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DISCLAIMER

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures describes herein and that the report represents a true and accurate record of the results obtained.

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GROWER SUMMARY

Headline

Marketable flowering species are utilised by biological control agents, increasing their abundance and persistence in the field and may support biological control of pests when grown in combination with Brassicas.

Background and expected deliverables

The horticultural industry faces a range of issues linked to crop protection. These include a reduction in the available products approved for use; problems with resistance in the target organisms; increasing pressures from consumers and retailers for residue-free produce; and a need to comply with legislation and industry initiatives (e.g. Water Framework Directive and the Voluntary Initiative). These pressures lead to a need for a more rational approach to pesticide use, and for the full exploitation of the range of methods available for maintaining pest populations below the economic damage thresholds. This project tests methods of enhancing conservation biological control of Brassica pests by providing supplementary resources that will increase the density, diversity and activity of naturally colonising biological control agents.

Typically in intensive agricultural and horticultural systems, the effectiveness of biological pest control is critically limited by the absence of alternative or supplementary food sources. Many biological control agents depend on flowering plants as a source of energy-rich nectar and pollen. The scarcity of floral resources in modern horticulture severely constrains predator survival and activity, undermining the effectiveness of biological pest control. This bottleneck can be addressed by diversifying the cropping system with flowering plant species. This can be achieved by planting selected flowering non-crop vegetation in field margins. While this approach has been proven to be effective, it reduces the area available for crop cultivation. This project aims to test and promote combined cropping as an alternative technology to provide predators with floral resources, without compromising acreage. This studentship aims to select a variety of nectar/pollen providing crops and test their impact on the efficiency of both generalist and specialist biocontrol agents when grown adjacent to vegetable crops lacking floral resources.

The project focusses on combinations of marketable crops with a view to optimize economic as well as ecological benefits. Two classes of nectar and pollen providing crops will be studied in the project: - vegetable crops which produce both extrafloral nectar as well as flowers (e.g. broad beans) and pharmaceutical flowering crops (e.g. borage, evening primrose and St John's wort).

The medicinal plant industry is currently expanding at a great rate across the globe. Currently valued at more than €45B annually, it is growing steadily at c. 8% p.a. with the EU as the leading importer of medicinal plants and extracts (Williamson & MacTavish 2007). The UK complementary medicines market was estimated to be worth £147M in 2004 having grown by 47% since 2004 (Williamson & MacTavish 2007). Currently, >700 species are traded in the UK, of which 90% are collected from the wild. There is considerable concern over the quality and identity of much imported material and meany species are CITES listed as concern grows over their conservation status. Consequently, there is growing interest in the expansion of medicinal plant crops in the UK (Williamson & MacTavish 2007).

Overall aim of the project

The project aims to develop novel technologies to harness biodiversity benefits for sustainable pest control in horticulture, without compromising crop acreage.

Specific objectives

1) To determine the potential of selected pharmaceutical flowering plant species as pollen and nectar sources for biological control agents in adjacent crops lacking floral resources.
2) To determine the potential of extrafloral nectar producing vegetable crops as supplementary food sources for biological control agents in adjacent crops lacking floral resources.
3) To establish the impact of pollen and nectar feeding on the effectiveness of biological control agents in controlling pests under field conditions.
4) To determine the impact of in-field supplementary resource provision on crop yield (quantity and quality) in Brassicas.

Summary of the project and main conclusions

Field trials of several marketable flowering plant species examined whether the presence of floral-resource strips intercropped within a Brassica crop affect natural enemy (parasitoids and predators) abundance and subsequent control of pest herbivores. These field trials were undertaken at Stockbridge Technology Centre, Myerscough Agricultural College, Lodge Farm in Wistow and Huntapac, a commercial grower in Lancashire.

Throughout the growing season flying insects were trapped in the flowering plots and samples were analysed for the abundance of key potential biological control agent groups including rove beetles, ladybirds, parasitic wasps, hoverflies and several other predaceous fly groups. The abundance of predators in the adjacent Brassica crop was also recorded, as was the abundance of the key pests (butterfly and moth larvae and aphids).

Trials revealed that the floral-resource providing species do increase the abundance of important groups of biological control agents, and can help them persist for longer in the crop. Specialist biological control agents such as parasitic wasps were more abundant closer to the floral-resource strips, whereas generalist predators, such as rove beetles, were found either in the middle of the crop, or at the furthest distances from the floral-resource strips. This suggests the parasitic wasps are utilising the floral resources and then flying to search for pests, whereas generalist predators are following pest aggregations in the crop. The variability in natural enemy abundance and in the effectiveness of the flower species at different sites however, warrants further investigation.

Financial benefits

The pharmaceutical plant species used in this project are commercially useful, especially buckwheat which has multiple uses and can be cropped twice in the same growing season. Growers should be aware that intercropping can reduce the need for pesticides as part of IPM, which could have a financially significant effect on crop production in Brassicas.

Action points for growers

Growers should note:

- There is potential for intercropping floral-resource species, specifically buckwheat and borage, to enhance natural enemy numbers in Brassica crops.
- The site can have a very influential effect on the effectiveness of intercropping in promoting biological pest control.
- This project and previous research suggest that there should be no more than approximately 15m in between floral-resource strips.

SCIENCE SECTION

Introduction

The horticultural industry faces a range of challenges linked to crop protection. These include a reduction in the available products approved for use; problems with resistance in the target organisms; increasing pressures from consumers and retailers for residue-free produce; and a need to comply with legislation and industry initiatives (e.g. Water Framework Directive and the Voluntary Initiative). These pressures lead to a need for a more rational approach to pesticide use and for the full exploitation of the range of methods available for maintaining pest populations below the economic damage thresholds. A key element of future sustainable pest-control strategies will be the utilisation and optimisation of production-supporting ecosystem services, for example, the regulation of pest species by crop-associated biodiversity (Diaz et al 2005; Wilby & Thomas 2007). The challenge is to develop techniques that enhance the abundance and activity of naturally colonising predators and parasites of pests, a concept commonly known as conservation biological control (Jonsson et al. 2008).

One of the key constraints on conservation biological control is that the simplified landscapes that characterise intensive horticultural and agricultural systems tend to have reduced natural enemy (predator and parasitoid) diversity (Tscharntke et al. 2002; Wilby and Thomas 2002). In a review by Bianchi et al (2006), 74% of the studies on natural enemies found that more complex landscapes resulted in enhanced enemy populations. The effect is due in part to monocultures not being able to satisfy the pollen and nectar requirements of natural enemies (Stephens et al. 1998) and because simplified landscapes do not provide sufficient refuges and overwintering sites (Tscharntke et al 2007).

Predators and parasitoids may use a wide range of plant substrates to meet their energy requirements, including floral and extrafloral nectar, fruits, plant sap exudates and honeydew, a sugar-rich excretion from phloem feeding arthropods (Wäckers et al. 2008). Provision of floral resources can lead to increased fitness in adult parasitoids and also lead to increased parasitism in field settings (Witting-Bissinger et al. 2008). Nectar sources have been shown to increase longevity, fecundity and parasitism of hosts in parasitoids (Wackers 2004; Lavandero et al. 2006), and in some insect groups (such as Syrphid flies) floral resources are essential for egg maturation (Bowie, et al. 1995). Many natural enemies also have relatively restricted dispersal away from floral resources suggesting that their provision within field may be necessary for efficient pest regulation (Bianchi et al. 2006). Indeed, studies commonly show that pest-control benefits decline rapidly with distance from floral (or refuge) strips (Hossain et al 2002; Pfiffner et al 2009).

The disadvantage to growers of providing floral resources to promote conservation biological control of pests is that acreage that would otherwise be productive must be sacrificed in order to grow resource-providing plants. This is particularly problematic if, as the evidence suggests, flowering resources must be provided approximately every 30 m to ensure efficient natural enemy numbers across the crop (Hossain et al 2002). In this project we aim to ease this constraint by utilising novel crop combinations to promote pest control. The aim is to test whether resource providing plant species, which are marketable in their own right (as pharmaceutical crops or vegetables), can at the same time support biological pest control in adjacent Brassica crops.

Materials and Methods

The influence of pharmaceutical plant species on natural enemy abundance, and floral resource utilisation – 2009 season

In the first year of the project (2009 season) seven potential natural-enemy supporting crops were studied in small-scale field plots to test whether they are utilised by natural enemies and whether they confer pest-control benefits to an adjacent cabbage crop. These were *Arnica chamissonis* (Arnica*)*; *Borago officinalis* (borage*); Fagopyrum esculentum* (buckwheat), *Hypericum perforatum* (St. John's wort); O*enothera biennis* (evening primrose); *Tanacetum vulgare* (tansy), and V*icia faba* (faba bean). These species were chosen using several criteria relating to their provision of pollen and/or nectar, their ease of cultivation and their potential marketability. Details of these criteria can be found in Table 1 for the species chosen.

The field trials in 2009 were conducted at Stockbridge Technology Centre at Cawood near Selby in North Yorkshire (SE 562 367). Three experimental blocks were sown within a single field. Each experimental block consisted of eight 2 x 4 m plots arranged in a 32 x 2 m strip, to which the seven test species and a grass control were randomly allocated. Seed for the flowering plant species were purchased from Suffolk Herbs, Essex, UK (*Borago officinalis)* and the rest from Herbiseed, Berks, UK and sown at rates recommended by the suppliers (Table 1). The control treatments were sown with a mixed graminaceous assortment recommended by the Countryside Stewardship Scheme (provided by Stockbridge Technology Centre) containing the native perennial *Cynosurus cristatus* (crested dog's-tail) and *Festuca* spp. A 32 x 2 m strip of cabbages (var. Kilazol white cabbage) was sown immediately adjacent to the test species at a density of 4 plants per m^2. Flowering species were sown on 22nd April 2009 and cabbages were transplanted on 29th April 2009

Problems were encountered due to poor germination of several of the flowering plant species – *Arnica chamissonis, Borago officinalis, Hypericum perforatum* and *Oenothera biennis*. Despite resowing, *B. officinalis* and *A. chamissonis* did not successfully establish, so these plots were used as an alternative bare ground control. These plots were kept bare by hoeing so that flowering weeds did not interfere with the other flowering plant treatments

Table 1: Candidate species information

Species	Common name	Demand due to	Notes	World demand	Price/ dry kg	Sow in:	Floral resources
Arnica Chamissonis	Arnica/wolf's bane (family: Asteraceae)	Increasing rarity due to intensive agriculture. Effective vasodilators, anti-inflammatory and assist normal healing processes	European. Grows well in nutrient poor, meadows and uplands. Harvest seeds when ripe.	Estimated 300 arnica-containing tinctures, ointments and treatments	Dried flowers in 1998 - £40/kg, 100 capsules - £1 – £15	Early spring into cold frame at 1 g/m^2, plant out in May, flowers May - August	Single flower head
Borago offcinalis	Borage (family: Boraginaceae)	Regulation of metabolism and hormonal system, alleviation of colds bronchitis (anti-inflammatory), lowers cholesterol	Grows on almost any soil, reseeds generously. Harvest when blue flowers have given way to hairy, oval seed pods	Potential gamma-linoleic acid market	Fallen to £1.60/kg	Mid spring at 3 g/m$^{2.}$ Flowers June to killing frost	Nectar
Fagopyrum esculentum	Common buckwheat (family: Polygonaceae)	Strengthening of capillary walls and biological pest control	Annual, up to 1.5 m. Suits to light and medium-textured soils. Can produce seed yield after 100 days. Will produce seed until first frost.	5 million acres (Canada has 70% acreage). Established market for animal feed and Japanese Soba noodles etc…	£4-5/bushel	Mid-spring – early summer at 9.6 g/m$^{2.}$ Flowers through summer and produces copious flowers. Flowers 5-6 weeks after sowing	Small white or pink-tinged flowers with readily accessible nectaries. Nectar production strongly influenced by plant age and inflorescence.
Hypericum perforatum	St Johns Wort (family: Clusiaceae)	Potential for extended use. Potential use in AIDS treatment	Well-known and extensively studied. Grows to 1.2 m. Cut flowers when fully open and pick leaves as required.	Established market as antidepressant for mild depression, potential for growth	Trader price: £1-6/kg (as of 2000) depending on whether organically	Autumn or Spring at *2* g/m$^{2.}$ Perennial, flowers June - September	Yellow flowers, produces pollen but not nectar.

Species	Common name	Demand due to	Notes	World demand	Price/ dry kg	Sow in:	Floral resources
Oenothera biennis	Common evening primrose (family: Oenagraceae)	Astringent & sedative properties. Treats multiple sclerosis, eczema, acne, brittle nails, rheumatoid arthritis and alcohol-related liver damage. Reduces blood cholesterol levels, lowers blood pressure. Contains rare essential fatty acid – gamma-linoleic acid.	Prefers sandy loam. Biennial. High tolerance to drought. Colonises bare ground quickly and has naturalised elsewhere. No major pests. Small seeds harvested by hand.	China produces 3000 tonnes/year, estimated 90% of total supply. Potential treatment for a large number of medical conditions, including eczema, cancer, multiple sclerosis. Pharmaceutical licences granted in the United Kingdom.	Approx. £2 – 11/kg	Late spring to early summer at *2* $g/m^{2.}$ Biennial, flowers June - September	Conspicuous, fragrant yellow flowers, open in the evening. Bright nectar guide pattern.
Tanacetum parthenium	Feverfew (family: Asteraceae)	Used to treat headaches, arthritis, digestive problems. Contains parthenolide (recently found to induce cell death in leukaemia cancer cells)	Native to Eurasia. Grows into small bush approx. 18 in. high, spreads rapidly. Full sun. Harvest leaves and buds before flowering.	Used for relief of migraines, and interest in parthenolide as promising cancer drug	100 capsules - £5 – £7	Spring at 3 $g/m^{2.}$ Flowers July - August	Daisy-like flower
Vicia Faba	Faba/broad bean (family: Fabaceae)	Food. Rich in L-dopa, a substance used medically in treatment of Parkinson's disease, and human libido	Legume, prefers rich loams. Black bean aphid and pea aphid are pests. Harvest when pods swell	60% world supply grown in China		March – May at 4.8 g/m^2	Continuous flowering, white flowers

Direct pest and natural enemy counts

To measure the abundance of aphid *spp*. (*Brevicoryne brassicae* and *Myzus persicae)* and *Pieris spp.* (*P. brassicae* and *P. rapae*), all herbivores on 10 randomly selected cabbages from a 2 x 4 m plot immediately adjacent to each flowering treatment were counted in each block (Clement et al. 2004). All natural enemies observed (including Hymenopteran parasitoids, Syrphidae, Phoridae, Staphylinidae, Aranae and Coccinellidae) were also counted.

Pan trap counts

Pan traps were used to capture aerial insects during the sampling period using brown plant pot dishes (19.5 cm across, 3.3 cm deep), filled with water and a small amount of detergent to break the surface tension. One trap was placed just below the flower canopy in each flowering treatment (Girma et al. 2000), at the centre of the plot. Pan traps contents were stored in 70% alcohol before identification of the key pest and natural enemies to family level.

Principal results

There were significantly higher abundances of *Pieris rapae* ($P < 0.001$) and *Pieris brassicae* ($P < 0.001$) in all of the flowering treatments. Flower treatment had no effect on pest aphid abundance. Parasitoid abundance was significantly higher in the *F. esculentum* ($P < 0.001$) and *T. vulgare* ($P < 0.001$) treatments (Figure 1). This trend continued at parasitoid family level, with Braconidae, Figitidae, and Ceraphronidae recorded. There were significantly fewer Syrphidae in the crop adjacent to the bare ground control ($P = 0.002$) and *T. vulgare* ($P = 0.016$), and significantly fewer 'other natural enemies' (comprising of Syrphidae, Staphylinidae, Tachinidae, Dolichopodidae, Anthocoridae and Coccinellidae) in the *T. vulgare* treatment as well ($P = 0.021$).

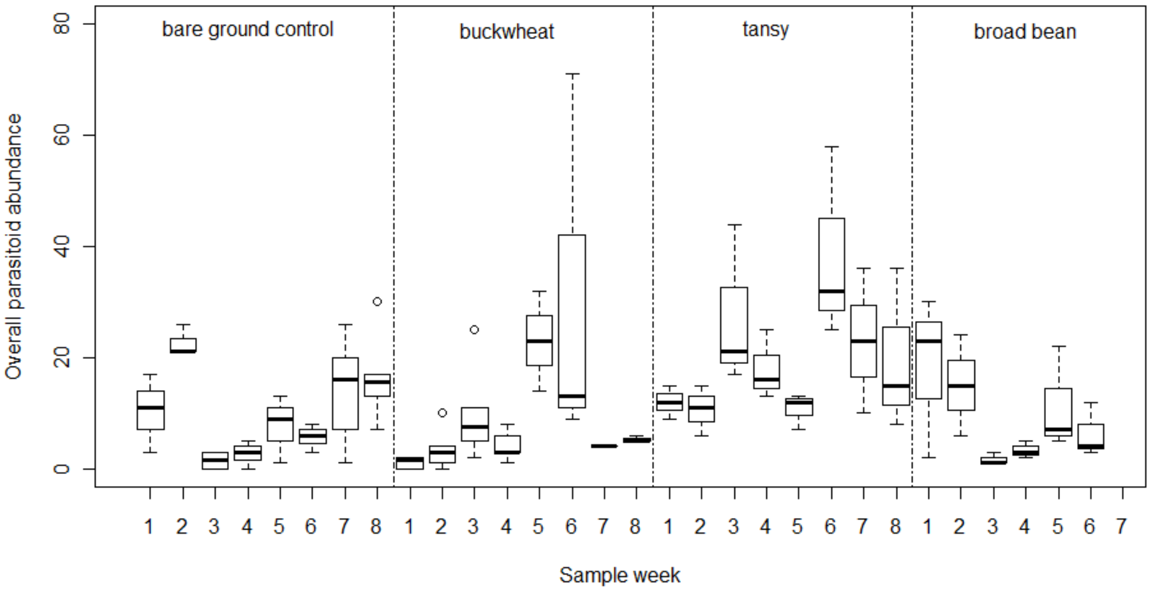

Figure 1: Overall parasitoid abundance (number per trap) across time for each flower treatment. Buckwheat = *F. esculentum*; tansy = *T. vulgare*; and broad bean = *V. faba*.

Floral strip influences on biological control agents and pest regulation in adjacent Calabrese plots – 2010 season

Study site

The field trials in 2010 were conducted at Lee Farm, which is affiliated with Myerscough College in Preston, Lancashire. The field in which the experiment was conducted had previously had been used to grow a rapeseed crop for forage. The three flowering species used during the field season were *Borago officinalis* (borage), *Fagopyrum esculentum* (buckwheat) and *Vicia faba* (faba bean) sown at the following rates:

- *Borago officinalis* – 2394 g (3 g/m^2)
- *Fagopyrum esculentum* – 7661 g (9.6 g/m^2)
- *Vicia faba* – 3830 g (4.8 g/m^2)

Flowering plants were sown in 3 m x 25 m strips adjacent to 12 m x 25 m plots of (Calabrese var. ‘Ironman F1’ (supplied by Lynway Nurseries, Boston, Lincolnshire). The broccoli plants were transplanted into the site at 50 cm plant and row spacing between the 7th and 13th May 2010. The experiment comprised five experimental blocks of four plots to which each of the flower treatments and a bare-ground control were randomly allocated. The bare-ground control was regularly rotivated to prevent weed establishment (Figure 2). There was a 5 m strip between each block, which was regularly mown to prevent flowering of weeds, as was a 20 m buffer strip in the adjacent fallow land.

Insect sampling was done fortnightly by direct counts of three broccoli plants randomly chosen from the central 15 m of each plot at 2, 6 and 10 m from the flowering strip. Pan traps were also used to collect aerial insects; these were placed in the centre of the plot in the flowering strip and in the broccoli at 2 and 10 m from the flowering strip (Figure 2)

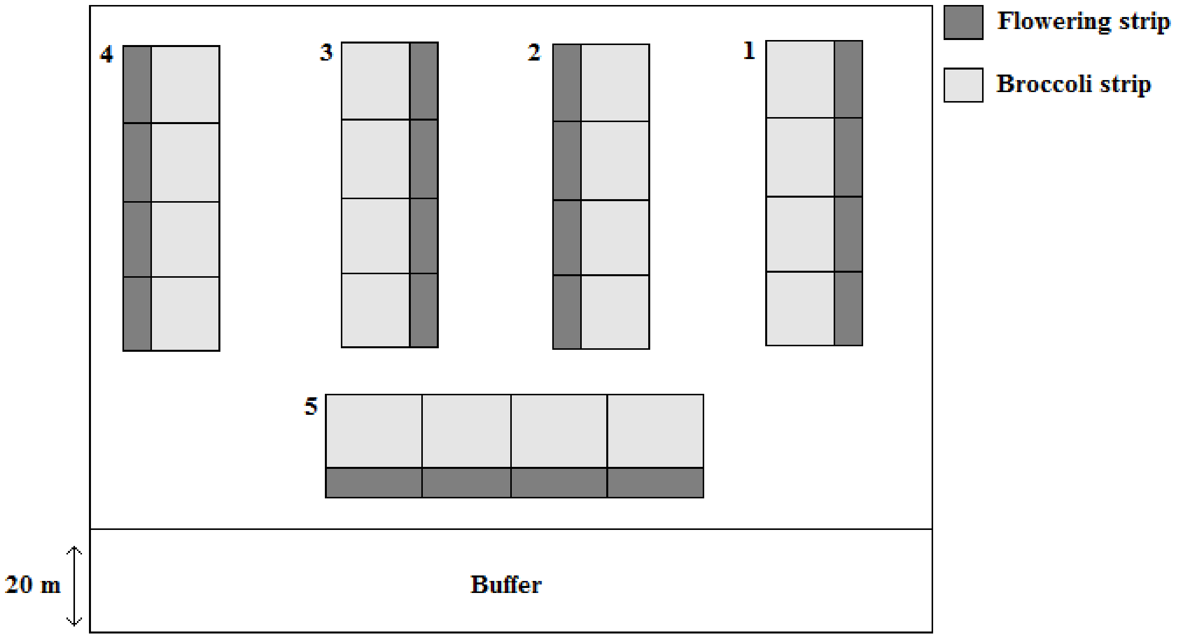

Figure 2: Layout of 2010 field experiment

Principal results

Treatment significantly affected the total abundance of natural enemies observed in the direct broccoli counts, which was largely explained by higher abundance in the broad bean treatment than the control, though observations were too infrequent to analyse individual enemy groups. However, the pan trap data revealed a negative effect of distance from the flowering strip in hymenopteran parasitoid abundance with the pattern most noticeable in the buckwheat plots (Figure 3). Within this group, both the Braconidae and the Chalcidoidea exhibited a similar response to the overall parasitoid abundance.

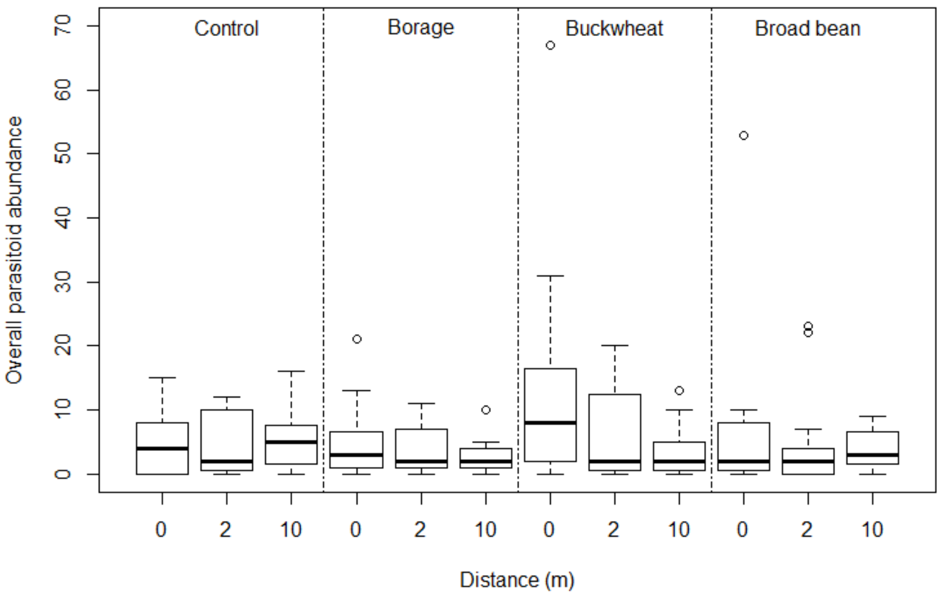

Figure 3: Overall parasitoid abundance (number per trap) at each distance for each flower treatment

The direct observations of broccoli plants revealed that there was a higher abundance of pests overall in the control treatment (Figure 4a), which was also the only treatment where aggregations of *Pieris brassicae* were found. The buckwheat treatment had the lowest abundance of pests overall, and the lowest number of pest caterpillars. However, the highest numbers of aphids were found in buckwheat (Figure 5).

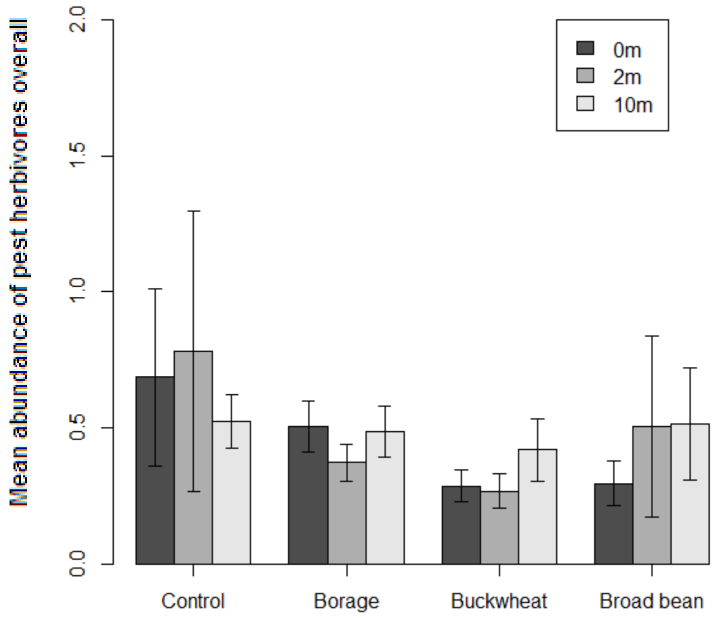

Figure 4: Abundance of herbivores on broccoli plants (mean number per plant). Error bars denote standard error of the mean.

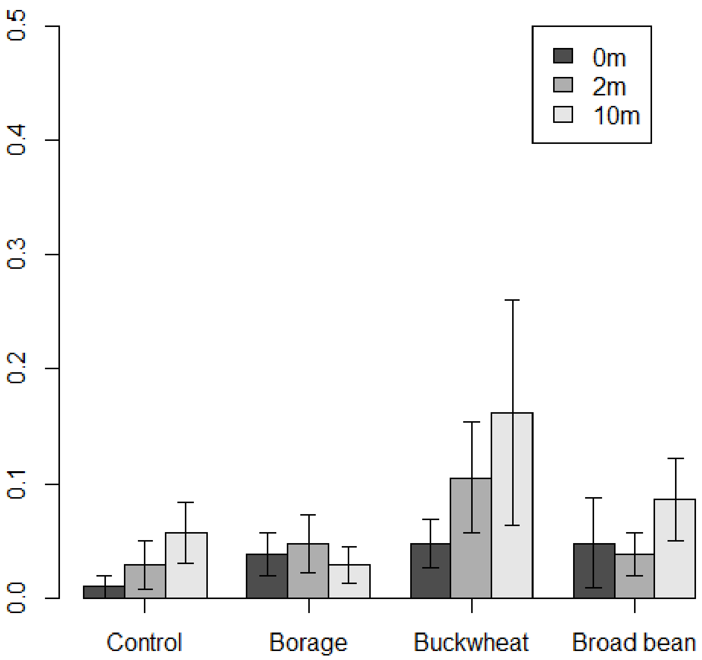

Figure 5: Abundance of aphids on broccoli plants (mean number per plant). Error bars denote standard error of the mean.

Increased flower densities (inflorescence numbers) of *B. officinalis* were found to significantly increase natural enemy abundance (P = 0.009). Increased buckwheat inflorescence number significantly decreased parasitoid numbers (P = 0.005), but despite this, *F. esculentum* maintains a higher abundance of parasitoids over a longer time period than any of the other flower treatments (Figure 6).

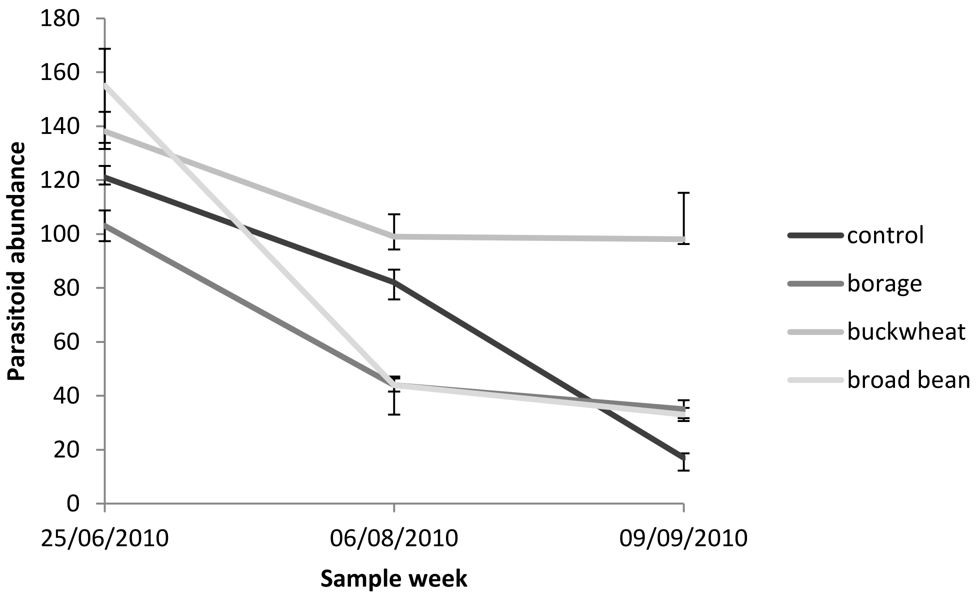

Figure 6: Parasitoid abundance recorded in pan traps for each flower treatment across each sample occasion. Error bars denote standard error of the mean.

Lepidoptera abundance was significantly lower in the crop adjacent to the *B. officinalis* (P < 0.001) and *F. esculentum* (P = 0.001) flower treatments in relation to flower density (Figure 7).

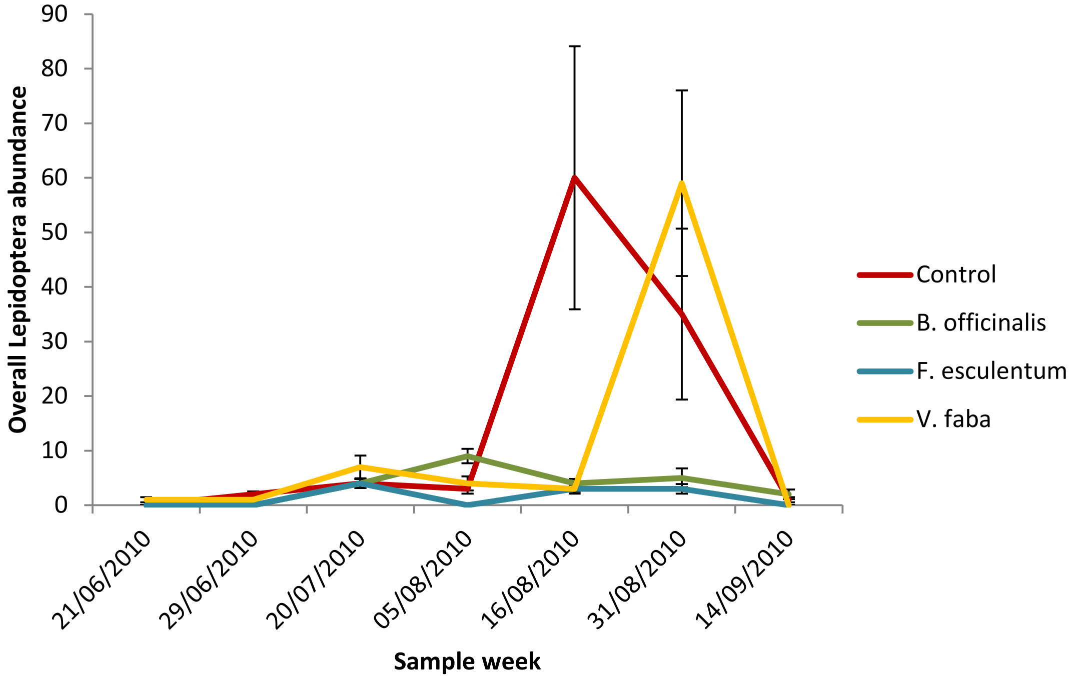

Figure 7: Overall Lepidoptera abundance per pan for each flower treatment. Error bars denote the standard error of the data.

Utilisation and efficacy of floral strips at a commercial scale – 2011 experiments

Methods

Three flower species *Borago officinalis* (borage), *Fagopyrum esculentum* (buckwheat), *Tanacetum parthenium* (feverfew), and a mixed treatment including all three species, as well as a grass control were sown in 10 x 2 m strips within brassica fields at two sites: Wistow, near Selby in Yorkshire, and Huntapac at Tarleton in Lancashire. The dimensions of the strips were designed to minimise disruption of crop management activities during the cropping season. A replicated randomised block design was used such that each flowering treatment was included in a 100 m x 2 m continuous strip with 10 x 2 m grass buffers between the flower strips (Figure 8 and 9). Six replicate strips were sown at Huntapac across two fields, three in Calabrese (var. Ironman F1) and three in Cauliflower (var. Fargo F1) with 48 m between strips. Two strips were sown at Wistow with 72 m spacing within a single Calabrese (var. Ironman F1; Marshalls Produce World, Boston, Lincs) field. All flowering strips were laid on 19th April 2011, the broccoli plants were transplanted on 12th May 2011 at Wistow and 13th May 2011 at Huntapac, cauliflower were planted on 15th May.

Both sites were managed by commercial growers, the Huntapac site being subjected to a spraying regime – the crop was sprayed with an insecticide and fungicide on the 21st July and with an insecticide and trace elements on the 5th August.

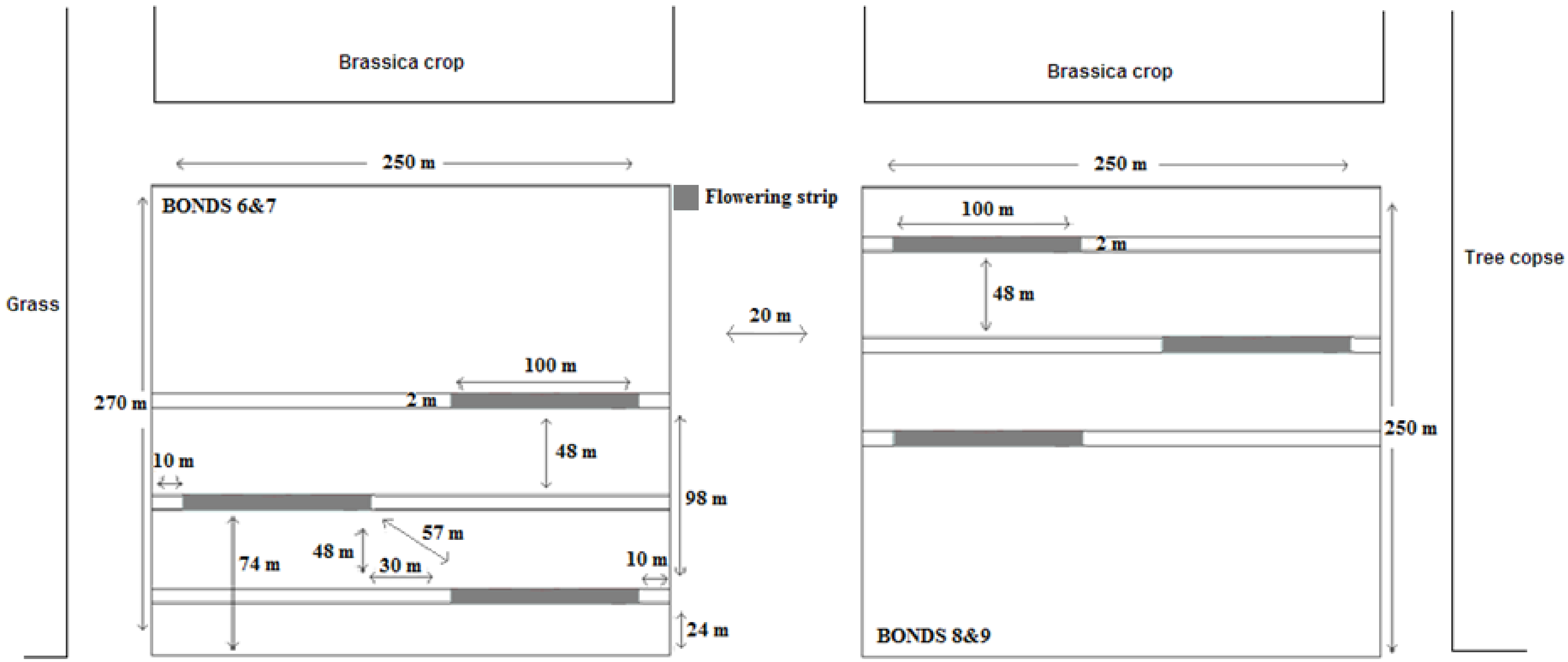

Figure 8: Experimental layout at Huntapac.

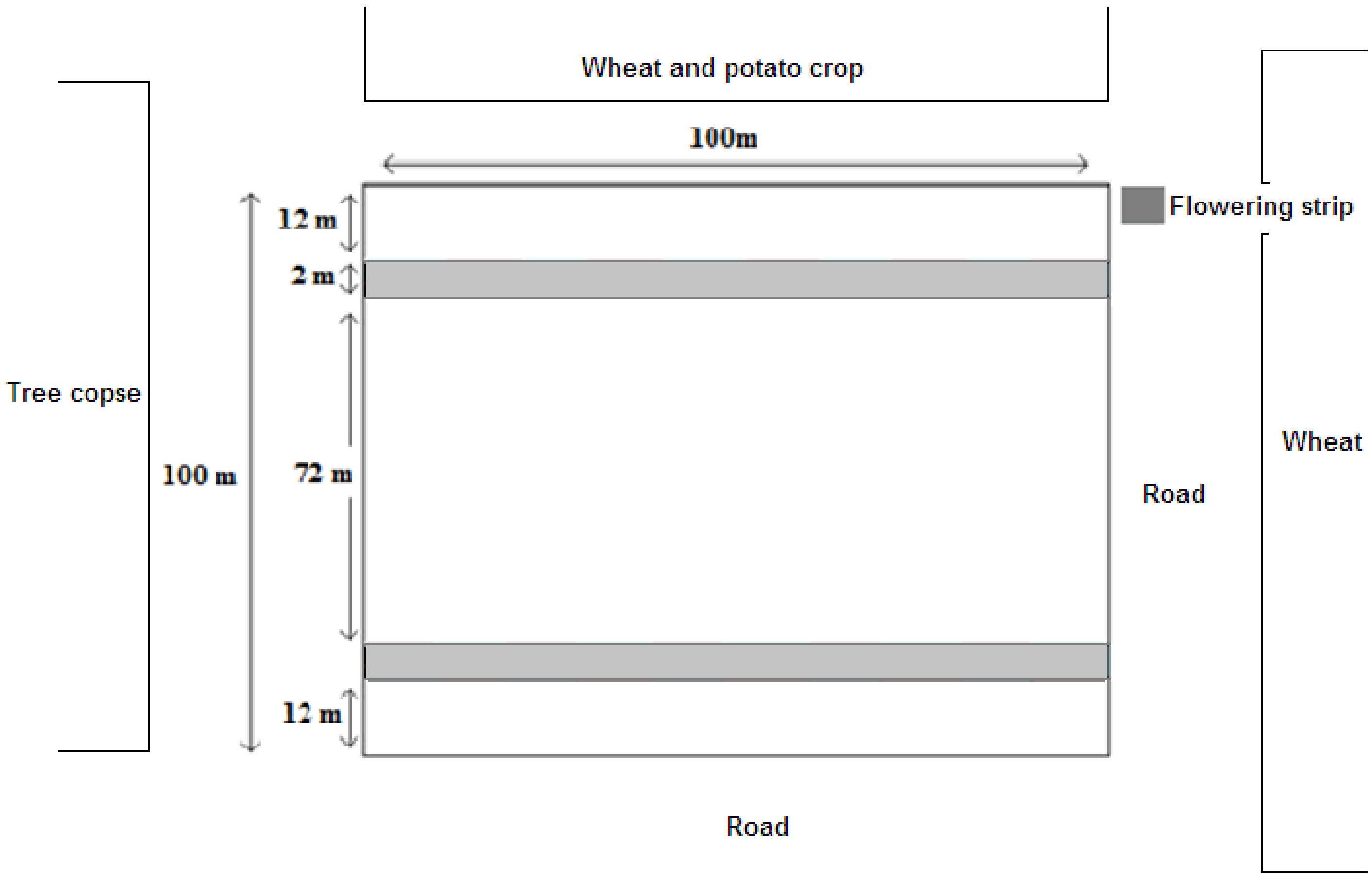

Figure 9: Experiment at the Wistow site

Counts of natural enemies and pests were done at each site on seven occasions during the season. Three Brassica plants were chosen at 2, 4, 8 and 16 (plus 32 m at Huntapac) from each flowering plot and exhaustively searched recording abundance of key natural enemies and herbivores. Utilisation of the flowering strip by natural enemies was monitored by 10 minute visual survey of the identity and abundance of insects visiting a 1 x1 m observation quadrat demarcated in each plot. Inflorescence number was recorded every 3 weeks, approximately, from when the first flowers opened in mid-June to the end of the Brassica cropping season in mid-September. A 1 x 1 m quadrat was used to randomly select 1 m^2 of each flower treatment to record the number of inflorescences. This was carried out once in each flower plot on each sampling occasion during the cropping season.

Pan traps were set on the 29th June, the 27th July and the 12th September to provide data on the treatment impacts on aerial insect abundance. One pan trap was placed in the flowering strip, the other pans mirrored the distance intervals used for the observational counts (at 2, 4, 8 and 16 m from each flowering plot at the Wistow site, and 2, 4, 8, 16 and 32 m from each flowering plot at the Huntapac site) (Figure 10). The solution used in the pan traps was 1.6 g salt per 100 ml water, with a drop of washing up liquid to break the surface tension.

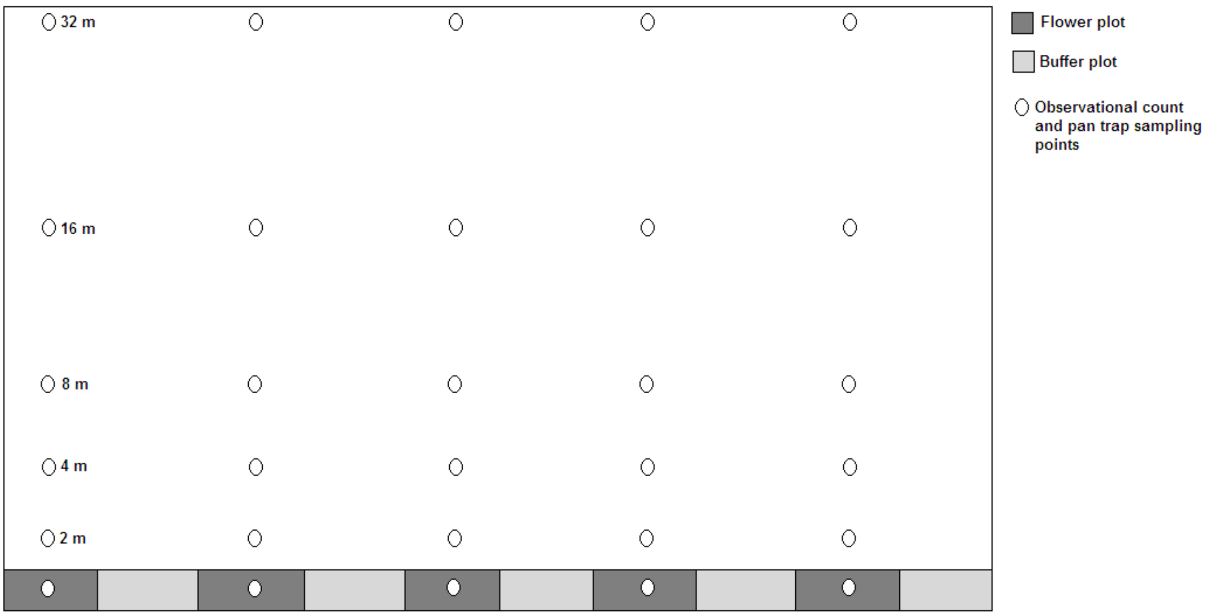

Figure 10: Example flower strip illustrating the sample point layout

In order to measure biological control activity, sentinel cabbage (var. 'Derby day') plants were placed at 2, 4, 8, 16, and 32 m from each flower plot. The cabbage plants were planted into 12 cm pots on the 15th August. Each plant was infested with 25 *Myzus persicae* individuals. This allowed us to record parasitism and predation levels in the field, with regard to distance from the different flowering treatments, and was done by counting the number of aphids on each plant each week.

Principal results

T. parthenium had by far the highest number of inflorescences across both experimental sites (14713) compared with any of the other flower treatments throughout the cropping season (Figure 11). *F. esculentum* did not fare well in the mixed flower treatments, with very little germinating successfully, resulting in approximately 17 times fewer *F. esculentum* inflorescences in the mixed (308) compared with individual *F. esculentum* treatment (5385 inflorescences)

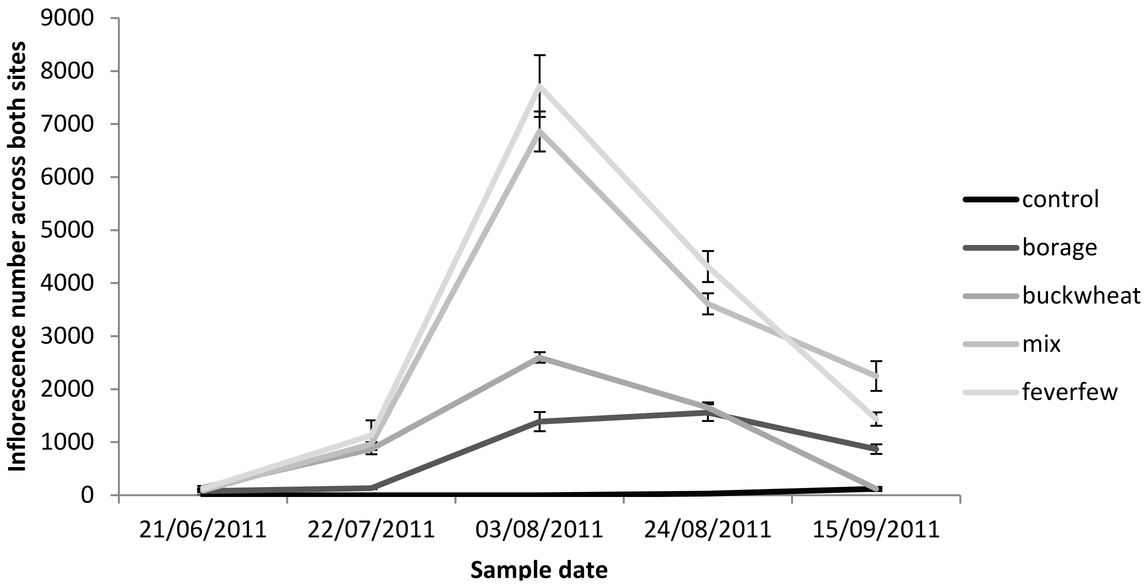

Figure 11: Inflorescence abundance for each flower species across the growing season. Error bars denote the standard deviation of the data.

Site played an influential role on the abundance of natural enemies, with up to 18 times more individuals found at the Wistow site (P = 0.006) compared with the Huntapac site. This was the case across a range of insect families from parasitoid families to Phoridae (Diptera) and

Staphylinidae (Coleoptera). The crop adjacent to the *F. esculentum* treatment had a significantly higher abundance of natural enemies overall than the control or other treatments (P = 0.027). For adult parasitoid abundance, *F. esculentum* (P = 0.017), the mix treatment (P = 0.014), and *T. parthenium* (P = 0.011) all significantly increased parasitoid numbers in comparison to the control. Increasing distance from the flower strip significantly decreased parasitoid abundance (P < 0.001). However, patterns were not consistent at family level. For example, there was a significant decrease in Braconidae abundance in the mixed flower treatment (P = 0.039), whereas Figitidae wasps were found in significantly lower numbers in the *T. parthenium* flower treatment (P = 0.036). In contrast, Ceraphronidae abundance was higher in the *T. parthenium* treatment (P = 0.002) (Figure 12).

Parasitised aphid (mummy) abundance was significantly higher in the crop adjacent to the *B. officinalis* (P < 0.001), *F. esculentum* (P < 0.001) and *T. parthenium* (parameter estimate = 1.503 (P = 0.037) treatments, compared with the control treatment. Significantly more mummies were recorded 8 m (P < 0.001) from the flower strips, but then their abundance had significantly declined by 16 m (P < 0.001).

Predatory Syrphid larvae were found in significantly higher abundances at the Wistow site (P = 0.015), as were Aranae (P < 0.001). Significantly higher abundances of generalist predators such as Phoridae (P < 0.001) and Staphylinidae (P = 0.04) were found in higher abundances further away from the flower treatments, with significantly more Staphylinidae found in the crop adjacent to the borage treatment (P = 0.013).

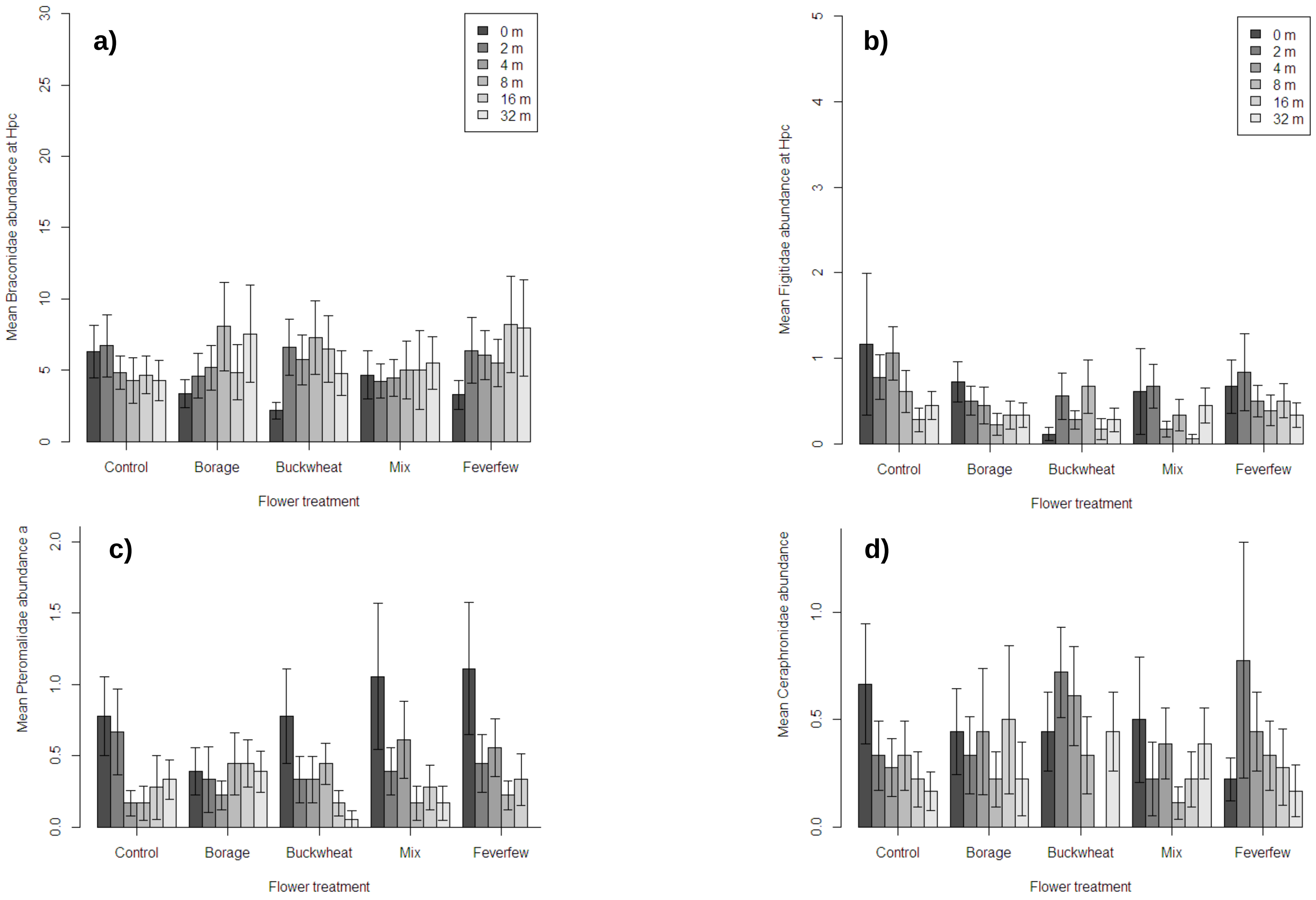

Figure 12: Abundances (number per trap) for parasitoid wasp families, a) Braconidae, b) Figitidae, c) Pteromalidae, d) Ceraphronidae at the Huntapac site. Error bars denote standard error of the mean.

Examining pests overall, there were approximately 19 times more pest herbivores at the Wistow site compared with the Huntapac site, a highly significant difference ($P < 0.001$). Distance had a negative effect on aphid abundance ($P < 0.001$), although this effect is not consistent between sites (Figure 13b).

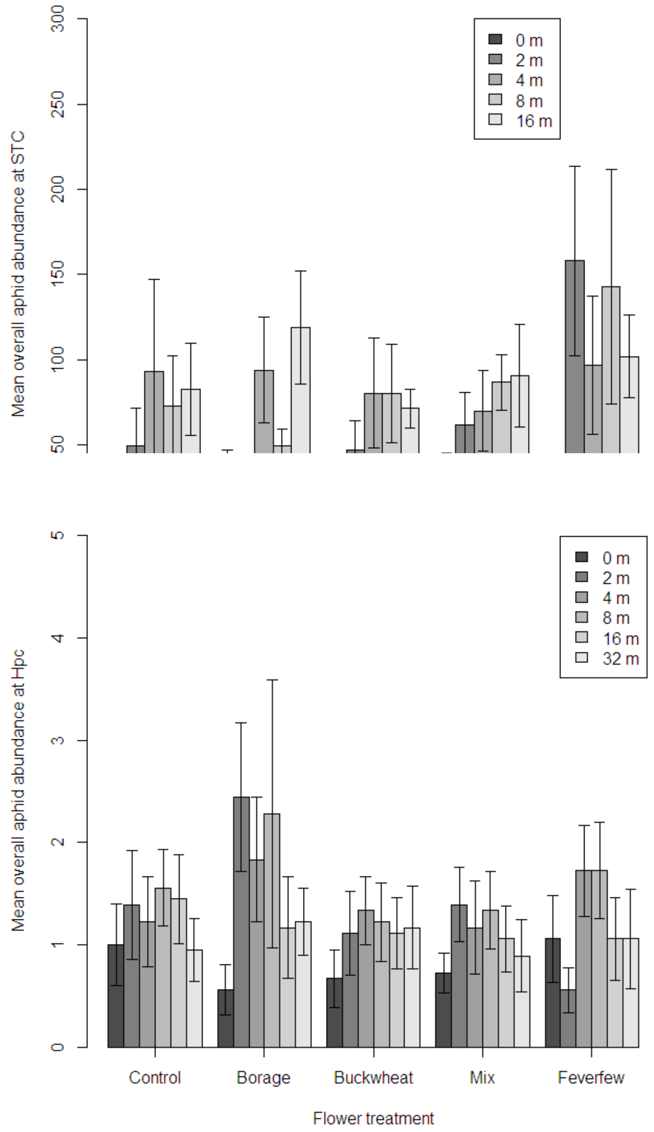

Figure 13: Overall aphid abundance in pan traps at each distance for each flower treatment at a) Wistow, and b) Huntapac. Error bars denote the standard error of the mean.

Quantifying biological control

The sentinel aphid colonies revealed an unexpected pattern in the level of population suppression at Huntapac. The mixed flower (P < 0.001) and *T. parthenium* (P = 0.004) treatments were significantly worse at suppressing *M. persicae* numbers on the sentinel cabbage plants (Figure 14), in comparison to the control.

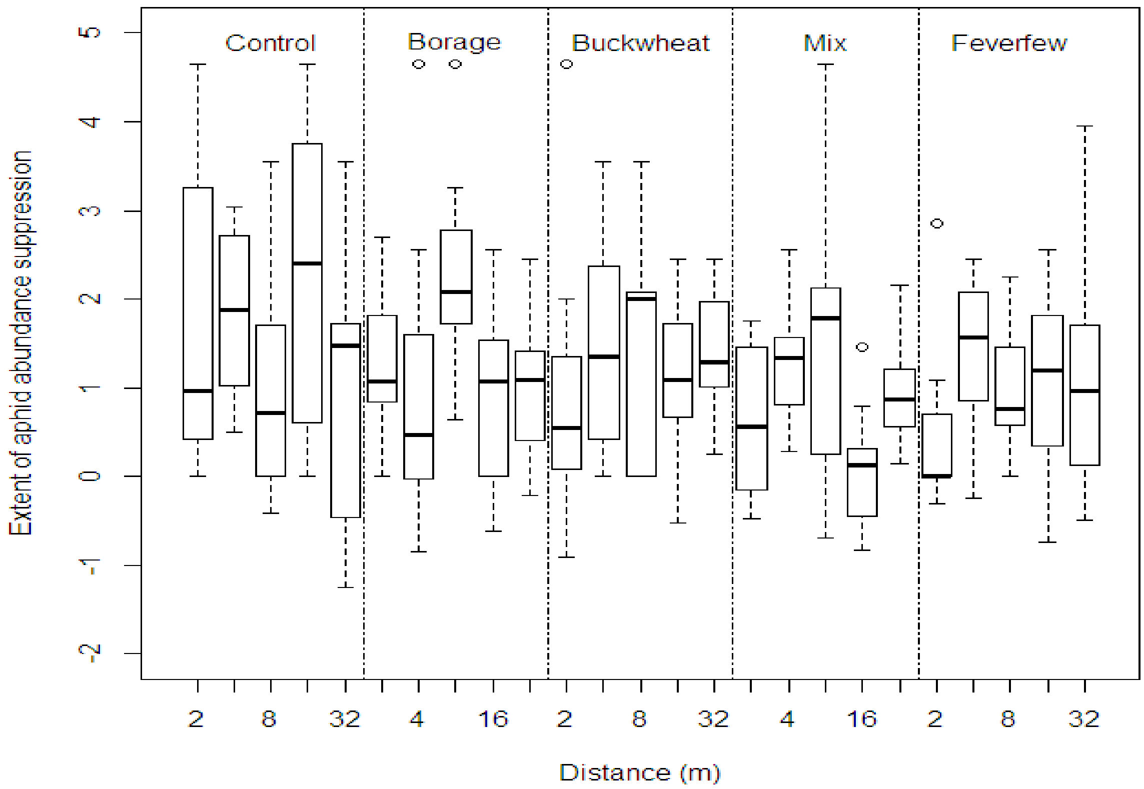

Figure 14: Extent of Myzus persicae population reduction

Inflorescence density

Inflorescence number in *B. officinalis* (P < 0.001), *F. esculentum* (P < 0.001), the mix treatment (P < 0.001) and *T. parthenium* (P < 0.001) at the Wistow site all positively and significantly affected the abundance of Syrphidae. There was a significant interaction between site and the number of inflorescences in the *F. esculentum* treatment, with significantly more parasitoids found in this treatment at the Wistow site (P = 0.005). Coccinellidae were also more abundant in the *F. esculentum* treatment at the Wistow site (P = 0.003) as well as in the mix (P = 0.012) and *T. parthenium* treatments (P = 0.004).

Attractiveness of different Fagopyrum esculentum varieties to natural enemy species - 2011

Methods

Study site

The field site was located at Stockbridge Technology Centre near Cawood, North Yorkshire (grid reference: 456047, 436978), and was bordered by arable and horticultural crops on three sides, the last side being bordered by fallow land. The field has previously been used to grow Brassicas, and some Brassica crops were growing on site nearby, although not directly adjacent to the buckwheat plots (approximately 100 m west of the site). It was expected that these plots would be accessible to a range of natural enemies of key Brassica pest herbivores, which are known to be highly mobile (parasitoids, Syrphids, Carabids, Staphylinids, Coccinellids, (Bohac 1999, Holland et al. 1999, Gillespie et al. 2011, Simpson et al. 2011)). The site was in the corner of a large field that was bordered by trees and hedgerows. The overall size of the experimental area was 25 x 20 m.

Experimental layout

Five varieties of buckwheat were sown on May 18th 2011. The experiment was laid out in a randomised block design, and within each block the different varieties sown in a strip, each variety being sown in a 1 x 1 m plot with 1 m in between each variety (see Figure 1). This was replicated five times so that there were 25 plots in total. The varieties sown were:

- Bamby
- Čebelica
- ČRNA Gorenjska
- Darja
- Kings Seeds (variety unknown)

All varieties except the Kings Seeds variety were provided by Vladimir Meglič from the Slovenian Agricultural Institute. The Kings Seeds variety was supplied by Kings Seeds from the UK and was the variety used in each of the experiments outlined above, though the variety is unknown. Once the plants had begun flowering, each 1 x 1 m plot in each block was observed for 10 minutes fortnightly to count direct flower feeders. During the observation period, any insects found directly feeding on the flowers were recorded. Parasitoids remained as 'parasitoids,' as it is difficult to identify them to family level in the field, as was the case for Aranae. All other natural enemies found were identified to family level. This provided information on which species were directly utilising the floral resources and at what frequency. After observing the flower visitors, insects, larvae, eggs and pupae found on the plants but not the inflorescences were also recorded. This was done by examining the whole of each plant in each plot from the base to the flowers and recording what was found.

As a result of glyphosate spraying in adjacent fields, there was poor establishment in some of the plots and the loss of two blocks. Therefore the experiment was re-sown at a later date (22^{nd} July 2011) in the same place and in the same design. We consequently have insect data covering the growing season of Brassicas, with flowers present from 16^{th} June to the 30^{th} September. Inflorescence number for each treatment was recorded weekly across both buckwheat experiments, resulting in a total of 12 inflorescence sampling occasions across the growing season.

Principal findings

The two experiments revealed strong utilisation of the floral resources by natural enemies throughout the growing season. There were far more Syrphidae and Coccinellidae recorded in the first experiment (Figure 15), but a great deal more parasitoids and Anthocoridae recorded in the second (Figure 16).

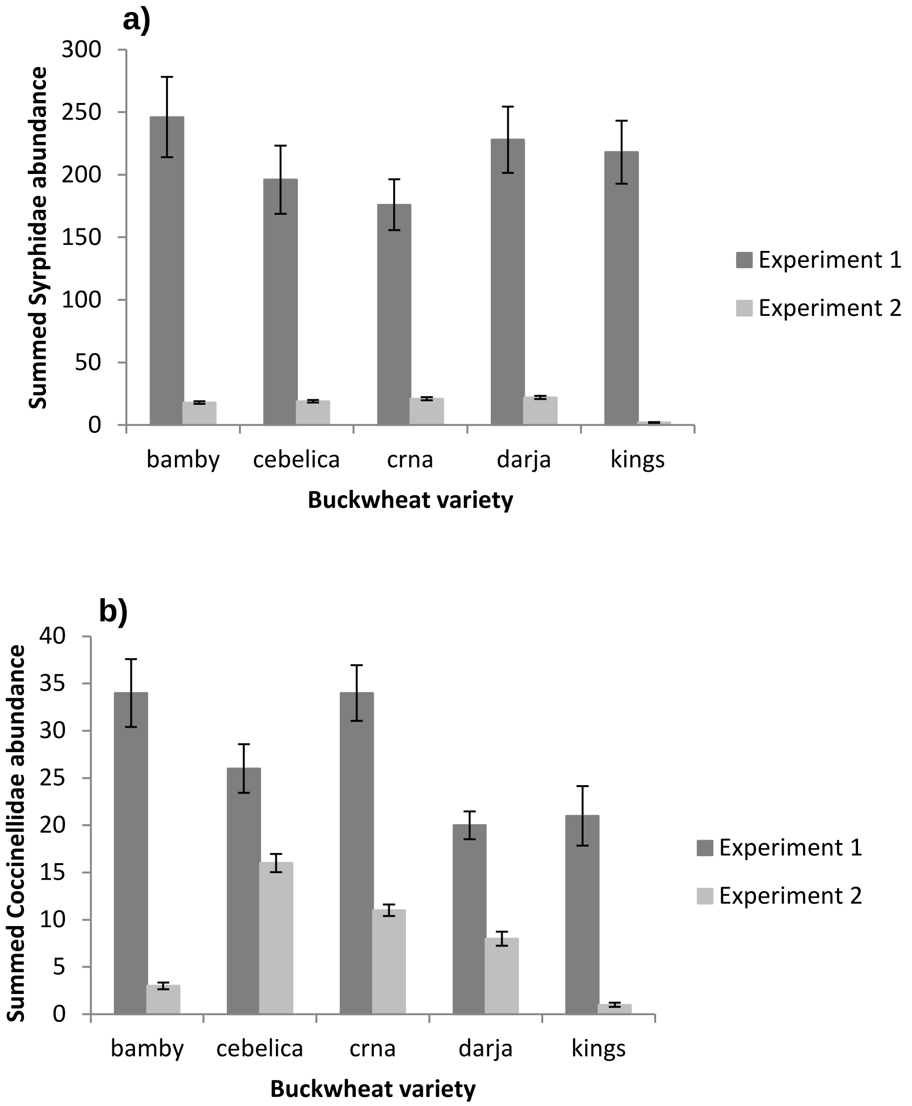

Figure 15: Comparison of summed abundance for a) total number visiting Syrphidae, and b) visiting Coccinellidae early (Experiment 1) and late (Experiment 2) in the growing season. Error bars denote the standard error of the mean.

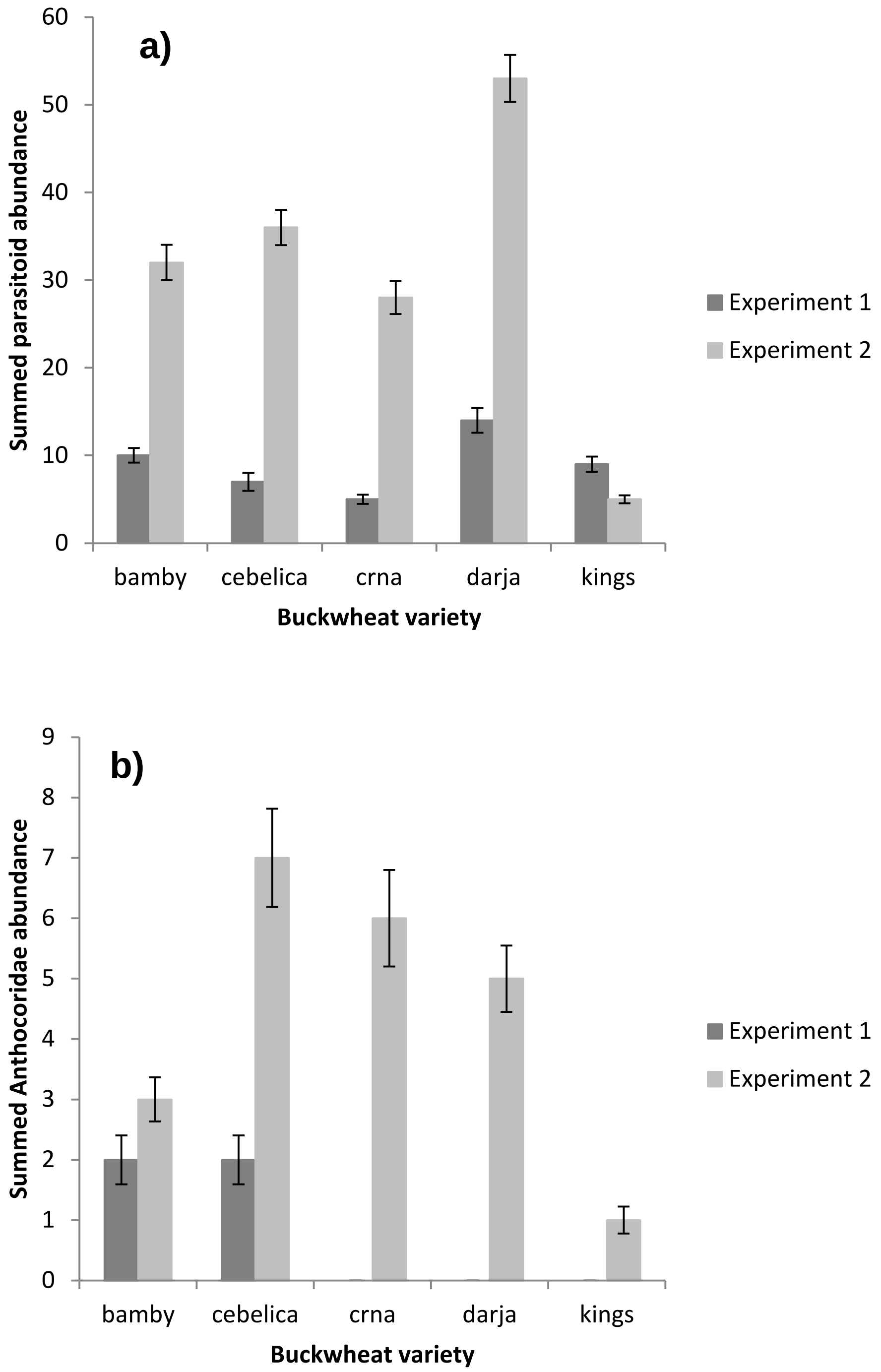

Figure 16: Comparison of summed abundance for a) visiting parasitoids and b) visiting Anthocoridae early (Experiment 1) and late (Experiment 2) in the growing season. Error bars denote the standard error of the mean.

The number of inflorescences produced by different varieties was affected by the time of sowing, with varieties that performed well in the first experiment, performing badly (in terms of number of inflorescences) in the second (Figure 17), i.e. Kings Seeds variety.

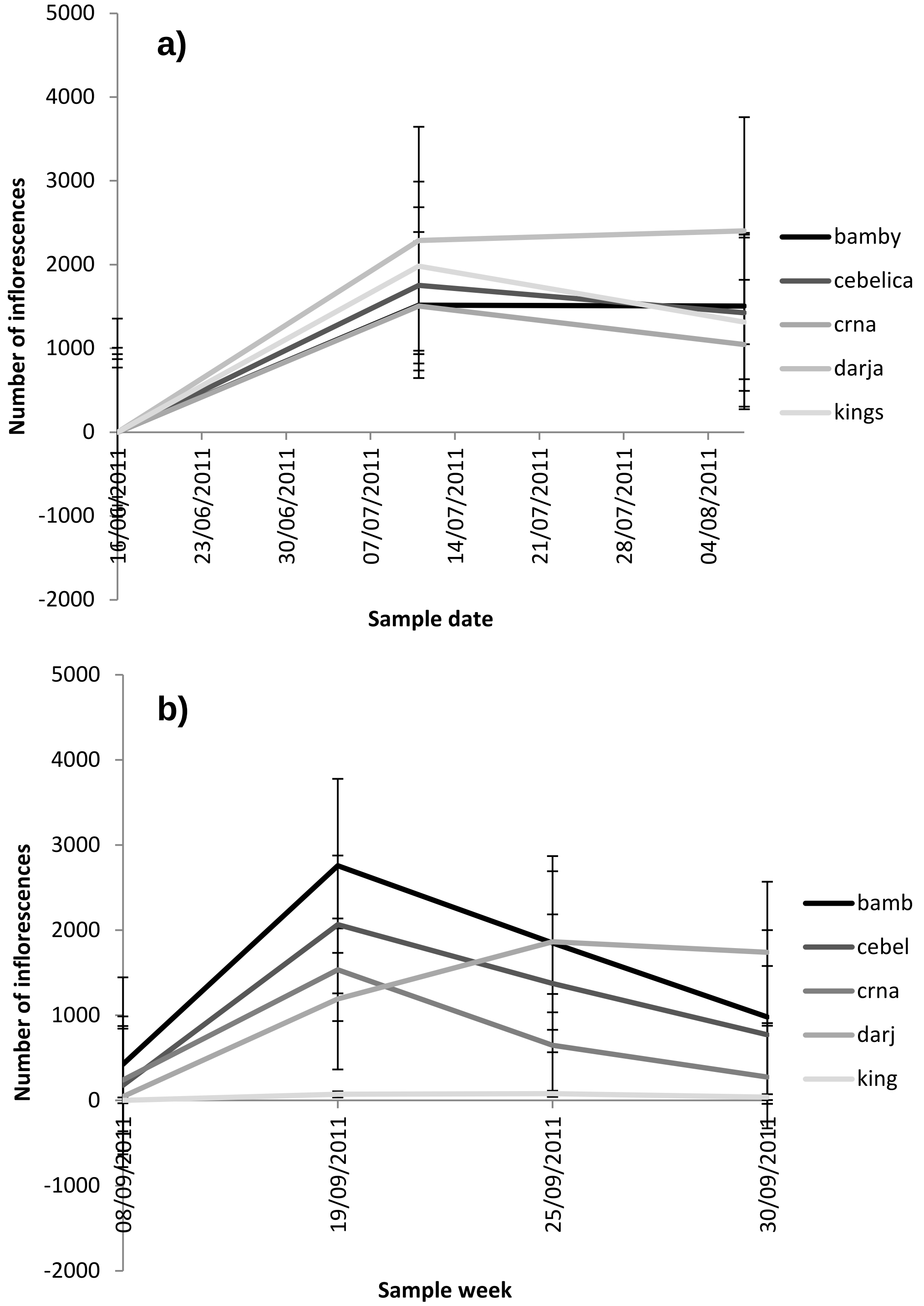

Figure 17: Inflorescence number across sample dates for a) the earlier season experiment, and b) the late season experiment. Error bars denote standard error of the mean.

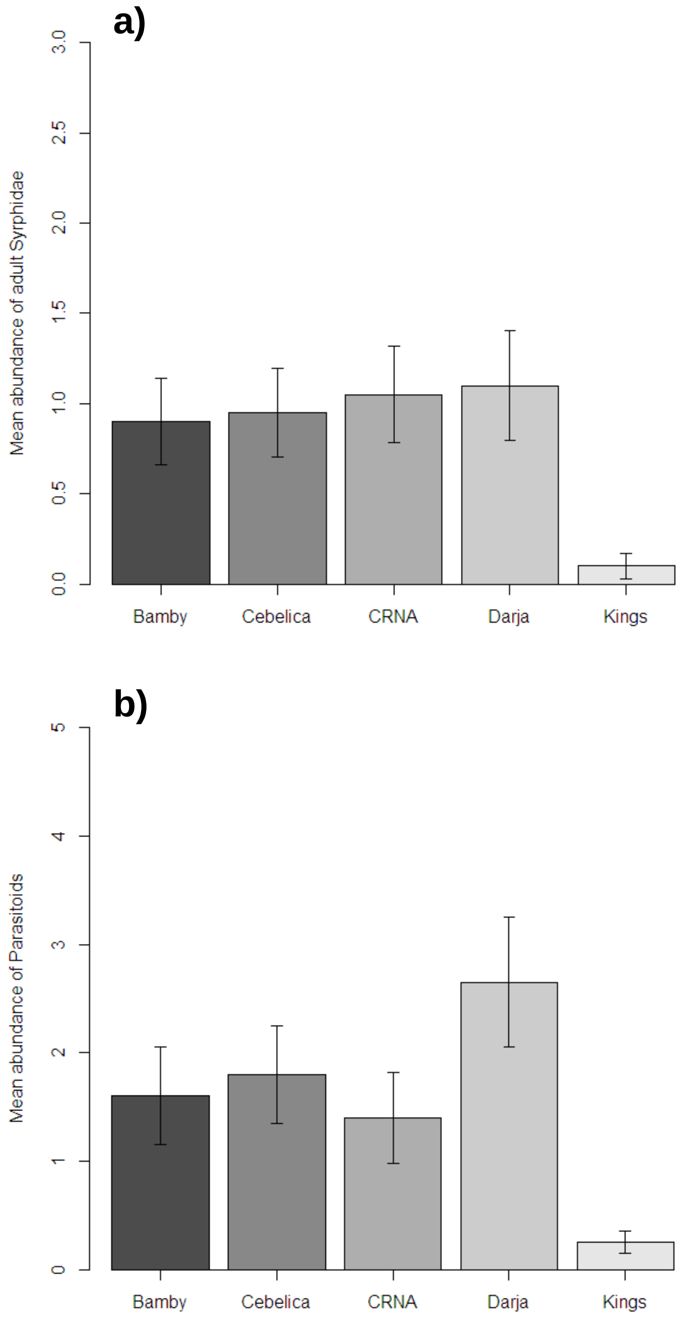

Figure 18: Abundance of a) adult Syrphidae, and b) parasitoids recorded in the buckwheat plots. Error bars represent the standard error of the mean

The number of inflorescences affected how many insects were recorded utilising the plants (e.g. the Kings Seeds variety) (Figure 18), although there was some effect of variety as shown by the interactions in the models, for example the number of inflorescences and the variety Darja both significantly increased the number of parasitoids recorded (P = 0.012). Čebelica and Darja emerged as the best performers in terms of number of inflorescences across both experiments and the number of natural enemies such as Coccinellidae (P = 0.015) and pollinators such as Apidae (P = 0.012).

As buckwheat is a short sowing to seed plant, which also produces copious flowers throughout the lifespan of the plant (110 days (Bodroža-Solarov et al. 2011), as well as putting limited demands on the soil, it could be considered a good candidate for double cropping.

Discussion

Flower and Natural enemy response

The flower species performed best when planted individually rather than in a mix treatment, especially buckwheat, which was poor at competing with borage and feverfew. The inflorescence number and variety of flower species can affect natural enemy abundance differently throughout the growing season. Borage significantly increased natural enemy abundance with higher flowering densities, and borage and buckwheat suppressed the second generation of *Pieris spp*. When buckwheat varieties were examined more closely, Darja, ČRNA Gorenjska and Čebelica emerged as the best varieties in terms of consistency of number of inflorescences produced and attractiveness to natural enemies such as parasitoids, Syrphidae and Coccinellidae.

Gurr et al (2003) reported that relatively narrow strips (1.5. m wide) used at 24 m intervals benefitted natural enemies such as Syrphid flies (hoverflies), Chrysopidae (lacewings) and Coccinellidae (ladybird beetles), increasing their activity, fecundity and species diversity (Lys et al. 1994, Nentwig et al. 1998), and Hossain et al (2002) found that flower resources need to be provided approximately every 30 m to ensure sufficient natural enemy numbers across the crop. In the largest of the experiments reported here, strips were 48 m apart at their widest, meaning natural enemies were no further than 24 m away from floral resources wherever they were in the crop. Specialist natural enemies such as parasitoids were higher in abundance nearer to the flower strips, whereas more generalist predators were generally found either in the middle of the crop or at the further distances from the flower strips. Both the 2010 and 2011 experiments demonstrated this. Parasitism levels in aphids declined sharply between 8 m and 16 m from the flower strip. Natural enemy abundances however were very variable between different sites, and it appears that landscape or local management factors may have quite an influential bearing on the success of the intercropping to increase natural enemy numbers.

Pest response

Site also appeared to affect pest herbivore numbers. Examining pests overall, there were approximately 19 times more pest herbivores at the Wistow site compared with the Huntapac site in the last experimental season. Aphids did not have a consistent reaction to the flower treatments, with the crop adjacent to buckwheat containing more aphids in the 2010 season, but crop next to the borage containing more at the Huntapac site (2011), and crop next to feverfew containing more at the Wistow site (2011).

The control treatment often contained the most pest herbivores, with large aggregations of *Pieris brassicae* found only in the crop adjacent to this treatment. Syrphid abundance was also found to be lowest in the bare ground controls and in the crop adjacent to them, suggesting that bare ground is undesirable in an agricultural setting in terms of pest numbers.

Pest control

Higher numbers of parasitoids did not necessarily translate into higher parasitism levels, although the lower numbers of natural enemies in the control treatments and higher numbers of pest herbivores suggest that there is some level of suppression occurring in the crop adjacent to the flower strips. There were higher numbers of mummies (parasitised aphids) found at the Wistow site in the 2011 season, which suggests that site can be an influential factor in the level of pest control and in the and in the impact of floral strips. However the Wistow site had more pests and natural enemies overall, so it may be that the proportion of parasitised aphids did not increase in the presence of flower species, even though parasitoid abundance did.

Conclusions

This project has identified three strong candidates for intercropping with Brassica crops to promote conservation biological control; *Borago officinalis, Fagopyrum esculentum* and *Tanacetum esculentum*. These species were reliable in their establishment and profuse in their provision of flowers. Of the three species, *F. esculentum* increased natural enemy abundance, specifically key parasitoid families (depending on the variety), most consistently throughout the three growing seasons. However, positive effects of the floral-resource species appear to be site dependent, so further research is warranted to determine the reliability of these species across different sites.

Technology transfer

The 2011 growing season experiments were managed as commercial crops, with the flower strips fitting the management practices of the growers. The flower strips were 2 m wide, to align the experiment with the cultivation practices used by Huntapac and Lodge farm in Wistow. Intercropping is also a practice which makes growers’ produce more attractive to supermarket buyers (A. Molyneux, Huntapac Ltd., personal communication).

To harvest the flower strips, existing combine harvesters (if harvesting grain species such as buckwheat) or widely used grass mowers can be adapted to harvest the crop. For example, Valerian can be harvested using an oscillating potato harvester (Öztekin 2007), so if growing other crops, harvesting should not require increased investment in expensive harvesting equipment.

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