# SPATIAL DISTRIBUTION AND BIOLOGY OF *Gonometa postica* WALKER (LEPIDOPTERA: LASIOCAMPIDAE) WITH REFERENCE TO ITS KEY PARASITOIDS ON *ACACIA* SPECIES IN MWINGI, KENYA

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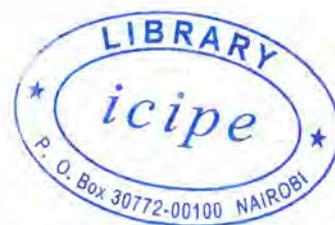
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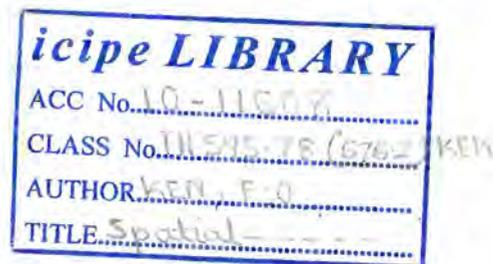
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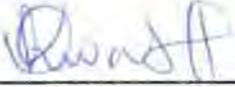
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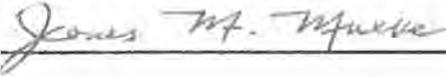
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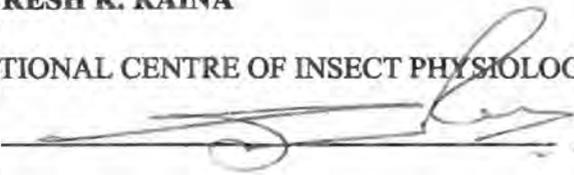
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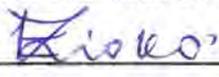
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DEDICATION

This thesis is dedicated to my dear wife, Sheila Dewodo Fening and lovely son and daughter Alexander Misah Fening and Alexandrea Yaa Asantewaa Botuo Fening for coping well with life in my absence for three years.

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To God be the glory for the great things He has done, and surely greater things He will do. I am grateful to the love and continual support of the Fening family that has encouraged me to reach this far.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA:	Analysis of Variance
ARPPIS:	African Regional Postgraduate Programme in Insect Sciences
CBD:	Convention on Biological Diversity
CIP:	Commercial Insects Programme
CIRAD:	Agricultural Research Centre for International Development
CSIRO:	Commonwealth Science and Industrial Research Organization
df:	Degrees of freedom
DRIP:	Dissertation Research Internship Programme
GPS:	Global Positioning System
IBA:	Important Bird Area
ICIPE:	International Centre of Insect Physiology and Ecology
Kg:	Kilogramme
MoU:	Memorandum of Understanding
RH:	Relative Humidity
P:	Probability
PFM:	Participatory Forest Management
SAS:	Statistical Analysis System
S.E.	Standard error
SNK:	Students-Newman-Keuls

ABSTRACT

The African wild silkmoth, *Gonometa postica* Walker produces silk of high quality. A study on the spatial distribution and biology of *G. postica* on host and non-host plants and the parasitism rates and reproductive strategy of its parasitoids was conducted during the long and short rainy seasons in 2006 and 2007. Three sites, each in the Imba and Mumoni forests of Mwingi eastern Kenya, were selected for sampling. One hundred trees of the host plants of *G. postica* were sampled at each site, in addition to the non-host plant species having *G. postica* pupae. In order of decreasing abundance, the host plants in Imba forest were *Acacia tortilis, A. elatior* and *A. nilotica;* and in the Mumoni forest, *A. tortilis, A. nilotica, A. mellifera,* and *A. brevispica.* Host plant species richness did not differ between the two forests but their evenness was significantly higher in Imba than in Mumoni. At Imba, the distribution of *A. tortilis, A. nilotica* and *A. elatior* was clumped while the non-host plants were random. *A. nilotica* and *A. brevispica* were clumped in Mumoni, whereas *A. tortilis, A. mellifera* and the non-host plants were randomly distributed. The distribution of *G. postica* larvae was clumped on all host plants in Imba, except on the non-host plants, where they were randomly distributed. In Mumoni forest, larval distribution was clumped on *A. tortilis* but random on the other host plants. *A. elatior* had significantly more larvae than other host plants in Imba. In Mumoni, *A tortilis* and *A. mellifera* had significantly more larvae, followed by *A. nilotica* and *A. brevispica.* The pupae of *G. postica* were randomly distributed on all host plants in Imba and Mumoni forests. Interestingly, the non-host plants harboured significantly more pupae than the host plants in both forests. Frequently, Imba had a significantly higher abundance of larvae and pupae than Mumoni. Generally, the female moth laid more eggs on the net sleeves, followed by the wooden board, plastic container and the twigs. The developmental periods for egg hatching, larva, pupa and the adult moth lifespan ranged between 11-12, 55-72, 101-126 and 3-10 days, respectively. Larval developmental period and quality of cocoons differed according to the larval food plant, season and site, for those reared in semi-captivity. However, the quality of cocoons was similar on the different larval food plants from the wild habitat, though it varied according to season and site. Larvae reared *on A. elatior* had the shortest developmental period and produced cocoons of the highest quality than those raised on *A. tortilis* and *A. nilotica.* Larval development was generally shorter in the sites and seasons where rainfall was high. Trapping of adult moths revealed that there were more males than females and that two distinct peak periods occurred during a year. Six parasitoids, vis., four hymenopterans and two dipterans, were collected during the study. The most common parasitoids were *Palexorista* sp. (Diptera: Tachinidae) and *Goryphus* sp.(Hymenoptera:Ichneumonidae) with parasitism rate ranging from 1.8 – 32.7 % and 2.2 – 7.5 %, respectively. Parasitism rate varied according to host or non-host plant, season and site. All the parasitoids were found to attack mature larva of *G. postica,* but emerged during the pupal stage of the moth, thus they were regarded as larval-pupal parasitoids and koinobionts. The current study offers baseline information on the spatial distribution, biology and parasitism rates on *G. postica* in relation to its host plants in the two forests of Mwingi. This information would be crucial in the monitoring, sustainable utilization and the conservation of this economically important silkmoth and its host plant species. The data on the bionomics and reproductive strategy of the key parasitoids will be a prerequisite in devising any management programme to boost cocoon production.

CHAPTER ONE

1 GENERAL INTRODUCTION

1.1 Background information

Sericulture is the process of rearing silk-producing insects in captivity or collecting their silk in the field for human use, mainly leading to the production of fabrics (Peigler, 1993). In the world, there are about 400-500 species of silk-producing moths, out of which 8-9 are known to produce silk of commercial value (Dingle *et al.*, 2005). Natural silk is broadly classified as mulberry or domesticated silk from *Bombyx mori* L. (Lepidoptera: Bombycidae), which produces 95-99 % of the silk under commercial use in the world today (Scoble, 1995; Raina, 2000, 2004; Dingle *et al.*, 2005; Raina *et al.*, 2007), and non-mulberry silk (Gongyin and Cui, 1996; Kioko *et al.*, 1999a,b, 2000a,b, 2007; Veldtman *et al.*, 2007a,b; Fening *et al.*, 2008a,b).

The domesticated silkmoth, *B. mori* originated from its wild counterpart, *Bombyx mandarina-moore* by gene duplication and chromosomal fusion mechanism (Botlagunta *et al.*, 2006). Tropical and temperate tasar, eri, Muga and *Anaphe* (Mbahin *et al.*, 2008) are the principal non-mulberry silk; and the others include fagara, Coan, mussel, spider and *Gonometa* silk (Kioko *et al.*, 1999a,b, 2000a,b, 2007; Ngoka *et al.*, 2008; Fening *et al.*, 2008a,b). Wild silkmoths or non-mulberry silkmoths are generally those that are not reared in captivity. Instead, native people collect cocoons from wild populations of the moths. In some cases, some rearing is done, often outdoors with little or no protection of the larvae (Jolly *et al.*, 1979; Peigler, 1993; Dingle *et al.*, 2005; Rai, 2005; Kioko *et al.*, 1999a, b, 2000a, b, 2007).

Despite great efforts by various National and International Agencies, raw silk production has failed to keep up with the steady rising demand. Some of the leading mulberry silk producing countries such as India, Japan and China appear to have reached saturation point, attributable to the acute scarcity of labour and the increasing cost of production. This offers developing countries an opportunity, with the enabling environment (surplus labour, land and ideal climate) to raise their silk production for the developed world market. For this reason, the high quality untapped non-mulberry silk has drawn the attention of silk users (Jolly *et al.*, 1979; Raina *et al.*, 1999, 2000; Kioko *et al.*, 2000a, 2007; Raina, 2000, 2004; Raje, 2005). In addition, the low volume of wild silk production offers an exclusive niche market where scarcity and naturalness is highly valued, leading to a high price for fabrics made from wild silk (Veldtman *et al.*, 2002; Raina, 2000, 2004). In Africa, development of sericulture technology as a rural cottage industry is needed to enhance the income generation potential of the poor-resourced rural communities and to ensure the conservation of the rich biological diversity (Peigler, 1993; Raina *et al.*, 1999, 2000, 2007; McGeoch, 2002; Raina, 2000, 2004; Rodgers, 2005; Salehe, 2005; Kioko *et al.*, 2007; Fening *et al.*, 2008a).

Biodiversity is identified as synonymous with species diversity and is measured by the number of species in an area (species richness) and their evenness or equitability (relative abundance) (Magurran, 1988; Kempton, 2002; Newton, 2008). Biodiversity is the basis of the livelihood and existence of communities living in Africa and in other developing countries (Rodgers, 2005; Salehe, 2005). It provides food, shelter, fuel, medicine, income, furniture, and others. Biodiversity is what gives us resilience, ability to withstand droughts and famine. In the East African setting, it is certain that

without the variability and interdependence of the biodiversity resources, mankind will perish and therefore there is need to conserve them. The current policies and policy instrument on biodiversity conservation are in support of community-based initiatives, since these forest adjacent communities are the people that utilise the biological resources and their destruction due to over-exploitation, or conservation as a result of positive and sustainable utilisation rest upon the community (Salehe, 2005; Fening *et al.*, 2008a).

The Mwingi forest reserves serve as major sources of fuel wood and poles for rural and urban markets in Mwingi. They protect and cool the soil, directly affecting soil fertility and productivity. They also act as store of carbon and are therefore relevant to dealing with climate change. They harbour significant biodiversity resources within a complex of thorn tree (*Acacia, Commiphora*) woodland communities (Kigomo, 2001; Abeele *et al.*, 2005; Fening *et al.*, 2008a). Recently, Mwingi valleys and hills were recognised as an Important Bird Area (IBA), joining 60 other such sites in Kenya (Mulwa *et al.*, 2007). Mwingi District shows a very high prevalence of poverty, which is estimated at 60 per cent with the poor residing in the driest divisions in the district namely Tseikuru, Kyuso, Ngomeni, Nguni and Nuu Divisions (Mwingi District Development Plan, 2002). The introduction of wild silkmoth farming will help alleviate poverty among the rural farming communities adjacent to these forests and also encourage the positive utilisation and conservation of the moths as well as their host plants species and this will help salvage the rapidly disappearing forest (Raina, 2000, 2004; Fening *et al.*, 2008a).

1.2   Problem statement

The real threat to the African flora and fauna is the rapid population growth, which has led to increased demand for agricultural land and fuel wood (Oberprieler, 1995; Kioko *et al.*, 2000a; McGeoch, 2002; Salehe, 2005; Veldtman, 2005). The current dependence on primary production, largely in agriculture to sustain demands for food and income generation to improve the people's living standards is limited and has largely contributed to the rapid dwindling of the continent's rich biodiversity (Oberprieler, 1995; Kioko *et al.*, 1999b, 2000a; Raina and Kioko, 2000; Rahab, 2005; Salehe, 2005). This has also resulted in most farmers having little income (Khamala, 1984; Mkanda, 1992). The population of wild silkmoths in Africa is declining due to deforestation, which robs them of their food plants and the over consumption of silkmoth larvae, which are favoured by some local communities for food (Ashiru, 1988; Munthali and Munghogho, 1992; Peigler, 1994; Oberprieler, 1995; Kioko *et al.*, 1999b; Raina and Kioko, 2000; McGeoch, 2000, 2002; Veldtman, 2005).

Much global attention has been focused on the destruction of tropical rainforest and its consequences, but less attention has been given to the tropical and sub-tropical dry forests and woodlands in Kenya, such as those in Mwingi. Yet these habitats have been degraded and are disappearing as fast or faster, and their loss is likely to have a more severe impact on people living nearby (Kigomo, 2001; Abeele *et al.*, 2005; Fening *et al.*, 2008a). Also in Kenya, wild silkmoth habitats and natural ecosystems such as Kakamega, Arabuko Sokoke and Mwingi forests have suffered severe encroachment as a result of the growing human population and the demand for agricultural land (Kioko *et al.*, 1999b; Rahab, 2005).

In Africa, information on the species of wild silkmoths is scarce (Ngoka *et al.*, 2008); very few studies have been conducted on wild silkmoths and despite their vast numbers; they represent an under-utilised resource in many parts of Africa. This might be the results of local communities not having an understanding of their diversity, biology, ecology, behaviour and host plant diversity, as well as how they can be conserved so as to derive maximum benefits from them. Also very limited literature is available on host plants of the African silkmoth species (Hartland-Rowe, 1992; Oberprieler, 1987; Kioko *et al.*, 1999a,b, 2000a; Raina and Kioko, 2000; Veldtman *et al.*, 2002, Veldtman, 2005; Fening *et al.*, 2008a). Problems associated with wild silkmoth farming such as attack on moths by different species of parasitoids, predators, pests such as birds and diseases also affect the interest of local communities participating in such a venture. A complex of egg, larval and pupal parasitoids have been found to be important in determining population abundance of the different wild silkmoth species (Hartland-Rowe, 1992; Kioko, 1998, 1999a; Ngoka, 2003; Veldtman *et al.*, 2002; Fening *et al.*, 2008b).

1.3   Justification

There is need to introduce economic incentives through wild silkmoth farming that integrate biodiversity conservation with economic development, especially for the rural communities. Recent studies in different African countries suggest that the economic incentives for biodiversity conservation carry an additional advantage of leading to voluntary changes in behaviour rather than forced changes (Child, 1988; Frost, 1991; Mkanda, 1992; Munthali and Munghogho, 1992; Kioko *et al.*, 1999b, 2000a). Wild silk production is an eco-friendly, agro-based venture with a great potential for environmental amelioration, employment generation, artisan's

development and export earnings. With the rich diversity of wild silkmoths recorded in Africa, wild silk farming has the potential to integrate conservation and economic development (Kioko *et al.*, 1999b, 2000a; Raina, 2000; Raina *et al.*, 2000).

In East Africa like elsewhere in the world, there is an increasing concern for biodiversity and its sustainable utilisation and conservation. Since some solution lies in introducing economic incentives that integrate conservation with the economic development of the people, a need exists to document some of the biological resources that can be utilised as models for both conservation and income generation. The introduction of wild silk farming in East Africa and Kenya in particular may offer an important economic incentive to farmers, not only for monetary gains from the sale of wild silk, but the enterprise will also enhance the conservation of the wild silkmoth species and their host plant species.

For successful utilisation of these species of wild silkmoths, further studies on the abundance, spatial distribution, biology, ecology and population dynamics on various host plant species in relation to the prevailing climatic conditions are needed. It is also important to identify the parasitoids, predators and other natural enemies of these silk moths so that their regulatory effects can be deliberately reduced (Kioko *et al.*, 1999a, 2000a; Raina and Kioko, 2000; Alam *et al.*, 2000, McGeoch, 2002; Ngoka, 2003; Veldtman *et al.*, 2002; Raina, 2004; Fening *et al.*, 2008b).

Mwingi area has low potential for conventional agriculture, and the local populations augment their agro-pastoralist income from the forest and woodland resources (Kigomo, 2001). Thus, wild silkmoth conservation and utilisation as an income-

generating option can raise the economy of communities within the district and protect the dry forest and also reduce land degradation (Raina, 2000, 2004; Kioko *et al.*, 2007). The information that will be obtained from the current study will be necessary for the long-term conservation of wild silkmoths and provide economic benefit to the communities living adjacent to forests within Mwingi, through the sustainable utilisation of the forest resources (Fening *et al.*, 2008a). This is in agreement with the overall strategy of the ICIPE's Commercial Insects Programme aimed at developing innovative technologies such as sericulture as a rural insect-based micro-enterprise for the resource-poor farming communities of Africa and to create off-farm employment and income generation in harsh agro-ecosystems where food production is marginal and the risk of crop failure is high (Raina *et al.*, 1999; 2007).

1.4   Hypotheses

(i) The spatial distribution of *G. postica* populations vary on different *Acacia* species in Imba and Mumoni forests in Mwingi, eastern Kenya.

(ii) Larvae of *G. postica* feeding on different species of *Acacia* attract different species of parasitoids.

1.5   Objectives

1.5.1   General objective

To study the spatial distribution and biology of *G. postica* on different host and non-host plant species with reference to its key parasitoids to enhance the wild silk production in Mwingi.

1.5.2 Specific objectives

(i) To monitor the spatial distribution of *G. postica*, host and non-host plants diversity in Imba and Mumoni forests of Mwingi.

(ii) To study the biology of *G. postica* on different *Acacia* species in Imba and Mumoni forests.

(iii) To explore the diversity of parasitoids and host-parasitoid interaction in the wild.

(iv) To determine the developmental cycle of key parasitoids and their reproductive strategy.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Wild silkmoth diversity

The distribution of some of the world wild silk fauna has been outlined by both Jolly *et al.* (1979) and Peigler (1993) and about 25 species of wild silkmoths have been exploited for wild silk production, and this exploitation has been mainly by tribal communities as reflected in some of the names of the silks (Peigler, 1993; Raina, 2000; Rai, 2005). For historical, cultural, and economic reasons, India is clearly the foremost country in production of wild silks (eri, Muga and tasar)(Peigler, 1993). Globally, there are several varieties of wild silk (Table 2.1). These include the Asian wild silk (Muga, tasar, fagara, and eri), the European silk (Coan) and the African wild silk (*Anaphe, Gonometa, Argema and Epiphora*) (Peigler, 1993; Kioko *et al.*, 1999a,b, 2000a,b; Mbahin *et al.*, 2008; Ngoka *et al.*, 2008; Fening *et al.*, 2008a).

Table 2.1:   Some commercially important wild silkmoths of the world.

NO.	NAME OF SPECIES	FAMILY	TYPE OF SILK	DISTRIBUTION
1	*Antheraea paphia* Linn.	Saturniidae	Tropical Tasar	India
2	*Antheraea mylitta* Drury	Saturniidae	Tropical Tasar	India
3	*Antheraea pernyi* G & M	Saturniidae	Temp. Tasar	China, India
4	*Antheraea Yamamai* G & M	Saturniidae	Temp. Tasar	Japan
5	*Antheraea roylei* Moore	Saturniidae	Temp. Tasar	India, China
6	*Antheraea assamensis* Helfer	Saturniidae	Muga	India
7	*Argema mimosae Bsd.*	Saturniidae	Argema	Kenya, Botswana, South Africa, Angola,
8	*Samia ricini* Donovan	Saturniidae	Eri	India, China
9	*Samia Cynthia* Drury	Saturniidae	Eri	India, China
10	*Anaphe vanata* Butler	Notodontidae	Anaphe	Nigeria
11	*Anaphe infracta* Wals.	Notodontidae	Anaphe	Nigeria
12	*Anaphe reticulate* Walker	Notodontidae	Anaphe	Uganda
13	*Anaphe panda* Boisduval	Notodontidae	Anaphe	Zaire, Togo, Kenya
14	*Epanaphe molonei Druce*	Notodontidae	Anaphe	Nigeria
15	*Epanaphe carteri* Walsingham	Notodontidae	Anaphe	Cameroon
16	*Epanaphe vuilleti* Joan	Notodontidae	Anaphe	Cameroon
17	*Epiphora mythimnia* Westwood	Saturniidae	Epiphora	South/central Africa, Kenya,
18	*Attacus atlas* Linn.	Saturniidae	Fagara	India, China
19	*Attacus cramer* Fldr	Saturniidae	Fagara	India, China
20	*Attacus edwardsi* White	Saturniidae	Fagara	India, China
21	*Attacus doherteyi* Roth	Saturniidae	Fagara	India, China
22	*Attacus standingeri* Roth	Saturniidae	Fagara	India, China
23	*Pachypasa otus* Drury	Lasiocampidae	Coan	Italy, Greece
24	*Pachypasa lineosa* Vill	Lasiocampidae	Coan	Italy, Greece
25	*Gonometa postica* Walker	Lasiocampidae	Gonometa	South Africa, Kenya
26	*Gonometa rufobrunnea* Auri.	Lasiocampidae	Gonometa	South Africa

Source: Jolly *et al.*, 1979; van den Berg, 1990; Hitchcock and John, 1992; Peigler, 1993; Nayak, 1999; Kioko *et al.*, 2000; Raina, 2004; Raina *et al.*, 2007; Ngoka *et al.*, 2008; Mbahin *et al.*, 2008; Fening *et al.*, 2008a.

2.1.1 Muga silk

Antheraea assamensis (Westwood) (Saturniidae) is the source of Muga silk, a coarse golden brown or amber-coloured silk (Peigler, 1993, 1994; Akai, 2000). The word Muga is derived from ancient Sanskrit word meaning amber. Muga silk is only produced in the Assam region of northeastern India, and its production may date back
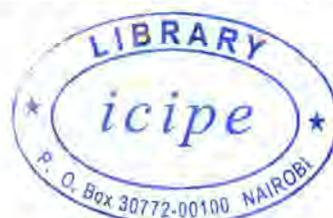
to 1662 B.C. or earlier. The main tribes involved in mugaculture are the Ahoms, Garos, Rabhas, and Kacharis. The larvae feed primarily on plants in the Lauraceae (e.g. *Cinnamomum obtusifolium* Nees), but also on certain Magnoliaceae (e.g. *Magnolia pterocarpa* Roxb.). Varieties of Muga silk include the white chapa or champa silk worn by Ahom nobles and kings of Assam in earlier times. The light-brown cocoon is easily reeled, and the fabric is durable and strong. During the nineteenth century and before, Muga silk was generally used for clothing by the middle classes of Assam, but in recent times it has been priced so high as to be out of reach of the average person. The fabric is expensive, because of the fondness of Indian women for muga silk saris (Akai, 2000). In the past and today, almost all was and is used locally, leaving virtually none for export to other parts of India or outside of India. Today the reeling and weaving of Muga fabric is done on a large scale almost as a monopoly in the Assamese village of Sualkuchi. Some authors refer to Muga cloth as "the Pride of India" (Peigler, 1993).

2.1.2 Tasar silk

Two categories of tasar silk are being raised on a large scale in India, namely the tropical tasar and temperate tasar. The word tasar is probably derived from the Sanskrit word trasara or tassara, meaning a shuttle, and this silk culture is said to date back to 1590 B. C. in India. The tropical tasar industry is based on *Antheraea paphia* (L.), commonly referred to in literature by the junior synonym *A. mylitta* (Drury). There are more than 25 "eco-races" in cultivation in various districts and on different host plants (e.g. *Terminalia tomentosa* Wight and Arn. (Combretaceae) and *Shorea robusta* Roxb. (Dipterocarpaceae). Up to the beginning of this century, most cocoons

were gathered in the wild, but today many cultures are "seeded" on trees outdoors by placing eggs secured from captive moths on them (Peigler, 1993).

Larvae are given some aid by deterring predaceous birds, killing arthropod predators, and other natural enemies. The huge cocoon, which is about the size of a hen's egg, suggests a long history of artificial selection. The fabrics vary considerably in colour and texture, depending on whether the silk was reeled or spun, how much it was dyed or bleached, and whether the weft and warp threads are the same or different. A common yellowish form is glossy and golden and is often made into saris worn by Indian women. Unreelable cocoons are boiled and the silk spun into thread by pulling loose silk from the cocoons and twisting it across a clay pot or one's thigh; known as *ghicha* spinning. Unlike Muga and eri silk that are consumed entirely domestically, India exports tasar silk finished products (such as saris, scarves, neckties, and other clothing) to foreign countries, particularly United States, Germany, and Japan since the 1960s, total hundreds of thousands of dollars annually (Peigler, 1993; Nayak, 1999).

The temperate tasar is reared on oak in the Himalayan belt from Jammu and Kashmir to Arunachal Pradesh. It is a product of a hybrid that was developed in the 1960s and widely introduced and exploited in the 1970s and 1980s. The hybrid was produced by crossing the native Himalayan *Antheraea roylei* Moore with the Chinese oak silk moth (Chinese tussah) *A. pernyi* (Guérin-Méneville) (Saturnidae). The hybrid has been dubbed *Antheraea proylei* Jolly, but this name has no standing in zoological nomenclature (Peigler, 1993). The temperate tasar has created a new opportunity for many tribes in the Himalayas to become involved in sericulture, makes use of a

natural abundance of oaks, and has favourably impacted the national economy of India. Several oak species in the foothills and mountains are used as host plants, the commonest being *Quercus lanuginosa* D. Don. In China, studies are underway to develop uses and markets for by-products of tussah sericulture in medicine, health foods, cosmetics, and for biocontrol, this last being the use of eggs of the moth for mass-rearing of *Trichogramma* parasitoids to combat forest pests (Peigler, 1993).

The Japanese oak silk moth is called *Antheraea yamamai* (Guérin-Méneville) (Saturnidae). The name comes from the Japanese *yama,* meaning forests or mountains, and *mayu* meaning cocoon, thus roughly translating to wild silkmoths. Today the common name in Japan is *tensan.* The cocoons are green or yellow, depending on how much light the spinning larvae were exposed to, but after degumming the silk is pure white like most varieties of mulberry silk. The higher cost of labour and much greater demand than supply has allowed this oak silk to command exorbitantly high prices in Japan. Additionally, the silk has great cultural and ritualistic significance. Items produced include small tablecloths, neckties, obis (belts), cloths for Buddhist altars, and family crests in frames (Peigler, 1993; Nayak, 1999).

2.1.3 Fagara silk

Probably the most beautiful of all wild silkmoths is the ailanthus silkmoth, commonly called the cynthia moth, *Samia cynthia* (Drury) (Saturniidae). This insect is a native of China, where its cocoons have been used for centuries to produce cloth, sometimes called fagara silk, and the practice continues today to a small degree. The cynthia moth feeds on tree-of-heaven, *Ailanthus altissima* (Miller) Swingle (Simaroubaceae).

The cynthia moth, with compact gray cocoons, was introduced widely in the 1800s in hopes of founding sericulture industries; it still persists as feral populations in Paris, Vienna, northern Italy, and the northeastern United States, but is extinct or nearly so in the locales in Spain, Germany, and Canada (Peigler, 1993).

Attacus atlas (L.) (Saturniidae), known as the atlas moth, is widely distributed in southeastern Asia and belongs to the genus containing the largest moths in the world. The silk is called in various localities fagara, tagore, or ailanthus silk. In Assam the moth is called *kotkari muga*. The large cocoons contain a considerable amount of brown silk, but it is not reelable. It must be made into floss-silk and spun silk yarn, forms that are spun into thread-like cotton. It is likely that *A. atlas* has had occasional significance in certain southeastern Asian countries through the centuries, but minimal usage of silk from this species occurs today (Peigler, 1993).

2.1.4   Eri silk

The domesticated eri silkmoth, *Samia ricini* (Boisduval), is closely related to the cynthia moth, and is used on a larger scale in the Brahmaputra Valley of India, both historically and in the present day. The eri silkworms are usually raised on the big palmate leaves of castor oil plants, *Ricinus communis* L. (Euphorbiaceae). This moth has been domesticated for centuries in India, China, and Japan, and in the last two centuries in Cuba, Uruguay, Egypt, France, and Italy. Larvae are raised in open pans like larvae of the mulberry silkmoth, and this domesticated form also cannot exist on its own in a wild state. It has large, puffy cocoons, reflecting a long history of artificial selection, that come in snow white and brick red forms. Fabrics obtained from eri silkmoths are very durable. This wild silkmoth is regarded as the most

popular in the world, producing cocoons soft to the touch, which are typical of "Hafunuke mayu" (thin-end) cocoon; but their thin-end makes them difficult to reel (Akai, 2000). The cocoons are spun into thread-like cotton, and the weaving is a cottage industry in Assam (Peigler, 1993).

2.1.5 Coan silk

Pachypasa otus (Drury) (Lasiocampidae) was the source of Coan silk much prized by the ancient Greeks and Romans. First recorded by Aristotle in the fourth century B. C., and later described by the Roman naturalist and encyclopedist Pliny the Elder (A. D. 23-79), the silk was sometimes dyed purple and worn by dignitaries in Rome. The insect ranges from southern Italy to southeastern Iran. The caterpillars feed on oak (*Quercus*), cypress (*Cupressus*), and juniper (*Juniperus*). The half-mature larvae over-winter. They are gregarious but do not form a communal nest. Although the accounts of Aristotle and the Elder Pliny leave no doubt that this silk came from a moth native to the island (historians agree that the mulberry silkworm from China could not have been reared at that place and time), a few have advocated that the Coan silk industry was based instead on the much larger and more common *Saturnia pyri* (Denis and Schiffermüller) (Saturniidae). *Saturnia pyri* is well known as peacock moth, and it ranges throughout southern Europe into western Asia. Unlike muga and Indian tasar, which have been found in tombs dating back more than two millennia, no ancient fabrics of Coan silk have survived, so we may never be certain which moth was used (Peigler, 1993).

2.1.6 *Anaphe* silk

The primary wild silkmoths of mainland Africa belong to the genera *Anaphe* and *Epanaphe* (Theumetopoeidae). Species that are used include *E. moloneyi* (Druce), *A. venata* Butler, and *A. infracta* Walsingham, all in Nigeria; *A. reticulata* Walker (= *A. ambrizia* Butler) in Uganda; and *A. panda* (Boisduval) in Zaire, Togo and Kenya (Mbahin *et al.*, 2008). *Epanaphe carteri* Walsingham and *E. vuilleti* Joan are used in Cameroon. Larvae are green or whitish, bear tufts of hair, and are apparently gregarious throughout their life, although one source says that they live separately and then reassemble for pupation. As they mature, they build a reddish brown communal nest on the host tree. Emergence of the adult moth is via a conical projection on the nest. Various trees serve as host plants, including several species of Sterculiaceae. Fabrics obtained from *Anaphe* and *Epanaphe* silk are stronger and more elastic than mulberry silk and have been used in velvet, plush fabrics, neckties, umbrellas, and even balloons. Only the outer covering of the bag nest is used; the actual cocoons within are of little or no value (Peigler, 1993; Kioko *et al.*, 2000; Mbahin *et al.*, 2008). The final fabric of *Anaphe* is highly valued for its special soft feeling and anti-bacterial function (Akai, 2000; Raina *et al.*, 2007).

2.1.7 *Gonometa* silk

Gonometa postica Walker and *G. rufobrunnea* Aurivillius (Lepidoptera: Lasiocampidae) are two indigenous South African moth species that produce high-quality silk, rivaling that of the domesticated silkmoth, *B. mori*. Although the fibres require specialised technology for processing, they are thicker than those of the domestic silkmoth, but finer than those of other wild silkmoth species. They have a natural gold colour and dye readily. The cocoons of both species are thus considered a

valuable natural resource (Hartland-Rowe, 1992; Freddi *et al.*, 1993; Raina, 2000; Kioko *et al.*, 2000a; McGeoch, 2002; Veldtman *et al.*, 2002; Ngoka *et al.*, 2008). The president of Botswana boasts of a national flag made from his country's native *Gonometa* silk (Peigler, 1993). Recently, ICIPE has developed the reeling technology of *Gonometa* silk using the paddle reeling machine (Raina *et al.*, 2000; Ngoka, 2003). Single cocoon reeling data indicated that 2,325 female cocoons and 4,762 male cocoons were required for one Kg of raw silk (Raina, 2000). Currently, a Memorandum of Understanding (MoU) was signed between Oxford University and ICIPE to develop tendons for medical use using wild silk as a template (MoU, ICIPE and Oxford University).

The potential of the African indigenous species for wild silk production has been documented in Uganda (Gowdey, 1913), Nigeria (Ashiru, 1988), Botswana (Hartland-Rowe, 1992) and Zimbabwe (Chikwenhere, 1992). Earlier, Schultze (1914) had noted that the African species of silkmoths produced strong silk of commercial value. A recent survey on the diversity of wild silkmoths species in East Africa recorded 58 wild silkmoth species in 170 localities in Kenya, Uganda and Tanzania from families Saturniidae, Lasiocampidae and Thaumetopoeidae (Kioko *et al.*, 2000a). *Anaphe* (Thaumetopoeidae), *Gonometa* (Lasiocampidae) and *Argema* (Saturniidae) were found to be the most promising genera with the potential for wild silk production (Kioko *et al.*, 2000a; Raina and Kioko, 2000).

Table 2.2, gives a summary of species diversity of cocoon forming silkmoth species collected during a field survey in Kenya.

Table 2.2:   Species diversity of cocoon forming wild silkmoths species collected during the field surveys in Kenya

SPECIES	FAMILY	LOCALITY	HOST PLANT
Gonometa sp.	Lasiocampidae	Nguni in Mwingi District and Sultan Hamud in Makueni District	*Acacia elatior* *A. Senegal*
Gonometa sp.	Lasiocampidae	Kamaguti in Uasin Gishu District	*Acacia hockii* and Wattle tree
Ceratopacha sp.	Lasiocampidae	Uasin Gishu District Kamaguti	Cocoons found on *Carissa edulis*
Epiphora vacuna	Saturniidae	Kakamega forest	Adult caught in light trap
Anaphe panda	Thaumetopoeidae	Kakamega forest	*Bridelia macrantha*
Lechriolepsis pulchra	Lasiocampidae	Kakamega forest	Unidentified shrubs
Argema mimosae	Saturniidae	Makueni District Wote & S'Hamud	*Sclerocarya birrea, Spirostachys venenifera and Lannea schweinfurthii*
Philotherma sp.	Lasiocampidae	Sultan Hamud	*Sclerocarya birrea*

(Source: Kioko *et al.*, 2000).

2.2   Biology of wild silkmoths

Silkmoths have four developmental stages namely egg or ovum (the embryonic stage), the caterpillar or larva (the principal feeding and growing stage), the chrysalis stage or pupa (a transition or cocoon spinning stage) and the adult or imago (the principal dispersive and sole reproductive stage (Pinhey, 1975; FAO, 1987; Oberprieler, 1995; Kioko, 1998; Braja, 1999; Kioko *et al.*, 1999a, 2000b; Ngoka, 2003 Rai, 2005). Silk moths spin silken cocoons in which they pupate. The silk contains proteins, which are produced by modified salivary glands in the mouth of the larva and is spun from a special spinneret in the floor of the mouth (Akai *et al.*, 1997; Akai and Nagashima, 1999). The silk filament is a mixture of fibroin or silk proper produced in the silk gland and sericin or silk gum produced in the stomach.

2.3 Taxonomic description of *Gonometa* spp

The genus *Gonometa* belongs to the order Lepidoptera, family Lasiocampidae and subfamily Gonometinae. It was first described by Walker in 1855 and contains some huge moths, that are very dimorphic since the males are often very small compared to their mates and frequently quite different in appearance (Pinhey, 1975; Vari *et al.*, 2002).

2.4 Geographical distribution of *Gonometa* spp

Gonometa postica occurs in the North West and North Cape provinces of South Africa; South and South-east Namibia; and South and South-west Botswana, whereas *G. rufobrunnea* is found in Northern Province of South Africa; East and North-eastern Botswana; and East and South Zimbabwe and Mozambique (Pinhey, 1975; Hartland-Rowe, 1992). *Gonometa fulvida* is found in Transvaal, Rhodesia and Botswana (Pinhey, 1975). In Kenya, Karanja and Chege (1985) reported that *Gonometa* sp. is found in Mugaga, Kakamega, Nairobi, Nakuru and Nyeri. *G. postica* has also been found in Kamaguti, in Uasin Gishu District (Ngoka, 2003; Ngoka *et al.*, 2008) and at Nguni, in Mwingi District and Sultan Hamud in Makueni District (Kioko *et al.*, 2000a). *Gonometa postica* have been reported in the Imba and Mumoni forests of Mwingi, eastern Kenya (Fening *et al.*, 2008a).

2.5 Life history and population dynamics of *G. postica*

The life stages and phenology of *G. postica* and *G. rufobrunnea* are thought to be similar, with both species being bivoltine (Hartland-Rowe, 1992; Veldtman, 2004b). The study on the phenology of *G. postica* in Kenya revealed two generations of moths per year, with generations coinciding with the two yearly rainy seasons. The

silkmoths passed through the dry seasons in the pupal stage that is enclosed in a tough silk cocoon, and moth emergence and consequent egg laying and the sprouting of new leaves from the host plants (*Acacia* spp.) had a unique synchronization (Kioko, 1998; Ngoka, 2003; Ngoka *et al.*, 2008).

Eggs of *G. postica* are oval in shape with a major axis of 2.321 ± 0.007 mm and a minor axis of 2.074 ± 0.008 mm (Kioko *et al.*, 1999a). At oviposition, the eggs are white or brownish and attached to the substrate with a brown gummy substance. There is a yearly bimodal oviposition pattern by the moth in the field, with oviposition by first generation moths observed in March to April and the second generation in October to November. The eggs are laid in clusters with a mean of 17.3 ± 14.3 to 34.1 ± 15.5 eggs and various substrates (upper and lower leaf surfaces, stem and netsleeve) are accepted for oviposition. The egg hatch within 11.3 ± 0.1 days into first instar larva (Kioko, 1998; Ngoka, 2003).

There are six instar larval stages. The first three are gregarious and thereafter become solitary. They have a mixture of white, brown and black hairs with much longer hairs on the lateral sides and are equipped with irritant spines, more prominent in the older instars. Larvae from the first generation of moths are found in the field in March, April and May, whereas those of the second generation are observed in the field in October, November and December. The mean larval period from first instar to onset of spinning at the end of the sixth instar period is 53.5 ± 6.2 days (Kioko, 1998; Ngoka, 2003).

When the caterpillar is matured, it prepares to change into the pupa, in which the transformation of the moth takes place. The pupa is enclosed in a tough silk cocoon which consists of proteins (sericin and fibroin) produced by modified salivary glands (middle and the posterior silk gland, respectively) in the mouth of the silkworm and is spun from a spinneret in the floor of the mouth (Yasuhiro and Hitoshi, 1980). The cocoon is compact and equipped with spines passed on from the larvae onto the cocoon during spinning. Akai *et al.* (1997) detected the needle-like bristles, 2-3 mm long all over the cocoon surface and concluded that they may be useful for protecting the cocoon against enemies, such as birds and other vertebrates. The cocoons are fixed to twigs along the side by a silk band. The cocoons of the first generation are found in the field from May to October, whereas those of the second generation are found from December to March. Female *G. postica* cocoons are usually bigger and heavier than that of males and varied significantly with means of 8.83 ± 2.77 g for females and 3.44 ± 0.91 g for the males. Length and width of the cocoons also show significant differences. The pupal stage is the longest developmental stage is the field with a mean pupal duration of 95.9 ± 16.5 days and this is an adaptation to survive the drought period in between the two seasons (Kioko, 1998; Ngoka, 2003).

Adult *G. postica* moth has a distinct sexual dimorphism, the female moths being larger in size than the males. The female moths have a mean wingspan of 110.61 ± 1.27 mm which is significantly higher than the 66.87 ± 0.40 mm for male moths. The moths have two yearly flight periods, are nocturnal and easily attracted towards a light source. The flight period of the first generation is between March and April and that of the second generation is between September and November in Eastern and Western Kenya. The moths have a mean life span of 6.4 ± 3.2 days. The mean weights of

female and male moths are 3.3 ± 2.0 gm and 0.9 ± 0.5gm, respectively. There is a positive correlation between the female moth weight and the number of eggs laid. The number of eggs laid varies with a mean of 301 ± 114.0 eggs per female (Kioko, 1998).

2.6   Host plants of *Gonometa* spp

Larvae of *G. postica* have a wide host range, feeding on the leaves of *Acacia* spp. [*A. erioloba* Meyer, *A. mellifera* (Vahl) Benth. and *A. tortilis* (Forssk.) Hayne], *Brachystegia* spp., *Prosopis grandulosa, Elephantorhiza, Burkea africana* (Pinhey, 1975; Hartland-Rowe, 1992; Veldtman *et al.*, 2002) and *Pinus radiata* (Taylor, 1965). The single most important host plant for the larvae of *G. rufobrunnea* recorded in South Africa is the mopane tree, *Colophospermum mopane* (J. Kirk ex Benth.) J. Kirk ex J. Léonard (Caesalpiniaceae) (Hartland-Rowe, 1992). Karanja and Chege (1985) in their annotated list of the forest insects of Kenya recorded some of the host plants of *Gonometa* sp. as *Acrocarpus fraxinifelius, Cupressus forbesii, Cupressus lusitanica, Cuppers* sp., and *Pinus patula. Gonometa postica* larvae have been found feeding on different *Acacia* species, Podo and *Cupressus* trees in East Africa (Raina and Kioko, 2000). The *Acacia* spp. in Kenya that *Gonometa* sp. larvae have been found includes *A. elatior* Brenan, *A. senegal* (L.) Willd., A. *hockii* De Wild. and *A. mearnsii* De Wild. (Kioko *et al.*, 2000a; Ngoka, 2003). The other includes *Acacia nilotica* (L.) Del. and *Acacia brevispica* Harms (Fening *et al.*, 2008a).

2.7   The Genus *Acacia*

Acacia is one of the largest of plant genera in the world with species represented on most continents; about 1000 in Australia, 150 in Africa, 185 in the Americas and 95

in the Asia-Pacific region (Orchard and Maslin, 2005). The current classification of *Acacia* recognises the genus as comprising three subgenera, namely:

1) Subgenus *Acacia*: about 160 species which are widely distributed in Africa (73 species), the Americas (about 60 species), Asia (36 species) and Australia (9 species). The Australian species are mostly confined to the tropical north of the continent, only *A. farnesiana* extends southwards through more arid areas but it is not likely that this species is a true native of Australia.

2) Subgenus *Aculeiferum*: 231 species that are also widely distributed in the Americas (125 species), Africa (69 species), Asia (43 species) and Australia (2 species). The Australian species are confined to northern Queensland.

3) Subgenus *Phyllodineae*: 960 species which are largely confined to Australia (less than 20 species occur outside the continent where they extend eastwards to some islands of the Pacific, north to the Philippines and west to Madagascar) (Maslin *et al.*, 2003; Orchard and Maslin, 2003).

On 16 July 2005, the Nomenclature Section of the XVII International Botanical Congress in Vienna voted to accept a recommendation to conserve the name *Acacia* with an Australian type. Until formal proposals to split *Acacia* have been published the generic names for species and infraspecific remain the same, i.e. they will still be called *Acacia*. Once the split begins, however, the generic names will likely be the following: *Acacia* for species ascribed to the present subgenus *Phyllodineae*; *Vachellia* for species ascribed to the present subgenus *Acacia*; *Senegalia* for most species ascribed to the present subgenus *Aculeiferum*. The common name Acacias

could obviously continue to be used informally for the whole complex (Maslin *et al.*, 2003; Orchard and Maslin, 2003, 2005).

2.8 Natural enemies of *Gonometa* spp.

In Botswana, Hartland-Rowe (1992), found out that, the impact of parasitoids and predation on *G. postica* was far more severe than that of climatic factors. According to his study, out of the 200 eggs produced by an average female of *G. rufobrunnea* about 21 or less survived till cocoon formation. Different natural enemies were seen attacking the different developmental stages of *G. rufobrunnea* in the field. These were egg and larval parasitoids (Chalcidoid wasps and Tachinid flies), egg, larval and cocoon predators (Reduviid bugs, birds, mouse, squirrel and man). These natural enemies caused a significant reduction in cocoon abundance. The parasitoids damaged cocoons by leaving exit holes as the adults emerged. The holes rendered the cocoons unprofitable or unsuitable for degumming and spoilt the continuity of silk filament during reeling (Hartland-Rowe, 1992; Kioko, 1998; McGeoch, 2002; Veldtman *et al.*, 2002, 2004a; Ngoka, 2003; Fening *et al.*, 2008b).

The egg parasitoids included *Pediobius anastati* Crawford, *Mesocomys pulchriceps* Cameron and *Anastatus bifasciatus* Fonscolombre. The percentage egg parasitism by *M. pulchriceps* recorded on *Gonometa* sp. in the field at Nguni in Kenya was 37 % and that of *P. anastati* was 0.4 % (Kioko, 1998). Among the larval parasitoids that attack *Gonometa* sp. larvae in the field include two species of Tachinid flies (*Pimelimyia semitestacea* (Villeneuve) and *Palexorista* species), and about four Chalcidoid wasps species. *Eurytoma transvaalensis* Cameron was the most abundant parasitoid species.

Other larval parasitoids included *Tineobius gonometa* (Ferriere), *Hockeria* spp and *Brachymeria* species. Kioko (1998) observed both dipteran and hymenopteran parasitoids emerging from field collected cocoons of *Gonometa* sp. Hartland-Rowe (1992) also showed that up to 70 % predaceous insects eat *G. rufobrunnea* larvae. These predators included Reduviid bugs *Callilestes gracilis* Miller and *Cosmolestes pictus* Klug. He also suspected predation from three species of birds, two roller species *Corcacias caudata*, and *C. garrulus* and one hornbill species *Tockus erythrorhynchus*. Two identified species of predators known to attack cocoons include the multimammate mouse (*Mastomys natalensis*) and the squirrel (*Parazerus cepapi*). Other vertebrates suspected to prey on cocoons included monitor lizards and crows. Kioko (1998) reported Hemiptera, Orthoptera, and Hymenoptera as the three insect orders, which prey on *Gonometa* sp. in the field.

2.9   Terminology used and taxonomy of insect parasitoids

Insects that are parasitic only during their immature stages are termed protelean parasites (Askew, 1971; Vinson, 1976). The protelean parasites that attack invertebrates nearly always destroy their hosts. These parasites are often described as parasitoids, a term coined by Reuter (1913) to differentiate them from the typical parasites. It has been noted that these particular entomophagous insects differ from true parasites in ways sufficient to set them apart and, accordingly, to justify the use of the distinguishing term 'parasitoids' (Doutt, 1959). They are recognised as being different because: (a) the development of an individual destroys the host; (b) the host is usually of the same taxonomic class, i.e., Insecta; (c) in comparison with their hosts, they are of relatively large size; (d) they are parasitic as larvae only, the adults being free-living forms; (e) they do not exhibit heteroecism; (f) as a parameter in

population dynamics their action resembles that of predators more than that of true parasites.

Parasitoids include a vast number of species of the so-called parasitic Hymenoptera, the Strepsiptera, and a few of the Diptera, primarily in the family Tachinidae. Others include Coleoptera, Lepidoptera, Trichoptera, and Neuroptera. The parasitic Hymenoptera traditionally embraces the superfamilies Ichneumonoidea, Chalcidoidea, and Cynipoidea. Of these superfamilies, the Ichneumonoidea constitutes one of the leading groups, both in numbers and effectiveness. The dominant families of this branch of the Hymenoptera Parasitica are the Ichneumonidae and Braconidae, both of which attack a wide range of host species (Clausen, 1940; Doutt, 1959; Vinson, 1975; Pennacchio and Strand, 2006). The family Braconidae contains more than 15,000 valid species (Quick and van Achterberg, 1990). Recent estimates suggest that 10 % to 20 % of all insects may be parasitoid wasps (Godfray, 1994; Quicke, 1997; Whitfield, 2003).

2.10 Insect parasitoids of *Gonometa* spp.

Table 2.3, summaries the different species of parasitoids that attack *Gonometa* spp.

from South and East Africa.

Table 2.3: **List of known parasitoids species of *Gonometa* spp. from South and East Africa**

Order Family	Species	Stadium attacked	Host species
Diptera			
Tachinidae	*Pimelimyia semitestacea* [1,11] (Villeneuve) (syn. *Sturmia semitestacea* Vill.)	larva [2]	*G. postica* [7,9,8,11], *G. rufobrunnea* [2,8]
	Tachina convergens [9] (Wiedemann) [syn. *Sturmia convergens* Wiedemann & *Sturmia dilabida* Villeneuve (Curran)]	?	*G .postica* [9]
	Carcelia evolans [9] (Wiedemann) (syn. *Zenillia evolans* (Wiedemann)	?	*Gonometa* sp.[9] (either *G. postica* or *G. rufobrunnea*).
	Palexorista gilvoides (Curran) [3] (syn. *Sturmia gilvoides* Curran [4])	larva [3,4]	*G. podocarpi* [3,4]
	Palexorista sp.1 *[2]	larva [2]	*G. postica, G. rufobrunnea*
	? *Palexorista* sp. * [1,11]	larva	*G. postica, Gonometa* sp. [5]
	? Tachinidae sp. [1,5]	?	
Hymenoptera			
Braconidae	? *Disophrys* sp. [1]	larva	*G. postica, G. rufobrunnea*
	Meteorus trilineatus (Cameron) [4]	larva [4]	*G. podocarpi*
Ichneumonidae	*Pimpla mahalensis* (Gribodo) [4]	larva [4]	*G. podocarpi*
	Pimpla sp.[11]	larva[11]	*G. postica*[11]
	Goryphus sp.[11]	larva[11]	*G. postica*[11]
Chalcididae	*Brachymeria* sp. 1 ** [1]	larva	*G. postica, G. rufobrunnea*
	Brachymeria sp. 2 ** [2]	larva [2]	*G. rufobrunnea* [2]
	Brachymeria sp.[11]	larva [11]	*G. postica*[11]
	Kriechbaumerella sp. [1]	larva	*G. postica, G. rufobrunnea*
	Hockeria sp. [2]	larva [2]	*G. rufobrunnea*
Eurytomidae	*Eurytoma transvaalensis* (Cameron) [1,2]	larvae; hyper pars.	*G. postica, G. rufobrunnea*
	Eurytoma tolidepepra Delvare [11]		? *Disophrys* *G. postica*[11]
Perilampidae	*Perilampus* sp. [1]	hyper pars.	*P. semitestacea*
Eulophidae	*Pediobius anastati* (Crawford) [2,5,12]	egg [2]	*G. postica* [10], *G. rufobrunnea* [2], *Gonometa* sp.

Table 2.3: **continued**

Order Family	Species	Life stage attacked	Host species
Hymenoptera			
Eupelmidae	*Anastatus bifasciatus* (Fonscolombe) [2]	egg [2]	*G. fasciata* [2]
	Anastatus sp. 1 [2]	egg [2]	*G. rufobrunnea* [2]
	Anastatus sp. 2 [3,4]	egg [3,4,6]	*G. podocarpi* [3,4]
	Mesocomys pulchriceps (Cameron) [2]	egg [6]	*G. postica* [5, 10,12], *G. rufobrunnea* [2] *Gonometa* sp. [5]
	Tineobius gonometae (Ferriere) [2]	larva [2]	
			G. postica [10], *G. rufobrunnea* [2]

The above table was adopted from Veldtman *et al.*, 2004a and modified with some additions of parasitoids from East Africa (Kenya). The numbers (in superscript) denote the information sources which are as follows:

(1) Veldtman *et al.*, 2004a; (2) Hartland-Rowe, 1992; (3) Austara, 1971; (4) Okelo, 1972; (5) Kioko, 1998; (6) Scholtz & Holm, 1985; (7) Crosskey, 1984; (8) Peigler, 1994; (9) Cuthbertson & Munro, 1941; (10) Records from the Biosystematics division of the Plant Protection Research Institute, Agricultural Research Council, South Africa; (11) Fening *et al.*, 2008b. (12) Ngoka, 2003. Similar numbers of asterisks indicate that unidentified species are of the same genus, region and have the same host species and may be thus the same species; hyper pars. = hyperparasitoid.

2.11 Life cycle of parasitoids

Insect parasitoids have a much-specialised life cycle that includes an immature stage that develops on or within a single insect host, ultimately killing that host. The life cycle begins when an adult female insect parasitoid lays her eggs on or in the body of

a host insect, such as a caterpillar. The parasitoid larvae, after hatching, feed on the body tissues of the host insect, eventually killing it. Once the larvae have fully developed, the larvae will either pupate inside the host or form a cocoon outside. The life cycle and reproductive habits of parasitoids can vary greatly between species. For example, in some species, only one parasitoid will develop in or on each host (solitary) while, in other species, hundreds of larvae may develop within the host (gregarious). Insect parasitoid life cycles may also vary depending upon the life stage of their host they attack. Some parasitoids will lay their eggs near the eggs of their host, while other species will lay their eggs in or on the larvae of their host. Usually insect parasitoids will only attack a particular life stage of one or several related species. Parasitoids can be parasitised by other parasitoids, a phenomenon known as hyperparasitism (Hoffmann and Frodsham, 1993).

While many gaps in our knowledge base remain, the phylogenetic and ecological literature overall suggests three key points. Firstly, ectoparasitic idiobionts (which prevent further development of the host after initial parasitisation) represent the ancestral ground plan for the parasitoid lifestyle and from which other developmental strategies subsequently evolved. Secondly, endoparasitoids develop in more intimate contact with host immune and developmental factors that have overall favoured greater specialisation, particularly of koinobionts (which allow the host to continue its development). The ability to adapt to a more specialised host environment has also generally favoured narrower host ranges in koinobionts than in idiobionts. Thirdly, environmental factors such as intraguild competition and host mortality risks have affected other developmental traits such as offspring development times and adult fecundities (Pennacchio and Strand, 2006).

2.12   Life history of ichneumonoids (Braconids and Ichneumonids)

Most ectoparasitic ichneumonoids are idiobionts that still develop on concealed hosts (Wharton, 1993) but a few groups, such as the Polysphinctin (Ichneumonidae, Pimplinae), are koinobionts that parasitise mobile hosts such as spiders (Shaw, 1994). Endoparasitism has also arisen multiple times in the Ichneumonoidea. Some of these endoparasitoids remain idiobionts, whereas others are koinobionts that parasitise larvae or eggs. In some taxa, such as rogadine braconids, the switch from an idiobiont to a koinobiont habit parallels the switch from attacking concealed hosts to attacking exposed hosts. In other taxa, endoparasitic koinobionts continue to develop in concealed hosts or have even switched from parasitising exposed hosts back to concealed hosts. Pupal endoparasitoids are restricted primarily to a few subfamilies of Ichenumonidae.

Polydnaviruses are associated with selected advanced lineages and are utilised by the parasitic wasps to counteract their host's immune response (Pennacchio and Strand, 2006). Adult braconids oviposit almost exclusively in, on or near other insects, with the immature stages completing their development at the host's expense (Wharton, 1993). Ectoparasitic braconids generally paralyse their host prior to oviposition (Shaw, 1983; Shaw and Huddleston, 1991). Endoparasitic braconids do not paralyse their host or only do so temporarily at the time of oviposition (Shaw, 1983; Wharton, 1984, 1993). Oviposition in the ectoparasitoid braconids is a two-step process, comprising venom injection and oviposition, which are separate events (Shaw, 1983). In most endoparasitoid braconids, eggs and venom-gland products (paralytic or otherwise) are injected simultaneously, and this process can be extremely rapid [1-10s

in a wide range of both solitary and gregarious species (Calvert and van den Bosch, 1972; Wharton, 1993)].

2.13 Life histories of Chalcidoids, Platygastroids, Cynipoids, and Prototrupoidea

Chalcidoids exhibit extreme diverse habits that include ectoparasitism, endoparasitism, predation, gall formation, seed feeding, and other forms of phytophagy. Platygastroids are endoparasitic idiobionts of eggs (Scelionidae) or endoparasitic koinobionts of larvae (Platygastridae). Cynipoids have a basal lineage of endoparasitic koinobionts that complete their development as ectoparasitoids. Their derived lineages include endoparasitic koinobionts (Figitidae) or gall formers (Cynipidae). Prototrupoidea are endoparasitic koinobionts of diverse hosts (Pennacchio and Strand, 2006).

2.14 Life history of Tachinids

There are about 10,000 species described worldwide (Irwin *et al.*, 2003; Stireman *et al.*, 2006). All Tachinids (with known life histories) are parasitoids of insects and other arthropods. In this respect, they are second only to the parasitic Hymenoptera in diversity and ecological importance as insect parasitoids. Because of their predominance as parasitoids of the larval stage of Lepidoptera and other major groups of insects herbivores, tachinids often play significant roles in regulating herbivore populations and structuring ecological communities, both natural and managed (Stireman *et al.*, 2006). Tachinids are more specifically endoparasitoids of arthropods, and as typical for parasitoids, they usually kill their hosts, but there are exceptions (English-Loeb *et al.*, 1990).

Although many tachinids emerge from the pupal stage of their hosts, none is known to attack pupae nor do any species attack the egg stage of their hosts. Most species of tachinids attack larval hosts, but a significant fraction, perhaps 5% to 10% of species, attack adults. Larval development is usually completed in one to three weeks, except for species that diapause in the host, where it can be prolonged over many months. Depending on the tachinid species, larvae develop either singly or gregariously and either pupate in the dead host or leave the host remains to pupate in soil litter (Stireman *et al.*, 2006).

Unlike parasitic Hymenoptera, tachinids lack a primitive piercing ovipositor. Thus with the exception of a few groups in which piercing structures have evolved from modified sternites, tachinids must deposit eggs externally on or near the host, and the newly hatched larva must gain entry into the host. This lack of ovipositor also prevents the injection of paralytic poisons, mutualistic polyDNA viruses (polydnaviruses) and other accessory substances that immobilise the host and/or its immune system. As a result, tachinids are classified as koinobiont parasitoids, that is, they allow their host to continue to feed and grow while they develop inside it rather than arresting its development in some way, as do idiobionts. Unlike parasitic Hymenoptera with similar life histories (koinobiont endoparasitoids) that tend to be highly host specific, many tachinid species are polyphagous, and a number have been reared from dozens of hosts in multiple families (Stireman *et al.*, 2006).

Adult tachinids can be found in most habitats, on leaves, tree trunks, flowers, rocks, or the ground. They are typically, but not always, diurnal or crepuscular and

extremely active. Little is known about the mating behaviour of tachinids aside from the general sexual aggregation sites of many species (e.g. hilltops, tree trunks) (Alcock and Smith, 1995). Adults of certain groups such as Phasiinae and Tachinini are often observed at flowers and may function as pollinators for a wide diversity of plant taxa, but their importance in this respect has been largely unexplored. At least one highly specific tachinid pollinates orchids in the genus *Trichoceros* via pseudocopulation, in which the female tachinid mimicking flowers lure tachinid males to attempt copulation and incidentally acquire pollinia (Dodson, 1962). The importance of adult resources such as nectar, salts, leaf exudates, or potential sources of protein (e.g. pollen) is poorly known, as are patterns of adult dispersal (Stireman *et al.*, 2006).

2.15 Benefits of wild silkmoths

Wild silkmoths can produce good quality silk fibre, food to some African and Indian local communities where the edible species are abundant. In tasar silkmoths, dead pupae, which remain after reeling, are very rich in protein (63-65%), oil (20-25%), carbohydrates (10%) and minerals (7-8%) (Agarwal *et al.*, 1974). Pupae of silkmoths are an excellent source of proteins for animals and their oil is extracted for making soaps, cosmetics and the remaining powder is used in the baking industry for the preparation of protein-rich biscuits in India (Agarwal *et al.*, 1974). Wild sericulture helps to generate income to poor-resource communities as well as the conservation of the forest for eco-tourism (Raina *et al.*, 2007; Fening *et al.*, 2008a).

Wild silkmoths have the potential of playing a role in eco-tourism, providing a focal point for raising international and local awareness of their unique biodiversity and of

the real and current threats to their existence (Raina and Kioko, 2000). This can be done by including these silkmoths in live butterfly house displays both at home and abroad. There are many people and firms interested in observing live silkmoths. The prices paid for live pupae range from US $ 1-8, depending on the species. Selling pupae will bring immediate benefits to the community farming and harvesting the silk moths. It will also provide a chance to farm silkmoth species, which do not spin silk cocoons but are the majority of species in Africa (Raina and Kioko, 2000) or those who spin silk cocoons of low quality; i.e. small, loosely spun cocoons (Kioko, 1998; Kioko *et al.*, 2000a).

Wild silkmoths can be used as ecological indicators of environmental change (Oberprieler, 1995; Kioko, 1998). This is because they often have a restricted distribution and food plant range. The decline in numbers of a silkmoth species in an area may be the first sign of degradation of the environment, whether by pollution, denudation of the natural vegetation, invasion of alien plants or other causes. Similarly, an increase in numbers may also be a signal of change in the environment for example the introduction of a palatable exotic species or an increase of the natural food plants. Before the wild silkmoth species in East Africa can be used to identify areas and ecosystems in need of conservation, and also to monitor such areas for possible decline and change in terms of species composition, detailed bioecological studies must be undertaken. Once thorough knowledge is gained on their life cycles and distribution, then these species will play a role in the future formulation of research and conservation strategies in this region (Kioko, 1998).

The cocoons of *Gonometa* spp. have had other uses in Africa. The Denver Museum of Natural History has three pairs of ankle rattles made by Bushmen in Botswana; each rattle is a string of numerous cocoons containing tiny chips of stone or ostrich eggshell (Peigler, 1993). Similarly, *A. mimosae* cocoons are much favoured by Zulus, who wear them as anklets giving a satisfying rattle (Pinhey, 1975). Recently at ICIPE, wild silk (*Gonometa* silk) is being weaved with mulberry silk to develop a cloth of high value (Raina *et al.*, 2007).

The *kente* silk cloth produced and worn by *Ashanti* traditional chiefs in Ghana is a good example of the prestige and high value attached to silk. The *Ashanti* people price the brilliant orange and conspicuous yellow colours of the cloth as much as they value their gleaming gold sculpture. Today you don't need to be a royal to wear *kente* cloth. Many people wear *kente* cloth in modern societies, including the United States. Its traditional importance as a prestige item worn only by royalty has prompted modern people to wear it as a sign of pride in Africa or African heritage. Currently at many college graduation ceremonies, African- American students wear a strip of *kente* cloth with their graduation gowns (Frank, 1993; Mary, 1999; Shaw-Eagle, 1999; Rosemary, 1999; Christopher, 1999; Fening, 2007).

Wild silk powder recently successfully obtained from the silkmoths *A. pernyi*, *Samia cynthia ricini* and others, has been used in non-textile product: high valued cosmetics, food additives and silk-spread materials (Akai, 2000). These products require a large quantity of silk with differing characteristics, thus stimulating small industries in various areas of the world.

2.16   Prospects and problems of wild sericulture in Africa.

The national and global markets demand higher standards of goods. Various methods are being developed to enhance the aesthetic value of newly introduced mulberry silk. Among these are the introduction of African designs, use of eco-friendly natural dyes to enhance the organic value of silk fibre and fabrics, and application of strict quality control measures to meet international standards. In the case of wild species of silkmoths, the programme has focused on conservation of biodiversity through scientific training of local people (Raina and Kioko, 2000; Kioko *et al.*, 2007; Fening *et al.*, 2008).

Various methods are being developed to minimise predators, parasitoids, pests and disease problems in wild silk farming to enhance yield and help rural people. For instance, in attempts to overcome egg parasitism of *A. mimosae* and *G. postica* in the field, cocoons are kept in enclosures for moth to emerge. The eggs laid, hatch indoors and the larvae are released in the field (Kioko *et al.*, 1999). The conservation programme also involves the protection and preservation of genetic diversity of silkmoth species (Raina, 2000, 2004).

The realisation of the above goals has necessitated the on-going research at ICIPE on the biology, ecology and population dynamics of the most promising species of wild silkmoths such as *Argema, Anaphe* and *Gonometa*. This particular research seeks to study the spatial distribution and biology of *G. postica* with reference to its key parasitoids on different *Acacia* species in the Imba and Mumoni forest reserves located in the southern and northern parts respectively, of Mwingi District. This will form the groundwork for further research and development on the possible control of

the key parasitoids of *G. postica*. It will also elucidate the behaviour of these silkmoth species and facilitate the development of management programmes aimed at protecting and preserving their genetic diversity and ecosystem. As part of this package, there is the creation of market places in different localities within the sub-region (e.g. Mwingi, Arabuko Sokoke and Kakamega silk marketplaces) to facilitate the sales of these wild silk products so that the local communities would obtain some income. The first silk quality-testing laboratory in Africa has been established in ICIPE to ensure high silk quality and good market value for the beneficiary communities.

In the future utilisation of wild silk, it is important that each product retains its own distinctive features and maintains a high market price. Consumers demand special individual characteristics from silk fabrics and the final products in which they are used (Akai, 2000). Branding of the wild silk products from ICIPE is done in such a way to reflect the ecosystem where they were produced. For example, we have woodland silk of *G. postica* from Mwingi woodland forests, Rainforest silk of *A. panda* from Kakamega evergreen forest and Coastal (sea breeze) silk of *A. mimosae* from Arabuko Sokoke forest (Raina *et al.*, 2007).

CHAPTER THREE

3 GENERAL MATERIALS AND METHODS

3.1 Study area

3.1.1 Geographical description of study area and location of study sites

Mwingi District is one of the thirteen districts in the Eastern Province of Kenya (Figures 3.1). It lies between latitudes 0^0 03' and 1^0 12'South and longitudes 37^0 47' and 38^0 57' East. Formerly, the District covers an area of 10,030.30 km^2 with nine divisions (Nguni, Mumoni, Kyuso, Central Mwingi, Nuu, Tseikuru, Ngomeni, Mui and Migwani) (Mwingi District Development Plan, 2002), but currently Kyuso, Ngomeni, Mumoni and Tseikuru have been cut off from Mwingi District to form the new Kyuso District. Field experiments, surveys and sampling were carried out at Mumoni (10,422 ha) and Imba (732 ha) forest reserves located at the northern and southern parts of Mwingi District, respectively (Figure 3.2). Laboratory studies were undertaken in the wild silkmoth research laboratory located at the silk marketplace in Mwingi town, Kenya.

3.1.2 Topography, vegetation and climate of study area

Mwingi District is generally plain with a few inselbergs in Mumoni, Nuu and Migwani Divisions. The highest point of the district is Mumoni Hill, with an altitude of 1,747meters above sea level. The landscape is generally flat, with a plain that gently rolls down towards the east and northeast where altitudes are as low as 400m. The highlands namely Migwani, Mumoni, Central and Mui Divisions receive more rainfall compared to the lowlands Nguni, Kyuso and Tseikuru Divisions. The drier areas experience severe droughts, which have led to livestock deaths and food

shortages. The district has red sandy soils, loamy sand soils and patches of black cotton soils. River valleys have saline alluvial soils of moderate to high fertility. Otherwise, soils are of low fertility and prone to erosion. Most hills are covered by shallow and stony soils unsuitable for crop farming (Mwingi District Development Plan, 2002).

The District has a total of 18,285.90 hectares of gazetted forests and these are located in Nuu and Mumoni divisions. The vegetation cover is mainly shrubs and woodlands. There are five forests in the District of which three are gazetted and two are trustlands. The gazetted forests are Mumoni (10,442 ha), Gaikuyu (3075 ha) and Nuu (3532.9 ha), while Imba/Chakuyu (732 ha) and the Maai (515 ha) are trustlands. The Mumoni and Gaikuyu forests consist of tall trees, shrubs and other bushes. *Acacia* spp. (mostly *A. tortilis* and *A. mellifera*), which serves as important host plants for *G. postica* are very common within the lower slopes of these forests (Mwingi District Development Plan, 1999; Abeele *et al.*, 2005). These forests are part of the East African *Acacia* Savannas Eco-region and are home to the threatened IUCN red listed Pancake tortoise, *Malacochersus tornieri* (Seibenrock), the endemic and threatened bird, Hinde's Babbler, *Turdoides hindei* and other globally threatened bird species (Malonza, 2003; Mulwa *et al* 2007).

Mwingi District is situated in an arid and semi-arid zone and its climate is hot and dry for most part of the year. The maximum mean annual temperature ranges between 26° C and 34° C. The minimum mean annual temperatures in the district vary between 14° C and 22° C. The district has two rainy seasons, i.e. March – May (long rains) and October – December (short rains). Rainfall ranges between 400 mm and 800 mm per

year, but is erratic. The short rains are more reliable than the long rains (Mwingi District Development Plan, 2002).

3.2 Biology of *G. postica*

The development of *G. postica* larvae (semi-captive breeding) on three *Acacia* spp. in the Imba forest (*A. elatior*, *A. nilotica* and *A. tortilis*) and two in Mumoni forest (*A. tortilis* and *A. nilotica*) was undertaken during the long and short rainy seasons of 2007. The total developmental period of *G. postica* from hatching of the egg to larva, pupa and adult lifespan was determined for moths reared in both forests. The oviposition experiments were undertaken in net-sleeved cages in an indoor environment for the two seasons, whereas the larvae were reared on their host plants enclosed in net sleeves (semi-captive rearing) until they spun their cocoons. A rain gauge and a digital thermohygrometer were used to measure the rainfall, minimum and maximum relative humidity (RH) and temperature in both forests, respectively. The minimum and maximum RH and temperature were also monitored in the laboratory experiments. The weight and size (length and width) of the *G. postica* cocoons were measured with an electronic balance and a pair of calipers. The cocoon weight and size were used to determine their quality and how this varies among host plants for cocoons from semi-captivity and those collected from the wild population.

3.3   Spatial distribution of *G. postica* larvae and pupae on different host and non-host plant species

A survey was undertaken at the Imba and Mumoni forests of Mwingi District during the long rainy season of 2006 to determine the spatial distribution of *G. postica* on different *Acacia* species. Three sites (replicates) were randomly chosen for sampling

of *G. postica* cocoons. The selection of sites in each forest was done to reflect the different zones. Sites were selected based on cocoon abundance, with a minimum of 40 new generation cocoons per site required for site selection (Kioko *et al.*, 2000a; Veldtman *et al.*, 2002). Sampling at each site was standardised by demarcating an approximately rectangular area incorporating 100 major host (*Acacia*) trees referred to as a grid (Veldtman *et al.*, 2002). This was done to compensate for possible tree-density differences between host plants and between geographically separated sites. Every cocoon on each tree within the grid was counted.

The sex of the collected cocoons was also determined. *Gonometa postica* cocoons found on the minor host plants within the grid were also recorded. The density of each major host plant was determined as the number of that host species per unit area. Minor host plants within the grid that had *G. postica* final instar larvae (prior to pupation) or cocoons were counted. A Global Positioning System (GPS: Garmin Geko 101) was used to measure the geographical position of each tree (major and minor host plants) and their distribution. Tree growth characteristics [height, canopy size (width), trunk diameter (girth) at breast height or at branching point from the main trunk and number of branches] were measured and categorised. Trees less than one metre in height were not included in the survey.

Those tree species habouring *G. postica* larvae (1st- 5th instars) and possibly found feeding were considered as host plants for *G. postica* and sample of the leaves were collected (pressed gently in newspapers) and sent to the National herbarium in Kenya for identification. Tree species, in which final instar larvae were found, were not used

to determine host range as they may already have moved to different tree species that may be preferred for pupation.

Figure 3.1: Map of Kenya showing the position of Mwingi District.
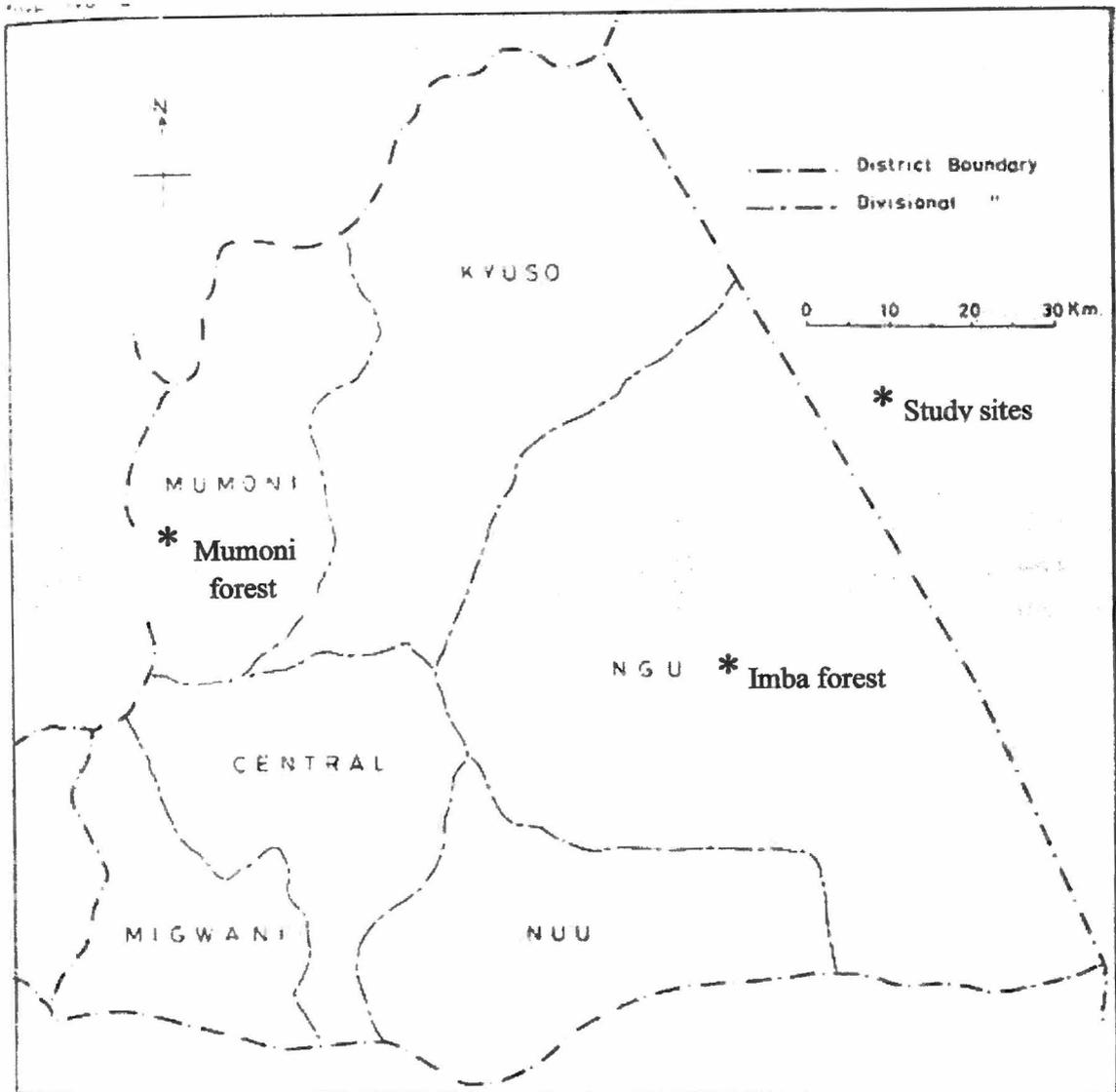
Figure 3.2:   Study sites in Mwingi District of Eastern province of Kenya.

3.4   Light trapping of *G. postica* moths

One ultra-violet light trap per site was set near the vicinity Imba and Mumoni forests to monitor the temporal and spatial distribution of *G. postica* adult moths over the study period. These traps were in operation for two nights per week as proposed by van den Berg (1990). The moths were collected and prepared for pinning and identification. The sex ratios of *G. postica* moths were determined and their abundance based on trap catches. Each trap consisted of an ultra-violet lamp with baffles, a funnel and a plastic container on which funnel empties into. Moths were attracted to the light at night, hit the baffles and dropped through the funnel into the container containing diluted alcohol (75%). The trap was powered by Chloride exide accumulator battery (12 volts). The *G. postica* moths were collected in the morning at 9 am, by sorting them out from the other moths in the container using a magnifying hand lens.

3.5   Parasitism rates of *G. postica* on different host and non-host plants

Three sites each were selected systematically from Imba and Mumoni forests for the study. The selection of sites in each forest was done to reflect the different forest zones. All trees within each defined area were inspected for the sampling of *G. postica* larvae and cocoons. All larvae seen were observed for any visible signs of parasitism. The cocoons collected were kept individually in rectangular plastic bottles (13 x 11 cm) covered with fine mesh (400 micron) to study the parasitisation rates.

The parasitoids that emerged were pinned, identified, sexed and the percentage parasitism for each species of parasitoid was calculated. The identification of parasitoids was carried out at the Biosystematics unit at ICIPE in Nairobi, Kenya and the Agricultural Research Centre for International Development (CIRAD) in France.

Sampling was done weekly from the three sites in each forest during the study period. The percentage parasitism (*Pi*) for each parasitoid species was calculated for the actual stage (s) of the host attacked using the

$$P_i = \frac{\sum_{t=0}^{T} P_{it}}{\sum_{t=0}^{T} d_{it}}$$

formula proposed by van Driesche (1983).

where d_{it} is the number of the susceptible hosts in stage i at week t, P_{it} is the number of parasitised hosts i at time t, and T is total weeks. The characteristics of emerged parasitoids from pupal cocoon such as number of emergent holes; diameter, position and shape of emergent holes were measured as postulated by Veldtman *et al.* (2004a).

3.6 Development cycle, reproductive strategy and aspects of parasitoids morphology

3.6.1 Development cycle of parasitoids

The life cycle of the key parasitoids attacking *G. postica* was studied from cocoons collected from the field. The developmental period from the time the freshly spun cocoons were collected from the field to emergence of the parasitoid and its lifespan was recorded.

3.6.2. Aspects of parasitoids morphology and reproductive strategy

The morphological characteristics of adult parasitoid mainly, type of mouthparts, the length, nature and description of ovipositor was noted and recorded. The reproductive strategy of parasitoids on host was ascertained. The parasitoid's ovipositor was

dissected under a stereomicroscope and the length of the ovipositor was measured under a stereomicroscope with an in-built digital camera.

3.7 Data analysis

The data on the developmental periods of *G. postica* eggs, larvae, pupae and adult moths between generations and forests were analysed using a *t* test ($P = 0.05$). Spatial distribution of *G. postica* larvae, cocoons, host and non-host plant species was analysed using the variance-to-mean ratio. This ratio was used because it has been reported to be relatively easy to calculate and is the most fundamental of all the aggregation indices (Taylor, 1961, 1984; Southhood & Henderson, 2000; Okolle *et al.*, 2006; Mbahin *et al.*, 2008). The variance-to-mean ratio was tested for departure from randomness with a Chi-square (χ^2) test: χ^2 (n - 1df) = σ^2 (n - 1)/μ, where n and μ are the sample size and sample mean respectively (Southhood & Henderson; 2000; Okolle *et al.*, 2006).

Data on host and non-host plant species abundance and their GPS values (spatial co-ordinates) were used to construct a map of the distribution of host and non-host plants of *G. postica* in the study area. Host plants diversity for *G. postica* within the Mumoni and Imba forests was analysed using Shannon index (species richness) and Shannon evenness (evenness) (Magurran, 1988; Kempton, 2002). A *t* test was used to compare the diversity between the two forest sites. The Shannon diversity index (H') = $-\sum p_i \ln p_i$, where p_i = the proportional abundance of the ith species ($p_i = n_i / N$); N = total abundance for all species sampled and n_i = abundance for each species of host plant, ln = natural log. The Shannon evenness (E) = H' / ln S, where S = the number of species sampled.

The variance in diversity (var H' or s^2) = $\dfrac{\sum p_i (\ln p_i)^2 - (\sum p_i \ln p_i)^2}{N}$ - $\dfrac{S-1}{(2N)^2}$

The formula for the t test is given by $t_{cal.} = \dfrac{H'_1 - H'_2}{(\text{var } H'_1 + \text{var } H'_2)^{\frac{1}{2}}}$,

where H'_1 = the diversity of site 1 and var H'_1 = variance of site 1. H'_2 = the diversity of site 2 and var H'_2 = variance of site 2.

The degree of freedom (df) = $\dfrac{(\text{var } H'_1 + \text{var } H'_2)^2}{(\text{var } H'_1)^2 / N_1) + (\text{var } H'_2)^2 / N_2)}$

The percentage parasitism was calculated for each species of parasitoid and the actual host stage attacked by using the formula proposed by van Driesche (1983) and adopted by Skovgard and Pats (1996) and Rwomushana *et al.* (2005). The percentage parasitism of the different species of parasitoids on the different host and non-host plants was compared between the two generations within each forest by using Mann-Whitney test (α = 0.05). Kruskal-Wallis test (α = 0.05) was used to compare the parasitism among the different species of parasitoids and host plants within each generation. When the Kruskal-Wallis test showed significance differences ($P = 0.05$), multiple comparisons was conducted using the Nemenyi test (α = 0.05, Zar, 1999).

[1]CHAPTER FOUR

4   SPATIAL DISTRIBUTION OF LARVAE AND PUPAE OF THE

AFRICAN WILD SILKMOTH, *GONOMETA POSTICA*, AND ITS

HOST AND NON-HOST PLANTS IN MWINGI FOREST

EASTERN KENYA

4.1   Introduction

Non-mulberry sericulture is universally known as forest or wild sericulture and

silkmoths existing in wild conditions are known as wild silkmoths (Peigler, 1993;

Mbahin *et al.*, 2008). The high quality of wild silk has attracted the attention of silk

users globally (Akai, 2000), thus providing excellent opportunities for African

countries to diversify and optimise any source of production (Jolly *et al.*, 1979; Raina,

2000, 2004; Mbahin *et al.*, 2008; Ngoka *et al.*, 2008). The wild silkmoth species,

Gonometa postica Walker (Lepidoptera: Lasiocampidae), is known to produce high-

quality silk comparable to that of the domesticated silkmoth, *Bombyx mori* L.

(Lepidoptera: Bombycidae) (Kioko *et al.*, 2000; Raina and Kioko, 2000; McGeoch,

2002; Veldtman *et al.*, 2002; Ngoka *et al.*, 2008). Consequently, this species is

currently utilised on a commercial scale for wild silk production in Mwingi, Kenya

(Kioko *et al.*, 2007; Fening *et al.*, 2008a).

As described by Taylor (1984), spatial distribution is one of the most characteristic

ecological properties of species. It yields characteristic parameters that segregate

species, and these parameters are the population expression of the individual's

behavior. These parameters determine the spatial distribution of temporal dynamic

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[1] This chapter is submitted as: Spatial distribution of larvae and pupae of the African wild silkmoth, *Gonometa postica* (Lepidoptera: Lasiocampidae), its host and non-host plants in eastern Kenya.

change and field sampling is unviable without understanding the underlying spatial distribution (Taylor, 1984) which must be taken into consideration to achieve sustainable harvesting of *G. postica* cocoons in the wild. However, understanding the spatial distribution of wild silkmoths in indigenous and mixed indigenous forests is one of the several challenges faced by wild silk production in many African producer countries, especially East Africa (Mbahin *et al.*, 2008). Therefore, there is need for more precise information on the spatial distribution of wild silkmoth species to assist in developing management plans for their conservation and sustainable utilisation for income generation (Veldtman *et al.*, 2007a; Mbahin *et al.*, 2008).

Unfortunately, the data on the spatial distribution of wild silkmoths and their host plants in Africa is inadequate for making management decisions (Veldtman *et al.*, 2007; Fening *et al.*, 2008a; Mbahin *et al.*, 2008; Ngoka *et al.*, 2008). Veldtman *et al.* (2007) is currently the only available quantitative description on spatial distribution of *G. postica* pupae in north-central South Africa and southeastern Botswana. However, the bioclimatic conditions in the eastern Africa region and by extension the diversity of host plants of *G. postica* differ markedly from southern Africa, and it would be expected that differences might exist in distribution of larvae and pupae. This study, therefore, was initiated to investigate the spatial distribution of *G. postica* larvae, pupae (enclosed in silken cocoons) and their host and non-host plant species in Kenya. This information would be crucial for commercial production of *G. postica* cocoons and would contribute to developing management plans for sustainable harvesting and utilisation of cocoons of this wild silkmoth species in the East African region.

4.2 Materials and methods

4.2.1. Study sites

The study was conducted in the Imba (0° 50' S, 38° 22' E) and Mumoni (0° 34' S, 38°, 2' E) forests of Mwingi, eastern Kenya. The natural vegetation of these forests is arid and semi-arid woodland (Mwingi District Development Plan, 1999). They harbour significant biodiversity resources within a complex of thorn tree (*Acacia, Commiphora*) woodland communities (Abeele *et al.*, 2005; Fening *et al.*, 2008a). A total of six sites, three in each forest were chosen systematically to reflect the different zones of each forest (Fening *et al.*, 2008a) and a minimum of 40 larvae or cocoons of *G. postica* was required for site selection as postulated by Veldtman *et al.* (2007). Minimum and maximum distances among sites within each forest were about 1 and 15 Km, respectively. Sampling of larvae and cocoons was carried out from March to June, and October to December 2006. These periods coincided with the long and short rainy seasons and were characterised by an abundance of *G. postica* larvae (March-April, and October-November) and pupae (May-June, and December).

4.2.2. Spatial distribution of *G. postica* host and non-host plants

One hundred primary host plants were sampled per site, as well as other non-host plants of *G. postica* that were > 1 m in height following the procedure by Veldtman *et al.*, 2007b. Non-host plants referred to plants that *G. postica* larvae do not feed on but are used for pupation (Veldtman *et al.*, 2002, 2007a; Fening *et. al.*, 2008a, b). The approximate rectangular area encompassing these plants was measured using a 100m measuring tape. The density of each species of host or non-host plant was determined as the number of that species per the defined area. This measure was then used for estimation of the aggregation index of the respective host and non-host plants.

4.2.3. Spatial distribution of *G. postica* larvae and pupae

Each of the 100 trees was carefully inspected, and the number of *G. postica* larvae or pupae counted and recorded. The larvae observed were in the fourth, fifth and sixth instar stages which have already passed the early instar stages. The plant species on which *G. postica* larvae were found vigorously feeding were considered as primary host plants (Veldtman 2005; Fening *et al.*, 2008a). The count data on larvae and pupae abundance was used for the calculation of the aggregation index on both host and non-host plant species.

4.2.4. Data analysis

The variance (σ^2) -to- mean (μ) ratio was used to determine if the spatial distribution of G. *postica* host trees, larvae and pupae is random in the Imba and Mumoni forests of Mwingi. This ratio was used because it has been reported to be relatively easy to calculate and is the most fundamental of all the aggregation indices (Taylor, 1961,

1984; Southhood & Henderson, 2000; Okolle *et al.*, 2006; Mbahin *et al.*, 2008). A distribution in which μ equals σ^2 (i.e. $\sigma^2 / \mu = 1$) is considered random (equidispersion) population, and if $\sigma^2 > 1$ (i.e. $\sigma^2 / \mu > 1$), there is aggregation (overdispersion or clumping) and if $\sigma^2 < \mu$ (i.e. $\sigma^2 / \mu < 1$) there is a uniform (regular or underdispersed) distribution. The variance-to-mean ratio was tested for departure from randomness with a Chi-square (χ^2) test: χ^2 (n - 1df) $= \sigma^2$ (n - 1)/μ, where n and μ are the sample size and sample mean respectively (Southhood & Henderson; 2000; Okolle *et al.*, 2006).

4.0   Results

4.3.1. Spatial distribution of *G. postica* host and non-host plant species

The list of host and non-host plants sampled in this study is as shown in Table 4.1. Both host and non-host plants of *G. postica* were either randomly distributed or clumped from both the Imba and Mumoni forests. In Imba, the spatial distribution of *A. tortilis, A. nilotica* and *A. elatior* was clumped while that of the non-host plants was random (Table 4.2). *A. nilotica* and *A. brevispica* were clumped in Mumoni, whereas *A. tortilis, A. mellifera* and the non-host plants were randomly distributed (Table 4.2). In order of decreasing clumping intensity, the host plants in the Imba forest were *A. elatior* > *A. tortilis* > *A. nilotica*, and in Mumoni forest, *A. nilotica* > *A. brevispica*. Generally, the degree of clumping of host plants was denser in Imba than in Mumoni forest. Furthermore, the degree of randomness of the non-host plants was higher in Imba than Mumoni forest.

Table 4.1: Host and non-host plants distribution of *G. postica* in Imba and Mumoni forests of Mwingi Eastern Kenya, long and short rainy seasons 2006

PLANT SPECIES	FAMILY	LOCALITY
Host plants		
Acacia tortilis	Mimosaceae	Imba and Mumoni forests
Acacia nilotica	Mimosaceae	Imba and Mumoni forests
Acacia elatior	Mimosaceae	Imba forest
Acacia mellifera	Mimosaceae	Mumoni forest
Acacia brevispica	Mimosaceae	Mumoni forest
Non-host plants		
Acacia ataxacantha	Mimosaceae	Mumoni forest
Acacia nubica	Mimosaceae	Imba forest
Capparis tomentosa	Capparidaceae	Imba and Mumoni forests
Balanites aegyptiaca	Balanitaceae	Imba and Mumoni forests
Grewia tembensis	Tiliaceae	Imba forest
Solanum renschii	Solanaceae	Imba forest
Lawsonia inermis	Lythraceae	Imba forest
Acalypha sp.	Euphobiaceae	Imba forest
Cordia sinensis	Boraginaceae	Imba forest
Combretum aculeatum	Combretaceae	Imba forest
Adansonia digitata	Bombacaceae	Mumoni forest

Source: Fening *et al.*, 2008a

Table 4.2: Variance to mean ratios of host and non-host plant species of *G. postica* in Imba and Mumoni forests of Mwingi eastern Kenya, long and short rainy seasons 2006

Plant species	Imba				Mumoni			
	Variance (σ^2)	Mean (μ)	Σ^2/μ^+	Pattern	Variance (σ^2)	Mean (μ)	Σ^2/μ^+	Pattern
A. tortilis	730.33	42.67	17.12	Clumped	2.33	61.67	0.04*	Random
A. nilotica	120.33	26.33	4.57	Clumped	100.33	20.33	4.94	Clumped
A. elatior	1443.00	31.00	46.55	Clumped	-	-	-	-
A. mellifera	-	-	-	-	16.00	11.00	1.45*	Random
A. brevispica	-	-	-	-	40.50	10.50	3.86	Clumped
Non-hosts•	9.33	4.67	1.20*	Random	0.33	3.33	0.10*	Random

+ σ^2/μ: Ratio of the variance to the mean.

-: Species was absent.

•: *C. tomentosa, B. aegyptiaca, G. tembensis, S. renschii, C. sinensis, L. inermis, Acalypha* sp., *A. digitata, A. nubica,* and *A. ataxacantha.*

*: Variance –to-mean ratio did not show a departure from randomness with a Chi-square test ($\alpha = 0.05$).

4.3.2. Spatial distribution of *G. postica* larvae

The distribution of *G. postica* larvae was clumped on all host plants in Imba (Plate 4.1), except the non-host plants, which were randomly distributed (Table 4.3). In the Mumoni forest, larval distribution was clumped on *A. tortilis* but was random on the other host plants. In order of decreasing clumping intensity, larvae of *G. postica* in Imba forest as occurred on the different host plants were *A. elatior* > *A. tortilis* > *A. nilotica*. *G. postica* larvae were more clumped on *A. tortilis* in Mumoni than in Imba forest. Additionally, the degree of randomness of *G. postica* larvae on the non-host plants was higher in Imba than in Mumoni forest. In Mumoni forest, the randomness of larvae was similar on *A. mellifera* and *A. brevispica*, followed by *A. nilotica* and the non-host plants.

Table 4.3: Variance to mean ratios of *G. postica* larvae on host and non-host plant species in Imba and Mumoni forests of Mwingi eastern Kenya, long and short rainy seasons 2006

Plant species	Imba				Mumoni			
	Variance (σ^2)	Mean (μ)	σ^2/μ^+	Pattern	Variance (σ^2)	Mean (μ)	σ^2/μ^+	Pattern
A. tortilis	8.44	3.33	2.53	Clumped	10.47	2.66	3.94	Clumped
A. nilotica	3.97	2.45	1.62	Clumped	1.20	1.74	0.69*	Random
A. elatior	21.52	4.84	4.45	Clumped	-	-	-	-
A. mellifera	-	-	-	-	2.35	2.00	1.18*	Random
A. brevispica	-	-	-	-	0.75	2.00	0.38*	Random
Non-hosts•	4.21	2.75	1.53*	Random	0.71	1.40	0.51*	Random

+ σ^2/μ: Ratio of the variance to the mean.

-: Species was absent.

•: *C. tomentosa, B. aegyptiaca, G. tembensis, S. renschii, C. sinensis, L. inermis, Acalypha* sp., *A. digitata, A. nubica,* and *A. ataxacantha.*

*: Variance –to-mean ratio did not show a departure from randomness with a Chi-square test ($\alpha = 0.05$).

Plate 4.1:   **Final instar larvae of *G. postica* clumped on host plant, *A. nilotica***

                     in Imba forest of Mwingi District.

4.3.3. Spatial distribution of *G. postica* pupae

The distribution of *G. postica* pupae was random on all host and non-host plants in

Imba and Mumoni forests (Table 4.4). In order of decreasing clumping intensity of *G.*

postica pupae on host/non-host plants in Imba forest were non-hosts > *A. elatior* > *A.*

tortilis > A. *nilotica*, and in Mumoni forest were *A. mellifera* = *A. brevispica* > non-

hosts > *A. nilotica* > *A. tortilis*. Generally, the degree of randomness of pupae was

higher in Imba than Mumoni forest.

Table 4.4: Variance to mean ratios of *G. postica* pupae on host and non-host plant species in Imba and Mumoni forests of Mwingi eastern Kenya, long and short rainy seasons 2006

Plant species	Imba				Mumoni			
	Variance (σ^2)	Mean (μ)	σ^2/μ^+	Pattern	Variance (σ^2)	Mean (μ)	σ^2/μ^+	Pattern
A. tortilis	0.60	1.41	0.43*	Random	0.02	1.03	0.02*	Random
A. nilotica	0.24	1.19	0.20*	Random	0.05	1.05	0.05*	Random
A. elatior	0.73	1.44	0.51*	Random	-	-	-	-
A. mellifera	-	-	-	-	0.11	1.11	0.10*	Random
A. brevispica	-	-	-	-	0.11	1.11	0.10*	Random
Non- hosts●	1.00	1.42	0.70*	Random	0.06	1.07	0.06*	Random

+ σ^2/μ: Ratio of the variance to the mean.

-: Species was absent.

●: *C. tomentosa, B. aegyptiaca, G. tembensis, S. renschii, C. sinensis, L. inermis, Acalypha* sp., *A. digitata, A. nubica,* and *A. ataxacantha.*

*: Variance –to-mean ratio did not show a departure from randomness with a Chi-square test ($\alpha = 0.05$).

4.4 Discussion

Information on the relative abundance and distribution of *G. postica* and its host plants in East Africa is lacking or inadequate for making proper management decisions on the conservation and sustainable utilisation of this important wild silkmoth and its host plant species (Kioko *et al.*, 2000a, 2007; Raina 2004; Raina *et al.*, 2007; Fening *et al.*, 2008a; Ngoka *et al.* 2008). This study examined the spatial distribution of larvae, pupae, host and non-host plants of *G. postica* in the Imba and Mumoni forests of eastern Kenya. Variance to the mean ratio data has shown that the host and non-host trees, larvae and pupae of *G. postica* were not uniformly distributed in the two forest habitats, but were either aggregated or random.

Spatial patterns can be used to describe the spatial distribution of individuals within populations, and to develop testable hypotheses about the underlying processes responsible for generating these patterns (such as seed dispersal, competition and herbivory) and other relationships to environmental heterogeneity (Dale, 1999; Fortin and Dale, 2005; Newton, 2008). The aggregated and random distribution of host and non-host plants of *G. postica* can be attributed to the dispersal mechanisms of these tree species and other environmental factors including disturbances by humans and livestock (Fening *et al.*, 2008a). The varying degree of the level of clumping and/or randomness of *G. postica* host, non-host plants, larvae and pupae in both forests indicates the differences in intensity of the selection pressures that determine their distribution. For instance, *A. tortilis* may dominate in secondary vegetation that emerged from an earlier disturbance of the virgin forest by humans or livestock (Dharani, 2006). Seeds of *A. tortilis*, *A. nilotica* and *A. mellifera* are dispersed through animal dung, whereas *A. elatior* seeds are dispersed by flood along river banks

(ICRAF, 1992). These mechanisms of seed dispersal could have influenced the observed distributions. Varied dispersion of host plants is generally a common feature in forest communities in Kenya. For instance, Mbahin *et al.* (2008) revealed that *Anaphe panda* (Boisduval) host trees species, *Bridelia micrantha* Hochst Baillon (Euphorbiaceae) were overdispersed and underdispersed in a mixed indigenous and indigenous forest habitats respectively, of the Kakamega forest of western Kenya.

The current study has revealed that the spatial distribution of *G. postica* larvae was generally clumped on the host plants in Imba forest and on *A. tortilis* in Mumoni forest. This trend of nonrandomness shown by insects can be due to active aggregation or some heterogeneity of the environment (Southwood, 1968; Bartlett, 1975; Veldtman *et al.*, 2007a; Newton, 2008). The behaviour of larvae (Hartland-Rowe, 1992; Anstey *et al.*, 2002), the dispersal characteristics of species (McGeoch and Price, 2004; Newton, 2008), escaping of natural enemies (Guildford, 1992; Wermelinger, 2002; Veldtman *et al.*, 2007a; Fening *et al.*, 2008b) and environmental thermal regimes (Klok and Chown, 1998, 1999;Veldtman *et al.*, 2007a) may all influence spatial distribution of insects. *G. postica* larvae were found to be aggregated at the lower portions of the tree stems during the day where they benefit from the shade provided by the tree canopy and possibly to escape their predators, which are mostly birds (Ngoka, 2003). Veldtman *et al.* (2007a) supported this view that variations in microclimate, such as differences in solar radiation may explain the patterns of *G. postica* larval and cocoon distribution on a tree.

Additionally, the different life stages of a species are subject to diverse conditions which influence their survival and the selection pressure imposed is likely to result in

a variety of behaviours and microhabitat choices, and subsequently variations in distribution (Price, 1997; Veldtman *et al.*, 2007a). As observed in this study, the clumping of *G. postica* larvae on the host plants and the random distribution of pupae are attributable to the fact that most of these larvae discriminate in selecting a preferred site on the host tree for feeding and resting, but do not discriminate in choosing a pupating site. This may also explain the wandering behaviour of the final instar larvae of *G. postica*, which mostly leave the host trees to pupate on the nearby non-host trees resulting in fewer larvae pupating on their host plants. This is likely to be a way of escaping their natural enemies (Fening *et al.*, 2008b). A recent study by Fening *et al.* (2008a) in the same locality revealed that the non-host plants harboured significantly more pupae than the host plants in these two forests. Moreover, when host plants have high larval densities, pupating on the same host plant will decrease the effectiveness of cocoon crypsis as an anti-predator defence (Brower, 1958; Veldtman *et al.*, 2007a).

The current observation that *G. postica* pupal distribution is random among trees agrees with earlier study by Veldtman *et al.* (2007a) in South Africa and Botswana, which revealed that pupal abundance of *Gonometa rufobrunnea* Aurivillius (Lepidoptera: Lasiocampidae) and *G. postica* were generally spatially random among all trees, but they also found that certain trees contribute significantly to the formation of clumps of pupal abundance. Thus, they found that *G. rufobrunnea* pupae were mostly clumped on non-host plants whereas *G. postica* pupae were often clumped on the host plants (Veldtman *et al.*, 2007a).

This study has established that the distribution of *G. postica* larvae, pupae, host and non-host plants is fashioned in a way to increase their chances of survival and this varying trend in distribution must be taken into consideration during any harvesting or sampling plan or efforts aimed at conserving the population of this important wild silkmoth, their host and non-host plant species in the East African *Acacia* Savannas eco-region. Further, the current study has shown that both host and non-host plants should be taken into consideration when sampling for *G. postica* pupae.

CHAPTER FIVE

5 LIFE CYCLE OF *GONOMETA POSTICA* AND MONITORING OF THE ADULT MOTH POPULATION BY LIGHT TRAPPING

5.1 Introduction

Larva of the African wild silkmoth, *Gonometa postica* Walker (Lepidoptera: Lasiocampidae) *is* moderately polyphagous because it feeds only on leaves of two angiosperm families, Mimosaceae and Caesalpiniaceae (Veldtman *et al.*, 2007b). *G. postica* feeds mainly on the *Acacia* and *Brachystegia* spp. (both Mimosaceae) (Hartland-Rowe, 1992; Kioko *et al.*, 2000; Veldtman *et al.*, 2002; Ngoka *et al.*, 2008). It also feeds on the alien, *Prosopis glandulosa* Torrey (Caesalpiniaceae) and *Burkea africana* Hook (Hartland-Rowe, 1992; Veldtman *et al.*, 2007 a, b). There are six larval instar stages with the matured larvae possessing protruding spines on the body (Hartland-Rowe, 1992; Ngoka *et al.*, 2008). Larvae are gregarious with a mean larval developmental time of 53.5 ± 6.2 days on *Acacia elatior* Brenan (Kioko, 1998).

In 24 hours, the silkworm larvae spin silken cocoons in which they pupate. The spun cocoon wall also has protruding spines and may be used in protecting the pupa against natural enemies. The pupal stage (enclosed in a silken cocoon) is the longest period that lasts for over three months (95.9 ± 16.5 days) and it is an adaptation to survive the drought period. In Kenya, *G. postica* has been recorded in Kamaguti in Uasin Gishu District, Nguni in the Mwingi District, and in Wote and Sultan Hamud in the Makueni District (Kioko *et al.*, 2000; Ngoka *et al.*, 2008).

In Nguni, *G. postica* has been reported to have two generations in a year. The first generation occurs between the months of March and September, while the second

generation begins in October and ends in March (Kioko *et al.*, 2000; Kioko *et al.*, 2007). A study by Ngoka *et al.* (2008) in Kamaguti also revealed two distinct generations of *G. postica* per year. The two generations coincide well with the onset of the long (March to July) and short (October to December) rainy seasons, allowing synchronization between larval growth period and larval food availability. *G. postica* has two generations per year in southern Africa, one with and another without diapause (Hartland-Rowe, 1992; Veldtman *et al.*, 2004b).

G. postica is known to lay its eggs on various substrates and thus possesses a potential for wild silk production (Hartland-Rowe, 1992; Kioko, 1998; Ngoka *et al.*, 2008). Detail information on the biology of *G. postica* in different ecological systems is necessary for developing strategies for their sustainable utilisation and conservation. This study explores the biology of *G. postica* emphasizing on the egg laying and substrate preferences by *G. postica* female in a net sleeve cage. Such information is essential in developing a strategic plan for rearing, sustainable utilisation and conservation of this species of economic importance.

Although there are a number of day-flying species of moths that can be found in different habitats, the nocturnal moths are frequently experts in camouflage, so it can be a long and fruitless exercise to simply go out looking for them. However, there are various methods that can be used to attract them to a particular spot, one being to set up a light trap. Light trapping remains an excellent method of determining moth distributions and seasonality (Thomas, 1989; Paul and Martin, 2003; Fening, 2004; Ahmad and Dany, 2006).

The information obtained on light trapping would be essential in monitoring *G. postica* adult moth population and their seasonality.

5.2   Materials and methods

5.2.1   Study sites

The developmental period of *G. postica* larvae on three different food plants was studied in the vicinity of Imba (0° 50' S, 38° 22' E) and Mumoni (0° 32' S, 38° 0' E) forests of Mwingi District of eastern Kenya during the long (March-May) and short rainy (October-December) seasons in 2007. The Imba forest was selected subsequent to an earlier survey on the diversity of silkmoths in which *A. elatior* was found to be an important host plant of *G. postica* in this area (Kioko, 1998). Similarly, Mumoni forest harbours significant biodiversity resources within a complex of thorn trees, including *Acacia* species (Fening *et al.*, 2008a).

5.2.2.   *Gonometa postica* initial population stock

The initial population of *G. postica* was set up from healthy pupae in cocoons collected from host food plants in the study areas in the short rainy season of 2006. The cocoons were enclosed in 2 x 2 x 2 m net sleeve cage for the moths to emerge. Enclosed in the cage was a short-trimmed *Acacia* plant to provide a point of attachment for the emerging moths. The cocoons were attached with strings to the tree branches for the moths to emerge freely. This set-up was placed under a shady tree outdoor.

5.2.3 Oviposition preference experiment in a multiple choice set-up

Freshly emerged moths of the same cohort were isolated and placed in pairs in a net-sleeved cage (1.0 x 1.0 x 0.7 m) for mating and oviposition (Plate 5.1). There were a total of 16 cages and 41 pairs of moths were used for the experiment. All the cages were similar with each having a wooden base with supporting frames all enclosed in a net sleeve. Placed at the center of each cage was a plastic container with a short-trimmed small dry acacia plant (twigs). Hence, each cage had four substrates for moth to choose where to oviposit, i.e. net sleeve, wooden board, plastic container and twigs whereby the moths could lay its eggs. These set-ups were kept indoors at ambient conditions of minimum and maximum temperatures and relative humidity levels of 23.7-27.4 $^{\circ}$C and 52.1-73.6 %, and 23.2-27.5 0°C and 40.1-63.2 % during the long and short rainy seasons, constituting the first and second generations of the moths, respectively. Each pair of moths were placed in one cage to allow mating and oviposition and they were replaced with a new pair after their death. The eggs were collected daily and kept in separate labeled net-sealed containers (0.10 x 0.10 x 0.06 m) for transfer to the field. The eggs were taken to the field once per week as they hatch in about 11 days after laying. The proportion of eggs fertilized was calculated from the number of eggs hatched divided by the total number of eggs laid by a female moth.

Plate 5.1 **Breeding cages for mating by male and female *G. postica* moths in the laboratory.**

5.2.4 Larval development

The fertilised eggs from a mated female moth were kept in a net sleeve tied onto the branches of young *Acacia* trees (Plate 5.2). One hundred first instars of the silkworms were kept in each netsleeve after hatching but were subdivided into 50 silkworms at the 3rd instar stage, as each net sleeve had a holding capacity of about 50 silkworms at their final instar (Plate 5.3). These larvae were reared on their food plants till they spun cocoons (Plate 5.4). The food plants used for rearing included *A. tortilis*, *A. nilotica* and *A. elatior* in Imba, whereas only *A. tortilis* and *A. nilotica* were used in Mumoni, as *A. elatior* was absent. There were ten sets for each host plant species, comprising of ten plants with the net sleeves attached and a holding capacity of 50 matured silkworms.

Plate 5.2   Seeding of *G. postica* eggs on a branch of *Acacia tortilis* enclosed in a net sleeve in Mumoni forest.

Plate 5.3   *G. postica* final instar larvae enclosed in a net sleeve on a branch of *A. nilotica* in Imba forest.

Plate 5.4   *G. postica* cocoons attached to host plant, *A. nilotica* in Imba forest

The period between the hatching of the eggs and the spinning of cocoons was recorded as the larval period. The minimum and maximum temperature and relative humidity were monitored in each experimental site using a digital in/outdoor thermo-hygrometer (model No. ETH529, England, see Plate 5.5) and a rain gauge (Nylex "500", 25mm/250 mm, see Plate 5.6) to measure the rainfall over the period of the study. The average of the minimum and maximum daily temperature and humidity were calculated as the mean in each forest site. The larval period monitoring extended from March to May, and October to December 2007. The temperature, humidity and rainfall data were recorded.

Plate 5.5   **Digital in/outdoor thermo-hygrometer in Imba forest**

Plate 5.6   Nylex rain gauge in Imba forest

5.2.5 Pupal development

Larvae formed silken cocoons at the end of the larval period. The newly formed (about 24 hour old) cocoons were recorded daily. The harvesting was done seven days after spinning to allow the silken cocoons to become dry and the larvae to transform into pupae. After harvesting, the cocoons were kept in separate labelled net-sealed containers (0.15 x 0.15 x 0.11 m) in the laboratory until moth emergence. The time between spinning and emerging date of moth was recorded as the pupal developmental period. The daily minimum and maximum temperature and relative humidity were measured in the laboratory using a digital in/outdoor thermo-hygrometer (model No. ETH529, England).

5.2.6 Adult development

The newly emerged moths were kept in pairs (a male and a female) in a netsleeve cage until they mated and died. The period between moth emergence and death was recorded to confirm the adult moth lifespan.

5.2.7 Light trapping of adult *G. postica* moths

One ultra-violet light trap was set at each site near the Imba and Mumoni forests to monitor the temporal and spatial distribution of *G. postica* adult moths during the period of study. These traps were in operation for two nights per week during the study period as proposed by van den Berg (1990). The moths were collected and prepared for pinning and identification. The sex ratios of *G. postica* moths were determined and their abundance was based on trap catches. Each trap consisted of an ultra-violet lamp with baffles, a funnel and a plastic container on which funnel empties into (Plate 5.7). Moths were attracted to the light at night, hit the baffles and dropped through the funnel into the container containing diluted alcohol (75%). The trap was powered by Chloride exide accumulator battery (12 volts). The *G. postica* moths were collected in the morning at 9 am, by sorting them out from the other moths in the container using a magnifying hand lens. The catches were identified using museum reference collections based at National Museums of Kenya.

Plate 5.7   **Light trap and some *G. postica* males trapped in Imba forest.**

5.2.8   Data analysis

Data on moths' oviposition, sex ratio and adult lifespan was compared using *t* test between forests and seasons ($P \leq 0.05$). Data on oviposition preference of adult moth,

developmental period of *G. postica* larvae and pupae (among host plants and substrate preference for egg laying by adult female) within each season were analysed using proc GLM Analysis of variance (ANOVA) procedure of SAS. When ANOVA showed significant differences between means ($P \leq 0.05$), *post-hoc* mean separation was conducted using the Student Newman-Keul test (SAS Institute Inc., 2003).

5.3   Results

5.3.1   Egg characteristics and incubation

The mean number of eggs laid by a female moth was significantly higher for the first generation moths than the second generation moths in samples taken from Imba and Mumoni forests (Table 5.1). Similarly, the mean total number of egg clusters was significantly higher in the first generation than in the second generation.

The mean egg laying period was significantly longer in the first generation than the second generation in the Imba sample. The mean peak oviposition day and the mean total number of eggs laid on the peak oviposition day were significantly longer and more for the first generation than the second generation for both Imba and Mumoni samples. The mean number of eggs fertilised was significantly higher in the first generation than in the second generation in Imba. However, the mean egg hatching period was significantly higher in the second generation than in the first generation in Mumoni samples.

The number of eggs laid on the rubber container was significantly higher for samples taken from Mumoni than those taken from Imba for the second generation ($df = 46$, $t = -2.415$, $P = 0.0199$). Conversely, the number of eggs laid on the twigs was

significantly higher for the second generation in Imba than from Mumoni (df = 46, t = 2.600, P = 0.0226). Generally, the female moth laid more eggs on the net sleeves, followed by the wooden board, rubber container and twigs (Table 5.2).

Table 5.1   Oviposition patterns of *G. postica* females in Imba and
             Mumoni forests of Mwingi

Site	Mean number of eggs laid per female ± SE		
	Generation I	Generation II	df, *t*, *P* values
Imba	373.44 ± 28.86 aA	241.20 ± 20.36 bA	41, 3.860, 0.0004
Mumoni	321.44 ± 31.96 aA	191.09 ± 17.95 bA	37, 3.813, 0.0005
df, *t*, *P* values	32, 1.211, 0.2348	46, 1.833, 0.0732	
	Mean total number of egg clusters laid per female ± SE		
Imba	22.22 ± 2.08 aA	13.56 ± 1.09 bA	41, 3.969, 0.0003
Mumoni	15.25 ± 1.92 aB	10.26 ± 1.27 bB	37, 2.263, 0.0296
df, *t*, *P* values	32, 2.440, 0.0204	46, 1.982, 0.0534	
	Mean number of egg clusters laid per day ± SE		
Imba	4.52 ± 0.40 aA	3.62 ± 0.26 aA	41, 1.950, 0.0581
Mumoni	3.57 ± 0.43 aA	2.79 ± 0.29 aB	37, 1.555, 0.1285
df, *t*, *P* values	32, 1.617, 0.1158	46, 2.101, 0.0412	
	Mean number of eggs laid per cluster ± SE		
Imba	17.42 ± 0.70 aB	17.75 ± 0.66 aA	688, -0.344, 0.7307
Mumoni	21.15 ± 1.03 aA	18.73 ± 1.15 aA	455, 1.576, 0.1158
df, *t*, *P* values	587, -3.114, 0.0019	556, -0.798, 0.4254	
	Mean egg laying period (days) ± SE		
Imba	5.11 ± 0.47 aA	3.88 ± 0.27 bA	41, 2.427, 0.0197
Mumoni	4.25 ± 0.36 aA	3.43 ± 0.31 aA	37, 1.718, 0.0942
df, *t*, *P* values	32, 1.426, 0.1634	46, 1.100, 0.2771	
	Mean peak oviposition day ± SE		
Imba	6.12 ± 0.59 aA	4.76 ± 0.30 bA	40, 2.258, 0.0295
Mumoni	6.81 ± 0.74 aA	3.87 ± 0.28 bB	37, 4.229, 0.0001
df, *t*, *P* values	31, -0.742, 0.4638	46, 2.189, 0.0337	
	Mean total number of eggs laid on peak oviposition day ± SE		
Imba	164.71 ± 25.56 aA	112.08 ± 9.43 bA	40, 2.203, 0.0334
Mumoni	159.69 ± 22.11 aA	113.22 ± 10.38 bA	37, 2.094, 0.0431
df, *t*, *P* values	31, 0.148, 0.8836	46, -0.081, 0.9355	
	Mean number of eggs fertilised (%) ± SE		
Imba	64.54 ± 4.31 aA	50.25 ± 5.16 bA	28, 2.099, 0.0450
Mumoni	64.94 ± 6.65 aA	58.12 ± 5.92 aA	28, 1.270, 0.2146
df, *t*, *P* values	30, -0.422, 0.6758	27, -1.067, 0.2953	
	Mean egg hatching period (days) ± SE		
Imba	11.05 ± 0.29 aA	11.25 ± 0.31 aA	32, -0.462, 0.6470
Mumoni	10.50 ± 0.27 bA	12.00 ± 0.45 aA	29, -2.928, 0.0066
df, *t*, *P* values	32, 1.694, 0.1724	29, -1.394, 0.1739	

Means within a column followed by the same capital and within a row followed by the same
lower case letter (s) are not significantly different. (*P* ≤ 0.05, *t* test).

Table 5.2 Choice of substrate for egg laying by adult *G. postica* females enclosed in a net sleeve cage in the wild silk laboratory, Mwingi.

| Laying substrate | Mean no. of eggs laid (%) ± *SE* | | | |
| | Generation I | | Generation II | |
	Imba	Mumoni	Imba	Mumoni
Net sleeve	55.02 ± 5.05 aA	51.13 ± 8.25 aA	40.92 ± 5.70 aA	40.57 ± 5.70 aA
Wooden board	37.00 ± 3.83 aB	43.86 ± 8.17 aA	49.56 ± 5.83 aA	40.87 ± 4.72 aA
Plastic container	1.65 ± 0.92 aC	1.80 ± 0.97 aB	5.16 ± 1.83 bB	18.35 ± 5.24 aB
Twig	6.33 ± 3.61 aC	3.20 ± 1.30 aB	4.36 ± 1.67 aB	0.21 ± 0.21 bC
df, *F*, *P* values	3, 43.91, 0.0001	3,15.00, 0.0001	3, 24.90, 0.0001	3, 14.23, 0.0001

Means within a column followed by the same capital letter (*SNK* test) and within a row and forests followed by the same lower case letter (*t* test) are not significantly different at $P = 0.05$

5.3.2 Larval, pupal and adult development

The mean developmental period of *G. postica* larvae varied significantly at each site according to the host plants on which they fed (Table 5.3).On the other hand, the mean pupal duration and adult lifespan varied significantly according to the sex and season (Table 5.4). There was a fairly negative significant correlation between temperature and pupal developmental time for the second season, whereas a weak positive significant correlation occurred between relative humidity (RH) and pupal developmental time over the same period (Table 5.5). Similarly, a fairly negative significant correlation existed between RH and pupal developmental time for the first season, whereas a weak positive correlation occurred between temperature and pupal developmental time over the same period.

Table 5.3   Mean developmental period (± SE) of *G. postica* larvae reared on different food plants, in Imba and Mumoni forests of

Mwingi District, long (March-May) and short (October-December) rainy seasons 2007.

Host plant species	Imba		Mumoni	
	Long rainy season	Short rainy season	Long rainy season	Short rainy season
Larval period (days)				
A. tortilis	72.18 ± 2.56 aA	63.86 ± 0.95 bA	54.67 ± 0.32 bB	58.67 ± 0.85 aB
A. nilotica	64.26 ± 0.64 aB	63.14 ± 0.86 aA	58.00 ± 0.47 bA	63.83 ± 0.54 aA
A. elatior	60.38 ± 1.30 aC	58.59 ± 0.87 aB	-	-
df	2	2	1	1
F	14.48	10.52	25.22	27.35
P	0.0001	0.0001	0.0001	0.0001
Mean field conditions*				
Temperature (^{0}C)	30.48 ± 0.49 a	30.39 ± 1.64 a	28.87 ± 1.19 a	29.77 ± 1.10 a
Relative humidity (%)	40.21 ± 2.35 a	49.88 ± 6.72 a	41.75 ± 8.03 a	53.50 ± 3.26 a
Rainfall (mm)	1.07 ± 0.11 b	1.76 ± 0.02 a	2.63 ± 0.60 a	3.59 ± 0.60 a

- = Species was absent. Means within a column followed by the same capital letter (*SNK* test) and within a row and forest followed by the same lower case letter (*t* test) are not significantly different at P = 0. 05. * Mean daily temperature, humidity, and rainfall.

Table 5.4   Mean pupal duration, adult lifespan and sex ratio ± *SE* for cocoons collected from Imba and Mumoni and kept in the laboratory for moths emergence

Sex	Mean pupal duration (days) ± *SE*					
	Imba			Mumoni		
	Season I	Season II	df, *t*, *P* values	Season I	Season II	df, *t*, *P* values
Males	109.43 ± 2.02 bA	114.44 ± 1.14 aA	127, -2.533, 0.0125	126.10 ± 1.16 aA	100.80 ± 0.44 bB	51, 20.318, 0.0001
Females	111.79 ± 2.94 aA	108.69 ± 2.08 aB	89, 0.8046, 0.4232	116.17 ± 1.55 aB	110.50 ± 1.95 bA	86, 2.303, 0.0237
df, *t*, *P* values	125, -1.005, 0.3169	91, 2.597, 0.0110		87, 4.979, 0.0001	82, -5.067, 0.0001	
	Mean adult lifespan (days) ± *SE*					
Males	2.72 ± 0.08 bB	3.33 ± 0.08 aB	136, -5.388, 0.0001	2.88 ± 0.09 bB	3.21 ± 0.12 aB	74, -2.321, 0.0230
Females	8.67 ± 0.34 aA	6.68 ± 0.24 bA	129, 4.934, 0.0001	10.13 ± 0.35 aA	6.67 ± 0.34 bA	70, 6.235, 0.0001
df, *t*, *P* values	106, -16.930, 0.0001	159, -13.857, 0.0001		94, -19.93, 0.0001	50, -10.198, 0.0001	
	Sex ratio (Female/total collections)					
	0.42 ± 0.03 b	0.52 ± 0.04 a	19, -2.053, 0.0541	0.47 ± 0.01 a	0.40 ± 0.04 a	19, 1.987, 0.0615
Mean lab cds*						
Temp. (⁰C)	25.18 ± 0.10 a	25.31 ± 0.15a	188, -0.706, 0.4814	25.18 ± 0.10 a	25.31 ± 0.15a	188, -0.706, 0.4814
RH (%)	58.30 ± 0.86 a	59.45 ± 0.68 a	188, -0.996, 0.3205	58.30 ± 0.86 a	59.45 ± 0.68 a	188, -0.996, 0.3205

Means within a column followed by the same capital letter (*SNK* test) and within a row and forest followed by the same lower case letter (*t* test) are not significantly different at *P* = 0. 05. Lab cds = laboratory conditions. * = The average of the minimum and maximum daily temperature and humidity was calculated as the mean for the study period.

Table 5.5 Correlating temperature, relative humidity and pupal developmental time for cocoons from Imba and Mumoni forests under laboratory conditions during the long and short rainy seasons of 2007.

Climatic factor	Statistical parameters: r, P and N							
	Imba				Mumoni			
	Season I		Season II		Season I		Season II	
	Males	Females	Males	Females	Males	Females	Males	Females
Temperature	-0.03, 0.7751, 92	0.25, 0.0244*, 80	-0.53, 0.0001*, 67	-0.49, 0.0001*, 60	-0.06, 0.6247, 75	0.02, 0.8722, 78	-0.56, 0.0001*, 62	-0.50, 0.0001*, 60
RH	0.06, 0.5716, 92	-0.51, 0.0001*, 80	0.26, 0.0363*, 67	0.26, 0.0490*, 60	-0.57, 0.0001*, 75	-0.62, 0.0001*, 78	0.35, 0.0056*, 62	0.24, 0.0616, 60

* = Significant.

A situation suggesting diapause occurrence was observed where live female cocoons kept in the laboratory since June 2007 were still not yet emerged as at August 2008 (Plate 5.8). Generally, female moths had a significantly longer lifespan than their male counterparts. In general, the sex ratio was slightly biased in favour of males and was significantly higher in the second season (generation) than the first season (generation) in Imba samples. According to this study, the developmental cycle of *G. postica* from larva to adult ranges between 170-220 (195 ± 25) days or 5.5-7.1 (6.3 ± 0.8) months (Plate 5.9).

Plate 5.8   Diapausing *G. postica* cocoons in the laboratory, Mwingi

Eggs (11-12 days)　　　Larva (55-72 days)　　　Female and male pupae
　　　　　　　　　　　　　　　　　　　　　　　　enclosed in silken cocoons
　　　　　　　　　　　　　　　　　　　　　　　　(101- 126 days)

Mating position (a few hours)　　　Female and male adult moths (3-10 days)
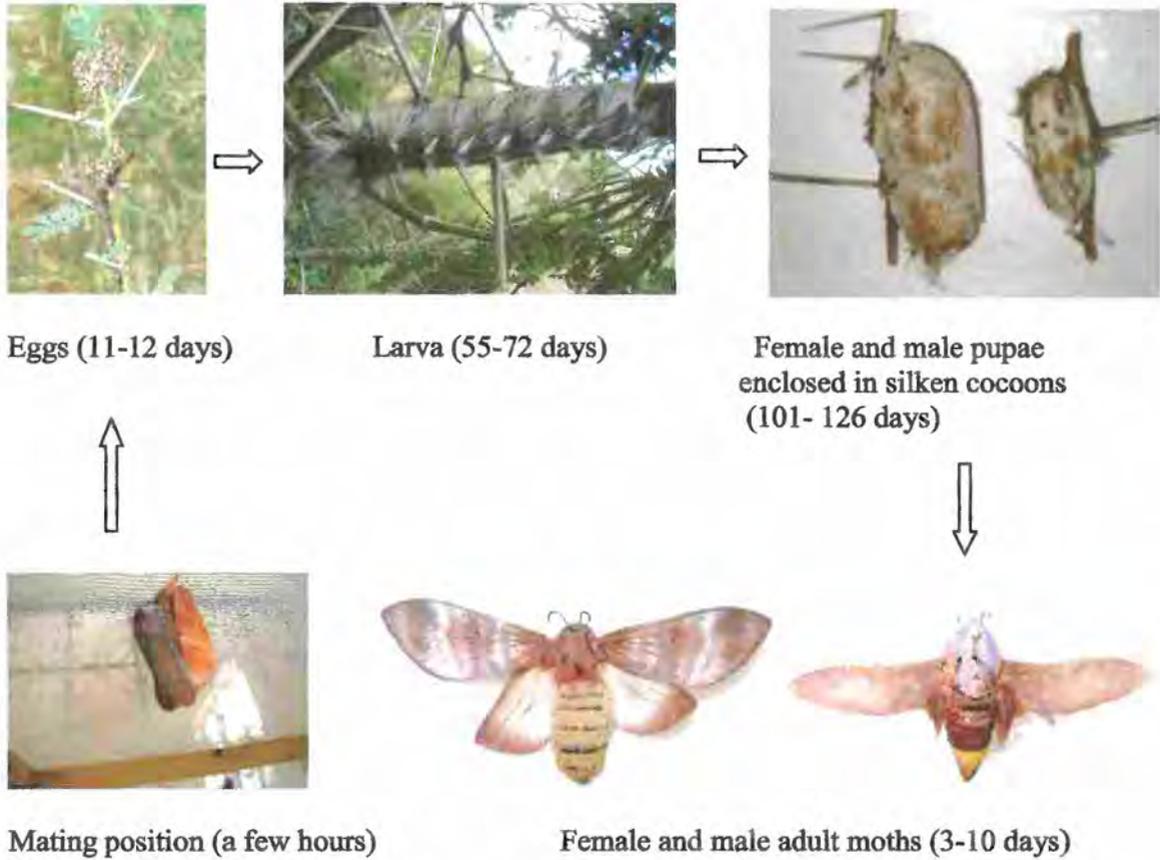
Plate 5.9　　Developmental cycle of *G. postica*

5.3.3　Monitoring of adult *G. postica* population

The light trapping of the adult moth revealed that more males were trapped than the females and that two distinct trapping periods (late October/early November and April) were observed in the year (Table 5.6).

Table 5.6   Abundance of adult *G. postica* moths based on light traps
            recordings in Imba and Mumoni forests of Mwingi, during two
            rainy seasons in 2006 and 2007

| Date of trapping | Imba | | | |
	No. of males	No. of females	Total	Sex ratio (female/total)
24-10-06	1	0	1	0.00
26-10-06	2	1	3	0.33
30-10-06	2	0	2	0.00
03-11-06	1	2	3	0.67
Subtotal	6	3	9	0.33
02-04-07	3	0	3	0.00
09-04-07	13	3	16	0.19
16-04-07	22	1	23	0.04
23-04-07	2	0	2	0.00
Subtotal	40	4	44	0.09
31-10-07	1	0	1	0.00
06-11-07	1	0	1	0.00
Subtotal	2	0	2	0.00
Total	48	7	55	0.13
			Mumoni	
01-04-07	0	1	1	1.00
05-04-07	2	0	2	0.00
13-04-07	2	1	3	0.33
Total	4	2	6	0.33
Grand total	52	9	61	0.15

5.4   Discussion

5.4.1   Oviposition patterns

The egg incubation period compared well with earlier studies in the Mwingi District of eastern Kenya, which had shown *G. postica* eggs to have an incubation period of 11.3 ± 0.1 days in an outdoor environment (Kioko, 1998; Kioko *et al.*, 2007).

However, the incubation period recorded in Kamaguti of western Kenya was higher than the ones observed in this study in Mwingi (Ngoka *et al.*, 2008). This is because, unlike Kamaguti, Mwingi is warm and less humid, thus egg development was faster. The study has revealed that *G. postica* female can lay its eggs on different substrates. This observation also agrees with earlier findings by Okelo (1972), Kioko (1998) and Ngoka *et al.* (2008) who reported that *Gonometa* spp. in Kenya might not be host-specific with regard to substrates when ovipositing. This concurs with Hartland-Rowe (1992) who reported that *G. rufobrunnea* in northern Botswana does not usually lay eggs on its food plant *Colophospermum mopane* Kirk ex Berth (Fabaceae), but on thin grass stems or other herbage beneath bushes, although sometimes it chooses to lay on *C. mopane* leaves. This characteristic behaviour in the African wild silkmoths can be exploited to enhance the laboratory egg production with the aim of reducing egg parasitism that takes place in the field (Ngoka *et al.*, 2008).

5.4.2   Larval, pupal and adult development

The larval period of 55-72 day recorded for *G. postica* in this study agrees with earlier work by Kioko (1998) and Veldtman *et al.* (2007) in Kenya and South Africa respectively with a developmental period of about two months. However, the larval period was longer (73-99 days) for *G. postica* larvae reared on *Acacia* spp. in Kamaguti of western Kenya (Ngoka *et al.*, 2008). The study has revealed that the

longest stage in *G. postica*'s life cycle is the pupal stage, which lasts for over three months. This is the way this moth survives harsh drought conditions by remaining as pupae in the cocoon or sometimes diapausing until the onset of the rains. Some female cocoons reared on *A. tortilis* in Mumoni forest, and harvested in June 2007, remained in diapause in the laboratory in Mwingi up to September 2008.

There was a variation in pupal periods during different seasons of the year. In Mumoni, the longest pupal period for males occurred during the period between the long and short rainy season (May and September), while the shortest period was recorded during the period between the short and long rainy season (December and February 2007). Males started spinning earlier than females, but the female moths emerged earlier or sometimes simultaneously with the males during the breeding season. This explains why males in some seasons seem to take a longer pupal period than the females. The longer pupal period coincides with the cooler months of June–July and the dry spell between August and mid-October in the study area in Kenya (Ngoka *et al.*, 2008). In South Africa, *G. postica* undergoes pupation in early autumn (March to April) for a second generation, which undergoes diapause, with the existing pupae of the first generation emerging the following spring (Hartland-Rowe, 1992; Veldtman *et al.*, 2004b).

The current results have demonstrated that temperature and RH influence pupal developmental time according to the season and the effect is opposite to one another as seen under the laboratory conditions. Increase in RH during the first season, caused a corresponding significant reduction in the pupal developmental time and this may explain the important role of RH in breaking the diapause of *G. postica* pupae.

Increasing RH is the result of good rainfall and this is necessary to ensure that moth emerges only when fresh foliage is available. This enhances the changes of survival when eggs are laid on host plants with enough food resource for larval feeding and also conducive environment for their survival. For instance, a current study by Ahmed and Dany (2006) in Shoulf (Mount Lebanon) revealed that emergence of the pine processionary moth, *Thaumetopoea wilkinsoni* Tams in reference to various weather conditions established a clear relationship between rainfall and moth emergence.

During the second season as seen from the laboratory results, increased temperature caused a corresponding reduction in the pupal developmental time. This could have been as a result of the temperature which was recorded in the laboratory (mean of $25.2 \pm 0.2 \ ^0C$, range of $22.9 - 28.3 \ ^0C$) for the period could have fallen within the optimal, thus favouring the pupal development. That is why increasing the RH was causing an increase in the pupal development time over the same period. A recent study in Southern Africa has revealed that temperature and rainfall before the emergence of adult moths were significantly correlated with their presence/absence (Delport, 2006).

As revealed by this study, the male moth lives for about three days, whereas the female's lifespan ranges between 7-10 days under laboratory conditions. Earlier work by Kioko (1998) established an adult lifespan of 6.4 ± 3.2 days. Veldtman *et al.* (2007b) in South Africa described *G. postica* females as short-lived with a lifespan ranging between 4-7 days. The short lifespan for the moths as compared to the prolonged longevity of the pupae could be an adaptation to increase their chances for survival. The long pupal developmental period enable it to survive drought periods

inside the cocoon. The adult lived for a few days, but ensures the mated female lays their fertilised egg load after which it dies. The moth lacks feeding mouthparts and thus do not feed. Thus, the larval stage is the feeding stage where the insect accumulates all its food reserve.

5.4.3 *Gonometa postica* generations

The light trapping data has revealed two distinct generations of *G. postica* per year in the study area. The two generations coincide well with the onset of the long (April to May) and short (October to December) rainy seasons, thus allowing synchronization between larval growth period and larval food availability. The dry season in East Africa occurs between January to mid-March and August to mid-October, during which *G. postica* undergoes diapause. In the Mwingi District of eastern Kenya, Kioko *et al.* (2000) also observed two generations (with diapause) of *G. postica* per year.

Similarly, larvae of *G. postica* were observed in both Imba and Mumoni forests in April and May, October and November corresponding to the long and short rainy seasons of the year, respectively. Moreover, adult moths of *G. postica* under laboratory conditions emerged between March, April and early May, and September, October and early November also corresponding to the long and short rainy seasons, respectively.

However, in South Africa, Veldtman *et al.* (2004b) observed an intermediate generation of *G. postica* in mid-summer (December to January), with pupation occurring in early autumn (March to April). This suggests that there are two generations of *G. postica* per year in South Africa, one with diapause and the other

without (Hartland-Rowe, 1992; Veldtman *et al.*, 2004b, 2007a, b). Sinha and Chaudhuri (1992) reported a close relationship between rain and the emergence phenology of the tasar silkmoth, *Antheraea mylitta* (Drury) (Lepidoptera: Saturniidae). The natural environment signals its developmental fate and regulates the whole mechanism by which partial synchrony is achieved. Furthermore, the appearance of suitable food for the establishment of young larvae on host plants with abundant leaves during the rainy season also provides optimum conditions for the silkmoths. From a production point of view, having two generations of *G. postica* per year is advantageous to farmers since this allows them to obtain two cocoon harvests a year and an increase in silk production (Raina, 2000; Ngoka *et al.*, 2008).

Sex ratio of the moths caught in the light trap was in favour of males. This is because the males are more active fliers due to their lighter weight and are attracted to the light trap. On the contrary, the females have limited flying ability (Veldtman *et al.*, 2007b) and as result a few of them were light-trapped. The females normally suspend on twigs or their empty cocoon shells after their emergence. They then release attractants that attract males to their vicinity for mating. A similar study in Shoulf (Mount Lebanon) revealed that 84% of the pine processionary moths light-trapped were males and only 16% were females (Ahmad and Dany, 2006). The present study has offered a detailed description of *G. postica* biology necessary for formulating management plans for its semi-captive breeding and sustainable harvesting.

[2]CHAPTER SIX

6 EFFECT OF SEASON AND LARVAL FOOD PLANTS ON THE

QUALITY OF *GONOMETA POSTICA* (LEPIDOPTERA:

LASIOCAMPIDAE) COCOONS

6.1 Introduction

The African wild silkmoth, *Gonometa postica* Walker (Lepidoptera: Lasiocampidae)

is currently the species being utilised for commercial wild silk production in Mwingi,

Kenya (Kioko *et al.*, 2007; Fening *et al.*, 2008a). It is known to produce high-quality

silk, contending with that of the domesticated silkmoth, *Bombyx mori* L.

(Lepidoptera: Bombycidae) (Hartland-Rowe, 1992; Kioko *et al.*, 2000; Raina and

Kioko, 2000; McGeoch, 2002; Wayne *et al.*, 2005; Veldtman *et al.*, 2007a,b; Ngoka

et al., 2008).

Previous studies in Nguni and Kamaguti in Eastern and Western Kenya, respectively,

have demonstrated that semi-captive rearing of *G. postica* larvae in netsleeves on

branches of *Acacia elatior* Brenan, *Acacia mearnsii* de Wild and *Acacia hockii* de

Wild can be used to raise large numbers of the silkworms to augment the natural

population of *G. postica* in the field (Kioko, 1998; Ngoka *et al.* 2008).

A current survey in the Imba and Mumoni forests of Mwingi District of eastern Kenya

has identified *Acacia tortilis* (Forssk.), *Acacia nilotica* (L.) Del and *A. elatior* as

among the important host plants of *G. postica* larvae (Fening *et al.*, 2008a). They are

utilized for the semi-captive rearing of this wild silkmoth by silk farmers to supply

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[2] This chapter is submitted as: Effect of season and larval food plants on the quality of *Gonometa postica* (Lepidoptera: Lasiocampidae) cocoons.

cocoons to the silk marketplace in Mwingi. The objective of this study was to determine how larval food plants, season and site affect the quality of *G. postica* pupae (enclosed in a silken cocoon). Data obtained from semi-captive rearing of *G. postica* larvae and data from wild populations was recorded and analysed. The information obtained will assist in improving wild silkmoth productivity and the production of quality cocoons.

6.2 Materials and methods

6.2.1 Study sites

The developmental period of *G. postica* larvae reared in semi-captivity and their cocoon quality on three different food plants were studied near the vicinity of the Imba (0° 50' S, 38° 22' E) and Mumoni (0° 32' S, 38° 0' E) forests of Mwingi District of Eastern Kenya during the long (March-May) and short rainy (October-December) seasons in 2007. In addition, *G. postica* cocoons were sampled from wild populations on these host plants in the two forests during the long and short rainy seasons in 2006 for analysis of their quality. The Imba forest was selected subsequent to an earlier survey on the diversity of silkmoths, in which *A. elatior* was found to be an important host plant of *G. postica* in this area (Kioko *et al.*, 2000). Similarly, the Mumoni forest harbors significant biodiversity resources within a complex of thorn trees, including *Acacia* species (Fening *et al.*, 2008a).

6.2.2 *Gonometa postica* initial population stock

The initial population of *G. postica* was set up from healthy pupae in cocoons collected from host food plants in the study areas in the short rainy season of 2006. The cocoons were kept in a 2 x 2 x 2 m net sleeve cages until emergence of moths.

Enclosed in the cage was a short-trimmed *Acacia* plant to provide a point of attachment for the emerging moths. The cocoons were attached with strings to branches of the *Acacia* tree for the moths to emerge freely. This set-up was under a shady tree outdoor.

6.2.3 Egg production

Freshly emerged female and male moths were isolated in pairs from the breeding stock and placed in another netsleeve cage (1.0 x 1.0 x 0.7 m) for mating and egg laying. This set-up was indoor to prevent egg parasitism. A total of sixty pairs were used for each season and thirty for each forest site. They were collected daily and kept in separate labeled, net-sealed containers (0.10 x 0.10 x 0.06 m) for transfer to the field. The eggs were taken to the field once per week as eggs hatch in about 11 days after they are laid.

6.2.4 Larval developmental period

The eggs from a mated female moth were kept in a net sleeve tied onto the branches of young *Acacia* trees of similar age and foliage density in the opening to ensure equitable distribution of sunlight. Fifty *G. postica* larvae were kept in each net sleeve and these larvae were reared on the same food plants till they spun cocoons. The food plants used for rearing larvae included *A. tortilis*, *A. nilotica* (Plate 6.1) and *A. elatior* (Plate 6.2) in Imba, whereas only *A. tortilis* (Plate 6.3) and *A. nilotica* were used in Mumoni, where *A. elatior* was absent. There were ten sets for each host plant species, comprising of ten plants with the net sleeves attached and a holding capacity of 50 matured larvae. The period between hatching of the eggs and spinning of cocoons was

recorded as the larval period. The ease of rearing was measured as those food plants that allow shorter larval developmental period.

The minimum and maximum temperature and relative humidity were monitored in each forest site using a digital in/outdoor thermo-hygrometer (model No. ETH529, England) and a rain gauge (Nylex "500", 25mm/250 mm) to measure rainfall over the study period. Averages of the minimum and maximum daily temperature and humidity were calculated as the mean in each forest site. Temperature, humidity and rainfall data were taken during the larval monitoring periods, which lasted from March to May, and October to December 2007.

Plate 6.1   *G. postica* **larvae and pupae on** *A. nilotica* **in Imba forest**

Plate 6.2   *G. postica* **larvae and pupae on** *A. elatior* **in Imba forest**

Plate 6.3   *G. postica* **larvae and pupae on** *A. tortilis* **in Mumoni forest**

6.2.5   Measurement of cocoon weight and size (length and width)

Newly formed cocoons were harvested seven days after spinning, giving time for their transformation of the larval stage into pupae inside the silken cocoons. The cocoons were kept in separate labeled net-sealed containers (0.15 x 0.15 x 0.11 m) and transported to the laboratory. An electronic balance (Mettler AM 100, Switzerland) was used to weigh each cocoon mass. Cocoon size was measured by vernier calipers. Similarly, the weight and size of cocoons collected from the natural population (50 cocoons per host plant) were also determined. This was replicated three times in each forest. All cocoons were separated into males and females before measurements, as *G. postica* shows sexual dimorphism with females being significantly larger than their male counterparts.

The weight of a cocoon always has a significant positive correlation with the amount of raw silk produced, and therefore can be used to determine its quality for silk fiber production (Kioko, 1998; Ngoka, 2003). In this study, the quality of the cocoons was assessed by their weight and size, with the heaviest weight and largest size rated as the best.

6.2.6 Statistical analysis

Data on the developmental period of *G. postica* larvae, cocoon weight and size according to sex and experiment (i.e. semi-captive rearing and wild), and climatic conditions were analysed using proc GLM Analysis of variance (ANOVA) procedure of SAS. When ANOVA showed significant differences between means (P ≤ 0.05), *post-hoc* mean separation was conducted using the Student Newman-Keul test (SAS Institute Inc., 2003). Comparison between the two seasons for each forest was done using Student t-test (P ≤ 0.05). Rainfall data was correlated against the larval developmental time.

6.3 Results

6.3.1 Semi-captivity rearing of *G. postica* larvae

During the long rainy season, *Gonometa postica* larvae reared on *A. elatior* had the shortest developmental period followed by *A. nilotica* and *A. tortilis* (Table 5.3). The larval developmental period was again shortest for larvae reared on *A. elatior*, but similar for both *A. nilotica* and *A. tortilis* during the short rainy season. In Mumoni, larval developmental period was significantly shorter on *A. tortilis* than on *A. nilotica* during both seasons.

There was a fairly good negative correlation between rainfall and larval developmental time on *A. elatior* ($r = -0.46$, $P > 0.05$; $r = -0.55$, $P > 0.05$) and *A. nilotica* ($r = -0.51$, $P > 0.05$; $r = -0.60$, $P > 0.05$) in Imba forest for both seasons. A negative and positive correlation existed between rainfall and larval developmental time on *A. tortilis* in Imba for the first and second seasons, respectively ($r = -0.39$, $P > 0.05$; $r = 0.10$, $P > 0.05$). A very weak negative and positive correlation existed

between rainfall and larval developmental time on *A. tortilis* in Mumoni for the first and second seasons, respectively ($r = -0.17$, $P > 0.05$; $r = 0.00004$, $P > 0.05$). There was a weak positive correlation between rainfall and larval developmental time on *A. nilotica* for both seasons in Mumoni forest ($r = 0.09$, $P > 0.05$; $r = 0.27$, $P > 0.05$).

The mean rainfall recorded during the short rainy season was significantly higher than that of the long rainy season in Imba ($df = 4$, $t = -3.981$, $P = 0.0164$) and this corresponds with a significantly shorter larval developmental period on *A. tortilis* during the short than the long rainy season in Imba ($df = 29$, $t = 2.720$, $P = 0.0109$). In Mumoni, the larval developmental period was significantly shorter during the long than the short rainy season on both *A. tortilis* and *A. nilotica* ($df = 34$, $t = -4.172$, $P < 0.0001$; $df = 51$, $t = -8.102$, $P < 0.0001$), although the mean rainfall recorded during the same period were similar for both seasons ($df = 4$, $t = -1.125$, $P = 0.3234$).

Generally, the weight, length and width of female and male cocoons from *A. elatior* were significantly heavier, longer and wider than their counterparts from *A. tortilis* and *A. nilotica* in Imba (Tables 6.1 and 6.2). Moreover, the weight and width of *G. postica* female and male cocoons were significantly higher for larvae reared on *A. elatior* for the short than the long rainy season, respectively ($df = 88$, $t = -4.687$, $P < 0.0001$ and $df = 8$, $t = -2.770$, $P = 0.0068$; $df = 98$, $t = -8.554$, $P < 0.0001$ and $df = 98$, $t = -2.501$, $P = 0.0141$) (Tables 6.1 and 6.2). In the Imba forest, the weight, length and width of the male cocoons reared on *A. tortilis* was significantly higher during the short than for the long rainy season ($df = 93$, $t = -13.950$, $P < 0.0001$; $df = 93$, $t = -13.090$, $P < 0.0001$ and $df = 93$, $t = -6.489$, $P < 0.0001$), whereas for female cocoons, only the length of the cocoons was significant ($df = 64$, $t = -5.220$, $P < 0.0001$).

Similarly, female and male cocoons from *A. nilotica* were significantly heavier, longer and wider during the short than the long rainy season in Imba, respectively (*df* = 72, *t* = -6.363, *P* < 0.0001; *df* = 60, *t* = -8.816, *P* < 0.0001; *df* = 72, *t* = -9.616, *P* < 0.0001 and *df* = 173, *t* = -16.711, *P* < 0.0001; *df* = 173, *t* = -16.370, *P* < 0.0001; *df* = 173, *t* = -8.756, *P* < 0.0001).

However, in the Mumoni forest, the long rainy season yielded significantly heavier, longer and wider female and male cocoons reared on *A. tortilis* than those in the short rainy season, respectively (Tables 6.1 and 6.2) (*df* = 52, *t* = 6.188, *P* < 0.0001; *df* = 52, *t* = 8.497, *P* < 0.0001; *df* = 52, *t* = 8.601, *P* < 0.0001 and *df* = 63, *t* = 3.402, *P* = 0.0012; *df* = 49, *t* = 15.765, *P* < 0.0001). Generally, in Mumoni, male cocoons during both seasons and females during the long season only, reared on *A. tortilis* were significantly heavier, longer and wider than those reared on *A. nilotica* (Tables 6.1 and 6.2); however, during the short season, female cocoons from *A. nilotica* were significantly heavier and longer than those reared on *A. tortilis* (Table 6.1).

Table 6.1 Mean (± *SE*) weight, length and width of female *G. postica* cocoons reared on different food plants in Imba and Mumoni forests, long (March-May) and short (October-December) rainy seasons of 2007

Host plant species	Imba		Mumoni	
	Long rains season	Short rains season	Long rains season	Short rains season
Mean weight of cocoon (g)				
A. elatior	6.50 ± 0.14bA	7.77 ± 0.25aA	-	-
A. tortilis	5.58 ± 0.21aB	5.85 ± 0.23aB	7.14 ± 0.16aA	5.62 ± 0.18bB
A. nilotica	3.96 ± 0.14bC	6.33 ± 0.30aB	5.93 ± 0.06aB	5.97 ± 0.05aA
df	2	2	1	1
F	67.27	14.55	49.59	4.43
P	0.0001	0.0001	0.0001	0.0396
Mean length of cocoon (cm)				
A. elatior	5.01 ± 0.04aA	5.06 ± 0.05aA	-	-
A. tortilis	4.34 ± 0.06bB	4.79 ± 0.06aB	5.13 ± 0.06aA	4.35 ± 0.07bB
A. nilotica	4.16 ± 0.05bC	4.94 ± 0.06aAB	4.83 ± 0.02aB	4.84 ± 0.02aA
df	2	2	1	1
F	83.02	5.82	22.24	73.13
P	0.0001	0.0039	0.0001	0.0001
Mean width of cocoon (cm)				
A. elatior	2.08 ± 0.01bA	2.16 ± 0.03aA	-	-
A. tortilis	1.94 ± 0.01aB	1.95 ± 0.02aB	2.27 ± 0.06aA	1.97 ± 0.02bA
A. nilotica	1.75 ± 0.02bC	2.11 ± 0.03aA	1.93 ± 0.01aB	1.94 ± 0.01aA
df	2	2	1	1
F	107.83	14.58	150.23	2.30
P	0.0001	0.0001	0.0001	0.1347

- = Host plant species was absent. Means within a column followed by the same capital letter (*SNK* test) and within a row and forest followed by the same lower case letter (*t* test) are not significantly different at $P = 0.05$

Table 6.2: Mean (± SE) weight, length and width of male *G. postica* cocoons reared on different food plants in Imba and Mumoni forests, long (March-May) and short (October-December) rainy seasons of 2007.

Host plant species	Imba		Mumoni	
	Long rains season	Short rains season	Long rains season	Short rains season
Mean weight of cocoon (g)				
A. elatior	2.50 ± 0.13bA	3.75 ± 0.06aA	-	-
A. tortilis	1.64 ± 0.06bB	2.86 ± 0.05aC	3.14 ± 0.01aA	2.87 ± 0.07bA
A. nilotica	2.30 ± 0.05bA	3.22 ± 0.30aB	2.68 ± 0.04aB	2.73 ± 0.05aA
df	2	2	1	1
F	18.65	87.01	143.24	2.79
P	0.0001	0.0001	0.0001	0.0996
Mean length of cocoon (cm)				
A. elatior	4.03 ± 0.04aA	4.11 ± 0.03aA	-	-
A. tortilis	3.28 ± 0.04bC	3.97 ± 0.03aB	4.19 ± 0.01aA	3.72 ± 0.02bA
A. nilotica	3.58 ± 0.03bB	4.15 ± 0.02aA	3.63 ± 0.01aB	3.65 ± 0.02aB
df	2	2	1	1
F	87.46	14.14	514.07	4.79
P	0.0001	0.0001	0.0001	0.0321
Mean width of cocoon (cm)				
A. elatior	1.71 ± 0.03bA	1.79 ± 0.02aA	-	-
A. tortilis	1.44 ± 0.01bB	1.58 ± 0.01aC	1.73 ± 0.01aA	1.70 ± 0.01aA
A. nilotica	1.47 ± 0.01bB	1.63 ± 0.01aB	1.52 ± 0.01aB	1.53 ± 0.01aB
df	2	2	1	1
F	54.50	55.99	229.38	92.87
P	0.0001	0.0001	0.0001	0.0001

- = Host plant species was absent. Means within a column followed by the same capital letter (*SNK* test) and within a row and forest followed by the same lower case letter (*t* test) are not significantly different at $P = 0.05$

6.3.2. Wild cocoons collection

Weights, lengths and widths of cocoons collected from the natural population did not vary significantly among food plants, but varied according to seasons (Tables 6.3 and 6.4). Thus, the weight and length of female cocoons from *A. elatior* in Imba forest were significantly heavier and longer during the short than the long rainy season ($df = 58$, $t = -2.070$, $P = 0.0429$ and $df = 58$, $t = -2.011$, $P = 0.0490$).

Table 6.3:   Mean (± SE) weight, length and width of female *G. postica* cocoons from the natural population on different food plants in Imba and Mumoni forests of Mwingi District, long (March-May) and short (October-December) rainy seasons 2006.

Host plant species	Imba		Mumoni	
	Long rains season	Short rains season	Long rains season	Short rains season
Mean weight of cocoon (g)				
A. elatior	9.01 ± 0.35bA	9.76 ± 0.18aA	-	-
A. tortilis	9.01 ± 0.37aA	9.69 ± 0.35aA	*	8.13 ± 0.25A
A. nilotica	8.94 ± 0.37aA	9.70 ± 0.27aA	*	8.38 ± 0.24A
df	2	2		1
F	0.01	0.02		0.50
P	0.9872	0.9775		0.04855
Mean length of cocoon (cm)				
A. elatior	5.36 ± 0.07bA	5.51 ± 0.04aA	-	-
A. tortilis	5.32 ± 0.07aA	5.37 ± 0.07aA	*	5.29 ± 0.07A
A. nilotica	5.35 ± 0.05aA	5.47 ± 0.06aA	*	5.28 ± 0.05A
df	2	2		1
F	0.10	1.28		0.01
P	0.9072	0.2826		0.9439
Mean width of cocoon (cm)				
A. elatior	2.32 ± 0.04aA	2.37 ± 0.03aA	-	-
A. tortilis	2.31 ± 0.03aA	2.35 ± 0.03aA	*	2.24 ± 0.04A
A. nilotica	2.26 ± 0.04aA	2.35 ± 0.02aA	*	2.22 ± 0.03A
df	2	2		1
F	0.48	0.34		0.17
P	0.6236	0.7098		0.6863

- = Species was absent. * = Cocoons were absent. Means within a column followed by the same capital letter (*SNK* test) and within a row and forest followed by the same lower case letter (*t* test) are not significantly different at $P = 0.05$

Table 6.4: Mean (± SE) weigh, length and width of male *G. postica* cocoons from the natural population on different food plants in Imba and Mumoni forests of Mwingi District, long (March-May) and short (October-December) rainy seasons 2006.

Host plant species	Imba		Mumoni	
	Long rains season	Short rains season	Long rains season	Short rains season
Mean weight of cocoon (g)				
A. elatior	3.62 ± 0.10aA	3.82 ± 0.07aA	-	-
A. tortilis	3.86 ± 0.13aA	3.96 ± 0.08aA	*	2.79 ± 0.13A
A. nilotica	3.90 ± 0.13aA	3.81 ± 0.07aA	*	3.09 ± 0.05A
df	2	2		1
F	1.62	0.88		0.0689
P	0.2060	0.4182		
Mean length of cocoon (cm)				
A. elatior	4.10 ± 0.04aA	4.19 ± 0.04aA	-	-
A. tortilis	4.22 ± 0.05aA	4.29 ± 0.03aA	*	3.80 ± 0.07A
A. nilotica	4.26 ± 0.05aA	4.27 ± 0.03aA	*	3.96 ± 0.04A
df	2	2		1
F	3.13	2.11		3.28
P	0.0495	0.1282		0.0773
Mean width of cocoon (cm)				
A. elatior	1.84 ± 0.03aA	1.82 ± 0.01aA	-	-
A. tortilis	1.85 ± 0.02aA	1.78 ± 0.03aA	*	1.69 ± 0.07A
A. nilotica	1.86 ± 0.02aA	1.80 ± 0.01aA	*	1.64 ± 0.02A
df	2	2		1
F	0.18	1.50		3.56
P	0.8365	0.2304		0.0659

= Species was absent. * = Cocoons were absent. Means within a column followed by the same capital letter (*SNK* test) and within a row and forest followed by the same lower case letter (*t* test) are not significantly different at $P = 0.05$.

6.4   Discussion

This study has shown that the quality of *G. postica* cocoons differ according to the larval food plants, seasons and sites. This was applicable to the larvae reared under semi-captivity for the 2007 seasons but was not valid for the cocoons sampled from the wild natural population, where the cocoon quality was similar irrespective of the host food plant during the 2006 seasons. The key factor here might have been the quality of the larval food plant, where larvae were confined to a single host plant in semi-captivity. But for the cocoons sampled from the wild population where larval mobility was not restricted, it was possible that the larvae might have fed on more than a single food plant before finally pupating on one of them, thus the effect of each host plants cannot easily be quantified. Variation in rainfall and its effect on food availability may partly explain the differences in the cocoon quality observed for different sites and seasons.

The current study has identified the riverine *Acacia*, *A. elatior* as the most suitable food plant for raising *G. postica* larvae in semi-captivity in terms of the quality of cocoons produced, and the ease of rearing in the Imba forest. This might be due to the fresh leaves of *A. elatior* and possibly its suitability for feeding. A recent study in the same locality revealed that *A. elatior* significantly habours more larvae than *A. tortilis* and *A. nilotica* from a survey of wild populations (Fening *et al.*, 2008a). Shekar and Hardingham (1995) stated that the quality of *Bombyx mori* L. cocoon produced depends on the quality of mulberry leaf on which the larva feeds. According to their study, freshness of leaves was an important factor that affects quality and suitability for feeding mulberry silkworms. In this study, both *A. tortilis* and *A. nilotica* produced

good quality cocoons in the Imba and Mumoni forests when larvae were reared in semi-captivity. Thus, these two host plants may have similar leaf suitability and preference by *G. postica* larvae for feeding. Therefore, *A. tortilis* and *A. nilotica* were found to habour similar number of *G. postica* larvae in the Imba forests of Mwingi, under natural conditions (Fening *et al.*, 2008a).

Comparing the cocoon weight and the size obtained from the current study (those reared in semi-captivity and sampled from the wild population) with the results obtained by Kioko (1998), Veldtman *et al.* (2002) and Ngoka *et al.* (2008), it can be concluded that the cocoons produced from this study competes well with theirs and thus have good quality and a great potential for raw silk fiber production.

In this study, the larval developmental period on the different food plants and sites was shorter than the results obtained by Ngoka *et al.* (2008), respectively on *A. hockii* and *A. mearnsii* in Kamaguti of Kenya. However, earlier work by Kioko (1998) recorded a much shorter developmental period on larvae raised on *A. elatior* in Nguni. Despite the fact that the developmental period for larvae reared on *A. elatior* obtained in this study was slightly longer than the one recorded by Kioko (1998), it was the shortest period when compared to its counterparts reared on *A. tortilis* and *A. nilotica* in the Imba forest.

The current study has revealed that, in one instance, the larval developmental period was shorter in Imba during the short rainy season where the rainfall was higher. This is because good rainfall is crucial for obtaining fresh leaves from food plants for the larvae to feed on. Since larva is the only feeding stage, the developmental differences

could be due to the effect of host food plant leaves, which were not covered in this study. This opinion is supported by earlier work by Ngoka *et al.* (2008) in Kamaguti. Also, the study has shown that rainfall of an area may be an important factor in the development of wild silkmoths. Thus, the hypothesis that climatic conditions and not latitudinal position influence the abundance and size of cocoons in *Gonometa* spp. still needs to be validated (Veldtman *et al.*, 2007a; Ngoka *et al.*, 2008).

CHAPTER SEVEN

7   MONITORING WILD SILKMOTH, *GONOMETA POSTICA*

WALKERABUNDANCE, HOST PLANT DIVERSITY AND

DISTRIBUTION IN IMBA AND MUMONI WOODLANDS IN

MWINGI, KENYA

7.1   Introduction

In East Africa, as elsewhere in the world, there is increasing concern for biodiversity and its sustainable utilisation and conservation. Since some solutions lie in introducing economic incentives that integrate conservation with the economic development of the local people, a need exists to document some of the biological resources that can be used for both conservation and income generation (Kioko *et al.*, 1999, 2000; Raina and Kioko, 2000; Raina *et al.*, 2007).

The Imba (732 ha) and Mumoni (10,442 ha) forests are two of the five forest reserves of Mwingi District, Eastern Kenya, that serve as major sources of fuel wood and poles for rural and urban markets (Abeele *et al.*, 2005). The Mumoni hills provide an important water catchment for the local population. These forests harbour significant biodiversity resources within a complex of thorn tree (*Acacia, Commiphora*) woodland communities (Kigomo, 2001; Abeele *et al.*, 2005; Kioko *et al.*, 2007; Raina *et al.*, 2007).

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[3] Fening, O.K., Kioko, E.N., Raina, S.K. and Mueke, J.M. (2008). Monitoring wild silkmoth, *Gonometa postica* Walker, abundance, host plant diversity and distribution in Imba and Mumoni woodlands in Mwingi, Kenya. *International Journal of Biodiversity Science and Management* 4: 104-111.

About 70% of the population in Mwingi District live below the poverty line (< 1US $ / day per person) (Mwingi District Development Plan 1999; Rubyogo *et al.*, 2005) with the poorest inhabitants residing in the driest divisions in the district (Mwingi District Development Plan, 2002). These forest resources have therefore degraded rapidly through unsustainable practices, such as charcoal burning (mostly *Acacia* spp.) as a means of survival (Raina *et al.*, 2007). Through the intervention of the International Centre of Insect Physiology and Ecology (ICIPE)'*s* Commercial Insects Programme (CIP) in 1996, communities adjacent to the Imba and Mumoni forests are now trained and are actively involved in beekeeping and wild sericulture on the *Acacia* species predominant in the area. A reversal in the degradation trend has taken place, as the forest is now regenerated through the conservation of bees, wild silkmoths and their host plant species (Raina and Kioko, 2000; Kioko *et al.*, 2007; Raina 2004; Raina *et al.* 2000, 2007).

This study seeks to quantify the abundance of *Gonometa postica* Walker larvae and pupae and the diversity, density and distribution of its host plants, so as to enhance the monitoring and conservation of the silkmoth and its host plant species in the Imba and Mumoni forests. Such monitoring is needed for assessment of the impact of the CIP, which aims to use honeybees and silkmoths for income generation, enhancement of livelihoods and biodiversity conservation in fragile ecosystems (Raina *et al.*, 2007).

7.2 Materials and methods

7.2.1 Study sites

The study was carried out in 2006 in the Imba and Mumoni forests of Mwingi District in Eastern Kenya (Figure 4.1), during the long rains of April-May and short rains of October-December corresponding to respectively, the first and second generations of wild silkmoths. In each forest, three sites were selected [i.e., site 1 (0° 51' S, 38° 22' E), site 2 (0° 50' S, 38° 22' E) and site 3 (0° 50' S, 38° 23' E) in the Imba forest, and site1 (0° 36' S, 38° 1' E), site 2 (0° 34' S, 38°, 2' E) and site 3 (0° 32' S, 38° 0' E) in the Mumoni forest]. Distances between sites within a forest were greater than 1 km. The sites were chosen systematically to reflect the different zones (i.e., farmland, buffer and core) based on the knowledge about the forest zonation and the availability of *G. postica* larvae or cocoons, at least 40 per site (Veldtman *et al.*, 2007a,b).

7.2.2 Abundance of *G. postica* larvae, pupae and its host plant diversity, density and distribution

A survey of abundance of *G. postica* larvae, pupae and host plants was undertaken in the long rainy season in 2006. One hundred primary host trees of *G. postica* were sampled in each forest site by demarcating approximately the rectangular area incorporating the 100 trees (Veldtman *et al.*, 2002, 2007a, b). This was replicated three times in each forest. Each tree was thoroughly inspected and the number of *G. postica* larvae or pupae (enclosed in a spun cocoon) seen were counted and recorded. The larvae observed were in the fourth, fifth and sixth instar stages. Those tree species where *G. postica* larvae were found actively feeding were considered primary or major host plants. Tree species in which pupae or G. *postica* final (sixth) instar larvae were found, and where no feeding was observed, were not used to determine host

range, as these larvae may have moved there only for pupation. Thus these trees were categorised as minor host (non-host) plant species (Veldtman, 2004). Only trees taller than 1 m were included in the survey. The first host tree (called the START TREE) was chosen by finding at least one larva or pupae of *G. postica* on it. This tree was marked as 1 and the others followed accordingly to the 100th tree. In addition to the 100 major host tree species, minor host tree species within the defined area (grid) having *G. postica* pupae were also counted and recorded as 101th tree, 102nd tree, up to the last. A hand held Global Positioning System (GPS: Garmin Geko 101) was used to determine the geographical position of each tree at the main trunk (Veldtman and McGeoch 2004; Veldtman *et al*, 2007a).

The density of each major host species was determined as the number of that host plant species per unit or demarcated area in m^2. The area encompassing the hundred primary host trees differs according to site, due to differences in the tree canopies at the different sites. Host plant samples were pressed in newspapers and sent to the herbarium at National Museums of Kenya in Nairobi for identification.

7.2.3 Host tree growth characteristics

Tree growth characteristics including plant height, canopy (width), trunk diameter (girth) and number of branches were measured for both major and minor host plants in each site. A visual estimate of the height of each tree was made to the nearest metre (m) (Veldtman, 2004b). The width of the tree canopy was measured with a measuring tape (100 m long surveyors' tape). The diameter at breast height (dbh) of each tree was measured and standardised at 1.3 m (Dallmeier, 1992). Trees that had extensive branching below breast height had their diameter measured at the point just before

they divided into branches. The number of branches emanating from the main tree trunk was counted and recorded.

7.2.4 Farmers activities within the forest and involvement in conservation initiatives

A focus group discussion was held among the wild silkmoth farmers living near the Imba and Mumoni forests. They discussed how human activities have impacted on the forests and their role in helping to reverse the trend in forest degradation. The discussions were conducted in their local language (*Kamba*) and interpreted in English for recording the necessary information. The research team only served as facilitators of the discussions.

7.2.5 Data analysis

Data on host plant abundance for *G. postica* were analysed to quantify the host plant diversity across the two forests. The Shannon diversity index $(H') = -\sum p_i \ln p_i$ was calculated, with p_i = the proportional abundance of the ith species $(p_i = n_i / N)$, N = total abundance for all species sampled, and n_i = abundance for each species of host plant (Magurran, 1988). The Shannon evenness $(E) = H' / \ln S$, was determined where S = the number of species sampled (Kempton, 2002). A t test was used to compare the diversity across the two forest sites. Arc-View GIS 3.2 software (Garmin Ltd., 2002) was used to map the geo-reference data for host plant species of *G. postica*.

Data on abundance of *G. postica* larvae, pupae, host plant characteristics (height, canopy size, girth and number of branches) and host species density for the two forests were analysed using the Analysis of variance (ANOVA) procedure of SAS.

When ANOVA showed significance differences between means ($P < 0.05$), *post-hoc* mean separation was conducted using the Student Newman-Keul test (SAS Institute Inc., 2001). Data on the abundance of *G. postica* larvae and pupae was log transformed before analysis. Back-transformed means are presented.

7.3   Results

7.3.1   Abundance of *G. postica* larvae, pupae and its host plant diversity, density and distribution

The major host plants of *G. postica* larvae included *Acacia tortilis* (Forssk.) Hayne (Momosaceae), *Acacia elatior* Brenan and *Acacia nilotica* (L.) Del. in the Imba forest and *Acacia tortilis*, *Acacia nilotica*, *Acacia mellifera* (Vahl) Benth and *Acacia brevispica* Harms in the Mumoni forest (Figure 7.1 and Plate 7.1). Minor host plants with non-feeding *G. postica* larvae and pupae in Imba forest included *Capparis tomentosa* Lam. (Capparidaceae), *Balanites aegyptiaca* (L.) Del. (Balanitaceae) (Plate 7.2), *Acacia nubica* Benth (Mimosaceae), *Grewia tembensis* (Tiliaceae), *Solanum renschii* Vatke (Solanaceae), *Lawsonia inermis* L. (Lythraceae), *Acalypha* sp. (Euphobiaceae), *Cordia sinensis* Lam. (Boraginaceae) and *Combretum aculeatum* Vent. (Combretaceae). *Capparis tomentosa, B. aegyptiaca, Adansonia digitata* L. (Bombacaceae) and *Acacia ataxacantha* DC (Mimosaceae) were recorded as minor hosts in the Mumoni forest. *Balanites egyptiaca* and *C. tomentosa* were common in both forests.

Density of the different major host plants differed between the two forests (Table 7.1). *A. tortilis* had a significantly ($df = 2$, $F = 5.03$, $P = 0.05$) higher density, followed by *A. elatior* and *A. nilotica* in the Imba forest. In Mumoni forest, *A. tortilis* had a

significantly (df = 3, F = 257.11, P < 0.0001) higher density, followed by *A. nilotica*; densities of *A. mellifera* and *A. brevispica* were similar. The density of *A. tortilis* was significantly (df = 1, F = 24.80, P = 0.008) higher in Mumoni than Imba. The densities of *A. nilotica* were similar (df = 1, F = 4.05, P = 0.110) in both forests.

Acacia elatior was recorded only in Imba forest, whereas *A. mellifera* and *A. brevispica* were recorded only in Mumoni (Table 7.1 and Figure 7.1).

Table 7.1: Host plant density of *G. postica* in Imba and Mumoni forests of Mwingi District Kenya during the long rainy season in 2006.

Host species	Tree density $\pm SE$	
	Imba (Area sampled = 3204.60 m^2 ± 623.89 m^2)	Mumoni (Area sampled = 2049.07 m^2 ± 150.99 m^2)
A. tortilis	42.67 ± 3.71bA	61.67 ± 0.88aA
A. nilotica	26.33 ± 2.73aB	20.33 ± 1.20aB
A. elatior	31.00 ± 4.58AB	-
A. mellifera	-	11.00 ± 2.31C
A. brevispica	-	10.50 ± 0.50C

- = species was absent.
Means within a column followed by the same capital and within a row followed by the same lower case letter (s) are not significantly different. (P = 0.05, SNK).
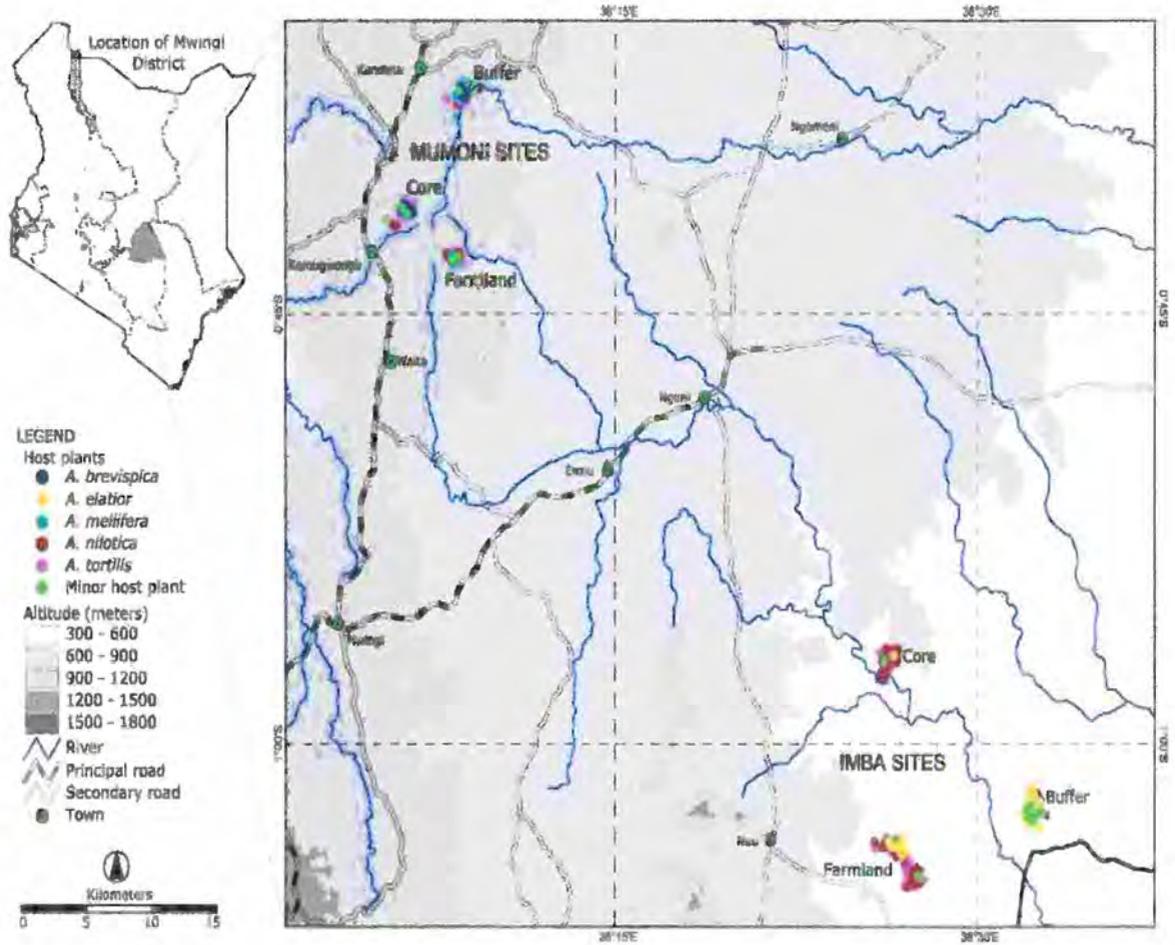
Figure 7.1: Map of study sites showing *G. postica* host plant distributions in

Mumoni   and Imba forests of Mwingi.

Plate 7.1:   Matured instar larva of *G. postica* on major host plant, *A. mellifera*
In Mumoni forest.

Plate   7.2:   Male cocoon of *G. postica* on minor host plant, *B. egyptiaca*
in Imba forest.

The abundance of *G. postica* larvae and pupae varied across the different host plant species within and between the two forests (Figure 7.2). In Imba, *A. elatior* had significantly ($df = 2$, $F = 8.62$, $P < 0.01$) higher densities of larvae than *A. tortilis* and *A. nilotica*. The abundance of larvae was significantly ($df = 3$, $F = 2.99$, $P < 0.05$) higher for *A. tortilis* and *A. mellifera*, followed by *A. nilotica* and *A. brevispica* in Mumoni. The number of larvae found on *A. tortilis* and *A. nilotica* were significantly ($df = 1$, $F = 8.23$, $P < 0.01$; $df = 1$, $F = 11.45$, $P < 0.01$) higher in Imba than Mumoni. In Imba and Mumoni forests, pupal abundance was significantly ($df = 3$, $F = 13.67$, $P < 0.0001$; $df = 4$, $F = 14.11$, $P < 0.0001$) higher on the minor host plants than the other major host plants. The number of pupae on *A. tortilis* was significantly ($df = 1$, $F = 4.21$, $P < 0.05$) higher in Imba than Mumoni.

The host species richness did not differ between the two forests ($t_{cal.} = 0.345$, $df = 140$, $P > 0.05$), but the evenness was higher in Imba forest than in Mumoni forest ($t_{cal.} = 2.667$, $df = 140$, $P < 0.01$) (Figure 7.3). The *Acacia* species were mostly found in the farmlands, buffer zones and at the base of the hills and lower slopes of the core zones in both forests (see altitudes of zones in Figure 7.1).
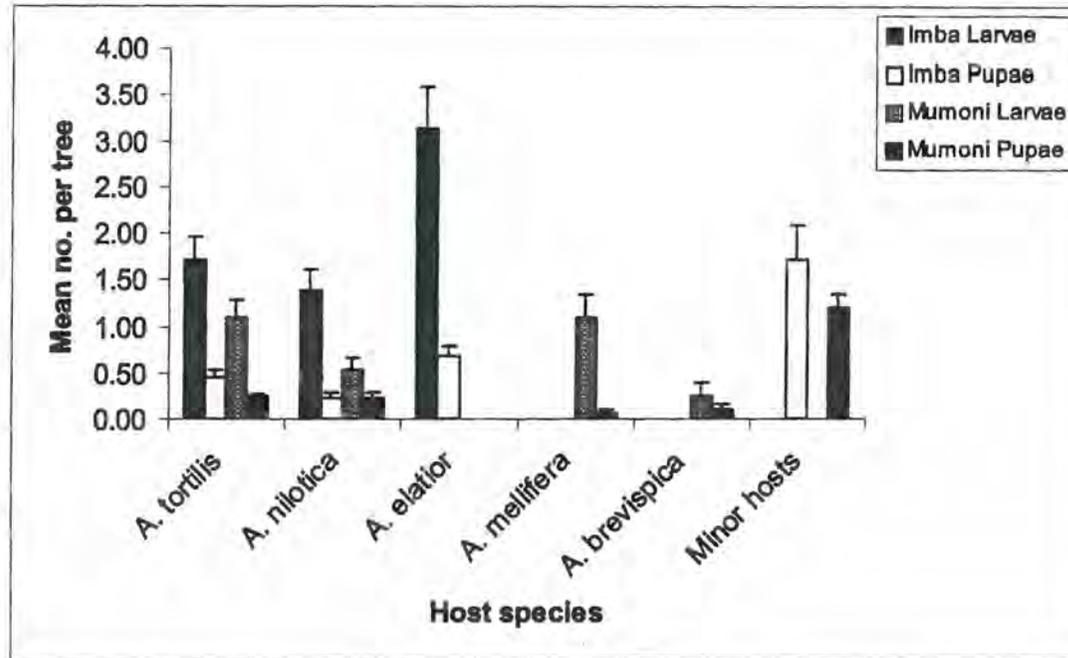
Figure 7.2: Abundance of *G. postica* larvae and pupae on different host plants in Imba and Mumoni forests of Mwingi during the long rainy season in 2006
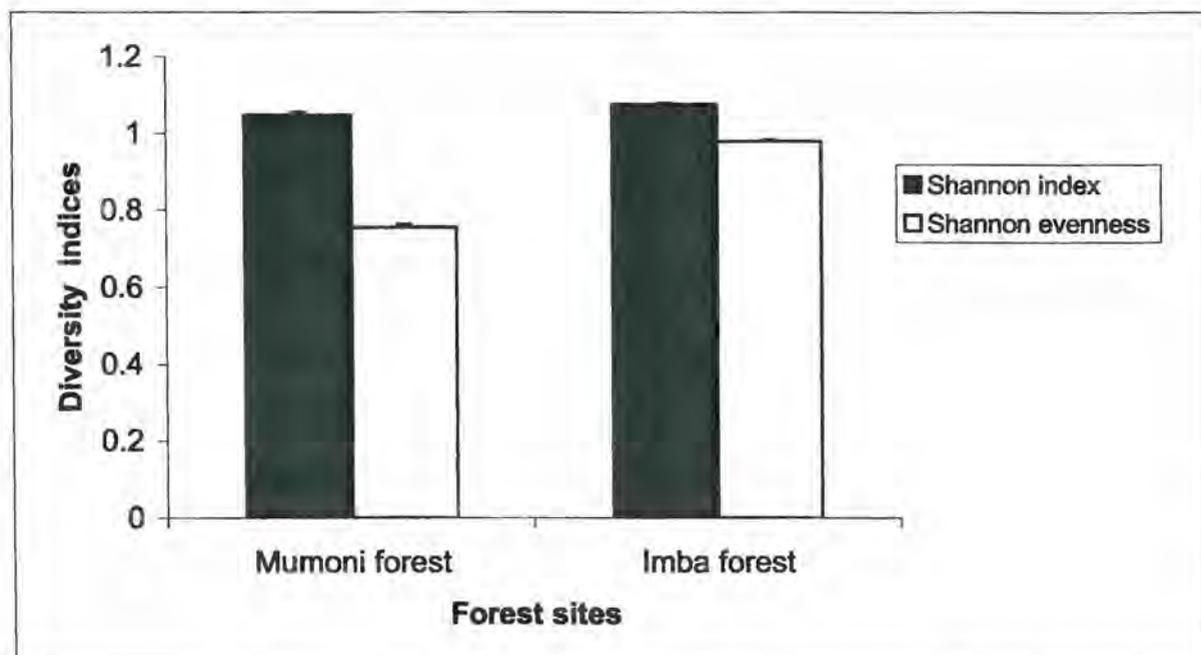
Figure 7. 3: *G. postica* **host plant diversity indices in Mumoni and Imba forests of Mwingi during the long rainy season in 2006.**

7.3.2 *Gonometa postica* host plant characteristics

The heights of the host plants were not significantly different across species ($df = 4$, $F = 3.28$, $P > 0.05$) in Mumoni forest, whereas in Imba forest, *A. tortilis* and *A. elatior* were significantly ($df = 3$, $F = 17.34$, $P < 0.0001$) taller than *A. nilotica* and the minor hosts (Table 7.2). *A. tortilis* and *A. nilotica* were significantly ($df = 1$, $F = 17.97$, $P < 0.0001$; $df = 1$, $F = 20.88$, $P < 0.0001$) taller in Imba than Mumoni.

In Mumoni forest, *A. tortilis*, *A. nilotica*, *A. mellifera* and minor hosts had significantly ($df = 4$, $F = 6.25$, $P < 0.0001$) wider canopies than *A. bevispica*, whereas in Imba forest, the canopy width differed significantly ($df = 3$, $F = 14.32$, $P < 0.0001$) among all the host plant species. *A. tortilis* had the widest canopy, followed by *A. nilotica*, *A. elatior* and minor hosts.

In Mumoni forest, *A. tortilis* had significantly ($df = 4$, $F = 4.53$, $P < 0.01$) larger dbh than *A. nilotica*, *A. mellifera* and minor hosts, which did not differ significantly in their dbh. *A. brevispica* had a significantly ($df = 4$, $F = 4.53$, $P < 0.01$) smaller dbh. In Imba, *A. tortilis* had a significantly ($df = 3$, $F = 24.8$, $P < 0.0001$) larger dbh than *A. nilotica*, *A. elatior* and minor hosts. The dbh of *A. tortilis* was significantly ($df = 1$, $F = 64.80$, $P < 0.0001$) larger in Imba than Mumoni.

The number of branches did not differ significantly ($df = 4$, $F = 1.12$, $P > 0.10$) among host plants in Mumoni, but in Imba, the minor hosts had significantly ($df = 3$, $F = 11.82$, $P < 0.0001$) more branches, followed by *A. tortilis*. *A. nilotica* and *A. elatior* had similar number of branches. In Imba, *A. tortilis* had significantly ($df = 1$, $F = 6.78$, $P < 0.05$) more branches than in Mumoni, whereas *A. nilotica* had significantly ($df = 1$, $F = 19.06$, $P < 0.0001$) more branches in Mumoni than Imba.

Table 7.2: Growth parameters of host species of *G. postica* in Imba and Mumoni forests of Mwingi District Kenya during the long rainy season in 2006.

Host species	Host growth parameters							
	Mean height (m) ± *SE*		Mean canopy (m) ± *SE*		DBH (m) ± *SE*		Mean no. of branches ± *SE*	
	Imba	Mumoni	Imba	Mumoni	Imba	Mumoni	Imba	Mumoni
A. tortilis	6.31 ± 0.24aA	5.01 ± 0.17 bA	6.87 ± 0.30aA	4.58 ± 0.16 bA	0.87 ± 0.05aA	0.44 ± 0.02bA	2.88 ± 0.12aB	2.55 ± 0.06bA
A. nilotica	4.49 ± 0.13 aB	3.80 ± 0.08bA	5.74 ± 0.27aAB	5.05 ± 0.20 aA	0.44 ± 0.03aB	0.39 ± 0.03aAB	2.33 ±0.07bC	3.03 ± 0.16aA
A. elatior	6.27 ± 0.26A	-	4.61 ± 0.29B	-	0.39 ± 0.03 B	-	2.17 ± 0.09C	-
A. mellifera	-	4.59 ± 0.19A	-	4.12 ± 0.34A	-	0.30 ± 0.03AB	-	2.94 ± 0.23A
A. brevispica	-	4.94 ± 0.21A	-	2.57 ± 0.37B	-	0.22 ± 0.03B	-	3.10 ± 0.41A
Minor hosts*	3.19 ± 0.52aC	3.91 ± 0.42aA	3.09 ± 0.60aC	3.89 ± 0.42aA	0.39 ± 0.10aB	0.40 ± 0.15aAB	3.50 ± 0.47aA	3.10 ± 0.59aA

- = species was absent.
* = *C. tomentosa, B. aegyptiaca, G. tembensis, S. renschii, C. sinensis, L. inermis, Acalypha* sp., *A. digitata, A. nubica,* and *A. ataxacantha.*
Means within a column followed by the same capital and within a row followed by the same lower case letter (s) are not significantly different. (*P* = 0.05, SNK). DBH = diameter at breast height.

7.4 Discussion

The conservation and monitoring of biological diversity has become an important issue receiving national and international attention and is regarded as essential to carrying out the directives of Articles 8, 9 and 10 of the Convention on Biological Diversity (CBD) (Noss, 1991; Glowka *et al.*, 1994; Teder *et al.*, 2007). It is also an important element of ecosystem management and of an adaptive management approach (Everett *et al.*, 1994; Gaines *et al.*, 1999). By documenting the abundance of *G. postica* larvae, pupae, host plant diversity, density and distribution in the Imba and Mumoni forests of Mwingi, this study takes the first step to provide the baseline data necessary for future monitoring and conservation of these important woodlands.

7.4.1 *Gonometa postica* abundance, host plant diversity, density and distribution

Information on the relative abundance and distribution of *G. postica* and its host plants in East Africa is lacking (Ngoka *et al.*, 2008) or is inadequate for proper management decisions on the conservation and sustainable utilisation of this important wild silkmoth and its host plant species (Kioko *et al.*, 2000, 2007; Raina 2004; Raina *et al.*, 2007). There is often a lack of basic data about the level and spatial distribution of biodiversity (Teder *et al.*, 2006).

This study has identified *A. tortilis* as the most abundant host plant of *G. postica* in the Imba and Mumoni forests. Veldtman *et al.* (2002, 2007a) in South Africa identified *A. tortilis* as one of the dominant woody host species utilised by *G. postica* at six sites in their study. Thus, the monitoring of *A. tortilis* and the other host plants (*A. elatior, A. nilotica, A, mellifera* and *A. brevispica*) and their sustainable utilisation

and conservation is of prime importance. *A. elatior* was the most preferred host plant by *G. postica* larvae in Imba; this might be due to their distribution mostly along riverbanks, thereby providing fresh leaves and favourable climate for the survival of larvae. Preliminary results for on-going work on the biology of *G. postica* larvae on different host plants in Imba show that pupae that developed from silkworms reared on *A. elatior* had significantly greater size and weight than those raised on *A. nilotica* and *A. tortilis. Acacia tortilis* was one of the most preferred hosts for larval development and the most abundant host species in the two forests. Thus, it must be given priority in conservation efforts, such as raising and planting this *Acacia* species in the buffer zones of these forests.

Wilson *et al.* (1996) identified attributes of biodiversity that can be assessed at each level of ecological organization. At the ecosystem level, richness, evenness and diversity of species, guilds, and communities are important. At the species level, abundance, density, and biomass of each species population may be of interest. This study has established that the relative densities of host species differed between the two forests. This might be the result of a combination of many factors including human disturbance (Riswan and Hartanti, 1995). For instance, local residents living adjacent to these forests used to cut these *Acacia* species for charcoal, and the intensity of the tree cutting might vary from one forest to another. This may partly explain the unequal evenness in the host plant species diversity. The high evenness of the host species in Imba might explain why the larval and cocoon abundance was generally higher in Imba than Mumoni.

As observed in the field, the *Acacia* species were predominantly found in the farmlands, buffer zones and on the lower slopes of both hilly forests. Abeele *et al.* (2005) also made a similar observation in the Mumoni hills where they concluded that *A. tortilis* and *A. mellifera* were among the main species of woody plants found on the lower slopes, but absent in the upper elevations of the hills. Thus sustainable utilisation, monitoring and conservation efforts of the *Acacia* species utilised by *G. postica* must be focused within these areas, especially the buffer zones of these two forests where most of the *Acacia* are located, experiencing more disturbance from the adjacent forest communities due to their proximity and accessibility.

7.4.2 *Gonometa postica* host plant characteristics

The measured growth characteristics of the host plants of *G. postica*, such as tree height, canopy size, diameter and number of branches, will now serve as baseline data to assess any change in the *Acacia* species composition within the same location over time. This baseline data is crucial for monitoring (Wilson *et al.*, 1996; Gaines *et al.*, 1999) and making management plans for sustainable utilisation of the silkmoths, their host plants and biodiversity as a whole.

The finding that the sampled trees are relatively young to middle aged suggests that most of them have come as secondary vegetation, following earlier encroachment by people. The intervention by CIP, Kenya Forest Service and Mwingi District Livestock Production Office in training communities adjacent to these two forests in beekeeping and wild silk farming on these *Acacia* as an income generation activity and forest conservation has probably contributed to the regeneration of these *Acacia* spp., which

previously had been over-exploited for charcoal (Abeele *et al.*, 2005; Raina *et al.*, 2007). These interventions through Participatory Forest Management (PFM) are providing economic incentives to communities adjacent to both forests to enhance forest conservation and are making some impact but would require constant monitoring. (Sahele, 2005; Kioko *et al.*, 2007).

A focus group discussion with farmers in the study area revealed rapid deterioration of the forests, which were previously dominated by *Acacia* species. Burning of charcoal has been reduced and limited to domestic use, especially with the groups involved in beekeeping and wild silk farming. This was so because they explained that they were reserving the *Acacia* species for their bees for foraging and also for raising the silkworms.

The present study provides baseline information necessary for future monitoring of *G. postica* population dynamics and host plant distributions, at several spatial and temporal scales in the Imba and Mumoni forests of Mwingi. Such information will be used in the development of sound sustainable management plans aimed at conserving the wild silkmoth and its host species in these woodlands.

⁴CHAPTER EIGHT

8 PARASITISM OF THE AFRICAN WILD SILKMOTH, *GONOMETA POSTICA* ON HOST AND NON-HOST PLANTS IN THE IMBA AND MUMONI FORESTS, OF MWINGI, KENYA.

8.1 Introduction

Gonometa postica Walker (Lepidoptera: Lasiocampidae) is currently the species being utilised for commercial wild silk production in Mwingi, Kenya (Kioko *et al.*, 2007; Fening *et al.*, 2008a). It produces high-quality silk, comparable to that of the domesticated silkmoth, *Bombyx mori* L. (Lepidoptera: Bombycidae) (Hartland-Rowe, 1992; Kioko *et al.*, 2000; Raina and Kioko, 2000; McGeoch, 2002; Veldtman *et al.*, 2007b; Ngoka *et al.*, 2008).

One of the factors that limit commercial silk production is attack of cocoonc by parasitoids, which cause a significant reduction in the abundance of live cocoons (Hartland-Rowe, 1992; Ngoka, 2003; Veldtman *et al.*, 2004a; Kioko *et al.*, 2007). Also exit holes left in cocoons by adult parasitoids render them unsuitable for degumming and spoil the continuity of silk filament during reeling (Kioko, 1998; Veldtman *et al.*, 2004a).

The studies by Kioko (1998) and Ngoka (2003) provided general information on the natural enemies and parasitism rates of the different stages of *G. postica* in Kenya.

The current study focuses on the larval-pupal parasitoids *of G. postica* in the Imba and Mumoni forests of Mwingi, Kenya. This study sought to assess the impact of parasitoids on the quality of *G. postica* cocoons in the Imba and Mumoni forests of Mwingi, Kenya.

8.2 Materials and Methods

8.2.1 Study sites

The study was carried out in 2006 in the Imba and Mumoni forests of Mwingi District in eastern Kenya (Figure 1), during the long rains of March-May and short rains between October-December corresponding to the first and second generations of wild silkmoths respectively. In each forest, three sites were selected [i.e., site 1 (0° 51' S, 38° 22' E), site 2 (0° 50' S, 38° 22' E) and site 3 (0° 50' S, 38° 23' E) in the Imba forest, and site1 (0° 36' S, 38° 1' E), site 2 (0° 34' S, 38°, 2' E) and site 3 (0° 32' S, 38° 0' E) in the Mumoni forest]. Distances between sites within a forest were > 1 km. The sites were chosen systematically to reflect the different forest zones (Fening *et al.*, 2008a) and the availability of 40 or more *G. postica* cocoons per site was a prerequisite for selection (Veldtman *et al.*, 2007a,b).

8.2.2 Parasitism rates of *G. postica*

In each forest, three sites were selected and one hundred host and other non-host plants of *G. postica* were randomly sampled in each site and all trees were inspected for presence of *G. postica* cocoons. Non-host plants referred to as plants that *G. postica* larvae do not feed on but are used for pupation (Veldtman *et al.*, 2004; Fening *et. al.*, 2008). Thus, *G. postica* cocoons were normally seen on both host and non-host plants. The cocoons were kept individually in plastic vials (13 x 11 cm) covered with

a fine mesh (400 micron), labeled and kept until adult moth or parasitoid emergence. The sex ratio of the parasitoids was computed as the proportion of females. The identification of Dipterans parasitoids was carried out using Crosskey's (1984) keys to the genera of Tachinidae at the Biosystematics unit of the International Centre of Insect Physiology and Ecology (ICIPE) in Nairobi, Kenya and voucher specimens were kept in their insect museum and the National Museum of Kenya. The Hymenopteran parasitoids were sent to Gerard Delvare of the Agricultural Research Centre for International Development (CIRAD) in France for identification.

Sampling was done weekly from the three sites at each forest during the study period. The percentage parasitism (Pi) for each parasitoid species was calculated for the actual stage (s) of the host attacked using the

$$ P_i = \frac{\sum_{t=0}^{T} P_{it}}{\sum_{t=0}^{T} d_{it}} $$

formula proposed by van Driesche (1983).

where d_{it} is the number of the susceptible hosts in stage i at week t, P_{it} is the number of parasitised hosts i at time t, and T is total weeks. For each species, parasitism was averaged across host plant species for determination of the key parasitoids in each forest. In addition, parasitism of the key species was calculated for the different host and non-host plants in the two forests sites. Dead cocoons of *G. postica* were dissected to determine unsuccessful parasitism if any.

8.2.3 Data analysis

The percentage parasitism of the different species of parasitoids on the different host and non-host plants was compared between the two generations within each forest by using Mann- Whitney test ($\alpha = 0.05$). Kruskal-Wallis test ($\alpha = 0.05$) was used to compare the parasitism among the different species of parasitoids and host plants within each generation. When the Kruskal-Wallis test showed significance differences ($P = 0.05$), multiple comparisons was conducted using the Nemenyi test ($\alpha = 0.05$, Zar, 1999).

8.3 Results

8.3.1 Diversity of larval-pupal parasitoids and parasitism rates of *G. postica*

Two dipteran (the tachinids *Palexorista* sp. and *Pimelimyia semitestacea* Villeneuve) and four hymenopteran (the ichneumonids *Pimpla* (*Apechtis*) sp., and *Goryphus* sp., the eurytomid *Eurytoma tolidepepra* Delvare, and the chalcidid *Brachymeria* nr. *albicrus* Klug) parasitoids were identified from the two forests. Five species of parasitoids (*Pimpla* sp., *E. tolidepepra*, *P. semitestacea*, *Palexorista* sp. and *Goryphus* sp.) were collected in the Imba forest and three (*Palexorista* sp., *Goryphus* sp., *Brachymeria* sp. in the Mumoni forest (Table 8.1). All the parasitoids identified in this study were found to attack the mature larvae of *G. postica* but emerged from the pupal stage (enclosed in a silken cocoon), thus referring to them as larval-pupal parasitoids.

In the Imba forest, *Palexorista* sp. (Plate 8.1) was the predominant species of parasitoid of *G. postica* for both generations followed by *Goryphus* sp., (Plate 8.2) ($df = 1, \chi^2 = 9, P < 0.005; df = 4, \chi^2 = 12.70, P < 0.025$) (Table 8.1). The parasitism rate

of the silkworm by *Palexorista* sp. was significantly higher ($df = 1$, $\chi 2 = 9$, $P < 0.005$) for the first generation than the second generation in Imba. In the Mumoni forest, parasitism rate of *Goryphus* sp. on *G. postica* was significantly higher ($df = 2$, $\chi^2 = 7.20$, $P < 0.05$) than that of *Brachymeria* sp. for the second generation.

Parasitism rate of *G. postica* by *Palexorista* sp. was significantly higher ($df = 3$, $\chi^2 = 8.775$, $P < 0.05$) on *A. tortilis* than on the non-host plants for the second generation cocoons in Imba (Table 8.2). In the Imba forest, parasitism rate of *G. postica* by *Palexorista* sp. was significantly higher ($df = 1$, $\chi^2 = 9$, $P < 0.005$) for the first generation than the second generation for the cocoons collected from all host and non-host plants. In Mumoni, the parasitoid, *Palexorista* sp. was only obtained from cocoons collected from *A. tortilis* and was similar for both generations ($df = 1$, $\chi^2 = 3$, $P > 0.05$).

For the first generation cocoons in Imba forest, parasitism rate of *G. postica* by *Goryphus* sp. was significantly higher ($df = 2$, $\chi^2 = 7.20$, $P<0.05$) on *A. tortilis* than on *A. elatior* (Table 8.3). In the Imba forest, parasitism of the second generation cocoons of *G. postica* by *Goryphus* sp. was significantly higher ($df = 2$, $\chi^2 = 7.20$, $P < 0.05$) on *A. tortilis* than on *A. nilotica*.
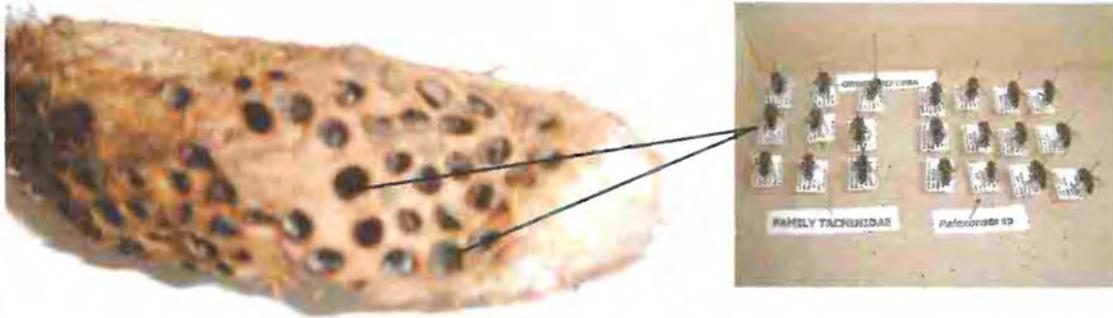
Plate 8.1: *G. postica* cocoon parasitised by *Palexorista* sp.
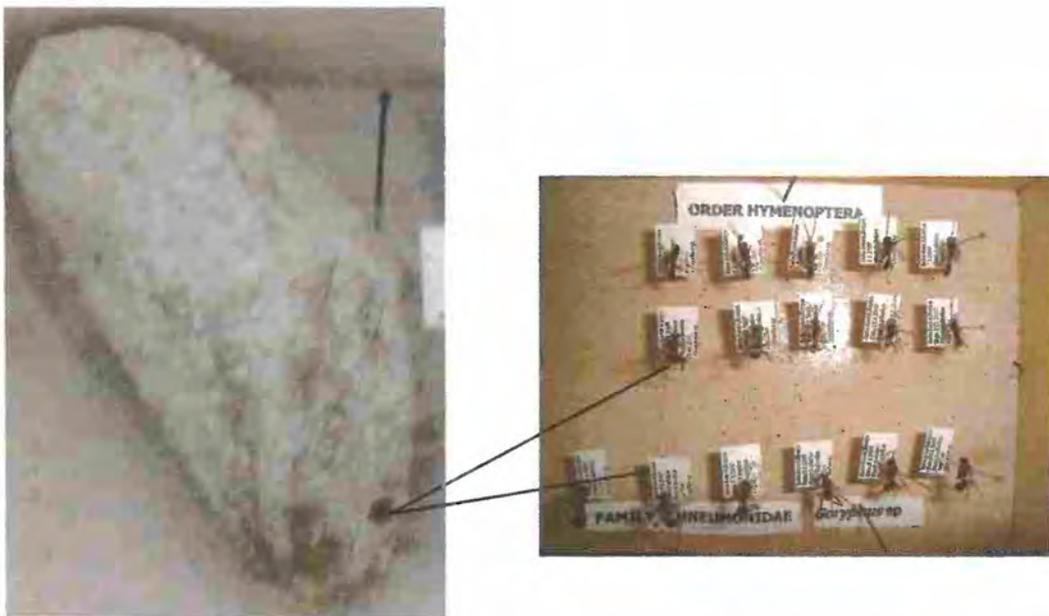
Plate 8.2: *G. postica* cocoon parasitised by *Goryphus* sp.

Table 8.1: Mean (± *SE*) percentage parasitism of *G. postica* larvae in Imba and Mumoni forest of Mwingi by different parasitoids, first and second generations, corresponding to the long and short rainy seasons, 2006.

Order	Species	Mean parasitism* (%) ± *SE*			
		Imba forest		Mumoni forest	
Family		First generation	Second generation	First generation	Second generation
Diptera					
Tachinidae	*Palexorista* sp.	32. 65 ± 5.48 aA	8.37 ± 0.88 bA	4.17 ± 1.15 aA	1.80 ± 0.32 bAB
	Pimelimyia semitestacea	0.00 ± 0.00	2.53 ± 0.66 AB	0.00 ± 0.00	0.00 ± 0.00
Hymenoptera					
Ichneumonidae	*Goryphus* sp.	2.96 ± 0.14 aB	4.33 ± 0.85 aAB	2.15 ± 0.63 aA	7.50 ± 1.86 aA
	Pimpla (*Apechtis*) sp.	0.00 ± 0.00	0.27 ± 0.06 B	0.00 ± 0.00	0.00 ± 0.00
Eurytomidae	*Eurytoma tolidepepra*	0.00 ± 0.00	1.48 ± 0.16 AB	0.00 ± 0.00	0.00 ± 0.00
Chalcididae	*Brachymeria* nr. *Albicrus*	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.49 ± 0.14 B

* Mean parasitism (%) was calculated from cocoons collected from all three sites and all host plants in Imba and Mumoni forests of Mwingi.

Means within a column followed by the same capital letter (Kruskal-Wallis test) and within a row and forest followed by the same lower case letter (Mann-Whitney test) are not significant at $P = 0.05$.

Table 8.2:   Mean (± *SE*) percentage parasitism of *G. postica* cocoon by *Palexorista* sp. in Imba and Mumoni forests of Mwingi, first and second generations, corresponding to the long and short rainy seasons, 2006.

Host plant species	Mean parasitism* (%) ± *SE*			
	Imba forest		Mumoni forest	
	First generation	Second generation	First generation	Second generation
A. tortilis	27.90 ± 5.67 aA	9.73 ± 1.28 bA	5.77 ± 0.58 a	6.28 ± 1.08 a
A. nilotica	28.33 ± 6.01 aA	5.87 ± 0.83 bAB	0.00 ± 0.00	0.00 ± 0.00
A. elatior	23.70 ± 2.54 aA	6.70 ± 1.81 bAB	-	-
Non-host plants	50.67 ± 3.31 aA	2.77 ± 0.28 bB	0.00 ± 0.00	0.00 ± 0.00

Means within a column followed by the same capital letter (Kruskal-Wallis test) and within a row and forest followed by the same lower case letter (Mann-Whitney test) are not significant at $P = 0.05$.

Table 8.3:   Mean (± *SE*) percentage parasitism of *G. postica* cocoon by *Goryphus* sp. in Imba and Mumoni forests of Mwingi, first and second generations, corresponding to the long and short rainy seasons, 2006.

Host plant species	Mean parasitism* (%) ± *SEM*			
	Imba forest		Mumoni forest	
	First generation	Second generation	First generation	Second generation
A. tortilis	6.20 ± 1.19 aA	8.93 ± 2.14 aA	1.73 ± 0.48 aA	5.53 ± 0.55 aA
A. nilotica	0.00 ± 0.00	1.10 ± 0.10 B	0.00 ± 0.00	0.00 ± 0.00
A. elatior	0.70 ± 0.13 aB	3.00 ± 0.46 aAB	-	-
Non-host plants	1.97 ± 0.48 AB	0.00 ± 0.00	1.13 ± 0.30 aA	9.53 ± 0.87 aA

Means within a column followed by the same capital letter (Kruskal-Wallis test) and within a row and forest followed by the same lower case letter (Mann-Whitney test) are not significant at $P = 0.05$.

8.4 Discussion

Most parasitoid species (except *Goryphus* sp. and *E. tolidepepra*) recorded in this study have been reported by previous workers in Southern Africa (Hartland-Rowe, 1992; Veldtman *et al.*, 2004a). Okelo (1972) identified the ichneumonid, *Pimpla mahalensis* (Gribodo) as a larval parasitoid of *Gonometa podocarpi* Aurivillius in East Africa. *Palexorista* sp. is among the key parasitoids of *G. postica* recorded in both forests, and *P. semitestacea* was the third most important parasitoid from the present study. Earlier studies by Cuthbertson and Munro (1941), Taylor (1961), Crosskey (1984), Hartland-Rowe (1992), Peigler (1994), and Veldtman *et al.* (2004a) described *P. semitestacea* and *Palexorista* sp. as the two most important dipteran parasitoids attacking *G. postica* and *G. rufobrunnea* larvae in Southern Africa.

The current work has shown that generally parasitism of *G. postica* by *Palexorista* sp. and *Goryphus* sp. is widespread on *A. tortilis* than some of the host and non-host plants. This observation might be due to the fact that *A. tortilis* is the most abundant host plant of *G. postica* in the two forests and habours greater population of *G. postica* larvae and pupae (Fening *et al.*, 2008a).

Parasitism by *Palexorista* sp. was high on *A. tortilis* and low on the non-host plants during the second generation in Imba. Thus, by pupating on non-host plants, the larvae very likely escaped parasitism, which indicates that parasitoids either attack the larvae before they move to the non-host plants or the non-host plant disrupts the searching ability of the parasitoids (Guildford, 1992; Veldtman *et al.*, 2007b).

The current study recorded a parasitism rate of 0.3 – 32.7 % from field-collected cocoons of *G. postica*. Earlier work by Hartland-Rowe (1992) in South Africa has shown that larval parasitoids caused 30% mortality in late larval instars of *G. rufobrunnea*. A similar study also established that larval parasitoids of *G. postica* and *G. rufobrunnea* resulted in a median parasitism rate of about 30% at the sampled locations in South Africa (Veldtman *et al.*, 2004a).

Finally, this study has identified six parasitoids of *G. postica* in the forests of Mwingi, Eastern Kenya and only two of them had a significant impact in reducing the quality of *G. postica* cocoons as expressed in the percentage parasitism. As these key parasitoids were recovered in both forests and generations, their possible roles in regulating the natural population of *G. postica* may be vital, as attacked larvae although pupate, fail to eclose. The results obtained from this study offer baseline information on the key parasitoids, which is a prerequisite for devising any management programme so as to boost the quality of cocoons.

CHAPTER NINE

9   BIONOMICS OF PARASITOIDS OF *G. POSTICA*

9.1   Introduction

Earlier work by various researchers has shown different parasitoids, mostly the insect orders Diptera (Tachinidae) and Hymenoptera (Ichneumonidae, Braconidae, Chalcididae, Eurytomidae, Eupelmidae, Eulophidae and Perilampidae attack different life stages of *G. postica* in the field (Hartland-Rowe, 1992; Peigler, 1994; Veldtman *et al.*, 2004a). The life cycle and reproductive habits of parasitoids can vary greatly between species (Pennacchio and Strand, 2006). For example, in some species, only one parasitoid will develop in or on each host (solitary) while, in other species, hundreds of larvae may develop within the host (gregarious). Insect parasitoid life cycles may also vary depending upon the life stage of the host they attack. Some parasitoids will lay their eggs near the eggs of their host, while other species will lay their eggs in or on the larvae of their host. Usually insect parasitoids will only attack a particular life stage of one or several related species. Parasitoids can be parasitised by other parasitoids, a phenomenon known as hyperparasitism (Hoffmann and Frodsham, 1993).

The family Ichneumonidae are koinobionts that parasitise mobile hosts (Shaw, 1994). The family Chalcididae are small wasps and they mostly attack pupae of moths, butterflies and flies (Insects of Australia, 1991). Although many tachinids emerge from the pupal stage of their hosts, none is known to attack pupae nor do any species attack the egg stage of their hosts. Most species of tachinids attack larval hosts, but a significant fraction, perhaps 5% to 10% of the species, attack adults. Larval

development is usually completed in one to three weeks. Depending on the tachinid species, larvae develop either singly or gregariously and either pupate in the dead host or leave the host remains to pupate in soil litter (Stireman *et al.*, 2006). Tachinids are classified as koinobiont parasitoids, that is, they allow their host to continue to feed and grow while they develop inside it rather than arresting its development in some way, as do idiobionts.

The aim of this study was to establish the diversity of larval-pupal parasitoids of *G. postica* and their reproductive strategy in the parasitised *G. postica* cocoons. This will be important in understanding the host-parasitoid interaction which is a prerequisite for devising any control method (s) for the key parasitoids.

9.2   Materials and methods

9.2.1   Morphology and reproductive strategy of *G. postica* parasitoids

Aspects of the morphological characteristics of adult parasitoids, mainly the type of mouthparts, the length, nature and description of ovipositor were established. The lower abdomen was dissected under a dissecting microscope (Wild TYP 355110, X6.5 - X40 magnification) to remove the ovipositor. The ovipositor was put under a stereomicroscope with an in- built digital camera, (Leica EZ4D, X8 – X35 magnification) and a measuring scale to measure the length (in millimeters) as displayed on a computer screen. A photograph of each specimen was also recorded. These measurements were done for each species of parasitoid with a sample size of thirty specimens. The development of parasitoid on host as solitary or/and gregarious, idiobiont or koinobiont, primary parasitoid or/and hyperparasitism and other development behaviours (endoparasitoids/ectoparasitoids) were observed and

recorded. The daily minimum/maximum temperature and relative humidity (RH) during the experimental period were measured with a digital thermohygrometer between 8 - 9 am each morning. The sex ratio of parasitoids was determined as the proportion of females.

9.3 Results

9.3.1 Reproductive strategy of six parasitoid species in parasitised *G. postica* cocoons

9.3.1.1 Diptera:

9.3.1.2 *Palexorista* sp. (Tachinidae)

Palexorista sp. formed multiple emergence holes ranging from 2-105, and a mean of 21.53 ± 2.15 holes. The diameter of the emergence hole ranged from 1.5 – 3.00 mm with a mean of 2.53 ± 0.04 mm. Each emergence hole was covered by an operculum prior to fly emergence (Plate 9.1). The weight of female *G. postica* cocoons which were attacked by *Palexorista* sp. ranged between 0.85 – 5.63 g, with a mean of 2.66 ± 0.13 g. The number of *Palexorista* sp. emergence holes ranged between 2 – 105, with a mean of 23.12 ± 2.50 holes for female cocoons of *G. postica*, which were parasitised. The diameter of emergence holes of parasitoids emerging from female cocoons ranged from 1.5 – 3.0 mm, with a mean of 2.55 ± 0.05 mm. The weight of *G. postica* male cocoons, which were parasitised by *Palexorista* sp. ranged from 0.49 – 1.85 g, with a mean of 1.31 ± 0.09 g. The number of emergence holes of *Palexorista* sp. from the attacked *G. postica* male cocoons ranged from, 2 – 46, with a mean of 14.53 ± 3.31 holes. The diameter of the emergence holes ranged between 2.0 – 3.0 mm, with a mean of 2.48 ± 0.10. mm. The male sex ratio of *G. postica* cocoons, which were attacked by *Palexorista* sp. was 0.19.

Upon the dissection of G. postica cocoons, it was observed that the puparia of *Palexorista* sp. were not separated into compartments inside the cocoon, though they appear so when viewed from the outside for an undissected cocoon (Plate 9.1). Prior to pupation, *Palexorista* sp. larvae were seen distending themselves out of the cocoon wall (mostly posterior portion), which looked wet and loose, though they never came out. They however, pupated inside the cocoon and attached themselves to the cocoon wall with the anterior region of each pupa partially protruding out of the cocoon wall covered by an operculum as an exit for emergence of the adult. Most of the cocoons parasitised by *Palexorista* sp. also had some deformation in shape, as it was observed in the field and laboratory (Plate 9.1).

The parasitised larva, though spins cocoon, the pupation process is not completed. The larval remains of G. *postica* were seen inside the cocoons after the dissection of such cocoons, which were parasitised by *Palexorista* sp. In Imba forest an observation was made of a final instar larva of G. *postica* that was so heavily parasitised by *Palexorista* sp. such that it became impossible for it to spin a cocoon (Plate 9.2). Most of the G. *postica* cocoons observed (92.9 %) were attacked by *Palexorista* sp. from the posterior region, with a few at the ventral (5.7 %) and very few at the anterior region (1.4 %). It appears that *Palexorista* sp. mostly attack larvae of G. *postica* from the posterior region, which can spread to other parts of the body, and in severe infestation, almost the whole body (except the head capsule) is consumed. About 14.3 % of the G. *postica* cocoons that were parasitised by *Palexorista* sp. were also predated by ants. Such parasitised and predated cocoons had no larval remains inside them after their dissection, and in a few instances, only the head capsule was seen.

Palexorista sp. was gregarious as several of them (between 2-28, with a mean of 18.30 ± 2.97) emerged from *G. postica* female cocoons which were kept individually in vials in the laboratory. The developmental period of *Palexorista* sp. for the samples that emerged from the field-collected cocoons kept in the laboratory at room conditions ($22.7 \pm 0.2 - 26.4 \pm 0.3\ ^0C$, $55.5 \pm 2.1 - 75.8 \pm 1.3$ % RH) was between 13 – 21 days, with a mean of 17.80 ± 0.59 days. This period extended from the time the freshly spun cocoons were collected in the field to the emergence of adult parasitoid and its lifespan. In Palexorista, both the male and female have very close resemblance and females lack an ovipositor. Hartland-Rowe (1992) reported that *Palexorista* sp. and *P. semitestacea* probably laid their eggs on the integument of the late instar larvae of *G. postica* for the parasitoids to enter the skin and live inside the caterpillar.

Palexorista sp. was described as koinobiont, as it was known to attack the final instar larvae of *G. postica* (Veldtman *et al.*, 2004a; Veldtman and McGeoch, 2004), and also does not kill its host immediately, but developed alongside the host, and emerged after the cocoon was formed, though in most cases pupae were not formed inside cocoons. Upon dissecting the cocoon, the larval remains of *G. postica* were observed in most cocoons, which were attacked by *Palexorista* sp. The maggots of *Palexorista* sp. after feeding on and killing the *G. postica* larvae, they embedded themselves in the cocoon wall, where they pupated and finally emerged through the emergence holes by breaking the operculum covering each hole. *Palexorista* sp. mostly emerged from *G. postica* cocoons in the morning from 8.00 – 11.00 am and thus were regarded as diurnal.

Emergence holes covered by operculum

Emergence holes
of *Palexorista* sp.
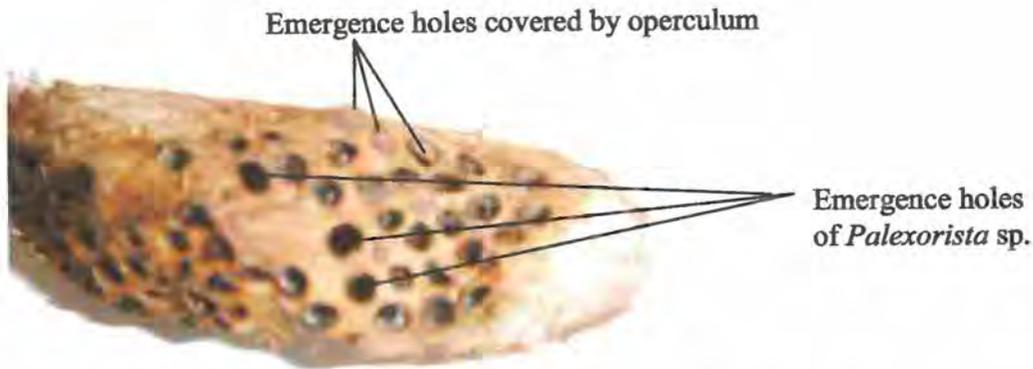
Plate 9.1: *G. postica* female cocoon parasitised by *Palexorista* sp., collected from Imba forest, April-May season, 2006. (Notice the deformation in the shape of cocoon).

Incompletely spun cocoon case

G. postica dead larva, with body wall embedded with pupae of *Palexorista* sp.
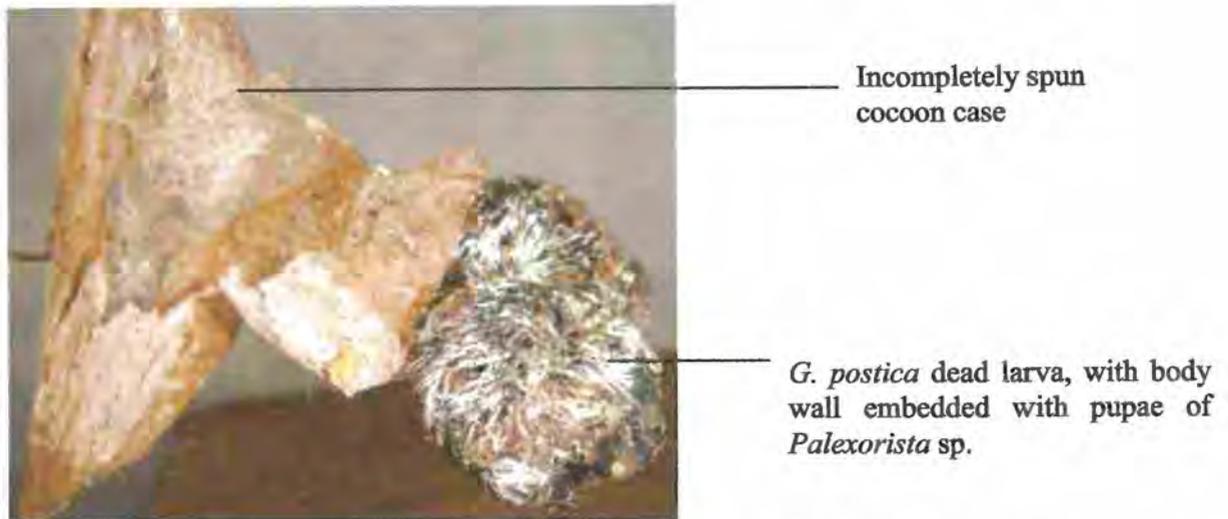
Plate 9.2: *G. postica* final instar larva, heavily parasitised by *Palexorista* sp., Imba forest, April-May season, 2006.

9.3.1.3 *Pimelimyia semitestacea* (Tachinidae)

Several larvae (maggots) of *Pimelimyia semitestacea* (between 4-15, with a mean of 9.25 ± 2.78) emerged from *G. postica* female cocoons kept individually in plastic vials in the laboratory through a single emergence hole and pupated inside the vials. Upon emergence larvae forced themselves out of the cocoon through a single, small irregular emergence hole, similar to the earlier description by Veldtman *et al.*, (2004) in South Africa. In the field, the maggots came out of the cocoons and pupated inside

the soil (personal obervation). The development time for the maggots that were reared in the laboratory ranged between 8 – 23 days with a mean of 21.09 ± 0.46 days, with 22.7 ± 0.2 – 26.4 ± 0.3 ^{0}C and 55.5 ± 2.1 – 75.8 ± 1.3 % temperature and RH, respectively.

The physical description of this parasitoid was similar to that given by Peigler (1994) from the specimen of *P. semitestacea* sent to him by Hartland-Rowe from Botswana in Southern Africa, which he described as a large fly, with chestnut eyes, black and grey stripped thorax, tan scutellum, and tan patches on the abdominal tergites. This species is described as koinobiont as it is known to attack the final larval instar of *G. postica* (Veldtman *et al.*, 2004a; Veldtman and McGeoch, 2004) and larvae emerged at the cocoon stage through an emergence hole described by Veldtman *et al.* (2004a) as tear-shaped.

9.3.2.1 Hymenoptera:

9.3.2.2 *Goryphus* sp. (Ichneumonidae)

Goryphus sp. was gregarious and several adults (ranging from 2-72, with a mean of 35.86 ± 6.39) emerged from the *G. postica* cocoon, mostly through a single emergence hole of a diameter between 1.9 – 3.0 mm, with a mean of 2.36 ± 0.1 mm. In a few instances, the adults emerged through double emergence holes from the posterior and anterior ends of a single cocoon. The sex ratio of *Goryphus* sp. that emerged depended on whether it was from a male or female *G. postica* cocoon. In cases where it emerged from male cocoons, the sex ratio of 0.13 was in favour of males and where it emerged from female cocoons, the sex ratio of 0.66 was in favour of females.

The female *Goryphus* sp. is distinguishable from its male counterpart by the presence of a much thicker abdomen (about twice that of the male in thickness) and a conspicuous ovipositor protruding from the abdominal tip [3.95 – 4.60 (4.31 ± 0.03) mm long] (Plate 9.3). The development behaviour of *Goryphus* sp. was observed to be koinobiont, as it is believed to attack the final larval instar of *G. postica*, but emerged at the cocoon stage. After dissecting the cocoons, it was found in most instances that the larval remains of *G. postica* were enclosed in a layer of white mass or floss. (Plate 9.4) The pupal remains of *G. postica* were found enclosed in white floss after dissecting a cocoon, which was attacked by *Goryphus* sp. A female adult *Goryphus* sp. was seen hovering around a freshly spun *G. postica* cocoon in the field in Imba forest (Plate 9.5). *Goryphus* sp. possessed very strong and tough chewing mouthparts. They emerged from the cocoon by chewing a circular emergence hole. They were capable of chewing the nylon net covering the container (even if it was doubled) in which they were kept in order to escape.

Ovipositor sheaths
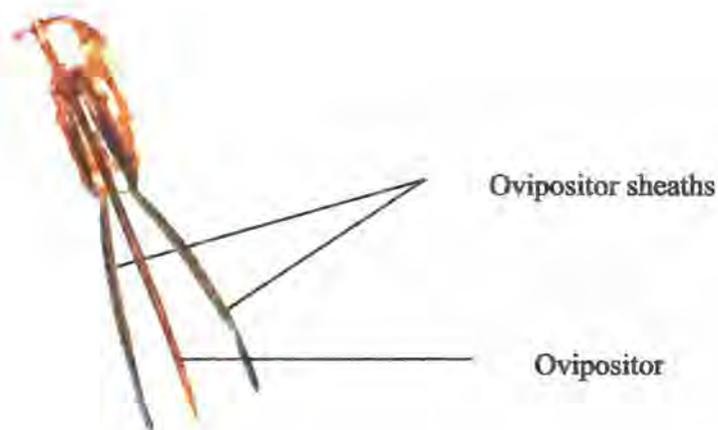
Ovipositor

Plate 9.3: Ovipositor of *Goryphus* sp. (Ichneumonidae) (Scale: 1 : 0.07).

White mass/ floss

G. postica cocoon
outer shell

Pimpla sp.
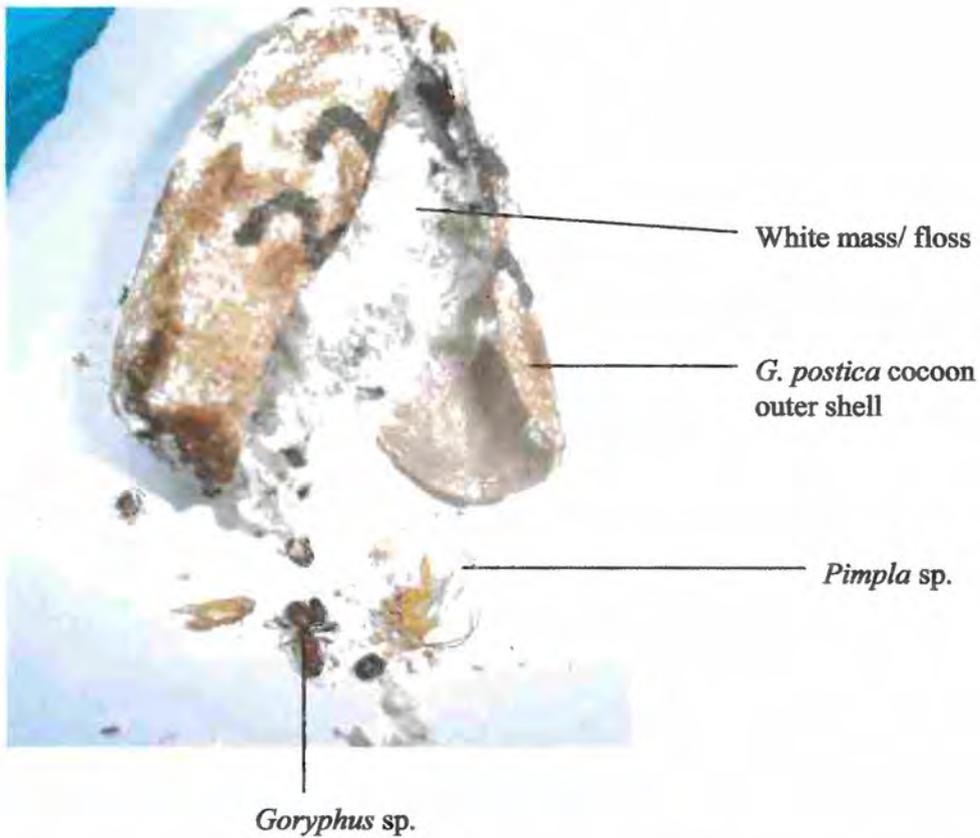
Goryphus sp.

Plate 9.4: Occurrence of *Pimpla* sp. and *Goryphus* sp. inside a female *G. postica* cocoon, collected from Imba forest, October-December, season, 2006.

Goryphus sp.

Plate 9.5: The parasitoid, *Goryphus* sp. hovering around a freshly spun male *G. postica* cocoon on *A. nilotica* in Imba forest.

9.3.2.3 *Pimpla* sp. (Ichneumonidae)

Twenty (20) of them (fourteen females and six males) emerged from a single female cocoon collected from *Acacia elatior* in Imba forest, through a circular emergence hole (2.00 mm in diameter) and were therefore gregarious. They might as well be solitary, as in another instance a female *Pimpla* sp. emerged singly from a male *G. postica* cocoon collected from *A. elatior* in the Imba forest, with emergence hole diameter of about 2.00 mm. The female *Pimpla* sp. is distinguishable from its male counterpart by the presence of a prominent ovipositor (Plate 9.6) protruding from the abdominal tip [3.97 – 4.00 (3.98 ± 0.01) mm long].

In one situation, several adults of *Pimpla* (six males and fourteen females) emerged from a single female cocoon collected from *A. elatior* in Imba, and upon dissection body remains of adult *Goryphus* sp. were seen inside the same cocoon (Plate 9.6). The male sex ratio of 0.70 was in favour of females from the specimen that emerged from cocoons kept in the laboratory. The adult wasp emerged from the cocoon by boring out the anterior end, and chewed its way out of the host cocoon, thus they possessed strong chewing mouthparts. This species might as well be koinobiont, as the larval remains of *G. postica* enclosed in a white mass were observed after dissecting the two cocoons that were attacked by this species.
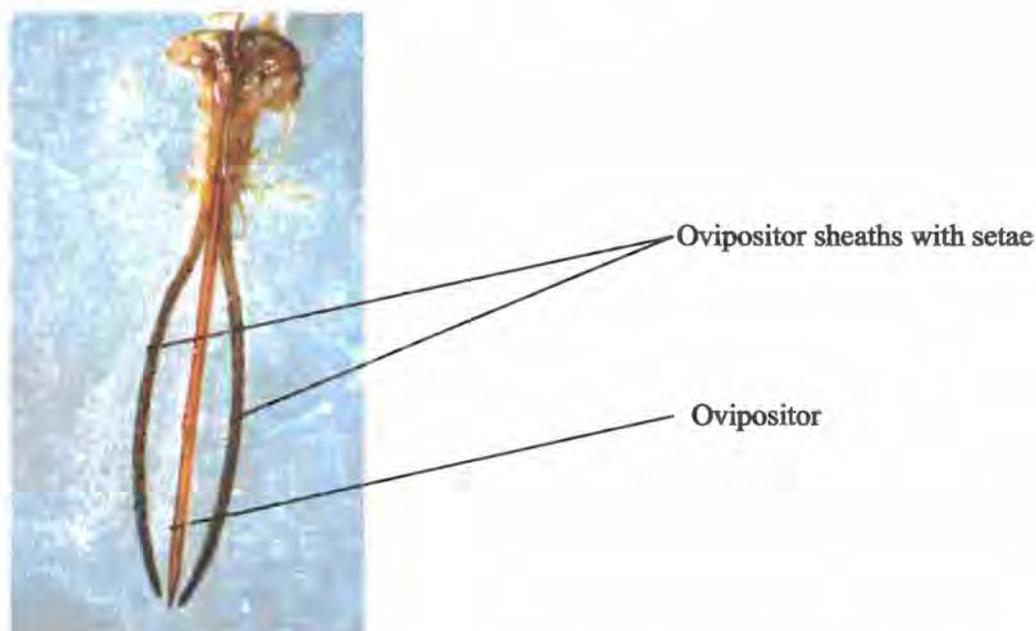
Plate 9.6: Ovipositor of *Pimpla* sp. (Ichneumonidae). (Notice the sharp slender tip). (Scale: 1: 0.05).

9.3.2.4 *Eurytoma tolidepepra* (Eurytomidae)

They were gregarious as several of them (between 11 − 90, with a mean of 40.25 ± 17.35) emerged from a single cocoon, through a single round emergence hole of a diameter ranging from 0.9 − 1.1 mm, with a mean of 0.96 ± 0.02 mm. They were also koinobiont, as they were known to attack the late instar larvae of *G. postica* (Hartland-Rowe, 1992). The larval remains of *G. postica* were observed after dissecting a cocoon, which was attacked by *E. tolidepepra*. This species was the smallest of all the parasitoids identified from the study in relation to the body sizes of the other parasitoid species.

In one instance, thirteen adult *Goryphus* sp. (twelve males and one female) emerged from a male *G. postica* cocoon collected from *A. elatior* in Imba. A day after death of some of the *Goryphus* sp., twenty four adults of *E. tolidepepra* were observed in the

same container that haboured the cocoon from which the *Goryphus* sp. emerged. After dissecting the cocoon, there were two dead *Goryphus* sp., one of which had the abdomen eaten inside, as it was hollow. Similarly, both *Goryphus* sp. and *E. tolidepepra* emerged from a single male *G. postica* cocoon collected from *A. elatior* in Imba. Two emergence holes (2.00 mm and 1.00 mm) were observed at the posterior and anterior ends of the cocoon, respectively. Furthermore, four adults of *E. tolidepepra* were found dead, and parts of the body remains of two adult *Goryphus* sp. (head capsule bearing antennae and parts of the upper thorax) were also seen with the abdominal region missing. In another situation, eleven adults of *E. tolidepepra* emerged from a male *G. postica* cocoon collected from *A. elatior* in Imba. However, no remains of a primary parasitoid were found after dissecting the said cocoon. Thus, *E. tolidepepra* might be a facultative hyperparasitoid of *Goryphus*.

9.3.2.5 *Brachymeria* sp. (Chalcididae)

They were gregarious as several of them (between 20-54, with a mean of 37.00 ± 8.74) emerged from a single female cocoon, through a single round emergence hole of diameter ranging from 1.6 – 2.8 mm, with a mean of 2.09 ± 0.07 mm. The females were distinguishable from their male counterparts by the presence of stout ovipositor protruding from the abdominal tip, 2.82 – 3.21 mm long (2.99 ± 0.06 mm) (Plate 9.7). They also possessed strong and tough chewing mouthparts and emerged from the cocoon by chewing a circular smooth hole. They were also capable of chewing the nylon net covering the container (even if it was doubled) in which they were kept in order to escape. They were also koinobiont, as they were known to attack the final instar larvae (Hartland-Rowe, 1992; Veldtman *et al.*, 2004a; Veldtman and McGeoch, 2004), yet they emerged from the pupal stage of *G. postica* kept in the laboratory. The

dissected *G. postica* cocoons, which were mostly attacked by *Brachymeria* sp. had the silkmoth pupal remains present, without any white floss. This species of parasitoid might as well be a pupal parasitoid. The sex ratio (0.82) of the parasitoids that emerged was in favour of females.
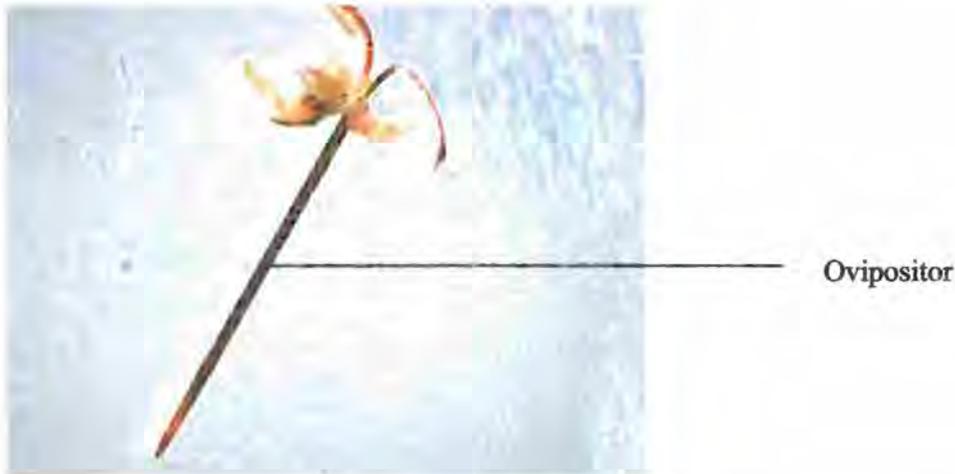
Plate 9.7:   **Ovipositor of *Brachymeria* sp. (Chalcididae) (Scale: 1:0.05).**

9.4   Discussion

The sex ratio of *G. postica* cocoons which were attacked by *Palexorista* sp. being in favour of females can be attributed to the fact that parasitoids always want to ensure the survival of their progeny by investing in a host with enough nutritional resources and requirements for the development of their progeny (Jane and Barbosa, 1981). Since female cocoons of *G. postica* were significantly bigger than their male counterparts (Ngoka *et al.*, 2008), then there is obviously more food resource in the female cocoons than the males, as in some cases host size may be related to food resource availability and quality (Sequeira and Mackauer, 1993; Jeffrey, 2000). The study by Jeffrey (2000) in the Netherlands revealed that parasitoids typically completed their development more rapidly in the larger *Pieris brassicae* L. than the

smaller *Pieris rapae* L. and those wasps that emerged from *P. brassicae* were larger than their counterparts that emerged from *P. rapae*.

Also, the nutritional demands of gregarious parasitoids, where many individuals may compete for the available resources in a single host, are greater than those of a single individual of a solitary parasitoid (Jeffrey, 2000). This observation further explains why these gregarious parasitoids may prefer a female host, which is significantly larger than the male host as observed in the study, as density dependent intraspecific competition for resources is less in the larger host.

Similarly, the sex ratio of *Goryphus* sp. being female-biased for female cocoons of *G. postica*, which was attacked by *Goryphus* sp. and vice versa for male cocoons, also demonstrated that the development of female parasitoids may require more food resources (both quantity and quality). Therefore, the parasitoid selectively laid its eggs depending upon the sex of the host. Research by Jane and Barbosa (1981) in Massachusetts, USA reported that female-biased sex ratio occurred in progeny from female red oak gypsy moth, *Lymantria dispar* L., while all other sex ratios were male-biased.

The deformation in the shape of *G. postica* cocoons which were attacked by *Palexorista* sp. could have been due to enzymatic breakdown of the affected portion of the cocoon for the larvae to embed themselves in the cocoon wall upon pupation. Veldtman *et al.*, (2004a) also acknowledges this view on their work on the parasitoids of *G. postica* in Southern Africa.

A caterpillar may escape parasitisation if the eggs laid on its integument by a tachinid parasitoid are lost if the larva molts before the eggs hatch. For this reason, many tachinids probably only oviposit on mature larvae and stinging spines are possibly not effective deterrents against parasitoids (Peigler, 1994). In this study, the final instar larvae of *G. postica* possessed protective spines, yet they were parasitised by two tachinid flies, *Palexorista* sp. and *P. semitestacea* in the field. The results have also established that exit holes left by adult parasitoids in *G. postica* cocoons offered an opportunity for secondary infestation by ants, which fed on the body remains and also, the empty cocoons served as preferred nesting sites for these ants.

The mature larvae of *P. semitestacea* emerged out of the cocoon wall through a brittle hole that looked like a crack or tear-shaped. Since these larvae did not have well developed mouthparts for chewing, they probably digested the cocoon wall and created their emergence hole by enzymatic breakdown of the silk cocoon. This view was also supported by Veldtman *et al.* (2004a).

The two tachinids identified in this study were both gregarious. *Palexorista* sp. pupated inside the dead host, and emerged as adult, whereas *P. semitestacea* emerged out of the cocoon as matured larvae and pupated outside. This opinion was shared by Stireman *et al.* (2006) who explained that depending on the tachinid species, larvae develop either singly or gregariously and either pupate in the dead host or leave the host remains to pupate in soil litter.

Hartland-Rowe (1992) described *E. transvaalensis* as the most abundant hymenopteran larval parasitoid of *G. rufobrunnea* in Botswana in Southern Africa. In

the present study, *E. tolidepepra* was recorded as the second most important larval hymenopteran parasitoid of *G. postica* found in the Imba forest after *Goryphus* sp. The results have established that *E. tolidepepra* is probably a facultative hyperparasitoid of *Goryphus* sp. as it can as well emerge as a primary parasitoid of *G. postica* larvae. Therefore, there is need to further investigate the interaction between *E. tolidepepra* and *Goryphus* sp. so as to explore the potential of using *E. tolidepepra* to control *Goryphus* sp. in the field, bearing in mind that it is also a primary parasitoid of *G. postica* larvae and thus might make it unsuccessful. Similar study by Veldtman *et al.*, (2004a) in South Africa identified *E. transvaalensis* as a facultative hyperparasitoid of *Disophrys* sp., as it also emerged as a primary parasitoid of *G. postica* species.

This study has also demonstrated a case of multiparasitism, where several *Pimpla* sp. successfully emerged from a *G. postica* female cocoon, which upon dissection had the remains of adult *Goryphus* sp., but it was unsuccessful to emerge from the same host cocoon. Peigler (1994) supported this idea, as he defines multiparasitism as the case where more than one species of parasitoid lives within a host, but one always wins out, as adults of two parasitoids of different species are never produced in a single host individual.

A study by Okelo (1972) on the life history of *G. podocarpi* Aurivillius in East Africa revealed that *Pimpla mahalensis* Gribodo parasitised the larva of *G. podocarpi* The *Pimpla* sp. identified in this study was koinobiont as it attacked the larval stage of *G. postica* and was gregarious.

The current study has identified six larval-pupal parasitoids of *G. postica* in the forests of Mwingi, eastern Kenya. Future studies aimed at devising possible control methods for these parasitoids will benefit from the repertoire of knowledge established by the current study. This will help formulate control methods for these parasitoids to boost commercial production of cocoons in the forests of Mwingi for sustainable biodiversity utilisation and conservation that will culminate into economic growth of the rural poor (Raina, 2000).

CHAPTER TEN

10 GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

10.1 General discussion and conclusions

This study has established that the distribution of *G. postica* larvae, pupae and host plants is fashioned in a way to increase their chances of survival and this varying trends in distribution must be taken into consideration during any harvesting or sampling plan or efforts aimed at conserving the population of this important wild silkmoth and their host plant species in the East African sub-region. Further, the current study has shown that both host and non-host plants should be taken into consideration when sampling for *G. postica* pupae.

The egg incubation period compared well with earlier studies in the Mwingi District of Eastern Kenya, which had shown *G. postica* eggs to have an incubation period of 11.3 ± 0.1 days in an outdoor environment (Kioko, 1998; Kioko *et al.*, 2007). The current study has revealed that *G. postica* female can lay its eggs on different substrates. This observation also agrees with earlier findings by Okelo (1972), Kioko (1998) and Ngoka *et al.* (2008) who reported that *Gonometa* spp. in Kenya might not be host-specific with regard to substrates when ovipositing. This characteristic behaviour in the African wild silkmoths can be exploited to enhance the laboratory egg production with the aim of reducing egg parasitism that takes place in the field.

The larval period recorded for *G. postica* in this study agrees with earlier work by Kioko (1998) in Kenya with a developmental period of about two months. The study has revealed that the longest stage in *G. postica*'s life cycle is the pupal stage, which

lasts for over three months. This is the way this moth survives harsh drought conditions by remaining as pupae in the cocoon or sometimes diapausing until the onset of the rains, which is coupled with favourable climatic conditions.

The current results have demonstrated that temperature and RH influence pupal developmental time according to the season and the effect is opposite to one another as seen under the laboratory conditions. A recent study in Southern Africa has revealed that temperature and rainfall before the emergence of adult moths were significantly correlated with their presence/absence (Delport, 2006).

As revealed by this study, the male moth lives for about three days, whereas the female's lifespan ranges between 7-10 days under laboratory conditions. Earlier work by Kioko (1998) established an adult lifespan of 6.4 ± 3.2 days. This is because the moth lacks feeding mouthparts and dies after mating and oviposition to ensure continuity of the progeny.

The light trapping data has revealed two distinct generations of *G. postica* per year in the study area. The two generations coincide well with the onset of the long (April to May) and short (October to December) rainy seasons, thus allowing synchronization between larval growth period and larval food availability. Similarly, larvae of *G. postica* were observed in both Imba and Mumoni forests in April and May, October and November corresponding to the long and short rainy seasons of the year, respectively. Moreover, adult moths of *G. postica* under laboratory conditions emerged between March, April and early May, and September, October and early November also corresponding to the long and short rainy seasons, respectively. The

sex ratio of the moths caught in the light trap was in favour of males. This is because the males are more active fliers due to their lighter weight and are attracted to the light trap. On the contrary, the females have limited flying ability and as a result only a few of them were light-trapped.

The present study has established that the development of *G. postica* larvae in the wild is not directly affected by the larval food plants, but may be affected by the seasons and sites. However, the effect of host food plant is seen when larvae are reared in semi-captivity. The principal reason might be the effect of host plant quality and suitability for feeding by silkworm larvae, though the prevailing climate may also be involved. For semi-captive breeding of the *G. postica* silkmoth, *A. elatior* is recommended in Imba forest. This is because it produces cocoons of the highest quality with the shortest larval development period. Also, it maintains green leaves throughout the rearing season. However, both *A. tortilis* and *A. nilotica* are recommended for semi-captive rearing of the silkmoth in Mumoni forest, where *A. elatior* is absent.

The initial phase in biodiversity surveys is estimating diversity at one point in time and location. The second phase is estimating diversity at the same location at more than one time period in order to draw inferences about change (Wilson *et al.*, 1996; Gaines *et al.*, 1999). The present study provides baseline information necessary for future monitoring of *G. postica* population dynamics and host plant distributions, at several spatial and temporal scales, in the Imba and Mumoni forests of Mwingi. Such information will be used in the development of sound sustainable management plans aimed at conserving the wild silkmoth and its host species in these woodlands.

Finally, this study has identified six parasitoids of *G. postica* in the forests of Mwingi, Eastern Kenya and only two of them had a significant impact in reducing the quality of *G. postica* cocoons. As these key parasitoids were recovered in both forests and generations, their possible role in regulating the natural population of *G. postica* may be vital, as attacked larvae although mostly pupate, fail to eclose. The results obtained from this study offer baseline information on the key parasitoids, which is a prerequisite for devising any management programme so as to boost the quality of cocoons.

10.2   Recommendations

1. There is need to monitor the temporal and spatial distribution trends of *G. postica* and their host plants over a longer period of time. This would offer sufficient information necessary in understanding the population dynamics of *G. postica* larvae, pupae and their host plants and consequently, the habitat requirements for their conservation and sustainability. This information is also needed for assessing the impact of wild silk farming in conserving the moth population and its host plant species diversity.

2. Continuous light trapping of the adult *G. postica* for a period of five years or more could be a useful tool in understanding the fluctuations in the population dynamics of this species in the field.

3. It is recommended that nutritional quality of the three most common host plants (*A. tortilis*, *A. nilotica* and *A. elatior*) of *G. postica* be carried out so as to confirm the observation that silkworms raised on *A. elatior* produced the

best quality cocoons (in terms of their weight and size) was as a result of their nutritional value or due to other factors.

4. There is need to conduct further research on the bionomics, and the endocrine regulation of the host-parasitoid interactions in the wild as a prerequisite for any control programme for the identified key parasitoids.

5. It is important to undertake additional research to establish the effectiveness of *E. tolidepepra* as a possible facultative hyperparasitoid of *G. postica* larva in the field.

5. There is need to investigate further the effect of the multiple emergence holes of parasitised cocoons (especially by *Palexorista* sp.) on the yield of raw spun silk produced.

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