Effectiveness of Biological Pest Control in Icelandic Greenhouses

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Introduction

Biological pest control (BPC) is defined as an "ecologically based pest management that uses one kind of organism (the 'natural enemies') to control another (the pest species)" (Hoddle and Van Driesche 2009). This method is often used as it reduces the reliance on pesticides and herbicides, which are known to be largely detrimental to human health, the ecosystem, and the crops themselves (Heimpel and Mills 2017).

Given the known drawbacks of pesticides and herbicides to human health and the environment, most greenhouses in Iceland adopt BPC methods. BPC has been a vital component of integrated pest management since the 1970s, a method to reduce pesticide usage and protect the health of the ecosystem, particularly the soils (Baker, Green and Loker 2020). The use of BPC allows growers to reduce their reliance on pesticides, subsequently reducing the rate of development of pesticide resistance (van Lenteren 2000).

In Iceland, excess electricity generated by geothermal energy is used to heat up the greenhouses to extend the short growing season (Butrico and Kaplan 2018). In 2012, the total surface area of all the greenhouses in Iceland was 194,000m^2, and half of this was used to grow edible plants (Ragnarsson 2015). The potential for BPC is especially high in greenhouses due to the fewer number of highly specialised greenhouse pests that cannot survive outdoors in the harsh climate of Iceland. Such a controlled environment makes it easy for greenhouse owners to identify the pests, which subsequently allows for the introduction of generic or specific natural enemies. Globally, there are about 100 BPC species used for the control of most of the pests of economically important crops (van Lenteren 2000).

Aims of the research

Despite the widespread usage of BPC across Icelandic greenhouses, there has yet been a comprehensive study of the effectiveness of BPC within greenhouses. One significant obstacle is the large number of factors that have to be considered. Even within a controlled environment like a greenhouse, the ecosystem is complex and can be affected by many factors: the type of growing medium (e.g. soil vs hydroponics), the type of crop grown, other pests present (Messelink 2012) and the usage of synthetic or organic fertilisers. The present study constitutes the first highly detailed analysis of the relationships between such factors and the effectiveness of BPC employed within Icelandic greenhouses.

Methods

Study Area and Site Selection

I emailed all the greenhouse farms in Iceland, through a contact at the Agricultural University of Iceland. Out of all the farms emailed, five responded and granted me permission to visit their greenhouses for the research. These greenhouse farms in Iceland were visited between 18 June 2022 to 30 June 2022. All five farms are powered by geothermal energy and grow crops year-round. The locations of the five greenhouse farms can be seen in Map 1.

Map 1: Location of greenhouses in Iceland.

Due to the vastly different nature of crops and growing techniques adopted across the greenhouses, each greenhouse will be discussed as a case study. The five greenhouse farms are as follows:

1) A tomato greenhouse farm (GH1)
    - Crops: Tomatoes, small quantities of lettuce
2) An ornamental flower greenhouse farm (GH2)
    - Crops: Roses, lilies and statices
3) A greenhouse farm growing only tree seedlings (GH3)
    - Crops: Spruce, birch, willows and poplar
4) An ornamental flower greenhouse farm (GH4)
    - Crops: Large variety of garden plants, flowers, herbs and tree seedlings
5) An ornamental flower greenhouse farm (GH5)
    - Crops: Large variety of garden plants, flowers, herbs and tree seedlings

Recording of observations

In each greenhouse twenty plants were randomly selected, and the number of leaves, pests, natural enemies and other observations of plant damage (including those caused by fungi or viruses) were noted. These were recorded based on the plants' heights: 0-30cm, 30-60cm and 60-90cm. Due to time constraints and difficulties reaching taller parts of the plants, only three segments of plant height were considered. A hand lens with a 10x magnification and a mobile phone camera were used to observe the insects. This was supplemented by interviews with the owners and staff of the farms to understand growing techniques and common pests present in the greenhouses. The population of pests and natural enemies were recorded using four symbols:

- 0 - absence of the pest or natural enemy
- x - one to five insects observed
- xx - five to ten insects observed
- xxx - more than ten insects observed

Results and discussion

Case Study 1

This farm specialises in growing tomatoes (*Solanum lycopersicum*), with four different types of tomatoes: piccolo, holland, plum and heirlooms (comprising various varieties). Only a small quantity of lettuces are grown, but these are not sold commercially. Imported bumblebees are used for pollination. The two main pests which are found in the greenhouses, according to the owners, are whiteflies (species unknown) and spider mites (*Tetranychus urticae*). GH1 is completely pesticide-free, and adopts BPC to tackle pest problems. Two species of natural enemies are used: *Macrolophus pygmaeus*, an omnivore belonging to the Miridae family that feeds on both whiteflies and plant sap, and *Phytoseiulus persimilis*, a predatory mite targeting spider mites.

Plant height	**Median no. of leaves**	**Median no. of tomato bunches**	**Population of whiteflies**	**Population of *Macrolophus pygmaeus****	**Populatio n of spider mites****	**Population of *Phytoseiulus persimilis***
0-30cm	32	2	0	x	xxx	0
30-60cm	61.5	2	x	x	x	0
60-90cm	77	2	0	x	x	0

Table 1: Data collected from the 20 tomato plants in GH1 (Kang 2022).

**The actual number of Macrolophus pygmaeus recorded was small, but there was a large presence of white insect moults (see picture 1) which is likely to be from one of the previous instars of Macrolophus pygmaeus.*
*** Out of the 20 plants which I observed, all the spider mites were only found on one heavily infected plant, in extreme quantities.*

Picture 1: White moult observed on many of the tomato leaves. This is likely moults from one of the instars of Macrolophus pygmaeus.

Table 1 highlights two interesting observations: first, there were more *Macrolophus pygmaeus* than whiteflies observed; second, there were no *Phytoseiulus persimilis* observed despite presence of spider mites. The first observation corroborates with the information obtained from the growing manager of GH1. *Macrolophus pygmaeus* tends to overbreed and cause more damage to the tomato plants instead of reducing damage caused by the whiteflies. While the growers have stopped using *Macrolophus pygmaeus*, the insects find their way into new greenhouses and are prevalent throughout the plants observed. The sizable population of *Macrolophus pygmaeus* despite the low populations of whiteflies observed suggests that the sap of the tomato plants is a crucial food source for *Macrolophus pygmaeus*. Yet, *Macrolophus pygmaeus* cannot increase in population size on tomato plants in the complete absence of whiteflies (Dionyssios and Dionyssios 2004). Whiteflies are clearly present in the greenhouse in order for *Macrolophus pygmaeus* to breed quickly and spread throughout GH1. The second observation could be due to the small size of *Phytoseiulus persimilis* which makes it hard to notice except in large quantities. Another possible reason could be due to the physiological similarities of *Tetranychus urticae* and *Phytoseiulus persimilis* (both being from the Arthropoda phylum), which made differentiating the species difficult, especially with just a hand lens.

Despite the presence of both whiteflies and spider mites, GH1 still produces large yields of tomatoes that are of extremely high quality, sold to local consumers. Clearly, the pests and phytophagy (consumption of plants) by *Macrolophus pygmaeus* does not cause serious damage to the tomato plants. BPC in GH1 is generally of high effectiveness, given that no pesticides are used. Another factor that contributes to the low pest populations within GH1 could be their stringent pest control measures, such as deep cleaning each greenhouse every two years and double door systems to prevent pests from spreading between greenhouses. The monoculture of tomatoes certainly simplifies pest management measures as compared to polycultures (which I discuss in case studies 4 and 5). However, it is worth noting that mosaic virus was present across almost all the tomato plants, with leaves showing signs of browning and folding.

Case Study 2

This farm grows only ornamental flowers - roses (*Rosa* genus), lilies (*Lilium* genus), statices (*Limonium* genus), gerbera (*Gerbera L.* genus) - and sells them to many garden shops around the country. Multiple species of pests are present within the greenhouses: aphids, spider mites, thrips and whiteflies. Management of these pests in GH2 includes widespread adoption of BPC, with 10 different species of natural enemies used:

- *Amblyseius swirskii* (generalist predator of whiteflies and thrips)
- *Transeius montdorensis* (generalist predator of whiteflies and thrips)
- *Orius laevigatus* (predator of thrips only)
- *Phytoseiulus persimilis* (predatory mite of spider mites, the same species used by GH1)
- *Aphidius colemani* (parasitic wasp of different species of aphids)
- *Aphidius ervi* (parasitic wasp of different species of aphids)
- *Aphelinus abdominalis* (parasitic wasp of different species of aphids)
- *Praon volucre* (parasitic wasp of different species of aphids)

- *Ephedrus cerasicola* (parasitic wasp of different species of aphids)
- *Aphidoletes aphidimyza* (a predatory midge that feeds on over 70 species of aphids)

Pesticides (organic neem oil concentration of 1 ml cm^{-3}) and fungicides (concentration of 2ml cm^{-3}) are used occasionally only in the event of extreme infestations. I observed the plants across two greenhouses - the first which was used to grow only roses and the second which grew lilies and statices.

	Roses	**Lilies**	**Statices**
Aphids	xxx	xxx	xxx
White flies	x	x	xx
Spider mites	xx	xx	xxx
Thrips	xx	x	x
Amblyseius swirskii	xx	x	BPC not used
Transeius montdorensis	xx	x	x
Orius laevigatus	x	BPC not used	x
Phytoseiulus persimilis	x	BPC not used	x
Aphidius colemani	x	x	x
Aphidius ervi	0	0	BPC not used
Aphelinus abdominalis	0	0	BPC not used
Praon volucre	0	0	BPC not used
Ephedrus cerasicola	0	0	BPC not used
Aphidoletes aphidimyza	BPC not used	x	x

Table 2: Data collected from 20 roses, lilies and statices in GH2. Grey squares indicate that the BPC was not used for the plant.

Due to the wide variety of BPC used in GH2, there were many difficulties in identifying all the BPC species used, especially between the various parasitic wasps. Physiological similarities between the five species of parasitic wasps made it extremely difficult to identify them with just a hand lens, which could account for the absence of *Aphidius ervi*, *Aphelinus abdominalis*, *Praon volucre* and *Ephedrus cerasicola*.

Aphids were a significant problem throughout both greenhouses for all plants. According to the owner of GH2, when aphid infestations are particularly bad, they will have to resort to using pesticides. Since all the plants are ornamental flowers, the growers are more open towards using pesticides compared to edible plants like the tomatoes in GH1. Fewer consumers are concerned about pesticide usage in ornamental plants. This was an interesting insight which surprised me, as I thought that more people would be concerned about the environmental impacts of pesticides too.

From table 2, thrips and whiteflies have the smallest populations out of the four pests, which suggest that the BPC species of *Amblyseius swirskii*, *Transeius montdorensis*, *Orius laevigatus* and *Aphidoletes aphidimyza* are highly effective. This is contrasted with the large observable populations of aphids and spider mites present across all three types of flowers. Other factors such as pesticide resistance could also lead to the bigger populations of aphids and spider mites.

There was also the presence of many small spiders throughout the various greenhouses in GH2. Spiders are opportunistic predators and indiciate the presence of many insects (both pests and natural enemies) which are prey to the spiders. Given the wider diversity of insects in GH2 than in GH1, it is only normal for spiders to be present in large quantities.

Despite the large adoption of BPC in GH2, its effectiveness is lower than that in GH1. This could be because of the wide variety of pests present and the occasional usage of pesticides which might affect the natural enemies too. Unlike GH1, GH2 does not adopt double-door systems or stringent pest management measures, which could have exacerbated the spread of pests between their greenhouses. Nevertheless, the flowers produced by GH2 are still of high quality and are supplied to smaller nurseries throughout Iceland.

Case Study 3

This farm only grows tree seedlings, which are supplied to the Icelandic Forestry Service for afforestation. Crops include *Picea sitchensis* (Sitka spruce), *Pinus contorta*, *Betula Pubescens*, *Sorbus aucuparia*, *Salix hookeriana*, *Salix x majalis 'Þorlákur'* and *Populus trichocarpa*. Common pests include fungus gnats and *Phratora vitellinae*, a beetle which feeds on *Populus* and *Salix* species. BPC has never been used in GH3 as most of the commercial BPC species are targeted towards high-value plants such as edibles or ornamental flowers, rather than trees. According to the owner of GH3, it might not be commercially viable for the use of BPC for tree seedlings as the market around the globe is much smaller, and there is much less research that has gone into the field. Pesticides are used occasionally in the event of a mass infestation. Due to time constraints I only observed *Picea sitchensis*.

Through my observations, I only saw small red mites (Picture 2) present near the soil, which could be feeding on soil-based microorganisms. There were also a few fungus gnats spotted near the soil. From these 20 *Picea sitchensis* observed, there were very few pests directly on the plants. This could be due, most pertinently, to the young age of the plant (they were only a few months old) which makes them a smaller target compared to the older and mature *Picea sitchensis* which was grown outdoors. Similar to GH2, there was the presence of many spiders (Picture 3) throughout the greenhouse, indicating the presence of many insects within the greenhouse. The spiders serve a similar function as BPC species used in GH1 and GH2, although they are generic predators.

Picture 2: Small red mite visible near the soil of one of the Picea sitchensis seedlings.

Picture 3: Spider common throughout the greenhouse of GH3.

Among the over 100 BPC species available worldwide, few are catered specifically towards trees (van Lenteren 2000). This is because they are not produced on the same scale as crops like tomatoes or roses. However, this presents a significant challenge to reforestation efforts in Iceland where tree seedlings are being damaged and killed by pests before they can even grow to maturity. Further research should be done to find new BPC species used for the control of pests of trees. In the meantime, encouraging natural generic predators could be the best that these greenhouse farms can use for controlling pest populations.

Case Study 4

This farm grows a large variety of plants, including indoor plants, herbs, flowers and tree seedlings. Tree seedlings are supplied to the Icelandic Forestry Service. Common pests include *Phratora vitellinae*, *Nematus ribesii* and *Heringocrania unimaculella*. Similar to GH3, no BPC is used because of the wide variety of pests and the lack of commercial BPC species for tree seedlings. Rather, the owner of GH4 works with various local researchers and growers to cultivate disease-resistant cultivars of the plants (selective breeding). Pesticides (permasect and permacide) are also used once or twice a year during events of mass infestation.

Unlike the previous three case-studies, there is an extremely wide range of plants that are cultivated at GH4. This diversity serves as a natural pest management measure as no pest species is overpopulated because specialist pests cannot attack enough plants. I was only able to observe 3 rose plants within the greenhouse as there were only a few of each species of plant within the greenhouse. There were no observable pests on the roses, unlike that in GH1. This could be another reason why BPC is not utilised - there are simply too many different species of pests. Only generic predators such as spiders can thrive inside the greenhouse as they are able to feed on almost any insect.

This model of polyculture (having many different species of plants) as compared to monoculture might be in itself a good method for reducing pest populations. Traditionally, polyculture is often adopted outdoors so that pesticide usage can be reduced, but the lack of pests within GH4 also shows the potential for having high plant diversity within a greenhouse. It has also been shown that high plant diversity around greenhouses can attract natural enemies which might then feed on native and non-native insect pests (Messelink *et al.* 2012).

Due to the lack of visible pests present within the greenhouse, I observed some of the outdoor plants too. Visible damage was present to many of the outdoor plants, especially shrubs and tree seedlings. Picture 4 shows the damage caused by *Heringocrania unimaculella* to a *Betula pubescens* seedling. The owner of GH4 was highly concerned with the presence of these pests, as all three pests *Phratora vitellinae*, *Nematus ribesii* and *Heringocrania unimaculella* are non-native invasive species brought over from other countries. This means that there are no natural enemies in Iceland and the plants have not adapted to the damage caused by these pests.

Picture 4: Damaged Betula Pubescens leaves caused by the mining larvae of Heringocrania unimaculella.

Case Study 5

This farm grows a large variety of plants, including indoor plants, herbs, flowers and tree seedlings. Tree seedlings are supplied to the Icelandic Forestry Service. Common pests include fungus gnats (*Sciaridae* family), *Phratora vitellinae*, *Elatobium abietinum* (spruce aphids). The only species of BPC used is *Steinernema feltiae* (nematodes) to control the population of fungus gnats. Pesticides are used occasionally in the event of a mass infestation.

Out of the 20 *Salix phylicifolia* (tea-leaved willow) observed, there were no noticeable pests at all. These plants were all a few months old, and no pesticides had been used yet. In contrast, the outdoor tree seedlings (not *Salix phylicifolia*) were all heavily infested with various pests. The populus tree seedlings had many *Phratora vitellinae* present on their leaves (Picture 5), and most of the leaves had signs of yellowing. A staff at GH5 said that the *Phratora vitellinae* come back every year despite them spraying pesticides often. Just as the owner of GH4 said, *Phratora vitellinae* is a versatile invasive species that has spread across Iceland; GH4 is located near Reykjavik in the southwest while GH5 is located at Akureyri in the north, but both greenhouses are plagued with the same pest.

Picture 5: Phratora vitellinae feeding on a Populus tree seedling*.*

The same staff of GH5 also said that he sprayed pesticides on the outdoor spruce seedlings that very morning, hence most of the *Elatobium abietinum* (Picture 6) was dead. Despite this, it is obvious that the scale of infestation by *Elatobium abietinum* was extremely large, with aphids feeding on the entire stem of the spruce trees. Considering that most of the tree seedlings would be sold for reforestation purposes, the presence of both *Phratora vitellinae* and *Elatobium abietinum* might be a serious setback to reforestation in Iceland, costing the country large sums of money.

Picture 6: Elatobium abietinum (spruce aphids) present on the outdoor spruce trees.

Conclusions

BPC has proven to be an effective solution for pest control within Icelandic greenhouses, but these tend to be combined with other pest management measures such as deep cleaning the greenhouses and using pesticides in events of mass infestations. More growers could start adopting BPC with outdoor crops as part of an integrated pest management method. This will not only save the growers money (less money spent on pesticides) and time, but also benefit the local wildlife and ecology, creating a better environment for all life to live in.

There exists a large potential for further research into the use of BPC for tree seedlings, as seen from the case studies of GH3, GH4, and GH5. With the increasing focus on reforestation and afforestation efforts in Iceland and around the world, it is all the more important for greenhouse growers to ensure that their tree seedlings are healthy and will survive once planted out in the wild. Trees play an essential role in helping us tackle climate change, and healthy trees are the first step towards creating a greener world.

The current BPC species are highly oriented towards edible crops and ornamental flowers of high value, rather than lower value crops such as tree seedlings. Further commercialisation and diversification of the BPC market could also benefit growers who adopt polyculture growing methods which are more ecologically-friendly. Increasing plant diversity around the greenhouse could also serve to attract more native natural enemies, which can suppress populations of native and non-native pests (Messelink *et al.* 2021). This can be seen from GH4, which has the highest plant diversity among all five greenhouse farms visited, and also has the fewest pest problems.

Reflections

My biggest takeaway from this entire experience was the need for adaptability. Before arriving in Iceland, I planned thoroughly with regards to the timing and equipments required. Despite this, nothing can ever be fully planned and there should always be room for last minute changes. This included my car getting stuck on the day of my first visit to GH2, which made me late by an hour. Thankfully, I still managed to reach the greenhouse and carried out my research. Since GH2 had the widest range of BPC species and pests involved, I also felt that I was underprepared for the vast amount of data that I had to collect. This presented a significant challenge for me: writing down all the crops, pests, natural enemies and other information on paper in an organised manner. I definitely could have spent more time in GH2 or even made a second visit back.

Since the greenhouses grew vastly different crops, their practices varied greatly. I did not expect to see such a large disparity between the greenhouses, and was particularly shocked by the fact that GH3 and GH4 did not use any BPC at all. I assumed that the owners of the greenhouses allowed my visit because they used BPC but that was not the case. As there were only five greenhouses which responded to my email, I had to seize every opportunity and thus accepted all the greenhouses. However, if I were to do this project again, I would definitely arrange a video call prior to the visit to explain my research aims and find out about their greenhouse practices. This way, I could potentially change the research aim according to the circumstances of the greenhouses.

Another thing I would do differently might be to make a sample trip to one or a few greenhouses near London, where I can attempt to observe some plants and count the pests and BPC species used. Such a sample research would allow me to understand how much time I expect to take in each greenhouse and gain a better understanding of commonly used BPC species. This would definitely require much more time but would have helped me refine my research methods and aim. Doing something completely new is always the hardest the first time, so having prior experience at another location would certainly have made me more comfortable with what I needed to do when I visit the greenhouse with a limited time span.

Lastly, since it was a solo research project, I realised the importance of building connections: being sincere and smiling to people could go a long way to helping strengthen the bond. I was pleasantly surprised when one of the greenhouse owners offered me to stay at her place for a night upon knowing that I was camping and it was pouring that evening. This applies to leadership as well: being sincere is important for your team members to understand that you truly mean well. The diverse range of experiences I encountered in Iceland truly helped me to understand my working style and myself better, which I will certainly use in the future. Constantly improving and seizing every opportunity is something that I will aim for.

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