



**The Interactions between Biological Control Agents against Glasshouse
Whitefly (*Trialeurodes vaporariorum*)**

A Dissertation Submitted to Newcastle University for the Degree of Master of
Science

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Abstract

Glasshouse Whitefly, *Trialeurodes Vaporariorum*, is one of the most economically significant pests in terms of its damage to vegetable crops in glasshouse conditions. It can damage vegetable crop, such as tomato and cucumber, easily. Chemical control was applied against this pest, but resistance has prevented the use of chemical control methods. In addition, chemical pesticides pollute the environment. Alternative methods are now being developed as an alternative to chemical control. Biological control, therefore, is one of the viable alternative methods being use in the control of Glasshouse Whitefly.

The aim of this present research is to use of biological control against Glasshouse Whitefly. Biological control using a parasitoid was used in this investigation. *Encarsia formosa* is well-known bio-control agents for Glasshouse Whitefly.

The effectiveness of *Encarsia formosa* was observed between three different varieties for this study. Two tomatoes (Moneymaker and Alicante) and one cucumber (Telegraph Improved), varieties were selected for this experiment. No significant difference was identified between the three varieties in terms of the parasitism rate. The percentage of parasitism is 67% for Moneymaker, 67% for Alicante, and 62% for Cucumber. The rates are similar to each other. No significant difference was identified between treatment and control plants with regard to the total number of eggs, but there was a different noted between Alicante and Cucumber in this study.

According to projected results, the biological control using *Encarsia formosa* against Glasshouse Whitefly is a successful method in the glasshouse conditions. This method can be used on tomato and cucumber plants for the control of Glasshouse Whitefly, *Trialeurodes Vaporariorum*, in glasshouses.

1. Introduction

The Glasshouse Whitefly, *Trialeurodes Vaporariorum*, is a significant pest for vegetables and many ornamental plants in glasshouses. According to research, 250 plant species have been identified as hosts for Glasshouse Whitefly worldwide, and vegetables in particular (Osborne and Landa, 1992). The Glasshouse Whitefly is a significant pest in economic terms with regard to glasshouse crops, due to the fact that this pest causes both direct and indirect damage, such as damaging leaves with honeydew, feeding on plant sap, and transmitting some plant viruses. In addition, moulds and fungi develop easily as a result of Glasshouse Whitefly (Mellor *et al.*, 1997).

The Glasshouse Whitefly is one of the most significant polyphagous species. Glasshouses provide the most appropriate conditions for the growth of this pest. Mediterranean glasshouses are particularly affected negatively by Glasshouse Whitefly. Certain control methods are insufficient, as the Glasshouse Whitefly develops resistance to insecticides, and causes some of the integrated control programs with insecticide in glasshouses to fail (Fargues *et al.*, 2003).

Many studies on the subject have concluded that resistance to insecticide is one of the major problems for glasshouses. Although insecticides kill the whitefly larvae, they also have a negative impact on non-target species such as their predators and natural enemies (Gorman *et al.*, 2002).

As a consequence, alternative methods are being developed in glasshouses. For example, biological control has now become one of the most important methods for managing these pests in glasshouses (Bale *et al.*, 2008). Biological control has been used in glasshouses for 100 years, and the use of natural enemies is a widely used method for successful biological control. There are two main methods identified for biological control (Classical biological control and Augmentative biological control (van Lenteren *et al.*, 2003).

Biological control methods are generally used with Integrated Pest Management (IPM). IPM has played an important role in pest management since 1980. IPM is not only used on vegetables, but can be applied to ornamental plants as well. The successful result of IPM is seen on eggplants, melons, strawberries, sweet peppers, tomatoes, and cucumbers, but the use of IPM on ornamentals has not had such a straightforward outcome as on vegetable crops (van Lenteren, 2000).

Augmentative biological control is widespread in European glasshouses. Generally, this method is applied against whiteflies, aphids, and other pests in tomato and cucumber glasshouses. The release of *Encarsia Formosa* is one of the most common bio-control methods used in glasshouses (Hoy, 2008).

There are many investigations being carried out with regard to the biological control of the Glasshouse Whitefly with parasitoids. *Encarsia Formosa*, in particular, is one of the most important parasitoids for Glasshouse Whitefly. These studies are based on the development of pest and parasitoid together, and then finding the resulting correlation between parasitoids-pest, parasitoid- host plant, and host plant-pests (van Roermund *et al.*, 1997).

Encarsia Formosa is a popular bio-control agent in biological control. It is applied on vegetable crops and ornamental plants in glasshouses throughout the world. The success of this parasitoid against Glasshouse Whitefly has been proven by many studies. When *E.Formosa* parasitize the whitefly eggs, the colour of eggs turn black. In addition, 15 host in aleyrodid genera is parasitized by *Encarsia Formosa*. However, there is no satisfactory study on the population of *E.Formosa* in nature (Hoddle *et al.*, 1998).

Encarisa Formosa requires a qualitative assessment because the success of this parasitoid depends on the quality control of parasitoids. Storage conditions, release methods are determinative factors for the quality control of *Encarsia Formosa*. In particular, the release rates of parasitoids can easily affect the parasitism rate. Another important factor for the success of *Encarsia Formosa* is the type of host plant. The features of host plants have an important impact on the behaviour of parasitoids. In addition, the differences in plant variety affect the effectiveness of *Encarsia Formosa* (Hoddle *et al.*, 1998).

The commercial production of natural enemies has been developing for 30 years, and the number of available natural enemies for biological control has increased significantly (van Lenteren, 2000). Environmental factors are likely to affect the commercial use of biological control. For example, biological control does not pollute the environment, is not hazardous to the health and working conditions of growers, and it results in chemical-free products for consumers (van Lenteren *et al.*, 1996). These factors have had a positive impact, and the consequent increased commercial use of *Encarsia Formosa* against Glasshouse Whitefly, *Trialeurodes Vaporariorum*, in glasshouses.

In contrast, some studies have concluded that the use of *E.Formosa* on ornamental plants is still not a suitable method because the populations of Glasshouse Whiteflies are not as great as on vegetable crops. This situation might affect the efficiency of parasitoid on ornamentals (Hoddle *et al.*, 1998).

Although *Encarsia Formosa* is a good bio-control agent on its own, its integration with other control methods could increase the effectiveness of this parasitoid against Glasshouse Whitefly. Generally, the use of cultural methods and other natural enemies are employed with *Encarsia Formosa*. For example, yellow sticky traps are used with *E.Formosa*. Sanitation might be used with the IPM program because it helps eliminate other source-plants of Glasshouse Whitefly. The use of *Encarsia Formosa* with other natural enemies has a greater impact on the reduction of Glasshouse Whitefly. The combination of bio-control agents may suppress the Glasshouse Whitefly. In addition *E.Formosa* and entomopathogenic fungi are a good combination for the biological control of Glasshouse Whitefly (Hoddle *et al.*, 1998).

Although insecticide is not a preferable method, selective insecticide might be combined with *Encarsia Formosa* in an IPM programme (Hoddle *et al.*, 1998). These selective insecticides have fewer negative effects on *Encarsia Formosa* and other natural enemies (van Lenteren *et al.*, 1996).

As can be explained above, biological control with natural enemies is one of the feasible control methods in the control of this pest. *Encarsia Formosa* has been produced commercially, and it has been used on vegetable crops in glasshouses. Quality test methods are still an important requirement for this parasitoid. These tests have a significant positive impact on the effectiveness of *Encarsia Formosa*.

New strategies are still being developed in relation to IPM. Biological control and other methods are used in combination for increased effect and efficiency in biological control. Other natural enemies and entomopathogenic fungi are used in IPM programs. In addition, cultural practices (such as yellow sticky traps, and sanitation) are used with *Encarsia formosa*. These developments are still carrying out for increasing the effectiveness of biological control in the pest management.

1.1. Objectives of the Study

The Glasshouse Whitefly is an economically significant pest in terms of its damage to vegetable crops in glasshouses. Due to the adverse effects of pesticides, alternative and feasible control methods have been developed for controlling the population of Glasshouse Whitefly in glasshouses. Biological control is one of the most effective alternative methods to chemical control. The effectiveness of parasitoids on Glasshouse Whitefly in glasshouse conditions has been proven by studies. Although all bio-control agents are successful against Glasshouse Whitefly, this project will focus on the effectiveness of *Encarsia formosa*.

The aim of this project is to discover the effectiveness of *Encarsia Formosa* in its use against Glasshouse Whitefly, *Trialeurodes Vaporariorum*, on three different varieties. Moneymaker (tomato), Alicante (tomato), and Telegraph Improved (cucumber) varieties will be used in this investigation. The main aim of this project is to compare three varieties in terms of difference between the percentages of parasitism.

2. Literature Review

2.1. Biological Control

The human population has been increasing rapidly since 20th century began. Production of sufficient food using commercial and sustainable farming systems has become more important for mankind. Non-polluting production systems are vital for the conservation of wild animals and the natural environment, which makes biological controls an important and non-polluting system for farming, in the future (Van Driesche & Bellows, 1996). Chemical control is one of the most common control methods for pests, and the use for pesticide has increased over the past 60 years. However, the use of chemical control causes problems including contamination of environment, resistance to pesticides by pests, as well as being harmful to human health. In addition pesticides are dangerous for natural enemies. For example acaricides kill predacious mites, and some fungicides have suppressing effects on beneficial fungi (these fungi kill the pest arthropods) (Van Driesche & Bellows, 1996). The 19th century saw the first step in understanding biological control using parasitoids and predators. During this time, scientists worked on taxonomy, biology, and ecology of the insect parasitoids and predators, and the first parasitoids were transferred between two continents in 1855 (from England to USA) (Van Driesche & Bellows, 1996). *Encarsia formosa* was first used against Glasshouse whitefly in 1926 by tomato grower in England. (van Lenteren *et al.*, 1996)

Biological control, therefore, was first used on pests during the 19th century. When the lifecycles of insects and microbes were beginning to understood properly, and so biological control became an alternative pest control method. Also, after World War II, the disadvantages of chemical control were now being discovered. For example, insects were developing resistance to chemicals, some adverse effects were observed on human health. It also became apparent that chemicals were not environmental friendly products. For these reasons, biological control has become increasingly popular over the past 60 years as a form of control (Waage *et al.*, 1988).

Biological control is one of the key methods for the suppression of pest populations using parasitoids, predators, pathogens, antagonists, or competitor populations (Van Driesche & Bellows, 1996). Generally biological control focuses on the reduction of pests population density in the glasshouse or field. But this method is not used on its own. Biological control is more efficient when used together with cultural techniques, physical barriers, and the use

of selective semio-chemicals with Integrated Pest Management (IPM) (Bale *et al.*, 2008). IPM, together with biological control, is economically productive and profitable for crop protection. Glasshouses are an especially suitable environment for enhancing the effects of such biological control. Although the developmental time is the same for both chemicals and biological control (table 2.1), the benefits are greater in the case of biological control than for chemical control in terms of the financial outlay. The risk of resistance and harmful side effects are greatly reduced by using biological control (Bale *et al.*, 2008). The total area of glasshouses worldwide is 300, 000 ha (50, 000 ha of glasshouses are covered by glass, 250, 000 ha with plastic). Biological control, in contrast to the use of chemicals, is an ideal method for glasshouses because glasshouse are small, contained areas, thereby providing an opportunity for growing and spreading bio-control agents quickly and efficiently (van Lenteren, 2000).

Table: 2. 1 Comparison of various aspects related to the development and application of chemical and biological control (Bale *et al.*, 2008)

	chemical control	biological control
number of 'ingredients' tested	> 3.5 million	3000
success ratio	1 : 200 000	1 : 20
developmental costs	180 million US\$	2 million US\$
developmental time	10 years	10 years
benefit per unit of money invested	2.5–5	30
risk of resistance	large	nil/small
specificity	low	high
harmful side effects	many	nil/few

2.1.1 Aims of Biological Control

Augmentative biological control is one of the most effective control methods. Natural enemies are applied during the growing season and bio-control agents do not become a part of the ecosystem permanently with this method. Augmentative biological control has been used practically since 1884. The main aim of this method is to introduce natural enemies before the pest population reaches economically damaging levels, and therefore the release of the natural enemies must be carried out before damage to crops occurs. The effectiveness of

the augmentative biological control depends on the total number individuals released. Biological control agents must be chosen carefully because bio-control agents must have adaptation with host plants, and the percentage success rate is related to the host plant. For example, a success rate in the range of 55-75% has been identified for classical biological control using weeds and arthropods. Therefore, the relationship with host plants and bio-control agents is one of the important factors for achieving the aims of biological control (Batra, 1982).

Cost-effectiveness is another major factor with regard to augmentative biological control. The marketing of the augmentative control is undertaken by several countries. For example the United States uses many bio-control agents commercially in order to increase the augmentative control. The cost of insects is between \$24.70 and \$29.60 per hectare for orchards, and between \$133 to \$2398 per hectare in glasshouses in the United States (Batra, 1982).

The key objective of the augmentative biological control is to increase effectiveness of native bio-control agents by releasing natural enemies. Releasing natural enemies should be carried out using small numbers in the early cropping season for the control of the target pest populations. In addition, pathogens and nematodes can be used for augmentative biological control (Hoy, 2008).

Classical biological control is another method of the biological control (Batra, 1982). The fundamental aims of the classical biological control are to provide long-term economic and public health benefits, but the use of this method is also attempt at preventing the adverse effects of mechanical and chemical methods (Howarth, 1991). In summary, classical biological control focuses on low cost, ecological advantages, and long term benefits on human health and environment (Bosch, 1971).

2.1.2 The benefits of Biological Control

Biological control provides many benefits in terms of human health and environment. These benefits consist of reducing and preventing pest population and damage, lowering pesticide use and decreasing environmental degradation, enhancing efficiency of agricultural production, and conserving the natural environment. Although biological control brings with it these benefits, there are also disadvantages, and potential effects on non-target organisms (Van Driesche & Bellows, 1996). Bio-control agents sometimes impact on non-target species directly or indirectly, and polyphagous agents are the greatest threat to non-target species

(Howarth, 1991). Careful host-range testing is an important part of the process for reducing potential risks to non-target species. In conclusion biological control has many benefits which range from economic, social, and ecological perspectives, while its disadvantages can be easily prevented by using sensible precautions (Van Driesche & Bellows, 1996).

2. Glasshouse Whitefly (*Trialeurodes vaporariorum*)

2.2.1 Glasshouse Whitefly: Pest Status and Distribution

Whiteflies belongs to Homoptera/Hemiptera (the suborder is Sternorrhyncha). The family is generally known as Aleyrodidae, but there are two subfamilies identified for whiteflies, namely the Aleurodiciinae and Aleyrodinae. Aleurodiciinae are widespread in Central and South America. The main difference between the two subfamilies is wing venation, with Aleurodiciinae having more venation than Aleyrodinae. The Aleyrodinae are characterised by having larger populations and are more widespread than Aleurodiciinae (Byrne and Bellows, 1991).

The Glasshouse Whitefly, *Trialeurodes vaporariorum*, is a serious pest in crop production because it has a negative economic impact on crops such as tomatoes, eggplant, beans, cucumber, and ornamentals (Thompson, 2011). The Glasshouse Whitefly is a polyphagous pest and attacks 249 genera from 84 plant families (van Lenteren *et al.*, 1996). Whiteflies can cause more than 50% yield reduction. Honeydew is a significant factor which increases sooty mould fungi. In addition to all these, whiteflies are vectors of several viral plant pathogens (Byrne and Bellows, 1991).

2.2.2 Lifecycle and, Morphology of Glasshouse Whitefly

Glasshouse Whitefly is widespread around the world, especially in the temperate and subtropical zones, and they can survive temperate winter conditions in glasshouses. The life cycle (from egg to adult) is about 25-30 days at 21°C. The life cycles include the egg, four nymphal instars, and the adult stage. The threshold for development of all life cycle stages is 8.5°C and optimum humidity is between 75-80% (Capinera, 2008).

Eggs

The eggs are oval and connected to the leaf by a short narrow stalk. The eggs are green and are dusted with white powdery wax, but change to brown or black when mature. The eggs are 0, 24 mm long and 0, 07 mm wide. The eggs are attached to the underside of the leaves. The

female Whiteflies generally choose youngest plant tissue for deposition of eggs. The egg's stages lasts between 10-12 days. (Capinera, 2008). As can be seen in figure 2.1, the adult Whiteflies deposit their eggs in circles (Augustin, 2002).



Figure: 2. 1 Figure: 2.1 Glasshouse whitefly eggs on the leaf (Augustine, 2002).

Nymphs

The Whitefly life cycle include four nymphal instars. First instar nymphs have functional legs and antennae. They are measured about 0.3 mm long and green with red eyes. The development of the first instar is completed in just over four days at 22.5°C. The second nymphal stage is similar to first, but is larger and the legs and antennae are not functional. The length is between 0.38-0.52 mm and development is completed in just over three days at 22.5°C. The third nymphal duration is similar to second. The fourth nymphal instar is known as the `pupae`. The pupa is 0.75 mm long and is thicker and more opaque. The fourth nymphal stage includes the starting of the feeding period and conversion to the adult stage. The pupal stage lasts approximately four days (Capinera, 2008).Figure 2.2 shows the general appearance of the nymphal stages on the leaves (Augustin, 2002).

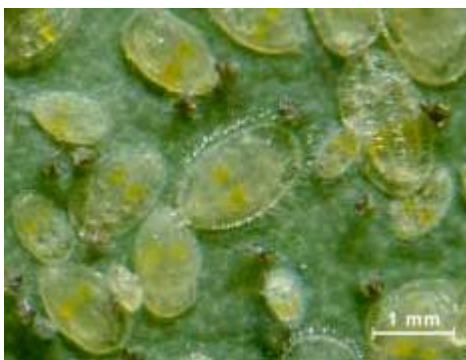


Figure: 2. 2 Different instars of the glasshouse whitefly (Augustine, 2002).

Adults

Adults are between 1.0-2.0 mm long and are generally white with white waxy or mealy materials and adults have reddish eyes. These insects are triangular in shape because the basal sections of the wings are narrower than the distal portions. The wings are held horizontally in the resting position. Between 175-200 eggs are produced on cucumber and tomato by Glasshouse Whitefly female adults (Capinera, 2008). Figure 2.3 demonstrates the adult stage of the Glasshouse Whitefly (Augustin, 2002).



Figure: 2. 3 Glasshouse whitefly adult (Augustine, 2002).

2.2.3 Host Plants and Distribution

Glasshouse Whitefly are one of the most significant pests because they have a wide range of host plants. The suitability of host plants depends on the family of plants. Vegetable plants such as bean, cantaloupe, cucumber, lettuce, squash, tomato, eggplant, and sometimes cabbage, sweet potato, pepper, and potato are all suitable. Tomato, cucumber, and eggplant are the common host plants in glasshouses. In addition some ornamental plants are suitable host for Glasshouse Whiteflies, for example ageratum, aster, chrysanthemum, and coleus (Capinera, 2008).

Host plant selection is an important factor for Glasshouse Whiteflies. Although Glasshouse Whitefly is a polyphagous species, the damage they cause, and their reproductive potential, is not similar on all of the host plants. For example, reproduction of Glasshouse Whiteflies is greater on tomato than *Brassica* spp (Byrne and Bellows, 1991). In addition, Whiteflies generally prefer young leaves for feeding and oviposition. Green and yellow colours (approximately 550 nm) are attractive for Whiteflies, and olfactory stimuli are not important factors in host plant selection for Whiteflies (van Lenteren *et al.*, 1996). Similarly, leaf shape and structure, are not important factor in host plant selection for the Glasshouse Whitefly (Byrne and Bellows, 1991).

2.2.4 Direct and Indirect Damage

The Glasshouse Whiteflies (*Trialeurodes vaporariorum*) are whose activities have serious economic implications in temperate regions, because they have negative impacts on plants in glasshouse, and open fields directly and indirectly. After feeding of the Glasshouse Whitefly, these insects excrete honeydew. Sooty mould fungi develops easily with the help of honeydew, with the result that the economic value of the produces are reduced (Lei *et al.*, 1998). Whitefly nymphs and adults are sap-sucking phloem feeders, and also excrete honeydew. Honeydew causes indirect damage, encouraging sooty mould fungal growth (Pilkington *et al.*, 2010). Glasshouse Whiteflies extract large quantities of phloem sap, causing more than 50% yield reduction (Byrne and Bellows, 1991). In addition, Whiteflies transmit many economically important viral pathogens (Byrne and Bellows, 1991). Tomato chlorosis virus (ToCV) and tomato infectious chlorosis virus (TICV) are two of the most significant viruses related to tomato plants, and these viruses are transmitted by the Glasshouse Whitefly (*Trialeurodes vaporariorum*). These viruses are described as phloem limited, bipartite closterovirus, but TICV has some structural differences. For example, TICV is established lack of serological and nucleic acid cross reactions (Wisler *et al.*, 1998). In addition, beet pseudo-yellows virus (BPYV) is transmitted by Glasshouse Whiteflies (Liu and Duffus, 1990). These viruses, transmitted by glasshouse whiteflies, can cause significant damage to plants.

3. Control of glasshouse whitefly (*Trialeurodes vaporariorum*)

The Glasshouse Whitefly, *Trialeurodes vaporariorum*, is an important pest for agricultural crops and ornamental plants worldwide, and this pest has been controlled with the use of various insecticides over the past 60 years, but the extensive use of insecticides has caused resistance problems. Biological control is an economically feasible control method (van Lenteren *et al.*, 1996). The use of parasitoids, predators, and entomopathogenic microorganisms provide successful control of Whiteflies, particularly the Glasshouse Whitefly (Osborne and Landa, 1992).

3.3.1 Chemical Control

Chemical control is one of the most common control methods used after the Second World War (van Lenteren, 2000), and Whitefly populations were managed by chemical insecticides (Er and Gökçe, 2004). After 1945, broad-spectrum insecticides were developed, and this led to a reduction in the use of other control methods. However, resistance problems occurred owing to the use of insecticides (Simmonds *et al.*, 2002). The Glasshouse Whitefly developed

resistance to insecticides, and this pest continued to be a major problem on agricultural crops (Avery *et al.*, 2004). In addition, the morphological and autoecological characteristics of Whiteflies are not conducive to chemical control. For example, their population colonizes the underside of the leaves and this pest has dense populations (Osborne and Landa, 1992).

According to some studies, insecticides were tried in Integrated Pest Management (IPM). For instance, botanical insecticides were used for the reduction of the whitefly populations. Botanical insecticides are plant-derived compounds, for example bioresmethrin, Margosan-O, and the extracts of *Nicotiana glauca*. Botanical insecticides have some disadvantages. For example, pyrethrum has toxic effects on Whiteflies, but is also toxic for *E.formosa*, so botanical insecticides are not suitable for chemical control (Simmonds *et al.*, 2002).

Chemical controls have phytotoxic effects on young plants, and are less pleasant than biological control in humid and warm glasshouses. Whiteflies develop resistance to insecticides easily. Chemical control requires a safe period before harvesting, so this may affect quality of the product. Chemical control has more risks than biological control with regard to environmental pollution (van Lenteren, 2000)

3.3.2 Biological Control of Glasshouse Whitefly

Whiteflies cause economic loss in glasshouse crop production. Non chemical methods have been developed against the Glasshouse Whitefly, *Trialeurodes vaporariorum*, such as resistance breeding and biological control. Biological control with the parasitoid *Encarsia formosa* is a widespread method, and 90% of growers use this method in the Netherlands, and in many other countries. During the 1970s, when the insecticide resistance first occurred, biological control with parasitoids was developed in glasshouses. The use of *Encarsia formosa* is a commercially viable alternative to chemical control in glasshouses today (van Roermund *et al.*, 1997)

3.3.2.1 Biological Control with parasitoid *Encarsia formosa*

The Glasshouse Whitefly was found in the UK's glasshouses in 1856. *E.formosa* (Hymenoptera: Aphelinidae) was identified for biological control in 1926. From the 1930s this parasitoid was introduced in other European countries as a control method. After World War II, when chemicals were developed, there was an important decrease in the use of the parasitoid. However, when the insects developed resistance to pesticides, the importance of

biological control with parasitoids became more popular. Figure 2.4 shows the general use of the *Encarsia formosa* against the Glasshouse Whitefly on tomato and cucumber between 1970 and 1990 (van Lenteren *et al.*, 1996). Biological control with *E.formosa* is used in more than 20 countries which have a developed glasshouse industry (van Lenteren *et al.*, 1996).

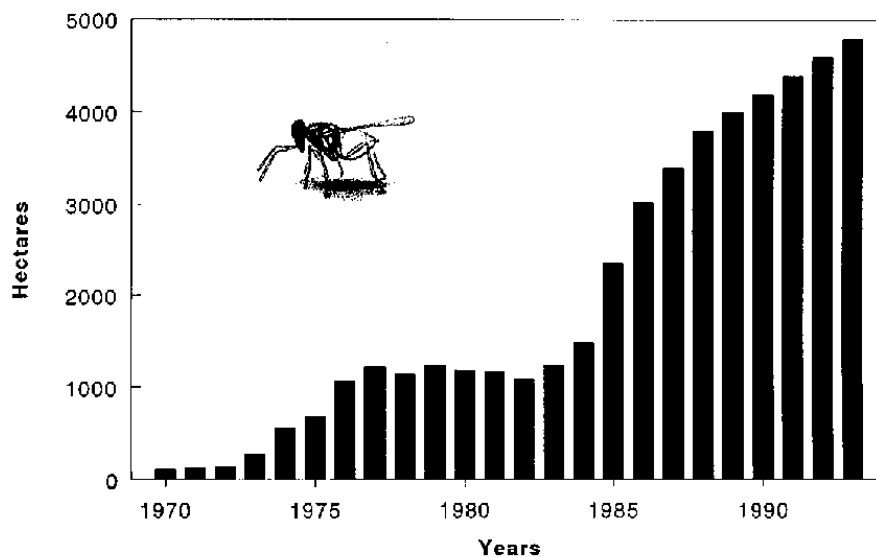


Figure: 2. 4 The use of biological control of glasshouse whitefly with *Encarsia formosa* in glasshouses since 1970 (World distribution) (van Lenteren *et al.*, 1996).

Encarsia formosa is a solitary, thelytokous endoparasitoid, and produces 8-10 eggs which are matured per day (Hoddle *et al.*, 1998). Females are approximately 0.6 mm long and are yellow with a black abdomen and opalescent wings. The males are totally black, and are larger than females (Mahr *et al.*, 2001). Tomato and cucumber are the main crops for the use of *E.formosa* in the control of the Glasshouse Whiteflies, but it is also used for eggplant, gerbera, poinsettia, marigolds, and strawberry. Host quality is one of the most important features for efficiency of parasitism. *E.formosa* searches the leaves infested by whiteflies using random flight, landing, and walking sequences. Visual and olfactory cues are not used by *E.formosa* for searching infested plants. In addition, the tendency of *E.formosa* is reduced from lower leaves surface to upper leaves surface because Whitefly nymphs are more widespread in lower surface. (Hoddle *et al.*, 1998).

Generally, *Encarsia formosa* tend to feed with pre-imaginal stage of the Glasshouse Whitefly rather than eggs for host feeding. In terms of oviposition, third and fourth instar and prepupal nymphs (pre-imaginal stages) are the most appropriate stage for *Encarsia formosa*. Adult wasps have generally begun to develop in third and fourth instar nymphs stages. In addition, the proportion of the successful emergence in *E.formosa* is the highest in the recommended stages (Hoddle *et al.*, 1998).

Approximately 50-100 eggs are deposited by the females of *E.formosa* in their life time. The development of the wasp larvae is completed in about 2 weeks at optimal temperatures. The colour of parasitized Whitefly pupae changes to black in about 10 days. After that, the adults of *E.formosa* emerge 10 days later and the Whitefly nymphs are killed. The adult wasps also make holes with their ovipositor in whitefly nymphs, for feeding (Mahr *et al.*, 2001).

Plant species and variety are also the most important factors affecting the efficiency of the *E.formosa*. Some species are better host plants than others in terms of the control of Glasshouse Whitefly using *Encarsia formosa*. For example, tomato is more satisfactory than the cucumber (Hoddle *et al.*, 1998). The presence of *Encarsia formosa* affects the Whitefly population in the tomato glasshouses. For example, the release of the *Encarsia formosa* causes the population of the Glasshouse Whitefly to decline by almost 40% in tomato glasshouses (Hoddle *et al.*, 1998). Although tomato leaves are not good hosts for Whitefly development, they are a good place for the parasitoid to forage. On the other hand, cucumber is more a suitable host for the development of the Glasshouse Whitefly, but is worse than tomato with regard to parasitoid foraging (Hoddle *et al.*, 1998). Biological control of glasshouse whitefly using *E.formosa* is more widespread on vegetables than ornamentals. The quality of parasitoid is one of the most significant factors for the success of the *E.formosa*, and quality assessment tests should be carried out for *E.formosa* before release on plants (Hoddle *et al.*, 1998). Figure 2.5 shows the general appearance of *E.formosa*. In addition, before and after parasitism process were shown in the figure 2.5 (Augustin, 2002).



Figure: 2. 5 The important life-stages of the *Encarsia formosa* (Augustine, 2002).

To sum up, *Encarsia formosa* is extensively used for the biological control of the Glasshouse Whiteflies. Glasshouse crops, especially vegetables, are more suitable for this method (Hoddle *et al.*, 1998). Whitefly populations in tomato and cucumber are controlled by *Encarsia formosa* by inoculative release of the parasitoid. In addition, if the parasitoids introduced in smaller numbers during the growing season, the success of parasitism may increase in the glasshouses (Mahr *et al.*, 2001). The plant factor is of great importance for the success of *Encarsia formosa* in controlling the Glasshouse Whitefly. Also, physical properties such as temperature can generally affect the efficiency of the control with parasitoid. Quality control testing of *E.formosa* impacts the success of the biological control in glasshouses (Hoddle *et al.*, 1998). If the above factors are optimised before the release of parasitoid, this may increase the efficiency and success of the biological control in glasshouses.

3.3.2.2 Predators

More than 75 predator species have been identified for biological control of the Glasshouse Whitefly. Many of the predators come from the families Anthocoridae (Hemiptera), Coccinellidae (Coleoptera), Chrysopidae (Neuroptera), Hemerobiidae (Neuroptera), and Miridae (Hemiptera). *Macrolophus* or *Dicyphus* are two of the most efficient predatory bugs for the biological control of the Glasshouse Whiteflies (van Lenteren *et al.*, 1996).

Macrolophus caliginosus is an important predator of the Glasshouse Whitefly. This species can attack all stages of Whitefly, but eggs and nymphs are preferred by the predator. Between 40-50 Whitefly eggs are killed by the adult *M.caliginosus* each day. However, if the population of Whitefly is limited, *M. caliginosus* can cause damage to tomato fruit by feeding

on it. *M. caliginosus* is also used for the biological control of thrips, mites, and caterpillars (Mahr *et al.*, 2001).

Dicphus tamaninii is a second important predator of Whiteflies. Although this bug has a wide range of prey, it generally prefers Whitefly nymphs to other insects. If the prey is limited, they may feed on tomato fruit, but they do not prefer cucumber fruit. *D.tamaninii* is not used commercially in glasshouses (Mahr *et al.*, 2001).

Orius spp. are also used for the biological control of Whiteflies. The nymphs and adults of *Orius* spp. can attack all stages of whiteflies. However, this species has some disadvantages as, during short days and low temperatures, this bug generally enter diapause. Many species of *Orius* spp. are used commercially (Mahr *et al.*, 2001).

3.3.2.3 Pathogens

Many pathogens are used for biological control, for example viruses, bacteria, rickettsiae, fungi, and entomophagous nematodes, but only fungi are recorded as being used for the biological control of the Whiteflies. Sufficient results are obtained from *Aschersonia aleyrodis* and *Verticillium lecanii* for biological control of the Glasshouse Whitefly (van Lenteren *et al.*, 1996).

Aschersonia aleyrodis is an important pathogen for the biological control of Whiteflies. This is a specialist for young Whitefly nymphs, because the infection is better than on other stages and older nymphs. After infection, Whitefly nymphs have the appearance of a fried egg. If the humidity is high, the colour of the infected nymphs may be more orange. This fungus can live in a wide range of temperatures, but it is not used for biological control commercially (Mahr *et al.*, 2001).

Verticillium lecanii is another significant fungus for control of Whiteflies. The fungal strain of *V.lecanii* includes large and small spores. The small spores are suitable for the infection of Whiteflies. This fungus needs high humidity (about 90%) and humidity has to remain high for at least 10 hours per day for the germination of spores and infection. The main disadvantage of this fungus is the increase of mortality of Whitefly parasites in glasshouses. It is only used commercially, with specific formulations in Europe (Mahr *et al.*, 2001).

Paecilomyces fumosoroseus is also used for biological control. This fungus can infect all stages of the Whiteflies, and it also used on thrips and aphids. Although *P. fumosoroseus* is most effective against Whitefly nymphs, this requires reapplication, and also almost 90% humidity for infection. *P. fumosoroseus* is utilized commercially in Europe but it was studied only on ornamentals (Mahr *et al.*, 2001).

4. Conclusion

Biological control has been carried out by several methods in glasshouses. Natural enemies (parasitoids and predators) and pathogens (fungi) are commonly used for the biological control of the Glasshouse Whiteflies.

Although the pest management industry is dominated by chemical insecticides, biological control has secured a place in pest management. The identification and release of natural enemies has been developing for 40 years (Bale *et al.*, 2008). IPM (Integrated Pest Management) is used on the glasshouse vegetable crops. The aims of IPM are to reduce the pressure of the chemical control and to increase the use of other alternative methods used together, for example biological control, host plant resistance, climate control and cultural control (van Lenteren, 2000). Thanks to IPM commercial biological control has increased such that for 2000 show that in Europe there were 26 natural enemy producers, with 65 producers worldwide (van Lenteren, 2000).

The Glasshouse Whitefly causes reduction in product quality of products, economic loss in glasshouses production, and therefore *Encarsia formosa*, one of the most effective natural enemies for the biological control of the Glasshouse Whitefly, is commonly used. *Encarsia formosa* is commercially used throughout the entire world as an alternative to chemical control due to the fact that this parasitoid is more effective in glasshouse crops.

Thanks to development of various biological control agents, glasshouse production will be properly sustained without chemical pesticides in near future, and this situation will increase the rate of pesticide-free food in sustainable glasshouse production (van Lenteren, 2000).

3. Materials and Methods

3.1 Tomato and Cucumber Plants

Forty-eight tomato (36) and cucumber (12) plants were sown during the experiment. Two tomato varieties (Moneymaker and Alicante) and one cucumber variety (Telegraph Improved) were used in the experiment.

Seeds were sown in pots in a glasshouse in the School of Biology. Prior to experiments, the plants were transferred to a growth room (24 °C 18:6 L:D). Perforated plastic bags (bread bags) were used to protect individual plants from other insects. The plants were watered regularly.

3.2 The Glasshouse Whitefly (*Trialeurodes vaporariorum*)

The Glasshouse Whitefly were sourced from a culture at Newcastle University. Whitefly Adults were maintained on grown aubergine plants in a mesh cage in a growth room and the plants were watered regularly. The Whitefly culture comprised approximately 200 Glasshouse Whitefly adults. The adults were transferred to the experiment plants using a suction device (pooter). After transferring the adults, the infested tomato and cucumber plants were put in the growth room, and each covered with a plastic bag.

3.3 Biological Control Agent (*Encarsia formosa*)

The parasitic wasps (*Encarsia formosa*) used for this experiment were ordered via www.ladybirdplantcare.co.uk. The commercial name of these products is **Bioline (Syngenta) and Encsure fc (bcp CERTIS)**. The parasitoid cards include the pupae of *Encarsia formosa* with each card having approximately 100 parasitoid pupae. Each treatment plant used 1 card for the experiment, and therefore 24 cards were used during the investigation. The parasitoid pupae were stuck to the cards, and the cards were hung in the middle of the plants for the proper spread of the parasitoids.

Cards must be protected from direct sunlight during storage, as direct sunlight affects the efficiency of the parasitoid cards. Fresh Parasitoid cards must be used to be fully effective. The *E.formosa* cards should remain on the tomato and cucumber plants until the black

parasitized egg is seen under the leaves. The minimum temperature is 18°C for the activity of the parasitoid, so the temperature of the growth room must be the higher than 18°C (temperature remained between 20°C and 24°C during this process). At the end of this process, cards were removed from the tomato and cucumber plants in order to measure the efficiency of the parasitoid cards.

3.4 The Design of the Experiment

Six tomato and six cucumber plants were used for each experiment. Three plants were used for the control, and three plants were used for the treatment. At the beginning of the process, Glasshouse Whiteflies were transferred from aubergine plants to the tomato and cucumber plants. Six Whitefly adults were transferred to plants, and the plants were bagged and placed in the growth room. These plants remained in the growth room (for approximately 24 hours) for oviposition.

After 24 hours, Whiteflies were removed from control and treatment plant, and returned to the Whitefly culture for use in another experiment. The plants with Whitefly eggs were left for approximately 16 days until the Whitefly nymphs reached third nymphal instar. This is the most suitable age for the use of the parasitoid in the control of Glasshouse Whitefly (*Trialeurodes vaporariorum*). One parasitoid card was used for each treated plant.

Treatment was designed as below:

Moneymaker (tomato) + six whitefly adult + *Encarsia formosa*

Alicante (tomato) + six whitefly adult + *Encarsia formosa*

Telegraph Improved (cucumber) + six whitefly adult + *Encarsia formosa*

Control:

Moneymaker (tomato) + six whitefly adult

Alicante (tomato) + six whitefly adult

Telegraph Improved (cucumber) + six whitefly adult

Table: 3. 1The Experimental Design

	Experiment 1		Experiment 2		Experiment 3	
	Treatment	Control	Treatment	Control	Treatment	Control
ALICANTE (tomato)	T3	T2	T1	T4	T1	T2
	T4	T5	T2	T5	T5	T3
	T6	T1	T3	T6	T6	T6
MONEYMAKER (tomato)	T3	T1	T1	T4	T1	T4
	T5	T2	T2	T5	T2	T5
	T6	T4	T3	T6	T3	T6
TELEGRAPH IMPROVED (cucumber)	C3	C1	-	-	C1	C3
	C4	C2	-	-	C2	C4
	-	C5	-	-	C5	C6
	-	-	-	-	C7	-

Table 3.1 shows the general structure of the design of the experiment. In the table, “T” is used to indicate the tomato, and “C” is used to indicate the cucumber. Three experiments were carried out during the course of the investigation. Forty-eight different results were obtained for three experiments (24 for treatment, 24 for control).

3.5 The Collection of Data

The process of data collection began with introduction of the Glasshouse Whiteflies. Following oviposition, Whitefly eggs were counted for each control and treatment plant using a magnifier and stereomicroscope.

The next stage involved counting parasitized nymphs. The whitefly nymphs turn from green to black after parasitism. The magnifier or stereomicroscope was used to count parasitized and unparasitized Whitefly nymphs.

3.6 The Analysis of Data

Microsoft Excel 2013 and IBM SPSS Statistic 21 were used for data analysis. Firstly, data was analysed using MS Excel 2013. The graphs were obtained with the help of Excel 2013. However, the main results were obtained as a result of statistical analysis using SPSS 21. The effectiveness of parasitoid cards between three varieties was assessed using descriptive statistical tests. Normality tests were initially applied, and One-Way ANOVA and Tukey (Post-hoc) tests were applied to analyse the data using IBM SPSS Statistic 21 programme. In addition, independent sample t-test were used in determining significant differences between treatment and control plants in terms of total number of eggs. The results of the statistical analysis are attached as Appendix at the end of the dissertation. The background information about statistical test were obtained from Kirk (2013) and Sheng (2008).

3.6 Limitations

The basic of the project plan was designed according to the experiment. The project was affected by certain limiting factors, which may have affected the final expected results.

The project suffered from several limitations. For example, as the length of plants varied for each experiment, it was difficult to obtain similar results. Physical damage is another important issue for plants. Plants can be easily damaged before the bagging process, and other unexpected insects might damage experiment plants until the bagging process has been completed. This may affect results in terms of target insects and plants.

Another important limitation is the escape and death of the Glasshouse Whiteflies during the transferring process. The suction device may kill the Whitefly during transfer, and also Whiteflies can escape from plastic bags. If the number of the transferred Glasshouse Whitefly is not same for each plant, this can affect the accuracy of results in the project.

Limited time factor is also a significant limitation for the project, as the waiting period is not adequate in order to realise the full effectiveness of the parasitoids. The parasitoid cards remained on the plants for only 12 days. Unfortunately, data collection must be stopped after 12 days, in order to assess the results.

The above mentioned factors, therefore, affected the accuracy of results during the experiment, and these results could have had unexpected effects on the targets of the project unexpectedly. However, we endeavoured to reduce the effects of these limitations before starting statistical analysis. Figure 3.1 explains the important stages of the experiment during the investigation.



whitefly infection



using parasitoid cards



counting whitefly eggs



counting parasitised eggs

Figure: 3. 1 Important stages in the experiment

4. Results

This investigation was carried out to determine the effectiveness of the *Encarsia formosa* in the control of Glasshouse Whitefly, *Trialeurodes vaporariorum*. Control and Treatment plant data were analysed using descriptive statistics. First of all, the laid eggs were assessed between control and treatment plants. In addition the number of total eggs were assessed between three varieties. The number of parasitized and unparasitized eggs were assessed with statistical analysis. Finally, the percentage of parasitism and unparasitism were assessed between three varieties. The statistical significance were measured for the interpretation of results.

4.1 Total egg count

The mean numbers of the total egg counts were initially calculated in respect of the control and treatment plants. There is no significant difference ($F_{2,088}$, $p > 0.05$) between control and treatment plants with regard to egg-laying under leaves [Treatment: 22.58 and Control: 22.25]. This demonstrates that there was no difference in the number of whitefly eggs in the treatment and control plants. This result was expected during the experiment because equal number of the whitefly adults were introduced in both the control and treatment plants. The Independent sample t-test was applied in order to determine differences between the treatment and control plants (Appendix).

The mean number of total eggs were calculated in respect of three varieties separately. According to statistical results, there was significant difference ($F_{4,036}$, $p < 0.05$) between Moneymaker, Alicante, and Cucumber in relation to total egg count [Moneymaker: 22.58 Alicante: 21.17 Cucumber: 24.50]. Tukey HSD test was applied in order to determine difference within varieties (Appendix 1). Significant difference was determined between Alicante and Cucumber in terms of laying eggs. No difference was identified between Moneymaker-Alicante and Moneymaker-Cucumber. One way ANOVA and Tukey HSD tests were applied for finding significant difference within varieties in terms of laid eggs (Appendix).

4.2 Parasitism

An assessment of the number of parasitized nymphs was carried out in order to determine differences between Moneymaker, Alicante, and Cucumber. There was no significant difference ($F_{2,024}$, $p > 0.05$) between parasitized nymphs between varieties [Moneymaker: 15.33 Alicante: 13.56 and Cucumber: 16.17]. The number of unparasitized nymphs were assessed for varieties. There was no significant differences ($F_{2,972}$, $p > 0.05$) between Moneymaker, Alicante, and Cucumber with regard to the number of unparasitized nymphs [Moneymaker: 7.56 Alicante: 6.44 Cucumber: 9.83]. One way Anova was applied to identify differences between three varieties (Appendix).

According to above results, the number of parasitized nymphs was higher than unparasitized nymphs. The main reason of the high number of parasitized nymphs was the length of time the parasitoid cards remained in place. The cards were placed on plants for approximately 12 days, and this had positive effect in terms of parasitized nymphs. But, there is no statistical difference for parasitized nymphs between varieties and there is no significant difference for unparasitized nymphs between varieties as well.

The parasitism rate were assessed to determine difference between varieties. There was no significant difference ($F_{0,587}$, $p > 0.05$) between Moneymaker, Alicante, and Cucumber in terms of rate of parasitism [Moneymaker: 67% Alicante: 67% Cucumber: 62%]. The rate of parasitism was almost 70%, there was no fluctuations on parasitism rate during the experiment. One way ANOVA test was applied for assessing three varieties (Appendix).

The unparasitism rate were calculated for analysis. There were no significant differences ($F_{0,587}$, $p > 0.05$) between Moneymaker, Alicante and Cucumber in terms of the rate of unparasitism [Moneymaker: 32% Alicante: 32% Cucumber: 37%]. The low percentage of the unparasitism was the expected results in terms of the duration of the experiment. One way Anova was applied to identify differences between three varieties (Appendix).

The ideal duration of parasitoid cards was identified as being between 2-3 weeks for plants and the parasitism rate was recorded as 90% (BCP CERTIS, 2014), (Syngenta, 2014). This experiment was carried out with shorter period than recommended in the technical information. Although the rate of parasitism was lower than 90% in the experiment's results, it serves to provide evidence for the success of the *Encarsia formosa* in controlling the Glasshouse whitefly (*Trialeurodes vaporariorum*) on tomato and cucumber.

Table 4.1 shows the data collected during the experiment. Six categories were recorded for analysis. Three different varieties (Moneymaker, Alicante, and Cucumber) were assessed during the experiment. The total number eggs under the leaves was recorded, as well as the number of parasitized and unparasitized eggs. Percentages of parasitism and unparasitism were calculated using MS Excel 2013. The average values were also calculated for the statistical analysis.

Figure 4.1 shows the results of the experiment for three varieties. The number of total eggs, as well as the numbers of parasitized and unparasitized eggs are given in below chart. This chart and data were used to help interpret the detailed information and the percentage of parasitism between Moneymaker, Alicante, and Cucumber.

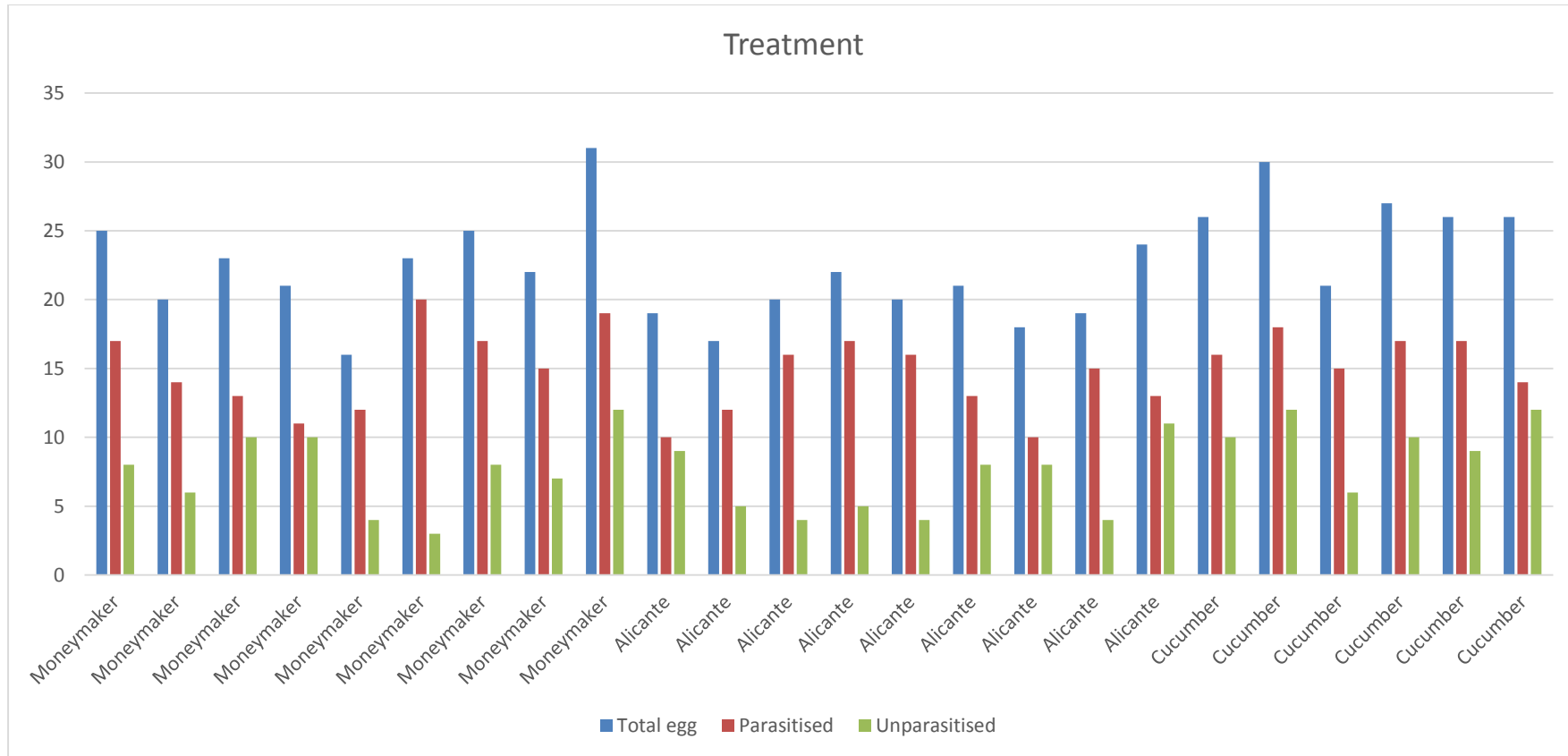


Figure: 4. 1 The Result of Experiment for Treatment Plant

Table: 4. 1 The Data of the Treatment Plants

Variety	Total egg	Parasitized	Unparasitized	(%) Parasitism	(%) Unparasitism
MoneyMaker	25	17	8	68	32
MoneyMaker	20	14	6	70	30
MoneyMaker	23	13	10	57	43
MoneyMaker	21	11	10	52	48
MoneyMaker	16	12	4	75	25
MoneyMaker	23	20	3	87	13
MoneyMaker	25	17	8	68	32
MoneyMaker	22	15	7	68	32
MoneyMaker	31	19	12	61	39
Alicante	19	10	9	53	47
Alicante	17	12	5	71	29
Alicante	20	16	4	80	20
Alicante	22	17	5	77	23
Alicante	20	16	4	80	20
Alicante	21	13	8	62	38
Alicante	18	10	8	56	44
Alicante	19	15	4	79	21
Alicante	24	13	11	54	46
Cucumber	26	16	10	62	38
Cucumber	30	18	12	60	40
Cucumber	21	15	6	71	29
Cucumber	27	17	10	63	37
Cucumber	26	17	9	65	35
Cucumber	26	14	12	54	46
Average	22, 58	14, 88	7, 71	66%	34%

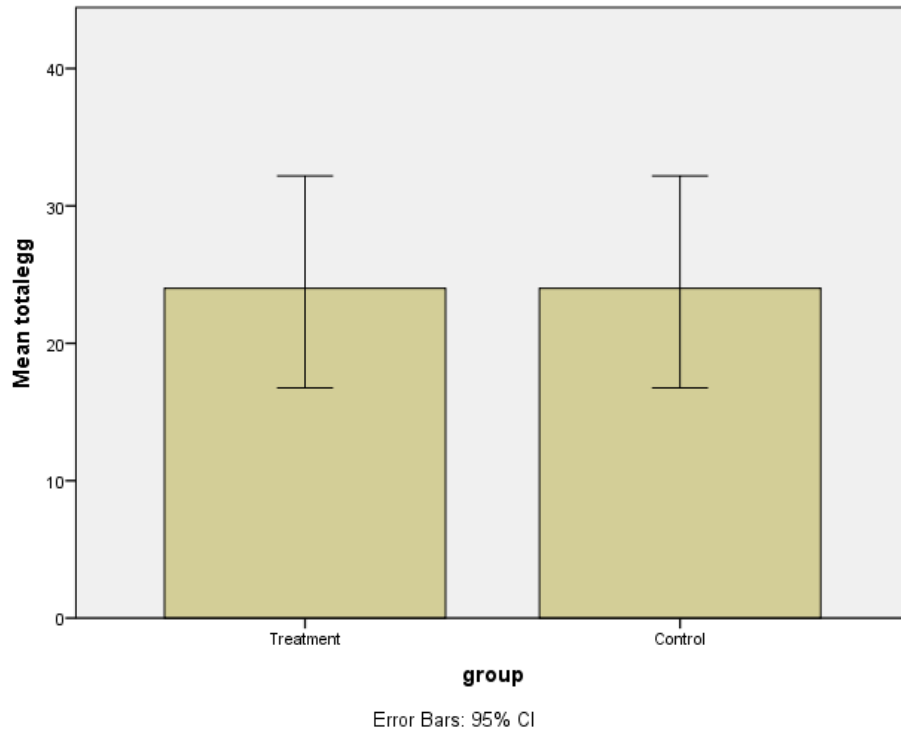


Figure: 4. 2 The Mean Number of Eggs

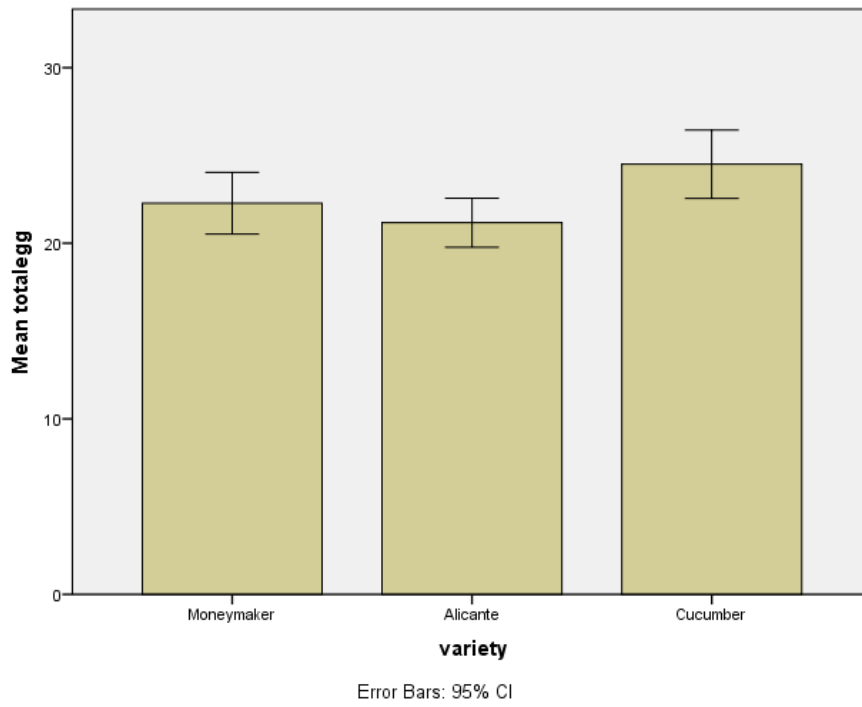


Figure: 4. 3 The Mean Number of Eggs between three varieties

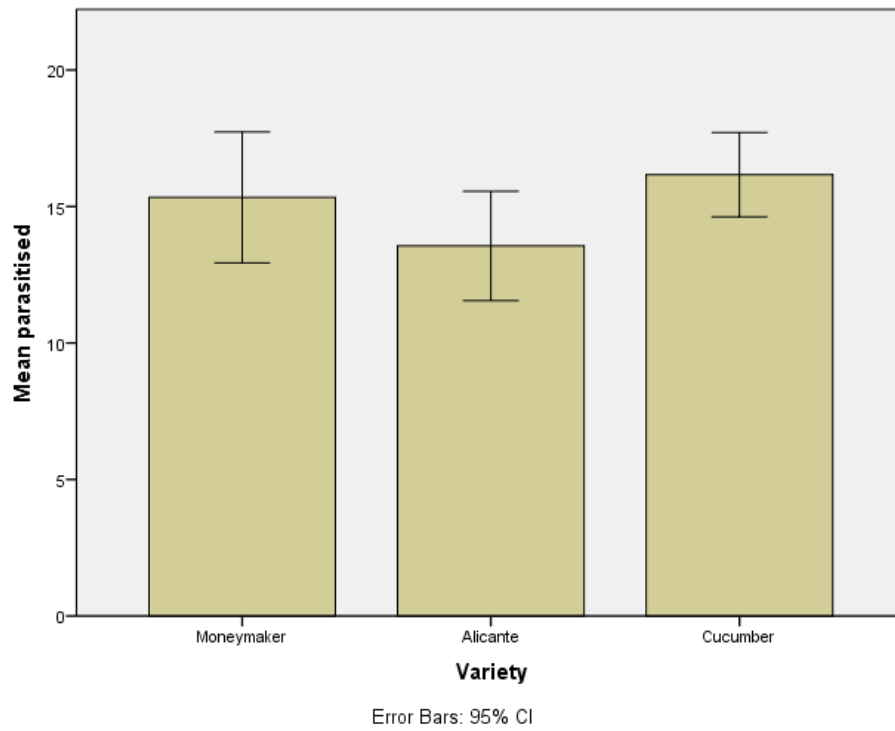


Figure: 4. 4 The Mean Number of Parasitized Eggs

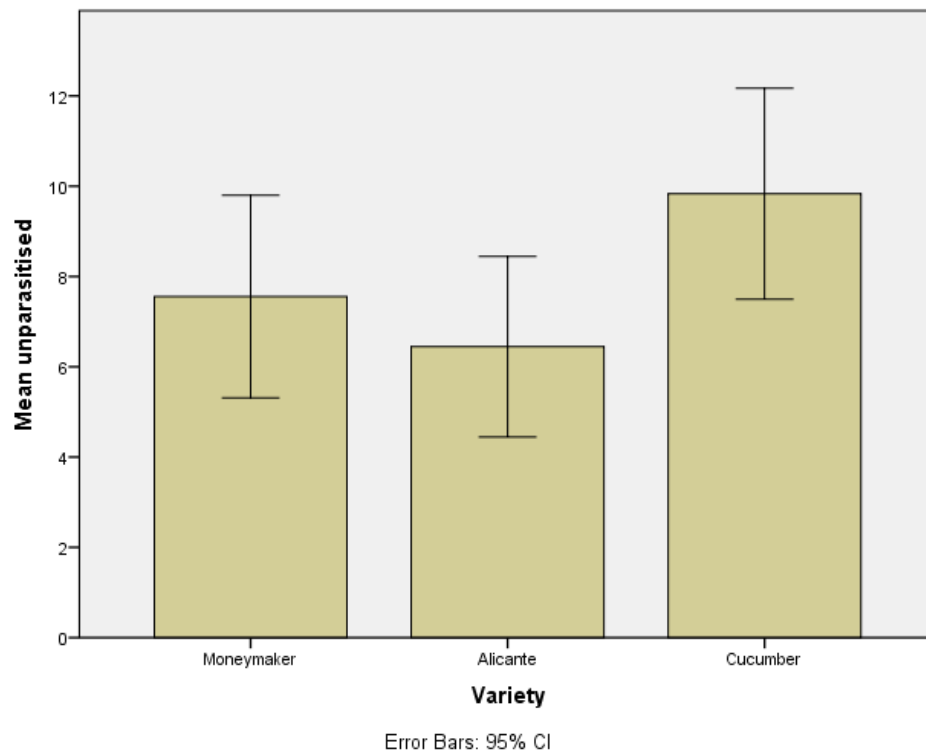


Figure: 4. 5 The Mean Number of Unparasitized eggs

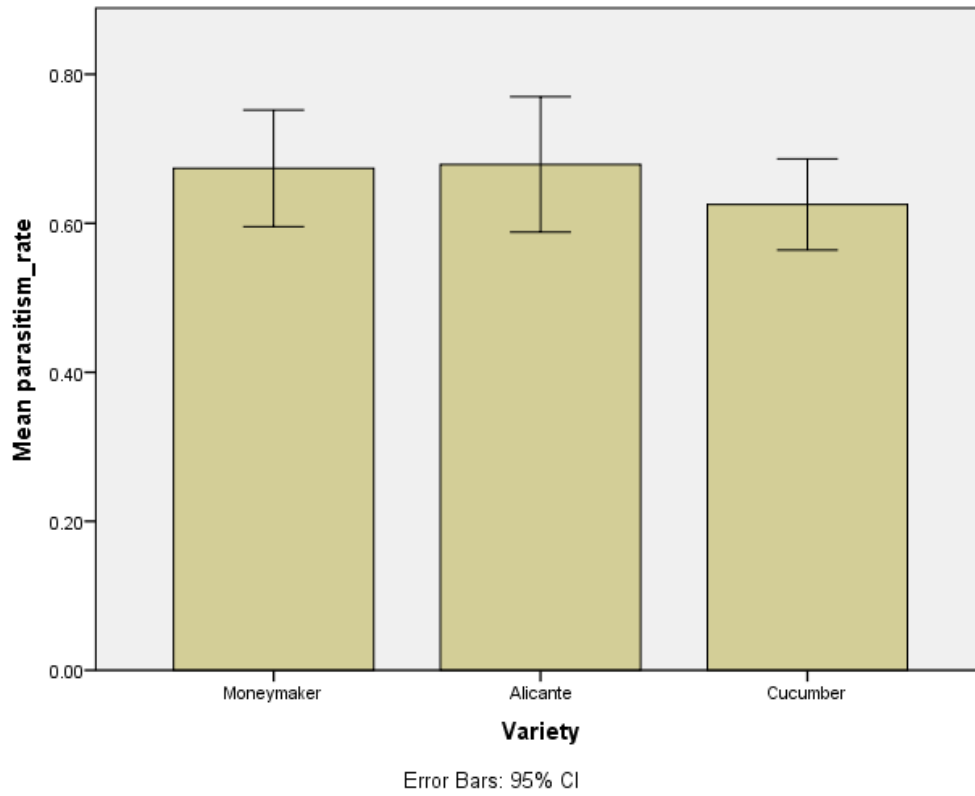


Figure: 4. 6 The Mean Percentage of Parasitism

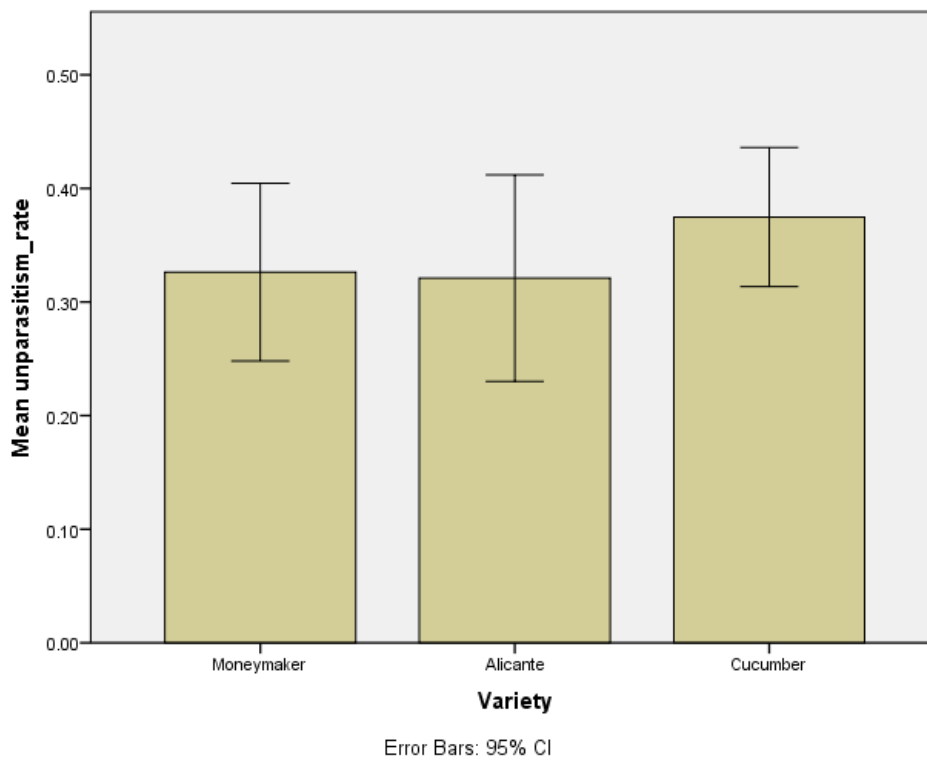


Figure: 4.7 The Mean Percentage of Unparasitism

The mean values for all varieties were calculated with IBM SPSS Statistic programme separately, and the graphics were made using SPSS as well. Figure 4.2 shows the average values of the total eggs for treatment and control plants. Figure 4.3 shows the average values of the total eggs for Moneymaker, Alicante, and Cucumber separately. Figure 4.4 and figure 4.5 demonstrate the mean values of the parasitized and unparasitized eggs with error bars. Figure 4.6 and figure 4.7 indicate the mean values of parasitism and unparasitism rate with error bars. The results of the statistical tests are given in the Appendix at the end of this report. The effectiveness of parasitism and unparasitism are discussed for Moneymaker, Alicante, and Cucumber in the next chapter.

5. Discussion

The inoculative releases of natural enemies is one of the most successful strategies in the biological control. Immigrations of pest populations cause unexpected results in glasshouses. Especially, *Encarsia formosa* is used for periodic whitefly invasions in glasshouses of Southern Europe. Periodic whitefly invasions sometimes affect the effectiveness of *Encarsia formosa* negatively (Castañé *et al.*, 2004). Although predators and entomopathogenic fungi are used in the control of Glasshouse whitefly, the introductions of the natural enemies is one of the most economically efficient method (van Lenteren and Martin, 1999). The importance of *Encarsia formosa* has been proven to have a notable success against Glasshouse Whitefly in glasshouses. The population of whiteflies have decreased with the inoculative release of *Encarsia formosa* on tomatoes (Hoddle *et al.*, 1998). *Encarsia formosa* is used on key glasshouse crops such as tomato and cucumber. In addition, *Encarsia formosa* can be integrated with other control methods, such as cultural practices and pesticides, or other natural enemies (Hoddle *et al.*, 1998).

This research has set out to prove the effectiveness of the *Encarsia formosa* against Glasshouse Whitefly. The effectiveness of parasitoid cards is demonstrated as being approximately 90% in the technical information sheet (Syngenta, 2014). The result of the experiment was about 70% for three varieties.

This section include the comparison of three varieties (Moneymaker, Alicante, and Cucumber) with regard to effectiveness of the *Encarsia formosa*. Section 5.1 discusses the effects of host plant on eggs laid by the Glasshouse Whitefly. Host plant suitability for Glasshouse Whitefly will be discussed in this section. Section 5.2 discusses parasitism potential of *Encarsia formosa* with different properties (Such as temperature and leaf structure). The number of parasitized and unparasitized eggs will be discussed in the section 5.3. The possible effects of different varieties on the number of parasitized and unparasitized eggs will be compared with other studies. In addition, the difference between three varieties will be discussed in terms of the percentage of parasitism and unparasitism. Section 5.4 include the success of biological control. The last section provides future recommendations for the use of *Encarsia formosa* in glasshouses.

5.1 Relationship between Host Plant and Laid Eggs

Whitefly- plant relationship is one of the most important factors in terms of effectiveness of parasitism, since the incompatibility between host plant and glasshouse whitefly can be useful in methods of control. Host plant can be developed resistance to glasshouse whitefly (Thomas, 1993). According to results of this experiment, the number of laid eggs did not vary between control and treatment plants, but there is variation detected between three varieties. Previous studies show that the development of the Glasshouse Whitefly was easily affected by quality of host plant (van Roermund *et al.*, 1997) and this caused the variation between laid eggs and host plants in the experiment. According to another previous study, cucumber was identified as a more suitable host plant than tomatoes for Glasshouse Whitefly (van Lenteren *et al.*, 1996).

The experiment result shows that a similar number of eggs had been laid under the leaves of the Moneymaker and Alicante; statistical significance was not detected between two varieties [Moneymaker: 22.28 Alicante: 21.17]. According to previous studies, the proportion of oviposition did not vary too much between different tomato varieties. The effect of genotypes did not affect the percentage of oviposition between tomato varieties significantly (van Roermund *et al.*, 1997). The experiment results are in line with those of Van Roermund *et al.* (1997). The mean number of total egg count are similar for both. Different tomato varieties did not affect the oviposition rate in this experiment.

Although there is no difference between Moneymaker and Cucumber. The number of laid eggs demonstrates significant difference between Alicante and Cucumber [Alicante: 21.17 Cucumber: 24.50]. Hoddle *et al.* (1998) identified in his study that cucumber is more suitable host plant for development of Glasshouse Whiteflies. In addition tomato was a less suitable host plant for the Glasshouse Whitefly. According to above, cucumber has more suitable conditions for oviposition of Glasshouse whitefly since the egg count was higher than Moneymaker and Alicante in the experiment.

5.2 Parasitism Potential of *Encarsia formosa*

Encarsia formosa is the primary method for biological control of Glasshouse Whitefly, since this parasitoid has been used in glasshouses since 1927. Much research has been carried out on the effectiveness of *Encarsia formosa* in the control of the Glasshouse Whitefly with other natural enemies. According to these studies, glasshouse environment was identified as the most suitable environment for *Encarsia formosa* (Cooper and Oetting, 1987).

Temperature is one of the important factors for the effectiveness of *E. formosa*. Cooper and Oetting (1987) concluded that the parasitism rate increased in higher temperatures. Lower temperatures have a negative impact on predominance of parasitic wasps. According to Burnett, 24°C is the appropriate temperature for the parasitism. If the temperature falls below 24°C, the population of Glasshouse Whitefly and *E. formosa* have same percentages (Cooper and Oetting, 1987).

The success of the experiment echoed that of Cooper and Oetting, because the temperature remained 24°C during the experiment. The parasitized egg and parasitism rate results showed the success of *E. formosa* in controlling Glasshouse Whitefly at 24°C. The mean parasitism was about 66.36% for this experiment. 14.88 eggs (the mean number of parasitized eggs) were parasitized in 22.42 eggs (the mean number of total eggs).

Leaf structure impacts on parasitoids significantly. Leaf hairiness, in particular, was studied by Sütterlin and van Lenteren (1997). Parasitic wasps search for Whitefly eggs on leaves as they walk, as walking activity is an important factor in oviposition. Sütterlin and van Lenteren (1997) showed that leaf hairiness affected the walking speed of *Encarsia formosa*, but the rate of parasitism was not affected by leaf hairiness. Sütterlin and van Lenteren (1997)'s study compared *Gerbera* and tomato. They found no correlation between leaf hairiness and parasitism in their study. Leaf hairiness did not limit the use of *Encarsia formosa* in the control of Glasshouse whitefly.

The experiment result was in accordance with the findings of Sütterlin and van Lenteren. The average value of the parasitism was around 66, 36%. In addition, each variety (Moneymaker, Alicante, and Cucumber) demonstrated a positive result for parasitism, with the percentage being above 60%. Although tomato and cucumber varieties have hairy leaves, the percentage of parasitism was not negatively affected in the experiment.

5.3 The Quality of Host Plants

There are two main factors for biological control of Glasshouse Whiteflies with *Encarsia formosa*, namely the quality of host plant and natural enemies. Host plant quality is an especially determinative factor since it can easily affect the inoculative release (van Lenteren *et al.*, 1996).

According to previous studies, cucumber is not good host plant for *E. formosa*. Although Glasshouse Whitefly population grows fast on cucumber, parasitism result is insufficient for biological control. The cucumber's characteristics are not suitable for *E. formosa*. The leaves are large and hairy, and the honeydew remains on the leaves for a long time (van Lenteren *et al.*, 1996). Another study showed that the surfaces of cucumber leaves have a negative impact on parasitoid foraging (Hoddle *et al.*, 1998).

Tomato is an important host plant for the biological control of Glasshouse Whiteflies with parasitoids. *Encarsia formosa* was tested in tomato glasshouses in several countries (van Roermund *et al.*, 1997). Although tomato is not suitable host plant for Whitefly development, the leaves of tomatoes are more appropriate in terms of the foraging behaviour of parasitoid. Previous studies investigated the percentage of parasitism on different tomato varieties. According to results, 12 tomato varieties were investigated and there is fewer differences between tomato varieties with regard to parasitism rate (Hoddle *et al.*, 1998). Another study on tomatoes concluded that the proportion of parasitism by *Encarsia formosa* to be in region of 40-70% (van Roermund *et al.*, 1997).

The results of the experiment back up previous studies. For example, the mean number of total eggs was the highest on cucumber in this experiment. [**Money maker: 22.28 Alicante: 21.17 Cucumber: 24.50**]. The cucumber is more suitable than tomatoes in terms of whitefly development. On the other hand, the percentage of parasitism on tomato varieties is higher than cucumber [**Money maker: 67.37% Alicante: 67.90% Cucumber: 62.53%**].

These result's match those of with Hoddle's and van Roermund. The parasitism rate of two tomatoes varieties (Money maker and Alicante) were almost equal in the experiment. In addition the average of parasitism rate was 68% on tomatoes. This result is similar with van Roermund's study on the parasitism rate on tomatoes. The percentage of parasitism on tomatoes was higher than that of cucumber's rate. As it mentioned in Hoddle's study, tomato varieties are more suitable than cucumber in terms of foraging behaviour in this experiment.

5.4 The Success of the Biological Control

Biological control has many benefits on the environment. For example, environmental pollution risks are lower than chemical control, biological control is not time consuming process, and the procedure is completely natural. These findings may be important reason for the development of the mass production of natural enemies. Natural enemies have been evolved using quality control methods, and this study demonstrates significant evidence for the success of biological control using natural enemies. The release of the natural enemies is not an expensive process. In addition, this control method has a positive impact on product quality (van Lenteren, 2000).

IPM is an important method for increasing success of the biological control, and has been used on vegetable crops in particular. For example, biological control and IPM has been used in tomato and cucumber glasshouses since 1980 and is being used currently on other vegetable crops. Vegetables are very tolerant to pest and disease and also chemicals have many side effects to plants. Biological control using natural enemies is environmental-friendly, and pests and plants do not develop any resistance to natural enemies (van Lenteren, 2000).

The greenhouse environment is an important factor for increasing success of the natural enemies. Glasshouses are contained areas, and so provide isolation from the spread of other pests, providing convenient conditions for the release and activity of biological control agents. Natural enemies are introduced on a limited pests, so as to increase the success of the biological control in glasshouses (van Lenteren, 2000).

The result of the experiment are in line with those produced by van Lenteren`s studies, as the experiment was carried out under stable condition; every plant was bagged, only Glasshouse Whitefly were introduced to tomato and cucumber plants, and the conditions of growth room were stable during the experiment. These conditions are important evidence for obtaining successful results at the end of the experiment.

5.5 Future recommendations

The basic aim of this project was to discover effectiveness of the *Encarsia formosa* in the control of Glasshouse Whitefly, *Trialeurodes vaporariorum*, on two different tomato varieties and one cucumber variety. This project was carried out with some limitations, such as limited time and inequality of quality of plant materials.

As mentioned in section 5.3, the parasitism rate is approximately 66%, but this rate could have been increased. The parasitized eggs were counted after 12 days. If the parasitoid cards had remained in place for longer than 12 days, the parasitism rate would have been greater. Another investigations should be carried out on the effectiveness of this natural enemy, and in field experiments, owing to fact that glasshouses are isolated area. The effects of *Encarsia formosa* on native species and non-target species might also be assessed properly with field experiments.

Further recommended for assessing the effectiveness of *Encarsia formosa* is the carrying out future quality control tests. Quality control tests are important for efficiency. Better natural enemies will provide greater product quality, and improved long term storage for natural enemies. These innovations in the area of natural enemies will reduce the costs of biological control (van Lenteren, 2000).

The main focus in terms of quality control needs to be knowledge of natural enemies. Lack of knowledge in this area has led to failures in biological control methods. Before releasing of the natural enemies, all quality test should be done in the laboratory. As the results of this study have shown, the production and release methods of natural enemies should be developed further in order to increase the effectiveness of the biological control programs (van Lenteren, 2000).

Finally, IPM Strategies must be developed to obtain a high efficiency rate in biological control. The integration of other control methods (cultural methods, sticky traps, and biological insecticides) alongside the use of *Encarsia formosa* should be carried out using both glasshouse and field experiments. The field experiments should be done against other pests to determine the effectiveness of *Encarsia formosa* on other plants. Quality control must be applied before production of parasitoids commercially.

Conclusion

The biological control of the Glasshouse Whitefly is an important subject in glasshouses across the world. *Encarsia formosa* is one of the most popular bio-control agents in the control of Glasshouse Whitefly. This natural enemy is also widespread in glasshouses. It has been used in biological control for many years.

The aim of this project was to discover the effectiveness of *Encarsia formosa* against Glasshouse Whitefly, *Trialeurodes vaporariorum*, on three different varieties. Two different tomatoes (Moneymaker, Alicante) and one cucumber (Telegraph Improved) variety were assessed for this project. The parasitism rate was measured for three varieties.

According to experiment results, parasitoid cards remained on plants approximately 12 days. There was no significant difference ($F_{0.587}$, $p > 0.05$) between the three varieties in terms of the effectiveness of *Encarsia formosa*. In addition, there was no difference between two tomato varieties. The parasitism rate was almost similar. A difference was only detected on total number of eggs on treatment plants. Whiteflies laid different number of eggs on Alicante and Cucumber. The results were statistically different ($F_{4.036}$, $p < 0.05$) from each other. However, there was no significant difference between Moneymaker and Cucumber, Moneymaker and Alicante in terms of total eggs on the plants. Generally the effectiveness of *Encarsia formosa* had high percentage of parasitism for three varieties.

This research concludes that, owing to the efficacy rate of *Encarsia formosa*, this is a successful bio-control agent against the Glasshouse Whitefly, *Trialeurodes vaporariorum*, in the glasshouse conditions. The parasitism result for tomatoes and cucumber are almost similar to each other. *Encarsia formosa* can be used effectively against Glasshouse Whitefly in glasshouses.

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Appendix

1. Independent sample t-test between treatment and control plants in terms of total eggs with normality test

Tests of Normality

	group	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
totalegg	Treatment	.117	24	.200*	.971	24	.688
	Control	.107	24	.200*	.960	24	.445

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Group Statistics

	group	N	Mean	Std. Deviation	Std. Error Mean
totalegg	Treatment	24	22.58	3.866	.789
	Control	24	22.25	2.832	.578

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means							
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference		
								Lower	Upper	
Total egg	Equal variances assumed	2.088	.155	.341	46	.735	.333	.978	-1.636	2.303
	Equal variances not assumed			.341	42.165	.735	.333	.978	-1.641	2.307

2. One way ANOVA and Tukey test was applied for total eggs between three varieties with normality test.

Tests of Normality

	variety	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Total egg	Moneymaker	.109	18	.200*	.967	18	.734
	Alicante	.161	18	.200*	.950	18	.424
	Cucumber	.188	12	.200*	.948	12	.609

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Descriptives

totalegg

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Moneymaker	18	22.28	3.528	.832	20.52	24.03	16	31
Alicante	18	21.17	2.813	.663	19.77	22.57	17	28
Cucumber	12	24.50	3.060	.883	22.56	26.44	19	30
Total	48	22.42	3.357	.485	21.44	23.39	16	31

ANOVA

totalegg

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	80.556	2	40.278	4.036	.024
Within Groups	449.111	45	9.980		
Total	529.667	47			

Tukey test

Multiple Comparisons

Dependent Variable: totalegg

	(I) variety	(J) variety	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	Moneymaker	Alicante	1.111	1.053	.547	-1.44	3.66
		Cucumber	-2.222	1.177	.154	-5.08	.63
	Alicante	Moneymaker	-1.111	1.053	.547	-3.66	1.44
		Cucumber	-3.333*	1.177	.019	-6.19	-.48
	Cucumber	Moneymaker	2.222	1.177	.154	-.63	5.08
		Alicante	3.333*	1.177	.019	.48	6.19
Games-Howell	Moneymaker	Alicante	1.111	1.064	.555	-1.50	3.72
		Cucumber	-2.222	1.213	.179	-5.24	.79
	Alicante	Moneymaker	-1.111	1.064	.555	-3.72	1.50
		Cucumber	-3.333*	1.104	.017	-6.11	-.56
	Cucumber	Moneymaker	2.222	1.213	.179	-.79	5.24
		Alicante	3.333*	1.104	.017	.56	6.11

*. The mean difference is significant at the 0.05 level.

3. One way ANOVA was applied for parasitized eggs with normality test

Tests of Normality

	Variety	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
parasitised	Moneymaker	.148	9	.200*	.958	9	.781
	Alicante	.159	9	.200*	.916	9	.364
	Cucumber	.214	6	.200*	.958	6	.804

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Descriptives

parasitised

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Moneymaker	9	15.33	3.122	1.041	12.93	17.73	11	20
Alicante	9	13.56	2.603	.868	11.55	15.56	10	17
Cucumber	6	16.17	1.472	.601	14.62	17.71	14	18
Total	24	14.88	2.724	.556	13.72	16.03	10	20

ANOVA

parasitised

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	27.569	2	13.785	2.024	.157
Within Groups	143.056	21	6.812		
Total	170.625	23			

4. One way ANOVA was applied for unparasitised eggs with normality test

Tests of Normality

	Variety	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
unparasitised	Moneymaker	.132	9	.200*	.969	9	.888
	Alicante	.266	9	.066	.858	9	.091
	Cucumber	.196	6	.200*	.890	6	.316

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Descriptives

unparasitised

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Moneymaker	9	7.56	2.920	.973	5.31	9.80	3	12
Alicante	9	6.44	2.603	.868	4.44	8.45	4	11
Cucumber	6	9.83	2.229	.910	7.49	12.17	6	12
Total	24	7.71	2.866	.585	6.50	8.92	3	12

ANOVA

unparasitised

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	41.681	2	20.840	2.972	.073
Within Groups	147.278	21	7.013		
Total	188.958	23			

5. One way ANOVA was applied for parasitism rate with normality test

Tests of Normality

	Variety	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
parasitism	Moneymaker	.191	9	.200*	.951	9	.702
	Alicante	.230	9	.185	.835	9	.051
	Cucumber	.166	6	.200*	.983	6	.968

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Descriptives

parasitism

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Moneymaker	9	.6737	.10183	.03394	.5954	.7520	.52	.87
Alicante	9	.6790	.11832	.03944	.5880	.7699	.53	.80
Cucumber	6	.6253	.05836	.02383	.5640	.6865	.54	.71
Total	24	.6636	.09865	.02014	.6219	.7052	.52	.87

ANOVA

parasitism

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.012	2	.006	.587	.565
Within Groups	.212	21	.010		
Total	.224	23			

6. One way ANOVA was applied for unparasitism rate with normality test with normality test.

Tests of Normality

	Variety	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
unparasitism	Moneymaker	.191	9	.200*	.951	9	.702
	Alicante	.230	9	.185	.835	9	.051
	Cucumber	.166	6	.200*	.983	6	.968

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Descriptives

unparasitism

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Moneymaker	9	.3263	.10183	.03394	.2480	.4046	.13	.48
Alicante	9	.3210	.11832	.03944	.2301	.4120	.20	.47
Cucumber	6	.3747	.05836	.02383	.3135	.4360	.29	.46
Total	24	.3364	.09865	.02014	.2948	.3781	.13	.48

ANOVA

unparasitism

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