALDI et al., 2015; VAN RIJN et al., 2016). It is a well-known fact that specialized nectar foragers like honey bees, bumble bees, other bee species and some dipteran groups are able to exploit particular flower types (KUGLER, 1970) due to their specialized mouthparts. In contrast, insects with less specialized, more primitive short, broad mouthparts ("chewing type") have only access to flower types with exposed nectaries and pollen. Most species acting as predators or parasitoids belong to this group. These biological determinants (flower trait, mouthpart morphology) need to be considered for the design of improved plant composition in flowering strips adjacent to agricultural fields or orchards (WÄCKERS and VAN RIJN, 2012). Recent research demonstrated the usefulness of this concept with the aim to promote particular beneficials and their ecosystem services like pest control or pollination (CAMPBELL, 2014; GARIBALDI et al., 2015; TSCHUMI et al., 2015; VAN RIJN et al., 2016).

Fig. 6. Wild bee *Halictus* sp. collecting pollen on flowers of flax (*Linum usitatissimum*).

Table 6. Diversity of the visitor profile of beneficial taxa (*Apis*, *Bombus*, other wild bees, Syrphinae, Eristalinae, parasitic Hymenoptera, Formicidae, Coccinellidae) in the considered flowering crop plants. The Berger-Parker-Index *D* was calculated to assess if the exploitation of the plant is mainly by a dominant taxon or by a more even distribution of relevant taxa. *: Faba bean is attractive also due to the extrafloral nectaries

Crop plant	Σ of beneficial taxa supported		Berger-Parker-Index of diversity		Duration of flowering period
	2013	2014	2013	2014	
Buckwheat	8	6	0.27	0.37	5 – 6 weeks
Carrot	6	--	0.34	--	6 – 7 weeks
Caraway	5	--	0.57	--	5 – 6 weeks
Parsnip	8	5	0.60	0.58	5 – 6 weeks
Mustard	7	8	0.49	0.59	4 – 5 weeks
Flax	8	6	0.33	0.44	3 – 4 weeks
Phacelia	6	--	0.49	--	4 weeks
Milk thistle	--	4	--	0.72	2 weeks
Lupine	3	--	0.52	--	1 – 2 weeks
Faba bean	--	5	--	0.71	3 – 4 weeks*

In addition to semi-natural habitats (flower strips, field margins, hedgerows etc.), also flowering crop plants may contribute to the availability of floral resources in the agricultural landscape. Oilseed rape is an early mass-flowering crop attractive for many beneficial groups (Jauker and Wolters, 2008; Holzschuh et al., 2013; Diekotter et al., 2014). But other cultivars may provide additional or even better opportunities, e.g. because they flower later in the year or their cultivation does not need the application of insecticides, which may harm flower visitors.

Buckwheat showed the highest diversity of the considered flower visitors in our study (Berger-Parker Index, lowest value $D = 0.27$), thus supporting a wider range of beneficial taxa (pollinators and pest control agents). Nectaries in buckwheat flowers produce nectar of high viscosity with sugar concentration around 60% sucrose (w/w) (Cawoy et al., 2008; Herz, unpublished data). Its positive effect on the fitness of beneficial insects, especially to parasitic Hymenoptera was demonstrated in numerous studies. Increase in survival and consequently realized fecundity of parasitoid females, having access to buckwheat flowers, was frequently reported (Lee et al., 2004; Lee and Heimpel, 2008a, b; Winkler et al., 2009; Laubertie et al., 2012; Pumarino et al., 2012; Sigsgaard et al., 2013; van Rijn et al., 2013). Nectar is secreted from nectaries located at the basis of the stamina which can easily be exploited by short-tongue flower visitors, but are also attractive to honey bees and other bee species. It was reported that buckwheat mainly produced nectar in the morning (Hedtke and Pritsch, 1993) and we observed a frequent "nectar harvesting" by ants in our experiment in the morning too. How this nectar depletion may affect other taxa with a different temporal foraging pattern needs to be explored under field conditions. Buckwheat has many interesting agricultural uses: it is useful as green manure, fodder and biofuel plant as well as pseudocereal in human food. Furthermore, honey production and use for medicinal purposes is possible (Cawoy et al., 2008). Buckwheat can be easily integrated into crop rotation schemes and the cultivation usually does not require the application of any pesticides or herbicides (Heyland et al., 2006). Due to its multifunctional use, several seeding dates are possible (early for seed production, late as green manure or cover crop) and as consequence buckwheat flowering can occur from early June to mid of September in the landscape. Buckwheat is often included as component in annual flower strip plant mixtures (Fig. 7).

Fig. 7. "Greening" mixture composed of yellow mustard, buckwheat and phacelia established along a corn field in 2016.

Also flax was visited by various beneficial groups (D = 0.33). It was highly attractive to wild bees (genus *Halictus*) as pollen source. Syrphinae were observed too, but it was not clear if they exploited pollen or nectar. Flax opened the flowers mainly during morning and sunshine. The total flowering period was about 3 to 4 weeks. This plant is autophilious, nevertheless nectar and pollen are apparently produced in higher amounts which makes it attractive for many insects. Due to its particular value for beneficial taxa the cultivation of this crop on a broader scale would be desirable. We used a cultivar for oilseed production in our trial. The demand for oilseed is rising (e.g. production of lineseed oil also for human nutrition), especially for the organic sector (Hiltbrunner et al., 2009). Flax is also recommended as a component of so called "greening" cover crops (Anonymous, 2016), which may increase the cultivation of this plant on a larger scale.

Mustard was found to attract many beneficial groups, whereby honey bees were dominant in both years of the study. Later in the year (second sawing in 2013), also Syrphidae (both Eristalinae and Syrphinae) visited the flowers frequently. The nectar is secreted plentiful at the base of the stamina where insects with prolonged mouthparts can reach it easily. Pollen was collected by many bee species, e.g. the oligolectic *Andrena agilissima*, indicating its value also for rare endangered species. Also higher numbers of small parasitic Hymenoptera were caught in the water traps in mustard plots, being probably attracted by this flowering plant. They might be able to enter the flower and to crawl to the nectaries for feeding, but this still needs to be confirmed. The different varieties of mustard (*Sinapis alba* and relatives) can be widely used in agriculture (Heyland et al., 2006). They are often used as cover crops and green manure. But they can also deliver oilseed, spices or seeds for technical and medicinal products. Together with buckwheat and phacelia, mustard is included in annual "greening" seed mixtures (Anonymous, 2016, Fig. 7) offering food for a broad range of beneficial taxa.

Due to their more specialized flower type, phacelia, milk thistle, lupine and faba bean provided reward especially for Apoidea, mainly bumble bees and honey bees, which were able to exploit the hidden nectar in the prolonged corolla of these plants. Beneficial taxa with less specialized mouthparts were not observed on the flowers, but ants and parasitic Hymenoptera visited the extrafloral nectaries of faba bean. These EFN already developed on the first leaves of the plants long before flowering. The potential role of these nectar providers for parasitic Hymenoptera requires further research in the field, because laboratory studies showed that parasitoids feed on them and their longevity and fecundity is increased (Jamont et al., 2013; Walach and Herz, 2015). Faba bean and other Leguminosae are suitable cover crops for green manure and within greening regimes and may be even become more important as human food.

Many vegetables belong to the Apiaceae. They are mainly cultivated for their vegetative parts (carrot, fennel, parsnip, celery, dill), although some cultivars are grown for seeds (caraway, coriander, fennel, dill) too. For organic seed production, these plants need to be cultivated till flowering and often require successful pollination by insects (Howlett, 2012). Apiaceae are known to support many natural enemies due to their exposed nectaries and stamina (Kugler, 1970; van Rijn et al., 2016) and wild forms are often recommended to be part of flower strips along arable crops (e.g. Isaacs et al., 2009; Sivinski et al., 2011). We included vegetable cultivars which grew more vigorously than the wild types. Parsnip developed rich nectar droplets of a high sucrose content (around 70% (w/w); Herz unpublished data), especially on the developing seeds (postfloral nectaries, Fig. 3). These droplets were systematically harvested by ants, but also by other insects with unspecialized mouthparts (beetles, wasps, many different Dipteran groups including Syrphidae). In addition, some wild bee species visited carrot and parsnip indicating the values of these plants for them. Seed cultures of Apiaceae certainly need a particular management, but their cultivation may be suitable for some regions and of particular value for organic growers. They flower mainly in the second half of the summer, thus providing an interesting nectar supply during this time which may be important for migrating and overwintering wasps and flies (e.g. Syrphidae, parasitic Hymenoptera).

To conclude, most of the tested plants in this small-scale study supported many beneficial taxa, although their value for particular groups differed in dependence on biological determinants. But due to this fixed relationship, it can be assumed that the findings here can be also found on a larger scale in the agricultural landscape. Certainly the surroundings of agricultural fields and their provision with available nectar and pollen resources affect the attractiveness of the flowering crop plants as it was demonstrated for the role of flowering strips and other semi-natural habitats (Haenke et al., 2009; Haenke et al., 2014; Jonsson et al., 2015). A more diverse array of different crop systems can also have other benefits (less attraction to particular pests), even with economic consequences (Letourneau et al., 2011; Iverson et al., 2014). Thus, strategies which favour crop diversification by including also alternative crops with new purposes may have the effect of benefitting providers of ecosystem services too. To reach this goal, the elaboration of guidelines is needed how these alternative crops can be integrated into the farm management and into the matrix of the surrounding agricultural landscape.

Acknowledgement

The author would like to thank Simon Feiertag for technical assistance and Gerti Roskosch and Susanne Ganzer for establishing and maintaining the field plots.

References

Agroscope, 2016: Alternative Kulturpflanzen. http://www.agroscope.admin.ch/grandes-cultures/07769/index.html?lang=de. Access on 16th September 2016.

Anonymous, 2016: Saatgut in Top-Qualität – TopQuh – Greening. Access at www.topquh.de on 09.08.16.

Altieri, M.A., 1999: The ecological role of biodiversity in agroecosystems. Agric. Ecosyst. Environ. **74** (1–3), 19-31.

Aviron, S., H. Nitsch, P. Jeanneret, S. Buholzer, H. Luka, L. Pfiffner, S. Pozzi, B. Schüpbach, T. Walter, F. Herzog, 2009: Ecological cross compliance promotes farmland biodiversity in Switzerland. Front. Ecol. Environ. **7** (5), 247-252.

Benton, T.G., J.A. Vickery, J.D. Wilson, 2003: Farmland biodiversity: is habitat heterogeneity the key? Trends Ecol. Evol. **18** (4), 182-188.

BfN (Bundesamt für Naturschutz), 2016: Praxishandbuch: Naturschutzfachliche Ausgestaltung von ökologischen Vorrangflächen. Hrsg.: Institut für Ländliche Strukturforschung an der Goethe-Universität (IfLS), Frankfurt am Main. http://www.ifls.de/fileadmin/user_upload/Abbildungen/Projekte/Handbuch_OEV Forsch/Handbuch_OEVForsch_mit_Merkblaettern.pdf. Access on 16th September 2016.

Bianchi, F.J.J.A., C.J.H. Booij, T. Tscharntke, 2006: Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control. P Roy Soc B-Biol Sci **273** (1595), 1715-1727.

BMEL (Bundesministerium für Ernährung und Landwirtschaft, Federal Ministry of Food and Agriculture), 2015: https://www.bmel.de/EN/Agriculture/EU-AgriculturalPolicy/_Texte/GAP-FAQs.html#doc5530798bodyText7. Access on 20th June 2016.

Campbell, A., 2014: Functional Agri-Biodiversity: improving pest control and pollination services by means of multi-functional flowering strips in cider apple orchards. PhD at Lancaster University.

Campbell, A.J., J.C. Biesmeijer, V. Varma, F.L. Wackers, 2012: Realising multiple ecosystem services based on the response of three beneficial insect groups to floral traits and trait diversity. Basic Appl. Ecol. **13** (4), 363-370.

Carvalheiro, L.G., R. Veldtman, A.G. Shenkute, G.B. Tesfay, C.W.W. Pirk, J.S. Donaldson, S.W. Nicolson, 2011: Natural and within-farmland biodiversity enhances crop productivity. Ecol. Lett. **14** (3), 251-259.

Cawoy, V., J.M. Kinet, A.L. Jacquemart, 2008: Morphology of nectaries and biology of nectar production in the distylous species *Fagopyrum esculentum*. Ann. Bot. **102** (5), 675-684.

Diekotter, T., F. Peter, B. Jauker, V. Wolters, F. Jauker, 2014: Mass-flowering crops increase richness of cavity-nesting bees and wasps in modern agro-ecosystems. Global Change Biology Bioenergy **6** (3), 219-226.

EU-Regulation, (EU) No. 1305/2013 of the European parliament and of the Council of 17 december 2013 on support for rural development by the European Agricultural Fund for Rural Development. Official Journal of the European Union, L 347: 487-548, published on 20.12.2013.

Garibaldi, L.A., I. Bartomeus, R. Bommarco, A.M. Klein, S.A. Cunningham, M.A. Aizen,... M. Woyciechowski, 2015: Trait matching of flower visitors and crops predicts fruit set better than trait diversity. J. Appl. Ecol. **52** (6), 1436-1444.

Geiger, F., J. Bengtsson, F. Berendse, W. Weisser, M. Emmerson, M. Morales, ... C. Winqvist, 2010: Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. Basic Appl. Ecol. **11** (2), 97-105.

Grass, I., J. Albrecht, F. Jauker, T. Diekotter, D. Warzecha, V. Wolters, N. Farwig, 2016: Much more than bees-Wildflower plantings support highly diverse flower-visitor communities from complex to structurally simple agricultural landscapes. Agric. Ecosyst. Environ. **225**, 45-53.

Guerrero, I., M.B. Morales, J.J. Oñate, F. Geiger, F. Berendse, G. de Snoo,... T. Tscharntke, 2012: Response of ground-nesting farmland birds to agricultural intensification across Europe: Landscape and field level management factors. Biol. Conserv. **152**, 74-80.

Haenke, S., A. Kovacs-Hostyanszki, J. Fruend, P. Batary, B. Jauker, T. Tscharntke, A. Holzschuh, 2014: Landscape configuration of crops and hedgerows drives local syrphid fly abundance. J. Appl. Ecol. **51** (2), 505-513.

Haenke, S., B. Scheid, M. Schaefer, T. Tscharntke, C. Thies, 2009: Increasing syrphid fly diversity and density in sown flower strips within simple vs. complex landscapes. J. Appl. Ecol. **46** (5), 1106-1114.

Hedtke, C., G. Pritsch, 1993: 1. Qualitative und quantitative Untersuchungen zum Beflug des Buchweizen (*Fagopyrum esculentum* Moench). Apidologie **24** (5), 476-477.

Heyland, K.- U., H. Hanus, E.R. Keller, 2006: Ölfrüchte, Faserpflanzen, Arzneipflanzen und Sonderkulturen. In: Hanus, H., K.-U. Heyland, R. Keller (eds.): Handbuch des Pflanzenbaues, Band 4. Stuttgart, Verlag Eugen Ulmer, 718 pp.

Hiltbrunner, J, T. Hebeisen, H.R. Hunzicker, C. Herzog, 2009: Eignung von neuen Sommerleinsorten für den Ökolandbau im Schweizer Mittelland. In: Mayer, J., T. Alföldi, F. Leiber, D. Dubois, P. Fried, F. Heckendorn, E. Hillmann, P. Klocke, A. Lüscher, S. Riedel, M. Stolze, F. Strasser, M. van der Heijden, H. Willer (eds.): Werte – Wege – Wirkungen: Biolandbau im Spannungsfeld zwischen Ernährungssicherheit, Markt und Klimawandel. Beiträge zur 10. Wissenschaftstagung Ökologischer Landbau, ETH Zürich, 11.-13. Februar 2009. Band 1, 219-220.

Holland, J.M., F.J.J.A. Bianchi, M.H. Entling, A.-C. Moonen, B.M. Smith, P. Jeanneret, 2016: Structure, function and management of semi-natural habitats for conservation biological control: a review of European studies. Pest Manage. Sci. **72** (9), 1638-1651.

Holzschuh, A., C.F. Dormann, T. Tscharntke, I. Steffan-Dewenter, 2013: Mass-flowering crops enhance wild bee abundance. Oecologia **172** (2), 477-484.

Holzschuh, A., J.-H. Dudenhöffer, T. Tscharntke, 2012: Landscapes with wild bee habitats enhance pollination, fruit set and yield of sweet cherry. Biol. Conserv. **153** (0), 101-107.

Howlett, B.G., 2012: Hybrid carrot seed crop pollination by the fly *Calliphora vicina* (Diptera: Calliphoridae). J. Appl. Entomol. **136** (6), 421-430.

Isaacs, R., J. Tuell, A. Fiedler, M. Gardiner, D. Landis, 2009: Maximizing arthropod-mediated ecosystem services in agricultural landscapes: the role of native plants. Front. Ecol. Environ. **7** (4), 196-203.

Iverson, A.L., L.E. Marín, K.K. Ennis, D.J. Gonthier, B.T. Connor-Barrie, J.L. Remfert, B.J. Cardinale, I. Perfecto, 2014: Review: Do polycultures promote win-wins or trade-offs in agricultural ecosystem services? A meta-analysis. J. Appl. Ecol. **51** (6), 1593-1602.

Jamont, M., S. Crépellière, B. Jaloux, 2013: Effect of extrafloral nectar provisioning on the performance of the adult parasitoid *Diaeretiella rapae*. Biol. Control **65** (2), 271-277.

Jauker, F., V. Wolters, 2008: Hover flies are efficient pollinators of oilseed rape. Oecologia **156** (4), 819-823.

Jonsson, M., C.S. Straub, R.K. Didham, H.L. Buckley, B.S. Case, R.J. Hale, C. Gratton, S.D. Wratten, Y. Clough, 2015: Experimental evidence that the effectiveness of conservation biological control depends on landscape complexity. J. Appl. Ecol. **52** (5), 1274-1282.

Krebs, J.R., J.D. Wilson, R.B. Bradbury, G.M. Siriwardena, 1999: The second silent spring? Nature **400** (6745), 611-612.

Kühn, I., S. Klotz, 2002: Systematik, Taxonomie und Nomenklatur. In: Klotz, S., I. Kühn and W. Durka (eds.): BIOLFLOR – Eine Datenbank mit biologisch-ökologischen Merkmalen zur Flora von Deutschland. Schriftenreihe für Vegetationskunde. Bonn.

Kugler, H., 1970: Blütenökologie. Stuttgart, Gustav Fischer Verlag, 345 pp.

Laubertie, E.A., S.D. Wratten, J.L. Hemptinne, 2012: The contribution of potential beneficial insectary plant species to adult hoverfly (Diptera: Syrphidae) fitness. Biol. Control **61** (1), 1-6.

Lee, J.C., G.E. Heimpel, 2008a: Effect of floral nectar, water, and feeding frequency on *Cotesia glomerata* longevity. BioControl **53** (2), 289-294.

Lee, J.C., G.E. Heimpel, 2008b: Floral resources impact longevity and oviposition rate of a parasitoid in the field. J. Anim. Ecol. **77** (3), 565-572.

Lee, J.C., G.E. Heimpel, G.L. Leibee, 2004: Comparing floral nectar and aphid honeydew diets on the longevity and nutrient levels of a parasitoid wasp. Entomol. Exp. Appl. **111** (3), 189-199.

Letourneau, D.K., I. Armbrecht, B.S. Rivera, J.M. Lerma, E.J. Carmona, M.C. Daza, ... A.R. Trujillo, 2011: Does plant diversity benefit agroecosystems? A synthetic review. Ecol. Appl. **21** (1), 9-21.

Lundgren, J.G., 2009: Relationships of natural enemies and non-prey foods. Progress in Biological Control 7. Springer Science + Business Media B.V., 453 pp.

Meehan, T.D., B.P. Werling, D.A. Landis, C. Gratton, 2011: Agricultural landscape simplification and insecticide use in the Midwestern United States. Proc. Natl. Acad. Sci. U. S. A. **108** (28), 11500-11505.

Mielke, H., B. Schöber-Butin, 2002: Pflanzenschutz bei Nachwachsenden Rohstoffen. Zuckerrübe, Öl- und Faserpflanzen. Mitteilungen aus Biologischen Bundesanstalt für Land- und Forstwirtschaft Berlin-Dahlem **391**, 96 pp.

Mielke H., B. Schöber-Butin, 2004: Anbau und Pflanzenschutz nachwachsender Rohstoffe (Sonderkulturen). Eiweiß-, Öl-, Färber-, Inulin- und Faserpflanzen. Mitteilungen aus Biologischen Bundesanstalt für Land- und Forstwirtschaft Berlin-Dahlem **395**, 128 pp.

Mielke, H., B. Schöber-Butin, 2007: Heil- und Gewürzpflanzen. Anbau und Verwendung. Mitteilungen aus Biologischen Bundesanstalt für Land- und Forstwirtschaft Berlin-Dahlem **411**, 288 pp.

Pfiffner, L., A. Müller, 2014: Wild bees and pollination. FiBL – Factsheet, 8 pp.

Pumarino, L., O. Alomar, J.G. Lundgren, 2012: Effects of floral and extrafloral resource diversity on the fitness of an omnivorous bug, *Orius insidiosus*. Entomol. Exp. Appl. **145** (3), 181-190.

R version 3.2.4 Revised (2016-03-16 r70336) -- "Very Secure Dishes", Copyright (C) 2016 The R Foundation for Statistical Computing, Platform: x86_64-w64-mingw32/x64 (64-bit).

Sigsgaard, L., C. Betzer, C. Naulin, J. Eilenberg, A. Enkegaard, K. Kristensen, 2013: The effect of floral resources on parasitoid and host longevity: Prospects for conservation biological control in strawberries. Journal of Insect Science **13**.

Sivinski, J., D. Wahl, T. Holler, S. Al Dobai, R. Sivinski, 2011: Conserving natural enemies with flowering plants: Estimating floral attractiveness to parasitic Hymenoptera and attraction's relationship to flower and plant morphology. Biol. Control **58** (3), 208-214.

Taki, H., K. Okabe, Y. Yamaura, T. Matsuura, M. Sueyoshi, S. Makino, K. Maeto, 2010: Effects of landscape metrics on Apis and non-Apis pollinators and seed set in common buckwheat. Basic Appl. Ecol. **11** (7), 594-602.

Tschumi, M., M. Albrecht, M.H. Entling, K. Jacot, 2015: High effectiveness of tailored flower strips in reducing pests and crop plant damage. P Roy Soc B-Biol Sci **282** (1814), 189-196.

van Rijn, P.C.J., J. Kooijman, F.L. Wäckers, 2013: The contribution of floral resources and honeydew to the performance of predatory hoverflies (Diptera: Syrphidae). Biol. Control **67** (1), 32-38.

van Rijn, P.C.J., F.L. Wäckers, M. Cadotte, 2016: Nectar accessibility determines fitness, flower choice and abundance of hoverflies that provide natural pest control. J. Appl. Ecol. **53** (3), 925-933.

Wäckers, F.L., P.C.J. van Rijn, 2012: Pick and mix: Selecting flowering plants to meet requirements of target biological control insects. In: Gurr, G.M. (ed.): Biodiversity and Pest management. Wiley-Blackwell, pp. 139-165.

Walach, S., A. Herz, 2015: Eignung der extrafloralen Nektarien der Ackerbohne als Nahrungsquelle für den Parasitoiden *Ascogaster quadridentata* Wesmael (Hymenoptera, Braconidae). Mitteilungen der Deutschen Gesellschaft für Allgemeine und Angewandte Entomologie **20**, 145-148.

Wheater, C.P., J.R., Bell, P.A. Cook, 2011: Practical field ecology: a project guide. Chicester, UK, Wiley, 362 pp.

Winkler, K., F. Wackers, D.M. Pinto, 2009: Nectar-providing plants enhance the energetic state of herbivores as well as their parasitoids under field conditions. Ecol. Entomol. **34** (2), 221-227.