SURVEY OF WILD SILKMOTH POPULATIONS IN THREE ECOLOGICAL ZONES AND EVALUATION OF THE PERFORMANCE OF *BOMBYX MORI* L. (LEPIDOPTERA: BOMBYCIDAE) ON THREE MULBERRY VARIETIES IN GHANA

BY

AGYEIWAA GLORIA

(10362634)

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DECLARATION

I hereby do declare that, with the exception of references to other scholars' work which have been duly acknowledged, this thesis consist of my original work and has neither on the whole or in part been presented, to any other institution for the award of any degree.

....

Gloria Agyeiwaa Prof. Daniel Obeng-Ofori

(Candidate) (Supervisor)

.....

Dr. Ken Okwae Fening

(Supervisor)

.....

Dr. Rosina Kyerematen

(Coordinator)

DEDICATION

I dedicate this work to the Almighty God, my mother Cecilia Bema and my siblings for their immense support during the study of this programme.

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ABSTRACT

The majority of the world's silk is mulberry obtained from the domesticated silkworm, *Bombyx mori* L. (Lepidoptera: Bombycidae) with wild silk being minimal. A survey was undertaken in three agro-ecological zones in Ghana to document the wild silkmoth populations and their host plants. In addition, the effect of three mulberry varieties; Mysore local, Kanva 2 and S36 on the performance of five *B. mori* L. strains; G2xV2xH1xKK, M2xN2xSN1xI1, Z/Y, ICIPE I and ICIPE II was evaluated in the Coastal Savanna agro-ecological zone of Ghana. One hundred and fifty newly emerged silkworms strains were fed on cut leaves of the different mulberry varieties in wooden trays in the laboratory under ambient conditions. Performance was assessed on the basis of measurement of larval developmental time, larval size and weight, cocoon size and weight, pupal and shell weight, and shell ratio. Consumption and utilization of mulberry leaves by the 5th instar silkworm strains as well as the quality of the raw silk from cocoons were also assessed. The survey found the African wild silkmoth, *Gonometa* sp. (Lepidoptera: Lasiocampidae) on *Acacia* sp. in Northern Ghana, and wild silkmoths belonging to this genus is known to produce cocoons of good quality for commercial silk production. Results on the mulberry silk production revealed that the interaction between silkworm strains and mulberry varieties was found to be significant for larval, cocoon, pupal and shell weight, and shell ratio. M2 strain exhibited the longest larval developmental time (23.17 days) while ICIPE 1 had the shortest (21.00 days). Z/Y strain obtained the longest and the widest larvae of (5.09 cm, 0.72 cm) and cocoon (3.25 cm, 1.73 cm) when fed with Mysore local mulberry variety. But in terms of larval, cocoon, pupal and shell weights, Z/Y and M2 strains performed better when fed on K2 and S36 mulberry varieties. In terms of raw silk yield, this study has revealed that the three silkworm strains from Bulgaria (Z/Y, G2 and M2) yielded higher than the two silkworm strains (ICIPE 1 and ICIPE 2) from Kenya. However, ICIPE 1 strain had the highest tenacity and elongation

percentage of (4.98 g/d, 21.33 %) raw silk when fed on Mysore local variety and was ideal for silk production but the increase in larval mortality was a major setback. ICIPE 1 silkworm strain obtained the longest filament of 982.13 ± 57.75 m followed by G2 894.38 ± 57.09 m when the larvae fed on S36 food plants. From the study, Z/Y, M2 and G2 were the most suitable silkworm strains in terms of cocoon yield, shell ratio and filament length and could be promoted in Ghana. The silkworms reared on S36 and K2 revealed good growth and development of the larvae, cocoon shell weight, shell ratio and raw silk quality and so its cultivation and use should be encouraged in the production areas. The semi-captive rearing technique could be used to augment the wild population of *Gonometa* sp. in order to exploit its full potential for commercial wild silk production in Ghana.

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LIST OF ABBREVIATIONS

ICIPE	International Centre for Insect Physiology and Ecology
CSIR	Council for Scientific and Industrial Research
ISC	International Silk Commission
IIR	Institute of Industrial Research
ML	Mysore Local
K2	Kanva 2
SSC	Silk Standard Committee
G2	G2xV2xH1xKK
M2	M2xN2xSN1xI1
FAO	Food and Agriculture Organization
ARPPIS	African Regional Postgraduate Programme in Insect Science

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Sericulture is the practice of rearing silk producing insects in captivity or collecting their cocoons from the wild for commercial production of raw silk (Peigler, 1993). It also includes operations required for the production of silk fibre. Natural animal silk is broadly classified into mulberry and wild (non-mulberry) silk. The mulberry silkworm *Bombyx mori* L. (Lepidoptera, Bombycidae) is a commercially important insect that spins 95-99% of the valuable silk fibres for both textile and non-textile industry making it one of the most beneficial insects to mankind (Tsukada *et al*., 2005). Wild or non-mulberry silk include tropical and temperate types such as Tasar, Eri, Muga and *Anaphe* silk (Mbahin *et al*., 2008). Others include Fagara, Coan, Mussel, Spider and *Gonometa* silk (Kioko *et al*., 2007; Ngoka *et al*., 2008; Fening *et al*., 2008).

Globally, around 50 countries participate in silk production and their annual raw silk production is about 80,000 tonnes which is still far below the world production of cotton and other synthetic fibres (Langerodi *et al*., 2010). China and India are the two important silk producers in the world accounting for 104,000 (81.89%) and 19,690 (15.50 %) tonnes, respectively, of the total raw silk production in 2009 (ISC, 2010). While most of the producers are in Asia, sericulture industries have also been established in Latin America and a few African countries have made modest progress to provide employment to people in rural communities (Thangavelu, 2002).

The demand for silk is increasing annually by 5%, and is bound to even increase further as the world population continues to grow and the demand for fashionable clothing and items

also increases (FAO, 2003). However, efforts by various national and international agencies for raw mulberry silk production have failed to keep up with the increasing demand as production in major silk producing countries are gradually diminishing due to reasons such as diversification, high cost of labour and increasing cost of production (Raje, 1999). For a country to secure the opportunity of increasing her silk production, it has to establish the performance of the silkworm strains available. Highly productive silkworm strains and mulberry varieties that are adapted to the local conditions (Nguku *et al*, 2009) and are also tolerant to adverse climatic conditions and diseases are required (Zhao *et al*., 2007). Mulberry sericulture being an emerging venture in Ghana will depend extensively on introduced silkworm hybrids, but the stability of the silk industry will depend greatly on the locally adapted strains.

Moreover, the untapped and highly promising non-mulberry or wild silk which has attracted the attention of silk users (Raje, 2005) should be given the needed attention so as to enhance production. Although, wild silk is about 1% of world silk production, its low volume supplies exclusive niche market where scarcity and naturalness is highly valued, leading to price increment for fabric made from wild silk (Veldtman *et al*., 2002, Raina, 2004).

Sericulture is an agro-based industry that can be managed sustainably to provide gainful employment, economic development and improvement in the quality of life of people in the rural communities, especially the resource-poor to conserve the fast depleting biodiversity (Raina *et al*., 1999, 2000, 2007; Kioko *et al*., 2007; Fening *et al*., 2008). It also fits into the socio economic structure of rural areas and can minimize rural-urban migration (Ogunleye and Popoolo, 2012).

1.2 Problem statement

Reduction of rural poverty continues to be a paramount goal in developing countries such as Ghana as the majority of the population resides in the country side. World Bank estimates more than 70% of the world's poor live in rural areas (Gangopadhyay, 2000). Various strategies have been pursued to address this concern and among the major ones is rural employment creation (Langerodi *et al*., 2010). The Food and Agriculture Organization (FAO) and the government of Ghana in 2002 assisted small scale farmers in cocoon and raw silk production and processing to make additional employment and income available to them but appears to have been fruitless (Ntaanu, 2006).

According to statistics from the Institute of Industrial Research (IIR) of Council for Scientific and Industry Research (CSIR), the body responsible for the silk industry in Ghana, cocoon production has been very low and a total of 1,039.7 kg was supplied to the industry between 2004 and 2011 (CSIR/IIR, 2012). The number of farmers who were actively involved in silkworm rearing on pilot basis in 2005 in different parts of the country had reduced drastically and mulberry farms have been either abandoned or replaced with remunerative crops (Per. Comm. P. K. Ntaanu). Currently, the silk industry is operating below capacity partly due to the supply of inferior quality cocoons by farmers (CSIR/IIR, 2012). In addition, lack of governmental support that will promote effective research and adequate extension for the silk industry is a major setback. Very little information is also available on the silkworm strains and mulberry cultivars that yield superior quality cocoon and are suitable to the local climate. A typical example is the massive loss of silkworms during the year 2005 where most farmers could not reach their expected production target due to inadequate mulberry leaves to sustain the rearing of silkworms, leading to loss of silkworms nationwide (Ntaanu, 2006). Another factor that hindered the progress was drought that affected the quality of the

mulberry leaves resulting in a steep decline in cocoon production from 112.4kg in 2004 to 65.5kg in 2005 (IIR/CSIR, 2012).

Little or no relevant information exist on the wild silkmoth species and their host plants in Ghana (Per. Comm. K.O. Fening).

1.3 Justification

In relation to wild sericulture, the survey will provide baseline data on existing wild silkmoths and their host plants and later set the stage for wild silk farming in Ghana. Regarding mulberry sericulture, the determination of high yielding silkworm strains and mulberry varieties will contribute to the production of quality cocoons and enhance silk fibre and fabric production in Ghana. This information will be vital for suitable management of healthy silkworm and improvement of silkworm strains used in the country. It will also boost the '*kente'* silk cloth industry in Ghana as silk yarns could be used in the weaving process, and also have a foreign exchange saving effects by reducing the current imports (Fening, 2007).

1.4 Objectives

The main aim of this study was to document wild silkmoth populations in three different agro-ecological zones and to determine the effect of mulberry varieties on the performance of selected mulberry silkworm, *B. mori* strains in Ghana.

The specific objectives were

1. To document wild silkmoth populations and their host plants in the Forest, Forest-Savannah Transition and Guinea Savannah agro-ecological zones in Ghana.
2. To assess the feed consumption and utilization among the mulberry silkworm strains fed on different mulberry varieties.

3. To assess the effect of different mulberry varieties on silkworm larval development, cocoon size and weight
4. To assess the quality standards of raw silk produced by the mulberry silkworm strains.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Historical origin of sericulture

The mulberry silkworm *Bombyx mori* Linnaeus (Lepidoptera: Bombycidae) evolved from its wild relative *Bombyx mandarina* Moore (Lepidoptera: Bombycidae) approximately 4600 years ago in China (Hirobe, 1968): The earliest known silk textile is considered to be almost 5000 years old (Kuhn, 1988). The industrial and commercial use of silk, the historical and economic importance of its production and application all over the world contributed to the silkworm promotion as a powerful laboratory model for basic research in biology (Ramesh-Babu *et al*., 2009).

Tradition credits Empress His-Ling-Shi, 14 year old wife of the China Emperor Huang Ti, with the accidental discovery of silkworm cocoon and the invention of the first silk reel and loom (Mbahin, 2008). The Empress developed sericulture, silk reeling, weaving and the manufacture of silk garment. For nearly 3 millennia, China successfully guarded this secret and had global monopoly on silk production until AD 300, when the secret was penetrated by Japan and later India (Robert De Gregorio, 1997). The demand for this exotic fibre eventually created the lucrative trade route known as the Silk Road, taking silk westward and bringing gold, silver and wool to the East (Robert De Gregorio, 1997). Sericulture was introduced into Ghana through the initiative of Mr. Paul Ntaanu, Founder and Technical Director of Sericulture Promotion and Development Association (SPDA) with support from FAO in 1992 (Ntaanu, 2006).

2.2 World Silk Production.

Raw silk production in the world has experienced a decline of 21% from 153,942 metric tonnes in 2006 to 126,995MT in 2009 (Table 2.1), of this the proportion of mulberry raw silk production stood at 115,092 tonnes in 2006 and 90,992 tonnes in 2008 (ISC, 2011).

Table 2.1 Trends in World Raw Silk Production (tonnes).

Country	2006	2007	2008	2009	2010	% share
China	130000	108420	98620	104000	115000	82.11
India	18475	18320	18370	19690	20410	14.57
Brazil	1387	1220	1177	811	770	0.04
Thailand	1080	760	1100	665	655	0.55
Uzbekistan	950	950	865	750	2448	0.10
Vietnam	750	750	680	550	550	1.75
Korea Rep	150	150	135	135	135	0.47
Japan	150	105	95	90	53	0.39
Others	1000	500	350	304	30	0.02
Total	153942	131175	121392	126995	140051	100.00

Source: International Sericulture Commission (ISC), D&B India update July, 2011

In Ghana, raw silk (cocoon) production technology was introduced in 1992 and actual production began in 2004 (CSIR, 2012). Raw silk production is on the decline (Table 2.2)

following a decrease in the number of farmers involved (CSIR/IIR, 2012). Irregular and insufficient supply of silkworm eggs has also contributed to the decline in production.

Table 2.2 Raw silk (cocoon) production in Ghana 2004 - 2011.

Year	**Total cocoons produced (kg)**	**No. of farmers**
2004	112.4	6
2005	65.5	5
2006	154.5	5
2007	134.2	10
2008	326.6	7
2009	146.5	4
2010	50	1
2011	50	1

Source: (CSIR-IIR/TR/JA/2012/002)

2.3 Biology of *Bombyx mori* L.

The mulberry silkworm *Bombyx mori* L. (Lepidoptera: Bombycidae) has been cultivated for almost 5000 years in China and currently around the world for educational and scientific study as well as for producing textiles and other products (Peigler, 1993). An estimated 4310 silkworm germplasm strains, comprising geographical strains, inbred lines and mutants are thought to be available worldwide (Goldsmith *et al*., 2004).

2.3.1 Life cycle of *Bombyx mori* L.

The duration of the life cycle may last for 6 to 8 weeks depending upon racial characteristics and climatic condition (Rao, 1998). Eggs of *B. mori* are usually laid in clusters and are ovoid in shape with a major axis of 1.0-1.3 mm and a minor axis of 0.9-1.2 mm (Rao, 1998). The author also observed that at oviposition the eggs are pale yellow and attached to the substrate with a gummy substance when undeveloped but changes to grey when embryonated. The *B. mori* races indigenous to temperate regions usually lay diapausing eggs, while those of tropical regions lay mostly non-diapausing eggs (Tazima, 1978). According to Krishnashwami *et al*. (1971) and Rao (1998) hatching of silkworm generally begins in the morning around 6.00 am and the maximum number of larvae hatches around 8.00 am in the morning. Newly hatched larvae are black or dark brown in colour and begin to feed on top mulberry leaves an hour later (Rao, 1998).

The larval period may last for 25-30 days under ideal conditions (Raina, 2000). Silkworm can be trimoulters, tetramoulters and pentamoulters depending upon the type of silkworm race. At the 5^{th} instar, the silkworm feeds for 6 to 8 days, and mature larvae which have reached their highest body weight, become translucent, restless and raise their heads in search of support to start cocoon spinning (Krishnaswami *et al*., 1973). Spinning of cocoons takes

approximately 3 days and within the next day or two the larvae moult for one last time and transforms into pupae (Krishnaswami *et al*., 1973). Cocoons protect the pupa against microbial degradation and desiccation during metamorphosis, and also potential predators. According to Hong-Ping *et al*. (2005) a cocoon is a natural polymeric composite shell made of a single continuous silk thread (fibroin) with a length of about 1000 - 1500 m long and conglutinated by sericin. Borrer *et al*. (1981) reported that about 3000 cocoons can be used in making a pound of silk.

Fully formed pupae are brown in colour and the pupal period may last for 8-14 days for adult emergence (Krishnaswami *et al*., 1973). For commercial purposes pupae are killed before the adults emerge otherwise the emergence of the moth breaks the fibre into pieces that makes it impossible for making reeled silk, except spun silk (Shah *et al*., 2007). The adult emerges by slitting through the pupal skin, and piercing the fibrous cocoon shell with the aid of a brown alkaline salivary secretion that softens the tough cocoon shell at the end. Adults are ready to copulate immediately after emerging from the pupae and the females lay eggs shortly after separation from the males. Adult life lasts from 3-10 days, with the males having much shorter lifespan. The moths are creamy white in colour with faint brownish lines. They do not feed and rarely fly. According to Krishnaswami *et al*., (1973), a female moth of the multivoltine race lays on average 400 eggs while the average number for the univoltine and bivoltine races of silkmoths is from 500-600 eggs.

2.3.2 Feeding behaviour of mulberry silkworm (*Bombyx mori*).

The mulberry silkworm is a domesticated and monophagous insect which feeds only on the leaves of mulberry for its nutrition (Sabhat *et al*., 2011). The method of feeding and the quality of mulberry leaf plays an important role in *B. mori* nutrition. Gangwar *et al*. (1993)

reported that silkworms prefer to feed on only fresh mulberry leaf and stops feeding once the leaf loses its moisture and becomes unpalatable. The authors also evaluated the ingestion of mulberry leaf by cross breed silkworm race MYI x NB4D2. Observations made indicated that ingested leaf per feed was greater during the night than the day and that the maximum leaf ingestion occurred at 22.00 hours, followed by leaf ingestion at 06.00 hours. They also indicated that consumption of leaf was high during the first two hours of feeding, as the leaf was fresh and palatable during this period. Early-age silkworms eat leaves from the surface while late-age silkworms feed from the edges (Krishnaswami *et al*., 1971).

2.4 Factors that influence successful silkworm development and silk production.

Different factors contribute to successful silkworm productivity and these include mulberry leaf quality (38.2%), climate (37.00%), silkworm rearing techniques (9.30%), silkworm races (4.2%), silkworm eggs (3.10%) and other factors (8.2%) (Miyashita, 1986). The two major factors that affect successful cocoon production are therefore leaf quality and environmental conditions.

2.4.1 Leaf quality and quantity.

Gabriel and Rapuses (1976) reported that the quality of mulberry leaf is influenced by several factors including maturity, variety, climate, season, exposure to light, irrigation and soil type on which the mulberry is grown. The quality of leaves is influenced by the duration of sunlight, rainfall, wind and temperature. Under optimal conditions of rainfall and sunlight, the mulberry plants grow vigorously, rendering the leaves more mature, soft and rich in moisture content, proteins and carbohydrates and other minerals that are essential for healthy growth and development of the silkworm (Firdose and Srinivasa, 2007). Paul *et al*. (1992) established that the water content of the leaf has a direct relation to the ingestion,

approximate digestibility and efficiency of conversion of ingested and digested food. Continuous dry weather which prevails in autumn and summer retards, the growth of the mulberry tree, reduces protein and water content rendering the mulberry leaves hard and unsuitable for feeding the silkworms (Sabhat *et al*., 2011).

Kumar *et al*. (2000) also reported that the nutritional status (leaf quality) of mulberry leaf varies with age or leaf maturity and temperature played a vital role in growth, development and productivity of the silkworm. Rangaswamy *et al*. (1976) reported that moisture, crude protein, reducing, non reducing and total sugars were more in tender leaves followed by middle and bottom leaves. Elumalai *et al*. (2001) studied the influence of medium coarse and coarse leaves on the rearing characteristics of silkworm and found that the medium coarse leaves enhanced most of the economic characters. Krishnaswami *et al*. (1971) reported that silkworm larvae require different ages of mulberry leaves during their growth stages, to ensure their healthy and uniform growth. Aruga (1994) observed that the first to third instars larvae fed with over matured mulberry leaves become more often afflicted with serious diseases in the fifth instar and the physiology of the silkworm gradually becomes abnormal. He further indicated that mulberry leaves subjected to continuous rain and high temperature are not suitable for late instar silkworm, because they contain less protein, vitamins and carbohydrates and more water.

Some mulberry genotypes have been observed to produce higher percentage of moulting ability in silkworm larvae (Rahman *et al*., 2000). Parra (1991) reported that the quantity and quality of mulberry leaves affect growth rate, developmental period, body weight and survival rate of larvae, as well as influencing the subsequent fecundity, longevity, movement and competition ability of the adult. The quantity of leaf consumed by silkworm directly or

indirectly influences the digestibility and conversion efficiencies of food (Ueda *et al*., 1969). Higher food intake tends to mobilize the gut contents faster and provides less time for enzyme activity and food absorption making digestion efficiency poor (Walbauer, 1968). Feed conversion efficiency is an important physiological criterion for evaluating the superiority of silkworm breeds (Trivedy and Nair, 1998).

2.4.2 Environmental conditions.

The mulberry silkworm is very delicate and highly sensitive to environmental fluctuations and unable to survive extreme natural fluctuation. Thus, its adaptability, growth and development, productivity and silk quality are greatly influenced by environmental conditions which are quite different from the wild silkworms (Rahmathulla, 2012).

2.4.2.1. Temperature.

Temperature plays a vital role in growth and productivity of silkworms (Ueda *et al*., 1975; Benchamin and Jolly, 1986). High temperature affects nearly all biological processes including the rates of biochemical and physiological reactions (Hazel, 1995; Willmer *et al*., 2004) and ultimately affecting the quality of cocoon. Kobayashi *et al*. (1986) observed that high temperature during incubation affects voltinism, and that the embryonic stage is sensitive to temperature. Reports by Tazima and Ohuma (1995) and Hussain *et al*. (2011) indicated that silkworm larvae are sensitive to temperatures above 25 ± 1ºC during 4^{th} and 5^{th} instar. Fifth instar silkworms prefer relatively lower temperature than young age and fluctuation of temperature during different stages of larval development was found to be more favourable for growth and development of larvae than constant temperature (Gowda and Reddy, 2007).

Exposure of male silkworm to temperatures above 33ºC from the time of spinning to pre-pupal periods results in male sterility (Sugai and Takahanshi, 1981) and more unfertilized eggs (Ming, 1994). Pilai and Krishnaswami (1987) noted reduced survival rate, pupation rate and cocoon quality due to high temperature above 30ºC. Talukder (1993) also observed temperatures above 28 ± 1ºC adversely affected larval and cocoon characteristics and disease incidence as well as yield of cocoons.

Junliang and Xiaoffeng (1992) observed that increase of temperature (20-30ºC) reduces the rate of leaf conversion by silkworm larvae to silk. Low temperature throughout the rearing period favoured higher silk conversion with better survival in bivoltine silkworm (Muniraju *et al.,* 1999). Though reduced temperatures have advantages, they must be avoided because they decrease the rate of growth, and the rearing lasts longer, affecting the cost involved (Ifantidis, 1982; Patil and Gowda, 1986). According to Singh and Samson (1999), cocoon weight and reproductive character are greatly influenced by different temperature regimes.

2.4.2.2 Humidity.

Humidity directly affects the physiological functions of the silkworm and indirectly influences the rate of withering of the leaves. Under dry conditions leaves wither very fast and consumption by larvae becomes very low, thus leading to retarded growth and susceptibility to diseases. Humidity interacts with the availability of free water and with the water content of the food and it indirectly affect growth and development of silkworms (Rahmathulla, 2012).

Humidity can affect embryonic development by causing dessication, spiracular diffusion and retention of ingested water (Mathur and Lal, 1994). According to Rahmathulla (2012) loss of water from silkworm eggs occurs when humidity is less than 60% and at 90% and above

leads to retention of physiological waste water inside the egg resulting in poisoning of the embryo. The optimum relative humidity required during incubation is 80%. An increase results in fugal growth on the eggs and exposure of the larva to fungal diseases (Ifantidis, 1982; Patil and Gowda, 1986). When high humidity occurs during cocoon spinning, water present in the spinning solution, silkworm urine and faeces are evaporated slowly thus, influencing the structure of the sericin (Gowda and Reddy, 2007). This may reduce the solubility of the sericin and increase the agglutination force between the cocoon filament and the cocoon shell. Akahane and Subouchi (1994) evaluated the relationship between water of cocoon layers during the spinning stage and the reelability of cocoon, and recommended that water content of the cocoon layer should be below 20% in order to obtain good quality cocoons with better reelability. Krishnaswami *et al*. (1973) reported that optimum humidity 75 ± 2% ensured normal growth of silkworm larvae.

2.4.2.3 Air and light.

During embryonic development, carbon dioxide gas is released as the end product of respiration and this affects the diapause nature of the eggs as well as the silkworm larval and pupal duration, cocoon weight and egg production (Kai and Hasegawa, 1971). According to Patil and Gowda (1986) the larval duration of silkworm fed in complete darkness is longer resulting in poor cocoon quality during its life cycle. Anonymous (1998) also observed that under artificial light female moths do not produce sex pheromones to attract male there by affecting the mating behaviour of the moths.

2.4.2.4 Population densities.

Rearing space plays a vital role in the success of a silkworm crop and improvement of cocoon quality. Islam (1981) reported that overcrowding during 4^{th} and 5^{th} larval instars reduced

larval period and might also increased the incidence of larval diseases such as Grasserie, Flacherie, Pebrine and Muscardine. Talukder *et al.* (1990) observed that increase in population density decreased the rate of cocoon production and adult longevity. Overcrowding leads to unequal and insufficient consumption of leaf, unequal growth of silkworms, susceptibility to diseases and low cocoon yield (Sengupta and Yusuf, 1974). Tribhuwan and Singh (2001) evaluated the performance of bivoltine silkworm breed under different spacing systems on nine economic traits (weight of mature larvae, effective rate of rearing, single cocoon weight, single shell weight, shell ratio, pupation, absolute silk content, female pupal weight and fecundity) and observed that the wider spacing of (23.34 - 27.84m^2 for 20,000 larvae) was the most appropriate for all the economic traits, except fecundity.

2.5 Mulberry plant (*Morus* spp).

Mulberry (*Morus* species) leaf is the sole food and source of nutrition for the silkworm *B. mori* due to the presence of morin (Tribhuwan and Mathur, 1989). Mulberry is a fast growing deciduous, deep rooting and perennial tree that grows throughout the temperate, subtropical and tropical regions (Dingle *et al*., 2005). The mulberry plant belongs to the genus *Morus* of the family Moraceae and subclass Urticales. There are about 68 species of the genus *Morus*, and the majority of them occur in Asia, especially in China (24 species) and Japan (19) (Datta, 2000). In India the main species are *M. indica*, *M. alba*, *M. serrata* and *M. laevigata*, which grow naturally in the north of the country (Ravindran *et al*., 1997). The most widely cultivated mulberry species in Ghana is *M. indica* which includes Kanva 2, S-36, V-1 and Mysore local varieties (Ampiah, 2013).

Cultivation can either be vegetative or through seeds. Vegetative propagation of mulberry plants is the most practised method in the tropics particularly in Ghana because of the speed

in raising saplings and its adaptability. Mulberry grows best in regions with rainfall ranging from 600-2500 mm and temperatures of 23-28ºC (Boraiah, 1994). The plant also performs best in areas receiving sunlight duration of 5 - 12.5 hours in temperate regions and 9 - 13 hours in the tropics. A relative humidity of 65 - 80% and altitude of 700 m above sea level is ideal for mulberry cultivation. The plant grows well in drained flat fertile land of clayey loam soil with pH of 6.5 - 7.0 (Rangaswami *et al*., 1976). Domestication of mulberry started several thousands of years ago as requirement for silkworm rearing. The chemical composition of mulberry leaves include moisture (75-82%), crude protein (24-36%), crude fat (3-4%), crude fibre (9-11%), ash (mineral) (7-8%), and carbohydrates (12-20%) (Ganga and Chetty, 1999). Chemical composition varies with age of leaf, climate, soil type, ground water, sunlight, pruning method and the variety. Qader *et al*. (1992) investigated the nutritive effects of leaves of three mulberry varieties on larval growth and cocoon characters of three *B. mori* races. The results revealed that mature larval weight, single cocoon weight, shell percentage and the length of filament were greatly influenced by the nutritive value of different mulberry leaves. Different species of mulberry may have compositional differences and might lead to varying effects on the *B. mori* growth and silk production (Mahmood *et al*., 1987).

2. 6 Influence of mulberry varieties on silkworm development and cocoon production.

Mulberry genotypes influence the growth and development of silkworm, and in turn cocoon yield and silk quality. Mulberry varieties have been reported to influence the efficiency of food conversion into body mass, cocoon and shell weight among silkworm breeds (Anantha *et al*., 1995). Legay (1958) observed that not only the quality of mulberry leaf had great influence on the amount ingested but also the characteristics of the mulberry genotype.

Bose *et al*. (1989) reported that moisture percentage and crude fibre are maximum in S-54 genotype and minimum in Mysore local. Total mineral percentage is maximum in Mysore local and minimum in S-41 genotype. Tayade *et al*. (1988) reported significant differences in larval duration, weight, single cocoon weight, shell percentage, fecundity and yield of cocoons when silkworms were fed with mulberry genotype viz., Kanva-2. Kosen, LM-1.LM-2, Mysore local, S-36, S-41 and S-54. However, S-54 was superior followed by S-41 and Kanva-2 for feeding in terms of yield and yield contributing traits.

2.7 Non-mulberry or wild silkmoth sericulture in the world.

In addition to the domesticated or mulberry silkworm, *B mori*, many indigenous wild silkmoths species have been utilized for over 2000 years (Peigler, 1993). Wild silkmoths cocoons are collected from the wild population and in some cases, rearing is done outdoors with little or no protection of larvae (Peigler, 1993; Kioko *et al*., 2007). Non-mulberry sericulture holds great promise for the world's forestry and can help arrest forest destruction, as it permits gainful utilization of its natural wealth (Jolly *et al*., 1975; Fening *et al*., 2008).

About 25 species of wild silkmoths have been exploited for wild silk production in the world (Table 2.3), and this has been done mainly by tribal communities as reflected in some of the names of the silk (Peigler, 1993; Raina, 2000).According to Peigler (1993), India is the foremost country in the production of wild silk (Eri, Muga and Tasar) mainly for reasons being historical, cultural and economic. Wild silk varieties obtained globally include the Asian wild silk (Muga, Tasar, Fagara and Eri), the European silk (Coan) and the African wild silk obtained from indigenous wild silkmoths belonging to the genera *Anaphe* , *Gonometa* , *Argema* and *Epiphora* (Mbahin *et al*., 2008; Ngoka *et al*., 2008; Fening *et al*., 2008; 2010).

Table 2.3 Non-mulberry or wild silkmoth species and their distribution in the world.

Name of species	Family	Distribution
Bombyx mandarina Moore	Bombycidae	China, Japan, Korea
Antheraea paphia Linn	Saturniidae	India
Antheraea pernyi G & M	Saturniidae	China, India
Antheraea yamamai G & M	Saturniidae	Japan,Taiwan
Antheraea assamensis Helfer	Saturniidae	(Assam) India
Antheraea mylitta Drury	Saturniidae	India
Antheraea roylei Moore	Saturniidae	India, China
Argema momosae Boisduval	Saturniidae	South Africa, Malawi, Mozambique
Attacus atlas Linn.	Saturniidae	China, India
Samia ricini Boisduval	Saturniidae	China, India, Japan, Cuba, Egypt, France, Italy
Samia cynthia Drury	Saturniidae	India, China
Anaphe carteri Walsm	Thaumetopoeidae	Uganda, Nigeria
Anaphe panda Boisduval	Thaumetopoeidae	Uganda,Tanzania, Kenya, Nigeria
Anaphe moloneyi Druce	Thaumetopoeidae	Uganda, Nigeria
Anaphe reticulate Walker	Thaumetopoeidae	Uganda, Nigeria, Kenya
Anaphe venata Butler	Thaumetopoeidae	Uganda
Anaphe vuillet De Jouan	Thaumetopoeidae	Congo, Sudan,Uganda
Gonometa postica Walker	Lasiocampidae	South Africa, Kenya
Gonometa rufobrunnea Auri.	Lasiocampidae	South Africa, Namibia
Borocera cajani Vinson	Lasiocampidae	Madagascar
Pachypasa otus Drury	Lasiocampidae	Italy, Greece

Source: Adapted from Peigler, 1993; Gongyin and Cui, 1996; Raina *et al*., 2011; Mbahin *et al*., 2008; Fening *et al*., 2008.

2.7.1 Wild silkmoths and their host plants in sub-Saharan Africa.

Most of the wild silkmoths in Africa belong to the families Saturniidae, Lasiocampidae and Thaumetopoeidae. The potential of African indigenous silkmoth species for wild silk production has been documented in Uganda (Kato, 2000), Nigeria (Ashiru, 1991), Kenya (Raina *et al*., 2007; Kioko 1998; Fening *et al*., 2008), Botswana (Hartland-Rowe, 1992), Zimbabwe (Chikwenhere, 1992), Cameroon (Malzy and Par, 1955), Madagascar (Razafimanantosoa *et al*., 2006), Angola (Rougeot, 1962) and South Africa (Veltman *et al*., 2004).

The quality of silk obtained from African wild silkmoth species are good and of high commercial value (Raina, 2004). Cocoons of *Gonometa rufobrunnea* Auri. have been reported to occur in South Africa and Namibia in the savannah where larvae feeds on *Colophospermum mopane* Kirk ex j. Leo (Hartland- Rowe, 1992). *Gonometa postica* is known to feed on *Acacia hockii*, *A. mearnsii A. tortilis*, *A. nilotica*, *A. elatior*, *A. mellifera* and *A. brevispica* in Kenya, East Africa (Kioko 1998; Fening *et al*., 2008; Ngoka *et al*., 2008). Wild silkmoths belonging to the genus *Gonometa* are known to produce cocoons of high quality silk but is slightly coarser than *B. mori* silk, but finer than other wild silk (Hartland-Rowe, 1992; Freddie *et al*., 1993).

In Kenya the larvae of the wild silkmoth, *Argema mimosae* Biosduval (Lepidoptera: Saturniidae) feed on *Shweinfurthii* spp, *Sclerocarya birrea* and *Ozoroa insignis* (Ngoka *et al*., 2008). The larvae of wild silkmoth *Anaphe* spp of Southern and Central Africa are polyphagous (Mbahin *et al*., 2008) but prefers host plants *Cynometa milleni* and *Bridelia micrantha*.

2.8 Diseases of silkworm.

Diseases of silkworm, *B. mori* are the main factors seriously affecting cocoon production (Watanabe, 1986).The susceptibility of silkworm to disease infection depends upon the breeds (Baumann *et al*., 1991). Mulberry silkworm is susceptible to different diseases including viral, microsporidian, bacterial and fungal.

2.8.1Viral diseases (Grasserie).

Grasserie disease of *B. mori* is caused by a nucleo polyhedrosis *Borrelina bombycis* virus (BmNPV) and is the most harmful virus in the sericulture industry, often causing severe economic losses (Ponnuvel *et al*., 2003). The disease may be induced when low temperatures or high temperature treatment is applied to the larvae immediately after moulting (Kobayashi and Kawase, 1980).

2.8.2 Bacterial disease (Flacherie and Sotto).

The etiology of the bacteria diseases are not fully understood because of the multiplicity of bacterial types involved in the infection (Choudhury *et al*., 2002). Flacherie is a syndrome associated with infectious flacherie, Densonucleosis (DNV), cytoplasmic polyhedrosis (CPV) and bacterial diseases. Symptoms associated with flacherie infection include loss of appetite, diarrhoea and vomiting then the larvae softens and die emitting a foul odour.

Sotto disease is also one of the most important bacterial diseases of silkworm. The sotto disease occurs when the silkworm larvae ingest mulberry leaves contaminated with *Bacillus thuringiensis* (Bt). *Bacillus thuringiensis* have been sold and used as bio pesticides against crop pests due to their efficacy against insects. It has been reported that Bt is widely distributed (96%) on mulberry leaves and causes severe damage to the silk industry (Krishnaswami *et al*., 1973; Sarker, 1998).

2.8.3 Fungal disease (Muscadine and Aspergillosis).

This is a fungal disease caused by several entomopathogenic fungi, *Beauveria bassiana* and *Aspergillus flavus, A.oryze* and *A. tameri.* Climatic conditions in the tropics are congenial for survival, infection and spread of this disease. The site of infection is generally the external integument, although infection through the digestive tract is possible (Gabriel, 1959). Fifth instar larvae are reported to be more susceptible than other instar larvae (Reddy, 1978).

2.8.4 Microsporidiosis (Pebrine).

The microsporidia are spore forming, small, obligate, intracellular living eukaryote infecting both beneficial and non-beneficial insects (Nataraju *et al*., 2005). Pebrine is one of the most dreaded diseases of *B. mori* and is caused by parasitic microsporidian called *Nosema bombycis* Nagali. This disease determines the success or failure of the sericulture industry in a nation, infects almost all ages, stages, breeds and hybrids of the silkworm by both peroral and transovarial infection (Singh *et al*., 2012).

2.9 Prevention and Control of silkworm diseases.

2.9.1 Physical control.

The physical methods include simple and effective treatment such as exposure of contaminated materials and equipment to direct sunlight, burying or burning of diseased silkworm, destruction of pathogens through disinfection, improvement of feeding and management to increase vigour and disease resistance. Since there are no specific preventive measures for the occurrence and spread of disease other than sanitized rearing methods, the only commercial practice today is to discard large stocks of silkworms in case of infection to avoid spread of disease (Acharya *et al.*, 2002).

To prevent the spread of viral disease, disinfection is implemented immediately after harvesting the cocoons as dead worm are the most concentrated source of infection (Liu and Zhong, 1989). Since pebrine disease is seed borne, surface sterilization of eggs immediately after egg laying and also during the pin-head stage of incubation should be followed to prevent the occurrence of disease from surface contamination (Singh *et al*., 1992).

2.9. 2 Chemical control.

The effectiveness of chemical disinfectant depends upon the concentration and duration of the chemical as well as the ambient temperature. Some common chemicals used as disinfectants include chlorine compounds, formalin, paraformaldehyde and lime powder (Pallavi and Kamble, 1997). Antibiotics are widely used in sericulture industry as a component of bed disinfectants and as therapeutic application against bacterial diseases (Subramanian *et al*., 2009). Broad spectrum antibiotics including penicillin, streptomycin, tetracycline and chloramphenicol were tried on silkworm and found successful (Venkatesh and Srivastava, 2010).

2.9.3 Resistant races.

In view of the inadequate disinfection and prevalence of unhygienic conditions in the rearing areas, the use of disease resistant silkworm strains can be a better option. Identification of silkworm lines and commercial hybrids tolerant to BmNPV and other diseases is very useful Sivaprasad *et al*. (2003). The utilization of disease resistant varieties to prevent disease infection has many advantages. No specific measures and chemical reagents are needed. The method saves labour, material and expenses, reduces the environmental contamination.

2.9.4 Quarantine of silkworm disease.

For pebrine disease of silkworm, the quarantine of silkworm disease is an essential step to prevent the embryonic infection. Several predictive inspection and early diagnosis of pebrine disease have been developed, such as monoclonal antibody- sensitizes latex for pebrine spore diagnosis (Shi and Jin, 1997), multiprimer PCR for the early and simultaneous detection of several kinds of microsporidia that cause silkworm pebrine. The predictive inspection of pebrine disease can help to adopt a corresponding measure for disease prevention.

2.10. Production of raw silk yarn from cocoons.

There are several steps involved in the production of raw silk yarn from cocoons (FAO, 1987). These include stifling, cooking, reeling, re-reeling, skein lacing and tying, bookmaking and bundling.

2.10.1 Stifling/ drying cocoons.

Drying of cocoon is done to protect cocoon quality, preserve condition of cocoons for reeling and prevent damage caused by long periods of storage. Drying kills the pupa and evaporates moisture that would ruin cocoons. Otherwise the emerging moth will pierce the shell and render the cocoon useless for conversion to raw silk. The following methods of cocoon drying have been recommended for commercial use: sun drying, steam stifling and hot air-drying.

2.10.2 Cooking.

Prior to cooking, defective as well as double cocoon are sorted out. Cocoon cooking unwinds the cocoon filament spun by the silkworm. The sericin covering the cocoon filament is agglutinated after silkworm spinning, then hardened through the cocoon drying process.

Cooking softens the sericin component (the proteinaceous silk gum) which binds the protein fibroin strands (baves) from which the silk thread is reeled by heat, water and steam (Ranjana, 2012). The silk fibre produced by silkworm is a composite material formed by fibroin protein surrounded by sericin protein which accounts around 67 – 75 % and 22 -2 5%, respectively (Mahmoodi *et al*., 2010). Mulberry cocoons can be easily reeled after cooking in hot water. However due to the irregular nature of the shell of wild silkmoth cocoon, and the presence of other components (natural waxes, colouring component, mineral matter), the use of various chemical like washing soda, sodium lauryl sulphate, hydrogen peroxide have been used (Fening *et al*., 2009). An alternative cooking method using enzymes have been developed as the chemical method tends to reduce the quality of silk thread (Mahmoodi *et al*., 2010). Cooking can either be done by pan or machine.

2.10.3 Reeling and re-reeling.

Reeling is the process by which a number of cocoon baves are reeled together to produce a single thread. Cooked cocoons are brushed and transferred to reeling basin filled with warm water (Plate 2.1). The cocoon are picked up by a reeler and passed through a jet boat to croissure wells. This is drawn upwards and wound around small reels (Plate 2.2).

Plate 2.1 Cooked cocoons ready for reeling.

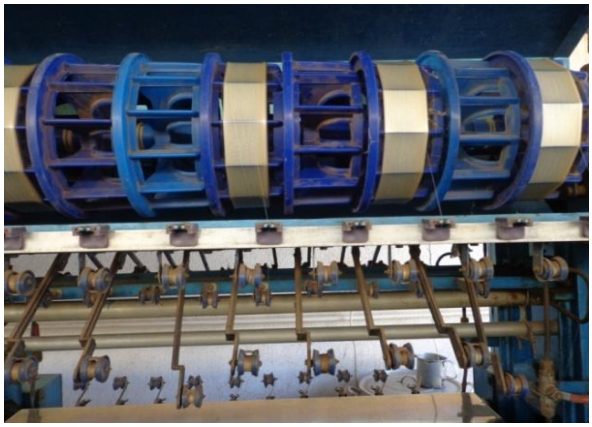

Plate 2.2 Raw silk on a multi reeling machine.

Three types of reeling units can be used, namely charka, cottage or domestic basin and multi-end reeling unit (Mande *et al*., 2000). Re- reeling makes standard sized hanks or skeins for marketing. It also eliminates defects, which might have occurred during reeling. This is done by dipping the raw silk around the small reels in water to soften the sericin (Plate 2.3).The already reeled raw silk is re-reeled from small reels onto standard size reels (Plate 2.4).

Plate 2.3 Raw silk being softened in water.

Plate 2.4 Re - reeling onto standard reels.

2.10.4 Silk tying and lacing.

The end of the silk is tied with cotton thread, in order to easily find the end of the silk thread during preparation for weaving. Skein lacing maintains the diamond cross originally in the skein (Plate 2.5).

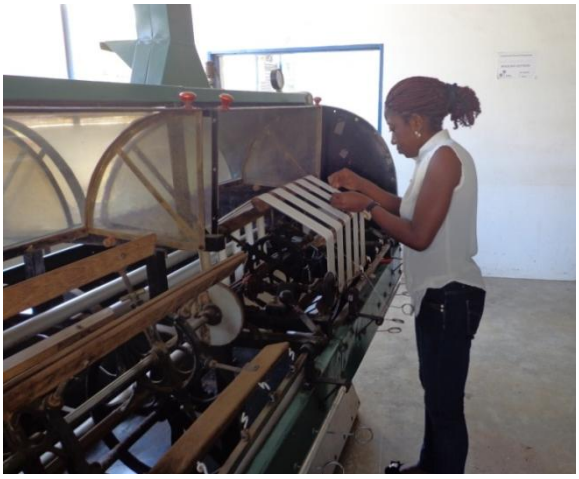

Plate 2.5 Lacing of silk skeins on standard reels at the silk processing laboratory, ICIPE, Nairobi.

2.10.5 Booking and Packing.

Around 30 skeins are bundled into a book if they are single skeins, whiles 20 skeins will be bundled into a book if they are double skeined. In packing, one bale contains 22 - 30 books and the standard weight is about 60 kg.

2.11 Silk testing and quality control.

Quality control has been found to be the most effective measure to maintain the pre-requisite quality and quantity to any textile product either at yarn or fabric stage and can be used to improve the product and achieve compliance to retailer specific standards (Sonwalker, 1993). Quality raw silk cannot be made just by producing good quality cocoons alone. Appropriate reeling or spinning technique is equally important for the production of good quality silk. Introduction of silk testing and grading is a step in the right direction for ensuring quality (Lee, 1999).

2.12 Economic Importance of Sericulture.

Silk, a by product of sericulture has some unique properties which makes it compete against artificial silk. *Bombyx mori* silk is widely used for producing various silk fabrics such as dresses, Kimonos, quilt covers and ties (Dingle, 2005). Silk is used to prepare screens for screen printing such as labels, shirts and billboards. Most foot ware especially in cold climates is produced with silk lining to protect feet from frost and it is also included in the design of fabric-based shoes to ensure strength and durability. Silk fibre can be used in industrial applications as sieves in flour and cement mill (Mondal *et al*., 2007). In medical science, silk is used extensively in making surgical suture, replacement of arteries (with prosthetic silk), artificial blood vessel and realignment of teeth (with silk braces) (Ishfaq and Akram, 1999).

Different parts of the mulberry plant have a variety of medicinal properties, as leaves are dried and used in infusion in Asia (Datta, 2000). Silk is used as tennis racket string, fishing lines and parachutes. It is also used in the electric industry as insulating material and as tyre linings (Mondal *et al*., 2007). Silkworm pupae are rich in oils and have been used in the preparation of sodium and potassium soaps, plasticizers for PVC, lubricants, printing inks, varnishes and dyes used in the textile and tannery industry. Hydrolysed protein, amino acids and vitamin B_{12} can also be obtained from it (Mahmood *et al*., 2001). The residue from the chrysalis oil extraction is used as natural organic fertilizer and as food for poultry, pigs and fishes.

Apart from silk, there are other by products from sericulture. Mulberry trees are highly appreciated for their delicious fruits, which can be consumed fresh, or in the form of juice or milk beverage (Liu and Zhong, 1989). They are also used for landscaping and their wood for

handicraft, cabinets and sporting items (Tipton, 1994). Mulberry leaf surplus from silkworm feeding are fed to farm animals and to herbivorous carp in polyculture fish pond (Gongfu *et al*., 1997). Litter from *B. mori* rearing is used as artificial diet for animals and green manure for crop (Ishfaq and Akram, 1999). *Bombyx mori* faeces are also mixed with biomass for maximum biogas production and mushroom cultivation (Somanna and Reddy, 1996).

Sericulture has the potential of playing a role in eco-tourism, by raising awareness both locally and internationally of the unique biodiversity of wild silkmoth species and the threat to their existence (Raina and Kioko, 2000). Wild silkmoths can also be used as ecological indicators of environmental change (Oberprieler, 1995). 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 signal of change in the environment, for example the introduction of a palatable exotic species or an increase in the natural food plants. Wild silkmoth powder obtained from *Antheraea pernyi* and *Samia Cynthia ricini* have been used in non- textile product: high valued cosmetics, food additives and silk-spread materials (Akai, 2000).

CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 Area of study.

This work was undertaken in the field and laboratory. Field survey of wild silkmoth populations was conducted in the Forest, Forest Savanna Transition and Guinea Savanna zones of Ghana. Cultivation of mulberry varieties was carried out at University of Ghana (UG) experimental farms, while the rearing of silkworms and post cocoon processing took place at laboratories at the University of Ghana, ARPPIS (African Regional Postgraduate Programme in Insect Science) and ICIPE (International Centre for Insect Physiology and Ecology) in Nairobi.

3.2 Survey of wild silkmoths and their host plants.

Field surveys were conducted on the vegetation along the major roads and nearby bush or forest in the Forest- Savanna transition (Ejura, Atebubu, Yeji), Guinea Savanna (Makango, Loagri, Tamale, Bolgatanga, Navrongo and Paga) and Semi-deciduous Forest (Atewa Range Forest Reserve) to document wild silkmoths and their host plants. The survey was conducted for a period of 3 months. Host plants of some wild silkmoth species including *Acacia* spp. and *Bridelia micrantha* and other non-host plants were thoroughly searched for the presence of insect cocoons. The geographical positions of the host plants with cocoons were recorded with a Global Positioning System (GPS) (Fening *et al*., 2008; Mbahin *et al*., 2008) and the number of cocoons recorded. Cocoons collected were kept in a net cage of size 0.35 m x 0.35 m x 0.30 m with net size 0.1mm at the laboratory till adult emergence. Moths were identified at UG in Accra by Dr. Ken Okwae Fening and confirmed by Dr. Boniface Mutua Ngoka at ICIPE. Voucher specimen has been kept at ARPPIS, UG and in the Commercial Insect museum at ICIPE. Plant parts, especially leaves and reproductive parts were pressed in

newspaper and sent to the herbarium of the Botany Department of UG for identification using reference specimen in their museum.

3.3 Cultivation of Mulberry varieties.

The experimental site for mulberry cultivation is located at the University of Ghana Research farm on latitude 5°39'37.264N and longitude 0°11'40.687W at altitude 97.24 m above sea level in the Coastal Savanna zone of Ghana. The mean annual rainfall and temperature in this area is 800 mm and 27.1°C, respectively. The soil type belongs to the Adentan series and it is a savanna acrisol.

The land was weeded and ploughed and later levelled for planting of mulberry cuttings. Mulberry varieties namely Mysore local, Kanva 2 and S-36 with 4-5 buds were planted (Plate 3.1- 3.3) on June 15, 2012 with a spacing of 0.9 m x 0.9 m. The plants were watered daily during the dry season and as and when necessary during dry spells in the rainy season. Mysore local and S-36 cuttings were obtained from Pukrom near Nsawam in the Akuapim South District and Kanva 2 variety was obtained from Kwatre near Sunyani in the Sunyani West District. The mulberry farm covered a total land area of 1495.92 m^2. Chemical fertilizers (Urea, Sulphate of ammonia and N.P.K 15: 15: 15) were applied two months after planting at equal rate of 5g/plant by ring method at 4 week interval for two consecutive times. Mulberry branches were pruned, six months after planting (February 2013), for fresh leaves to sprout, and these leaves were used to rear the silkworms in April-May 2013. Weeding was carried out at three months interval for three consecutive times while insecticide (Deltamethrin) was sprayed at recommended rate of 30ml/L to control pests that are likely to attack the mulberry plant, especially the defoliators. Mulberry leaves were harvested 8-9 months after establishment of the farm by picking leaves from the plants. Harvesting of

leaves was done early in the morning between 06.00 - 07.00 hours and transported to the rearing facility at ARPPIS Centre for use.

Plate 3.1 Mysore local variety.

Plate 3.2 Kanva 2 variety.

Plate 3.3 S-36 variety.

3.4 Silkworm rearing.

The silkworms were reared in the laboratory at the ARPPIS Centre between April and May 2013. The rearing room was thoroughly washed, cleaned and disinfected with slaked lime and dettol using a knapsack sprayer, and it was done 7days prior to rearing of the silkworms.

3.4.1 Incubation of eggs and rearing of larvae.

Five silkworm strains consisting of (G2xV2xH1xKK, M2xN2xSN1xI1 and Z/Y) from Bulgaria, and ICIPE I and ICIPE II from Kenya were used for the study. Healthy eggs of F1 generations each were kept in wooden trays (0.51 x 0.81 m) lined with newspaper (Plate 3.4) and incubated at a temperature of 28 ± 2°C and relative humidity 70% - 80%. The photoperiod was 12: 12 hr (L: D). The eggs were covered with another newspaper to maintain optimum temperature and RH. At the pin head or blue stage, the eggs were black boxed (i.e. the eggs were covered with black cloth) for 24 hours followed by exposure to day light in the morning to ensure uniform hatching (Anon, 1993). One hundred and fifty newly hatched larvae each of the five hybrids were fed with leaves from the topmost part of the mulberry plant, while 3rd - 5th instar larvae (8-25 days old) were fed with fully grown leaves from the mulberry plants (Minamizawa, 1997). Daily temperature and relative humidity for the rearing period was recorded with a thermo-hygrometer. Mortalities in each larval instar were recorded.

Plate 3.4 Silkworm strains reared in wooden trays at ARPPIS laboratory, UG.

3.5 Determination of larval food consumption and utilization.

This study was conducted using 5th instar larvae. One hundred (100) 5th instar larvae from each replicate were randomly selected for further rearing. The gravimetric method described by Waldbauer (1968) was used to determine food consumption and utilization. Accurately weighed mulberry leaves were fed to silkworms, four times daily. Sample of mulberry leaves used for each feeding was placed in separate trays for dry weight determination of ingested food. The excreta and left over leaves were separated and oven dried until constant weight was obtained. The study was laid down in a Completely Randomised Design. There were fifteen treatments (5 silkworm strains x 3 mulberry varieties) and each treatment had three replicates, totalling 45 replicates in all. Food consumption (ingesta), utilization (digesta) and approximate digestibility (AD) were assessed as follows:

Ingesta is the intake of the dry weight of mulberry leaves by silkworm larvae during the 5th larval stage up to spinning.

Ingesta = Dry weight of leaves fed - Dry weight of the left over leaves.

Digesta is total assimilated dry food from the intake or ingesta.

Digesta = Dry weight of leaf ingested - Dry weight of excreta.

Approximate Digestibility (AD) is the assimilation efficiency of mulberry leaves and depends on the passage rate of food through gut in silkworm and it is expressed as a percentage.

$$AD = \frac{\text{Ingesta}}{\text{Digesta}} \times 100$$

3.6 Effect of mulberry varieties on silkworm larval development and cocoon quality.

3.6.1 Measurement of larvae and cocoon quality.

The study was laid down in a Completely Randomised Design with three replications for fifteen treatments (5 silkworm strains x 3 mulberry varieties) and each replicate comprised 50 larvae. There were 45 replicates in all. At 5th instar larval length, width and weight were measured for each of the five silkworm strains. Thirty live larvae, 10 from each replicate were selected at random from each treatment, placed in a petri dish and weighed using electronic weighing balance (Kern 870) (Plate 3.5) (Richards and Villet, 2008). The larvae were killed by immersing them in hot water (above 80 °C) (Tantawi and Greenberg, 1993; Adams and Hall, 2003) and the length and width of each dead larva was measured with digital venier caliper 150mm (Plate 3.6) in a petri dish.

Plate 3.5 Silkworm larva being weighed in a petri dish on a balance.

Plate 3.6 Measurement of the length of 5th instar larva.

Matured silkworms (21-23 days old) from each replicate were handpicked and mounted on egg crates until they spun cocoons. The freshly spun cocoons (Plate 3.7) were harvested on the seventh day.

Plate 3.7: Spun silkworm cocoons on egg crates. **Plate 3.8** Opened cocoon with pupa.

Thirty cocoons from each treatment were also selected at random and the following measurements; cocoon length, width and weight, shell and pupal weights were taken. Digital vernier caliper was used to measure the length and width of the cocoons, and electronic top pan balance was used to measure cocoon, shell and pupal weight. Cocoon shell and pupa were weighed by cutting open the cocoons (Plate 3.8) with a razor blade to release the pupa. The empty shell and pupa were weighed separately.

Shell (%) was assessed using the formula below:

$$\textbf{Shell (\%)} = \frac{Shell\ weight}{Cocoon\ weight} \times 100\ \%$$

The remaining cocoons were oven dried for 5 hours to prevent moth emergence which breaks the continuous silk filament. The temperature was reduced after every hour starting from 115 - 55 °C (Gowda and Reddy, 2007).

3.7 Cocoon processing and quality analysis.

Cocoons obtained from each treatment were sorted and defective ones (double cocoons, malformed and thin end cocoons) which were not suitable for reeling were discarded.

A multi-end reeling machine was used to reel cocoons into raw silk. Cocoons were processed using the protocol by Lee (1999).

3.7.1 Tenacity and elongation percentage test.

A serigraph was used to test the degree of elongation (which was expressed as a percentage) and tenacity of the raw silk (Plate 3.9). A sizing reel of 1.125 m in circumference (100 revolutions equal to 1.125m) and a constant speed of 300 revolutions per minute were used to prepare the test sample. The sample skeins were weighed and conditioned at a temperature of 20°C and humidity of 65%. The clamp distance was 10 cm and the extension speed 15 cm per minute. The sample skeins were mounted on the serigraph and elongation and breaking force (N) recorded. The breaking force in Newton (N) was converted to grams and the tenacity was expressed as grams/denier using the formulae:

$$\text{Tenacity g/d} = \frac{Z}{n \times d}$$

Where Z= breaking force in grams.

n= number of strands tensioned.

d= denier

1 Newton = 101.9g

Plate 3.9 A serigraph for testing the tenacity and elongation of raw silk yarns at the silk quality laboratory at ICIPE, Kenya.

3.7.2 Cleanliness of silk.

This test was conducted to ascertain the imperfections in the silk filament. Cleanliness defects were classified as super major defect, major defect and minor defect. The cleanliness inspection was done from a position of 0.5 meters (2 feet) directly in front of the Seri board inspection panels on a Seriplane (Plate 3.10). The actual number of defects of each kind was counted on the yarns on both sides of the inspection panel. Each defect determined was categorized by comparing it with standard photographs for cleanliness defects. Each defect carried a penalty points and the difference of the total penalty point from 100 gave the test result.

Super major defect penalty = 1

Major defects penalty = 0.4

Minor defects penalty = 0.1

3.7.3 Neatness of silk.

Neatness defects are imperfections in silk yarn which are smaller than minor cleanliness defects. Inspection was conducted from a distance of 0.5 meters (2 feet), directly in front of the inspection panels on a Seriplane (Plate 3.10). Each panel on any one side of the inspection board was carefully compared with the standard photographs for neatness and its neatness value estimated in percentages.

Plate 3.10 A seriplane for testing cleanliness and neatness of raw silk in the silk quality laboratory at ICIPE, Nairobi.

3.7.4 Filament Length.

Three cocoons randomly selected from each treatment were boiled and reeled to find out the length of the cocoon using eprouvette. The length of the filament was determined by the following standard formula.

$L = R \times 1.125$

Where L is the filament length.

R is the number of revolutions recorded by the eprouvette.

1.125 is the circumference of eprouvette reel in meters.

3.8 Data Analysis.

Data on larval and cocoon morphometrics, food utilization and raw silk quality test were subjected to ANOVA statistical procedure of SAS (SAS Institute Inc., 2001). Student-Newman-Keuls (SNK) test was used to test the significant differences between treatment means. Differences were considered significant at $P < 0.05$. Data in percentages were arcsine square root transformed before analysis.

CHAPTER 4

4.0 RESULTS

4.1 Determination of wild silkmoth species and host plants.

The survey of wild silkmoth in the Forest, Forest-Savanna and Guinea Savanna agro-ecologies in Ghana yielded only cocoons of *Gonometa* sp. They occurred in low numbers on *Acacia* sp. in the Guinea Savannah zone (Table 4.1). A total of eight cocoons of *Gonometa* sp. (Plate 4.1) were collected during the survey, with three of them having the moths already emerged and the rest had the pupa inside the cocoon. Photos of male and female adult *Gonometa* sp. (Plate 4.2- 4.3) and eggs laid by female moth (Plate 4.4) are shown below. These cocoons were collected from host and non plants in Loagri (Tamale-Walewale road) and host plant, *Acacia* sp. in Makango (Yendi-Salaga road) (Fig 4.1).

Plate 4.1 Cocoons of *Gonometa* sp. collected during the survey in Northern Ghana.

Plate 4.2 Emerged adult male of *Gonometa* sp at entomology laboratory in ARPPIS, University of Ghana, Legon.

Plate 4.3 Emerged adult female of *Gonometa* sp**.** at the entomology laboratory.

Plate 4.4 Eggs laid by female *Gonometa* sp.

Table 4.1 Wild silkmoth species and their host plant in three ecological zones in Ghana.

Ecological zones	Host plants	Wild silkmoth species	Locality
Forest	*Bridelia macrantha*	-	-
Forest savannah	*Acacia* sp.	-	-
transition		-	-
Guinea savannah	*Acacia* sp.	*Gonometa* sp.	Makango, Loagri

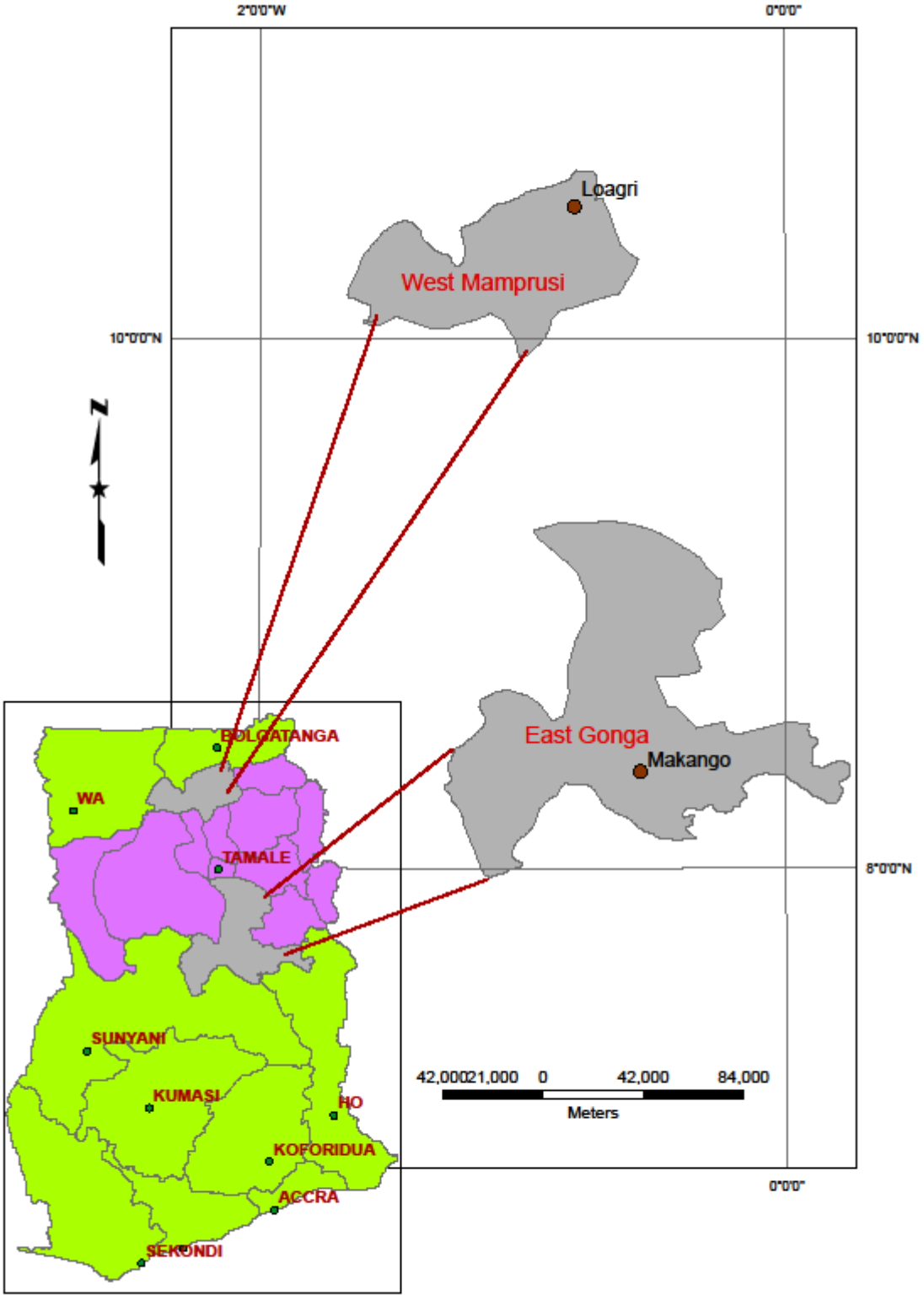

Figure 4.1 A map showing collection sites of cocoons of *Gonometa* sp. in northern Ghana during the off-season (January-February) of 2012.

4.2. Consumption and utilization of mulberry food plants by silkworm strains.

4.2.1 Ingestion

Significant differences were recorded in the ingestion of mulberry food plant among the silkworm strains. Z/Y, M2 and ICIPE 1 strains reared on K2 food plant had higher leaf ingestion than other silkworm strains fed on the same plant (Table 4.2). The mean ingestion of food plants by Z/Y strains differed significantly among the host plants it fed on. Z/Y strain fed on K2 resulted in maximum leaf ingestion of 4.88 ± 0.23 g than on ML and S36. Interaction effect of silkworm strains and mulberry food plant was not significant (df = 8, F = 0.95, P = 0.4905).

4.2.2 Digestion

There were no differences in the digestion of all the silkworm strains irrespective of the mulberry food plants they fed upon (Table 4.2). Interaction of silkworm strains and mulberry food plants was not significant (df = 8, F = 0.04, P = 1.0000).

4.2.3 Approximate digestibility

Similarly, there were no differences in the approximate digestibility of all the silkworm strains regardless of the food plants they fed upon (Table 4.2). Interaction of silkworm strains and mulberry food plants was not significant (df = 8, F = 1.31, P = 0.2747).

Table 4.2 Mean ingestion (g), digestion (g) and approximate digestibility (%) ± SE of mulberry leaves fed by silkworm larvae.

Variety/ Strain	G2	ICIPE 1	ICIPE 2	M2	Z/Y	*F*, *P* values
			Mean ingestion (g) ± SE			
K2	3.89±0.17bA	4.06±0.29abA	3.84±0.23b	4.82±0.11aA	4.88±0.23aA	5.50, 0.0133*
ML	4.21±0.32aA	3.19±0.34aA	3.36±0.17aA	4.16±0.35aA	4.21±0.11aB	3.29, 0.0579
S36	3.23±0.28aA	3.25±0.46aA	3.20±0.17aA	4.10±0.23aA	4.07±0.17aB	2.71, 0.0917
F, *P* values	3.54, 0.0965	1.69, 0.2623	2.87, 0.1336	2.51, 0.1613	5.70, 0.0410*	
			Mean digestion (g) ± SE			
K2	1.65±0.24aA	1.64±0.23aA	1.71±0.46aA	2.00±0.57aA	1.91±0.34aA	0.17, 0.9484
ML	1.63±0.17aA	1.37±0.34aA	1.39±0.40aA	1.64±0.58aA	1.57±0.47aA	0.10, 0.9807
S36	1.36±0.29aA	1.35±0.29aA	1.36±0.28aA	1.55±0.35aA	1.51±0.52aA	0.07, 0.9909
F, *P* values	0.46, 0.6494	0.31, 0.7474	0.23, 0.8046	0.22, 0.8125	0.23, 0.8036	
			Mean approximate digestibility (%) ± SE			
K2	42.55±4.09aA	40.39±3.52aA	44.57±1.79aA	41.47±2.37aA	39.12±2.88aA	0.47, 0.7588
ML	38.74±4.09aA	42.90±5.19aA	41.51±4.68aA	39.47±6.41aA	37.42±1.79aA	0.22, 0.9222
S36	42.17±5.82aA	41.44±2.94aA	45.85±2.06aA	37.73±3.59aA	37.79±4.08aA	0.75, 0.5780
F, *P* values	0.20, 0.8274	0.10, 0.9072	0.51, 0.6266	0.81, 0.8424	0.08, 0.9197	

Mulberry varieties; ML = Mysore local, K2= Kanva 2. Silkworm Strains; G2=G2xV2xH1xKK, M2= M2xN2xSN1xI1. * = significant**.**
Means within a column followed by the same capital letter and within a row followed by the same small letter(s) are not significantly different (P<0.05, Student- Newman-Keuls SAS, 2011).

4.3. Effects of mulberry varieties on silkworm larval development and cocoon quality.

4.3.1 Larval developmental period.

Among the silkworm strains, ICIPE 1 and ICIPE 2 larvae obtained shorter developmental time than G2, M2 and Z/Y strains when fed on K2, ML and S36 mulberry food plants. The larval developmental period of the silkworm strain among the mulberry food plants they fed on did not differ significantly (Table 4.3). Interaction of silkworm strains and mulberry food plants on larval developmental period was not significant (df = 8, $F = 0.08$, $P = 0.9996$).

Table 4.3 Mean larval developmental period (days) ± SE of five silkworm strains.

Variety/ Strain	G2	ICIPE 1	ICIPE 2	M2	Z/Y	*F*,*P* values
K2	23.00±0.27aA	21.08±0.23bA	21.04±0.36bA	23.17±0.24aA	23.08±0.26aA	14.29, 0.0004*
ML	23.13±0.26aA	21.00±0.14bA	21.08±0.22bA	23.00±0.29aA	23.00±0.17aA	24.27, 0.0001*
S36	23.04±0.22aA	21.17±0.29bA	21.00±0.29bA	23.08±0.14aA	23.04±0.27aA	19.14, 0.0001*
F, *P* values	0.07, 0.9362	0.13, 0.8770	0.02, 0.9803	0.13, 0.8813	0.02, 0.9759	

Mulberry varieties; Ml = Mysore local, K2 = Kanva 2. Silkworm Strains; G2 = G2xV2xH1xKK, M2 = M2xN2xSN1xI1. Means within a column followed by the same capital letter and within a row followed by the same small letter(s) are not significantly different ($P < 0.05$, Student- Newman-Keuls SAS, 2011).

4.3.2 Larval Length of 5th instar silkworms.

The mean larval length differed significantly among the silkworm strains and the host plants they fed upon (Table 4.4). G2 strain reared on K2 mulberry food plant had the longest larva of 4.97 ± 0.10 cm. Varying larval length were observed in the silkworm strains when fed with Mysore local (ML), however the performance was not significantly different with the exception of ICIPE 1 strains recording the shortest larvae of 4.08 ± 0.08 cm and Z/Y the longest larvae of 5.09 ± 0.11cm. The larvae of silkworm strains M2 and Z/Y were significantly longer 5.02 ± 0.12 cm and 5.02 ± 0.07 cm respectively, than the other strains when fed on S36 mulberry food plant.

Larval lengths of G2, ICIPE1, M2 and Z/Y strains encountered significant difference among the food plant they fed upon. Z/Y strain fed on ML food plant recorded the longest larvae of 5.09 ± 0.11 cm. This length was not significantly different when fed on S36 food plant (Table 4.4). The longest M2 larva was obtained when it fed on S36 mulberry food plant. The larvae G2 and ICIPE strains were longer 4.97 ± 0.10 cm and 4.63 ± 0.08 cm, respectively when both were fed on K2 food plant.

4.3.3 Larval width of 5th instar silkworm strain.

Significant differences were observed in the larval width among the silkworm strains and mulberry food plants. Silkworm strain Z/Y, reared on K2 recorded the widest larva of 0.71 ± 0.01 cm, this was however not significantly different from G2 and ICIPE 1 larval width of 0.69 ± 0.01 cm and 0.68 ± 0.01 cm respectively, when fed on the same food plant. Z/Y strain obtained the widest larvae of 0.72 ± 0.01 cm while ICIPE 1 larvae had the least width of 0.63 ± 0.01 cm when fed on ML. ICIPE 2 strain also recorded least larval width of 0.63 ± 0.01 cm when fed on S36 mulberry variety. Larval width of ICIPE 1 and ICIPE 2 strains were significantly different among the mulberry food plants (Table 4.4). Interaction effect of larval

width due to silkworm strains and the food plants was significant (df = 8, F = 4.36, P<0.0001).

4.3.4 Larval weight of 5th instar silkworm.

Larval weight among the silkworm strains and the food plants they fed on was significantly different. Z/Y larvae reared on K2 leaves recorded the heaviest larvae of 2.59 ± 0.05 g. Larval weight varied in all the silkworm strains when fed on Mysore local, however, Z/Y and G2 larvae were heavier 2.49 ± 0.05 g and 2.44 ± 0.05 g, respectively compared to the other strains. M2 strain fed on S36 mulberry food plant had the heaviest larvae of 2.59 ± 0.05 g; however, its weight was not significantly different from Z/Y larvae 2.58 ± 0.06 g when fed on the same food plant. Mean larval weight of silkworm strains G2, ICIPE 1, ICIPE 2 and M2 differed significantly among the food plants they fed upon (Table 4.4). Interaction effects of larval weight due to silkworm strains and food plants was significant (df = 8, F = 24.45, P < 0.0001).

Table 4.4 Mean larval length (cm), width (cm) and weight (g) of 5th instar silkworm larvae.

Variety/ Strain	G2	ICIPE 1	ICIPE 2	M2	Z/Y	*F*, *P* values
			Mean larval length (cm) ± SE			
K2	4.97±0.10aA	4.63±0.08bA	4.50±0.08bA	4.45±0.10bB	4.69±0.09bB	4.67, 0.0021*
ML	4.28±0.13bcB	4.08±0.08cC	4.40±0.08bcA	4.50±0.09bB	5.09±0.11aA	13.65, 0.0001*
S36	4.31±0.08bB	4.32±0.04bB	4.30±0.07bA	5.02±0.12aA	5.02±0.07aA	21.42, 0.0001*
F, *P* values	13.17, 0.0001*	14.69, 0.0001*	1.59, 0.2167	8.54, 0.0008*	4.83, 0.0129*	
			Mean larval width (cm) ± SE			
K2	0.69±0.01abA	0.68±0.01abA	0.65±0.01bB	0.66±0.01bA	0.71±0.01aA	3.92, 0.0063*
ML	0.68±0.01bA	0.63±0.01cB	0.68±0.01bA	0.68±0.01bA	0.72±0.01aA	10.31, 0.0001*
S36	0.67±0.01aA	0.70±0.01aA	0.63±0.01bB	0.69±0.02aA	0.70±0.01aA	4.71, 0.002*
F, *P* values	0.58, 0.5649	7.67, 0.0014*	10.05, 0.0003*	1.74, 0.1880	1.07, 0.3512	
			Mean larval weight (g) ± SE			
K2	2.15±0.06bB	2.29±0.07bA	2.10±0.06bA	2.34±0.07bB	2.59±0.05aA	9.20, 0.0001*
ML	2.44±0.05aA	1.67±0.05dC	2.08±0.04cA	2.25±0.05bB	2.49±0.05aA	46.67, 0.0001*
S36	2.16±0.07bB	1.89±0.03cB	1.85±0.05cB	2.59±0.05aA	2.58±0.06aA	36.52. 0.0001*
F, *P* values	6.35, 0.0039*	32.06, 0.0001*	7.35, 0.0018*	8.04, 0.0011*	0.95, 0.3936	

Mulberry varieties; ML = Mysore Local, K2= Kanva 2. Silkworm Strains; G2=G2xV2xH1xKK, M2= M2xN2xSN1xI1. * = significant**.** Means within a column followed by the same capital letter and within a row followed by the same small letter(s) are not significantly different (P<0.05, Student- Newman-Keuls SAS, 2011).

4.3.5 Larval mortality.

ICIPE 1 strain among other strains recorded a significantly higher (df = 4, F = 5.39, P < 0.0141) larval mortality when fed on K2 (Fig.4.2). The lowest larval mortality was recorded in Z/Y silkworm larvae fed with K2. There was no significant difference in the larval mortality among the silkworm strains when fed with ML and S36 (df = 4, F = 1.53, P = 0.2655; df = 4, F = 2.69, P = 0.0928). Interaction effect of mortality due to silkworm strain and mulberry varieties was not significant (df = 8, F = 1.31, P = 0.2747).

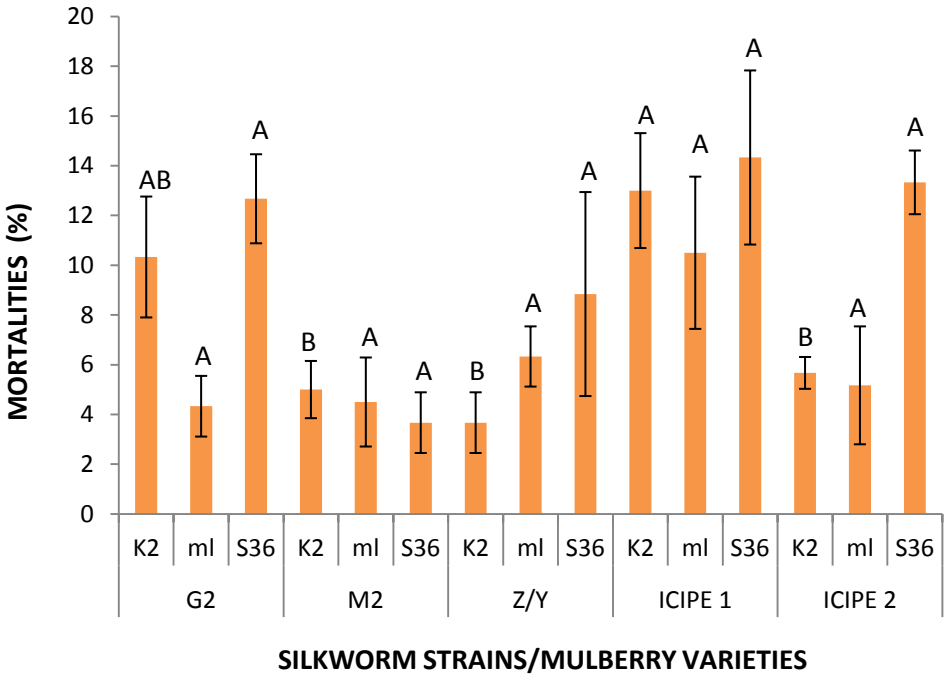

Figure 4.2: Percentage mortality of 5th larval instars of different silkworm strains fed on various mulberry varieties. Means with a common letter on the same mulberry variety indicate no significant difference (P<0.05 Student- Newman-Keuls SAS, 2011).

4.3.6. Cocoon length.

The mean cocoon length differed significantly among the silkworm strains and their food plants. M2 and Z/Y strains obtained longer cocoon of 3.24 ± 0.04 cm and 3.19 ± 0.05 cm, respectively than the other strains when the larvae were fed on K2. Silkworm strains ICIPE 1 and ICIPE 2 had shorter cocoons than the other strains which fed on ML food plant (Table 4.5). Z/Y strain obtained the longest cocoon of 3.25 ± 0.06 cm compared to other silkworm strains when the larvae fed on the S36 food plant. Cocoons lengths from G2 and M2 strain were significant among the food plants they fed upon. The silkworm strain G2, recorded longer cocoon of 3.24 ± 0.05 cm and 3.06 ± 0.07cm when its larvae were fed on ML and K2, respectively. Cocoons from M2 strain were also longer 3.24 ± 0.04 cm and 3.16 ± 0.04 cm when the larvae were fed on K2 and ML host plants, respectively. Interaction effect on cocoon length due to silkworm strains and food plant was not significant (df = 8, F = 1.78, P = 0.0830).

4.3.7 Cocoon width.

There were significant differences in the cocoon width among the silkworm strains and the food plant. M2, Z/Y and G2 cocoons were wider compared to ICIPE 1 and ICIPE 2 when their larvae were fed on K2 and ML food plants (Table 4.5). Meanwhile cocoon width from silkworm strains ICIPE 2 and M2 differed significantly among the food plants the larvae were fed upon. ICIPE 2 strain recorded the widest cocoon of 1.59 ± 0 .03 cm when the larvae were fed on ML food plants. Cocoons from M2 strains were wider 1.73 ± 0.02 cm and 1.69 ± 0.02 cm when the larvae were fed on K2 and ML, respectively than when fed on S36. Interaction effect on cocoon width by silkworm strains and host plants was significant (df = 8, F= 2.00, P < 0.0477).

4.3.8 Cocoon weight.

Mean cocoon weight among the silkworm strains and the food plants differed significantly. Silkworm strains ICIPE 1 and ICIPE 2 had the least cocoon weight of 1.11 ± 0.05 g and 1.01 ± 0.03 g when their larvae fed on K2 food plant. M2 strain recorded the heaviest cocoon of 1.64 ± 0.07 g when the larvae fed on ML food plant. Cocoons from Z/Y strain were the heaviest, 1.83 ± 0.06 g among other strains when their larvae fed on S36 food plant. Z/Y and ICIPE1 strains registered significant cocoon weight among the food plants (Table 4.5). Z/Y strain recorded the heaviest cocoon 1.83 ± 0.06 g when the larvae fed on S36 while cocoons from ICIPE 1 strain recorded the least weight of 0.90 ± 0.03 g when fed on the same food plant.

Table 4.5 Mean cocoon length (cm), width (cm) and weight of five silkworm strains fed on three mulberry varieties.

Variety/ Strain	G2	ICIPE 1	ICIPE 2	M2	Z/Y	*F*, *P* values
			Mean cocoon length (cm) ± SE			
K2	3.06±0.07bAB	26.33 0.0001*	2.79±0.05cA	2.79±0.05cA	3.19±0.05abA	18.76 0.0001*
ML	3.24±0.05aA	12.10, 0.0001*	2.85±0.03bA	2.85±0.03bA	3.25±0.06aA	26.33 0.0001*
S36	3.02±0.07bB	2.66±0.09cA	2.82±0.04cA	2.82±0.04cA	3.25±0.06aA	12.10, 0.0001*
F, *P* values	3.40, 0.0430*	1.23, 0.3018	0.51, 0.6033	0.51, 0.6033	0.38, 0.6846	
			Mean cocoon width (cm) ± SE			
K2	1.65±0.03aA	1.54±0.02bA	1.47±0.02bB	1.73±0.02aA	1.71±0.03aA	21.32, 0.0001*
ML	1.71±0.04aA	1.49±0.03cA	1.59±0.03bA	1.69±0.02aA	1.73±0.02aA	12.66, 0.0001*
S36	1.58±0.05aA	1.59±0.11aA	1.49±0.02aB	1.59±0.03aB	1.71±0.04aA	1.79, 0.1399
F, *P* values	2.81 0.0713	0.54, 0.5883	6.43, 0.0037*	11.44, 0.0001*	0.23, 0.7921	
			Mean cocoon weight (g) ± SE			
K2	1.33±0.07aA	1.11±0.05bA	1.01±0.03bA	1.46±0.05aA	1.39±0.02aB	16.21, 0.0001*
ML	1.46±0.06bA	1.02±0.03cA	1.04±0.05cA	1.64±0.07aA	1.44±0.06bB	26.15, 0.0001*
S36	1.41±0.08bA	0.90±0.03cB	0.95±0.02cA	1.44±0.08bA	1.83±0.06aA	43.72, 0.0001*
F, *P* values	0.89, 0.4175	6.32 0.0040*	1.85 0.1692	2.76, 0.0745	21.91 0.0001*	

Mulberry varieties; Ml = Mysore local, K2 = Kanva 2. Silkworm Strains; G2 = G2xV2xH1xKK, M2 = M2xN2xSN1xI1. Means within a column followed by the same capital letter and within a row followed by the same small letter(s) are not significantly different ($P < 0.05$, Student- Newman-Keuls SAS, 2011).

4.3.9 Pupal weight.

Significant differences were obtained in the pupal weight among the silkworm strains and their food plants (Table 4.6). M2, Z/Y and G2 strains recorded heavier pupae compared to ICIPE 1 and ICIPE 2 when their larvae fed on K2 food plant. The heaviest pupa of 1.32 ± 0.06 g was encountered when M2 strain fed on ML food plant. The strain Z/Y reared on S36 food plant recorded the heaviest pupae of 1.49 ± 0.05 g. The mean pupal weight of silkworm strains ICIPE 1 and Z/Y differed significantly among the host plants the larvae fed upon. ICIPE 1 strain recorded heavier pupae when its larvae fed on K2 and ML food plants than when fed on S36 food plant. Meanwhile Z/Y strain obtained the heaviest pupae when its larvae fed on S36 food plant. Interaction effect of pupal weight due to silkworm strains and host plants was significant (df = 8, $F = 6.84$, $P < 0.0001$, df = 8, $F = 6.98$, $P < 0.0001$).

Table 4.6 Mean pupal weight (g) ± SE of five silkworm strains fed on three mulberry varieties.

Variety/ Strain	G2	ICIPE 1	ICIPE 2	M2	Z/Y	*F*,*P* values
K2	1.06±0.06aA	0.89±0.04bA	0.80±0.02bA	1.16±0.05aA	1.14±0.02aB	14.34, 0.0001*
ML	1.19±0.04bA	0.81±0.03cAB	0.83±0.04cA	1.32±0.06aA	1.15±0.05bB	25.77, 0.0001*
S36	1.13±0.06bA	0.73±0.03cB	0.76±0.01cA	1.14±0.07bA	1.49±0.05aA	36.40, 0.0001*
F, *P* values	1.48 40.2385	5.76, 0.0061*	1.60 0.2140	2.83, 0.0700	19.72, 0.0001*	

Mulberry varieties; Ml = Mysore local, K2 = Kanva 2. Silkworm Strains; G2 = G2xV2xH1xKK, M2 = M2xN2xSN1xI1. Means within a column followed by the same capital letter and within a row followed by the same small letter(s) are not significantly different ($P < 0.05$, Student- Newman-Keuls SAS, 2011).

4.3.10. Shell weight.

Among the silkworm strains, ICIPE 1 and ICIPE 2 obtained the least shell weight compared to the other silkworm strains fed on the same K2 food plant. M2 strain obtained the heaviest cocoon shell of 0.32 ± 0.01 g when fed on ML. Shell weight of 0.34 ± 0.01 g from Z/Y cocoon was the heaviest when fed on S36 food plant. The mean shell weight of ICIPE 1 and Z/Y silkworm strains differed significantly among the mulberry food plants (Table 4.7). ICIPE 1 silkworm strain recorded the least shell weight of 0.17 ± 0.01 g when fed on S36 while Z/Y strains obtained the heaviest shell of 0.34 ± 0.01 g when fed on the same S36 food plants. Interaction of silkworm strains and mulberry food plants on shell weight was significant (df = 8, F = 2.02, P < 0.0001).

4 .3.11 Shell ratio.

There were significant differences in the shell ratio (expressed as a percentage) among the silkworm strains and food plants they fed on. ICIPE 1 and Z/Y strains obtained the lowest shell ratio when fed on K2 and S36 food plants, respectively (Table 4.7). The mean shell ratio of Z/Y silkworm strain differed significantly among the mulberry food plants. Z/Y strain obtained higher shell ratio of 19.74 ± 0.16 % and 19.73 ± 0.28 % when fed on K2 and ML food plants, respectively. Interaction effect of shell ratio due to silkworm strains and mulberry food plants was significant (d = 8, F = 2.0, P < 0.0454).

Table 4.7 Mean shell weight (g) and shell ratio (%) ± SE of five silkworm strains fed on three mulberry varieties.

Variety/ Strain	G2	ICIPE 1	ICIPE 2	M2	Z/Y	*F*, *P* values
			Mean shell weight (g) ± SE			
K2	0.28±0.01aA	0.21±0.01bA	0.20±0.01bA	0.30±0.01aA	0.28±0.00aB	23.77, 0.0001*
ML	0.28±0.01bA	0.20±0.01cA	0.21±0.01cA	0.32±0.01aA	0.28±0.01bB	32.61, 0.0001*
S36	0.28±0.01bA	0.17±0.01cB	0.18±0.00cA	0.29±0.01bA	0.34±0.01aA	64.23, 0.0001*
F, *P* values	0.05, 0.9481	8.43, 0.0008*	2.53, 0.0917	2.67, 0.0808	19.43, 0.0001*	
			Mean shell ratio (%) ± SE			
K2	20.76±0.43aA	19.24±0.32bA	19.99±0.26abA	20.54±0.38aA	19.74±0.16abA	3.52, 0.0113*
ML	19.32±0.33aA	19.78±0.24aA	19.78±0.24aA	19.54±0.44aA	19.73±0.28aA	0.40, 0.8096
S36	19.97±0.47aA	18.91±0.23abA	18.91±0.23abA	20.04±0.51aA	18.56±0.31bB	3.12, 0.0201*
F, *P* values	2.95, 0.0631	2.68, 0.0804	2.68, 0.0804	1.25, 0.2972	6.59, 0.0032*	

Mulberry varieties; Ml = Mysore local, K2 = Kanva 2. Silkworm Strains; G2 = G2xV2xH1xKK, M2 = M2xN2xSN1xI1. Means within a column followed by the same capital letter and within a row followed by the same small letter(s) are not significantly different ($P < 0.05$, Student- Newman-Keuls SAS, 2011).

4.4 Testing of raw silk quality.

4.4.1. Raw silk tenacity.

The mean raw silk tenacity differed significantly among the silkworm strains and host plants. G2 silkworm strain obtained the lowest raw silk tenacity among the silkworm strains when fed on the same K2 host plant. Varying tenacity were recorded in the strains when fed with Ml, however, their performance was not significantly different with the exception of G2 and ICIPE 1. ICIPE 1 recorded the highest tenacity of 4.98 ± 0.09 % while G2 the lowest 3.57 ± 0.24 %. G2 silkworm strain obtained the lowest raw silk tenacity among the other silkworm strains when fed on the same S36 food plant. Significant difference was observed in Z/Y strain silk tenacity among the food plants it fed on. Higher raw silk tenacity was obtained when Z/Y strain fed on K2 and ML than on S36 mulberry food plant (Table 4.8) (Plate 4.5-4.6). Interaction effect of raw silk tenacity in relation to silkworm strains and mulberry food plants was not significant (df = 8, F = 0.73, P = 0.6656).

4.4.2 Raw silk elongation.

There were no significant differences in the raw silk elongation among the silkworm strains when fed on K2 and ML (Table 4.8). However, ICIPE 1 recorded the highest elongation of 21.67 ± 0.88 % and G2 the lowest of 16.67 ± 0.67 % when fed on S36 food plant. Interaction effect of raw silk elongation due to silkworm strains and mulberry food plants was not significant (df = 8, F = 1.16, P = 0.3554).

Table 4.8 Mean tenacity (g/d) and elongation (%) ± SE of raw silk from five silkworm strains reared on leaves of three mulberry varieties.

Variety/ Strain	G2	ICIPE 1	ICIPE 2	M2	Z/Y	*F*, *P* values
			Mean tenacity (g/d) ± SE			
K2	3.81 ± 0.22bA	4.81 ± 0.04aA	4.17 ± 0.31abA	4.36 ± 0.09abA	4.19 ± 0.05abA	4.12, 0.0316*
ML	3.57 ± 0.24cA	4.98 ± 0.09aA	4.61 ± 0.36abA	4.04 ± 0.17bcA	3.89 ± 0.11bcAB	6.98, 0.0060*
S36	3.09 ± 0.07bA	4.46 ± 0.23aA	3.88 ± 0.24abA	3.80 ± 0.33abA	3.65 ± 0.17abB	4.83, 0.0198*
F, *P* values	3.59, 0.0942	3.52, 0.0972	1.45, 0.3056	1.64, 0.2707	4.94, 0.0539*	
			Mean elongation (%) ± SE			
K2	17.67 ± 0.33aA	21.00 ± 0.00aA	19.67 ± 0.67aA	20.67 ± 1.67aA	19.00 ± 0.00aA	2.70, 0.0924
ML	19.33 ± 0.88aA	21.33 ± 0.33aA	20.00 ± 1.00aA	19.33 ± 1.33aA	18.33 ± 0.66aA	1.49, 0.2778
S36	16.67 ± 0.67bA	21.67 ± 0.88aA	20.67 ± 1.33aA	18.00 ± 1.00abA	18.33 ± 0.33abA	5.09, 0.0168*
F, *P* values	4.08, 0.0760	0.38, 0.7023	0.24, 0.7928	0.96 0.4348	0.80 0.4921	

Mulberry varieties; Ml = Mysore local, K2 = Kanva 2. Silkworm Strains; G2 = G2xV2xH1xKK, M2 = M2xN2xSN1xI1. Means within a column followed by the same capital letter and within a row followed by the same small letter(s) are not significantly different ($P < 0.05$, Student- Newman-Keuls SAS, 2011).

Plate 4.5 Cocoons from Z/Y strain fed on S36 mulberry plant.

Plate 4.6 Raw silk yarn from Z/Y cocoon.

4.4.3 Filament length.

The mean raw silk filament length of ICIPE 1 and G2 silkworm strains differed significantly among the host plants (Table 4.9). ICIPE 1 silkworm strain obtained the longest filament of 982.13 ± 57.75 m followed by G2 894.38 ± 57.09 m when the larvae fed on S36 food plants. There were significant differences in the raw silk filament length of ICIPE 1 strain when fed on S36 and ML. ICIPE 1 silkworm strain had the longest filament when fed on S36 food plant than on ML and K2. Interaction effect of silkworm strains and mulberry food plants on the raw silk filament length was significant (df = 8, $F = 3.02$, $P < 0.0130$).

4.4.4 Cleanliness and Neatness.

There were no differences in the cleanliness and neatness of the silkworm strains irrespective of the different food plants they fed upon (Table 4.9). Interaction of silkworm strains and mulberry food plants on the cleanliness and neatness of the raw silk was not significant (df = 8, $F = 0.00$, $P = 1.0000$; df = 8, $F = 0.02$, $P = 1.0000$).

Table 4.9 Mean Filament length (m), Cleanliness (%) and Neatness (%) ± SE of raw silk from five silkworm strains.

Variety/Strain	G2	ICIPE 1	ICIPE 2	M2	Z/Y	*F*, *P* value
			Mean Filament length (m) ± SE			
K2	551.25±115.53aA	495.15±58.31aB	549.00±115.47aA	697.50±173.84aA	1013.64±57.80aA	3.49, 0.0495
ML	1033.88±173.27aA	664.88±173.85aAB	708.46±57.55aA	821.25±115.53aA	732.38±116.11aA	1.19, 0.3729
S36	894.38±57.09abA	982.13±57.75aA	590.38±57.58cA	658.13±58.38cA	740.25±57.79bcA	7.96, 0.0037*
F, *P* values	3.97, 0.0798	4.96, 0.0535*	1.03, 0.4128	0.46, 0.6503	3.82, 0.0852	
			Mean Cleanliness (%) ± SE			
K2	99.80±11.60aA	98.90±8.66aA	98.00±10.91aA	97.60±11.43aA	99.80±9.29aA	0.01, 0.9998
ML	99.80±5.83aA	98.00±9.757aA	99.80±12.76aA	99.50±9.93aA	99.00±10.91aA	0.01, 0.9999
S36	99.80±12.12aA	99.50±6.24aA	99.70±11.66aA	99.73±13.94aA	99.40±12.82aA	0.00, 1.0000
F, *P* values	0.00, 1.0000	0.01, 0.9919	0.01, 0.9927	0.01, 0.9904	0.00 , 0.9987	
			Mean Neatness (%) ± SE			
K2	98.00±5.77aA	95.00±14.43aA	93.00±13.27aA	94.00±15.01aA	98.00±5.77aA	0.04, 0.9966
ML	98.00±11.55aA	96.00±10.96aA	98.00±12.70aA	97.00±7.51aA	95.00±16.16aA	0.01, 0.9997
S36	98.00±8.66aA	95.00±10.18aA	97.00±12.12aA	97.00±8.66aA	97.00±13.8aA	0.01, 0.9998
F, *P* values	0.00 1.0000	0.00, 0.9977	0.04, 0.9579	0.03, 0.9752	0.01, 0.9858	

Mulberry varieties; Ml = Mysore local, K2 = Kanva 2. Silkworm Strains; G2 = G2xV2xH1xKK, M2 = M2xN2xSN1xI1. Means within a column followed by the same capital letter and within a row followed by the same small letter(s) are not significantly different ($P < 0.05$, Student- Newman-Keuls SAS, 2011).

CHAPTER 5

5.0 DISCUSSION

5.1 Wild silkmoth population, their host plants and potential for commercial silk production.

Even though, the survey was conducted on known host plants and other non-host plants for the presence of wild silkmoth species in the forest, forest- Savanna and Guinea Savanna agro-ecologies in Ghana, only cocoons of *Gonometa* sp. were observed in low numbers on *Acacia* sp. in the Guinea Savanna zone. The low abundance of *Gonometa* sp. in this agro-ecological zone may be attributed to the harsh weather conditions, worsened by frequent bushfires and possibly the presence of natural enemies (Fening *et al*., 2009). Rainfall may affect the availability and the quality of food plants on which larvae feed (Fening *et al*., 2010). Temperature and relative humidity may also affect larval growth and development (Fening *et al*., 2010). Heavy rainfall that causes high early instar mortality may also lead to large population reduction (Hartland-Rowe, 1992). Natural enemies may not only decrease their survival, but also cause a significant reduction in cocoon abundance (Veltman *et al*., 2004). Exit holes made by *Gonometa* parasitoids and predators also reduces the raw silk yield and renders cocoons unprofitable or unsuitable for degumming (Kioko, 1998; Fening *et al*., 2009). Cocoon predators including reduviid bugs, bird, mouse, squirrels and man can negatively affect *Gonometa* cocoon abundance (Veltman *et al*., 2004).

Host plant (*Acacia* spp.) preference, their abundance and how they were distributed could have affected the abundance of *Gonometa* sp. Human activity including cutting of *Acacia* trees for charcoal (Riswan and Hartanti, 1995; Fening *et al*., 2008) may cause a reduction in the abundance of the host plants and silkmoth species.

Although only *Gonometa* sp, were collected, wild silkmoths belonging to this genus are known to produce cocoons of very good quality, comparable to that of the domesticated silkmoth, *B. mori* (Freddie, 1993; Kioko, 1998; Fening, 2008; Ngoka *et al*., 2008).The semi-captive rearing technology, which involves the rearing of wild silkmoth larvae in semi-captivity (enclosed in a net sleeve attached to the host plant), could be used to protect the silkworms from predation so as to increase their numbers to augment their natural population (Ngoka *et al*., 2008; Fening *et al*., 2010). Increasing their abundance will help produce enough cocoon shells in order to realise their full potential for commercial silk production.

Other important wild silkmoth species in Africa include, *Anaphe panda* (Boisduval) (Lepidoptera: Thaumetopoeidae) (Mbahin *et al*., 2008), *Argema mimosae* (Boisduval) (Lepidoptera: Saturniidae) and *Epiphora bauhiniae* **(**Guerin-Meneville): (Lepidoptera: Saturniidae**) (**Peigler, 1993; Kioko, 1998). They feed on different indigenous host plant species. *Gonometa postica* feeds on some *Acacia* spp. (*A. tortilis, A. nilotica, A. mellifera, A. brevispica, A. hockii*, (Fabaceae), *A. panda* feeds on *Bridelia micrantha* (Hochst.) Baill. (Euphorbiaceae), *A. mimosae* feeds on *Sclerocarya birrea* (A. Rich.) Hochst. (Anacardiaceae) and *E. bauhiniae* feeds on *Ziziphus* spp. (Rhamnaceae). Wild silk farming has the potential as an economic incentive for forest-adjacent communities to participate in biodiversity conservation through sustainable utilization of forest resources in Africa where forest exploitation remains a major problem. Wild silk farmers could plant these host plants for silkworm rearing and collection along the farmlands and buffer zones so as to reduce the pressure on the core forest.

5.2 Consumption and Utilization of mulberry leaves by mulberry silkworm strains.

An individual which utilises the food it consumes to maximum extent for self gain can be considered more efficient than others. The rate of food consumption and leaf quality influence significantly larval growth, weight and probability of survival (Murugan and George, 1992). The level of ingestion and digestion by the silkworm strains was relatively high when they were fed on Kanva 2 (K2) followed by Mysore local (ML) and then S36. The high ingestion rates of K2 might have been due to palatability, nutritional superiority and water retention capacity of the leaves for longer duration. Paul *et al*. (1992) established that the water content of the feed has a direct relation to the ingestion, approximate digestibility and efficiency of conversion of ingested and digested food. Legay (1958) observed that not only the quality of mulberry leaf had great influence on the amount of ingestion but also the characteristics of the mulberry genotype which influence the amount of ingestion. According to Rahmathula *et al*. (2004), feeding leaves with higher moisture content to the 5^{th} instar silkworm has direct positive impact on their growth, food assimilation, conversion efficiency and hence cocoon productivity.

Ingestion and related nutritional characteristics vary from silkworm race to race. The present study revealed that the rate of food intake was more in Z/Y and M2, particularly on K2 than the other strains. Anantha *et al*. (1995) reported that the efficiency of converting ingested and digested food into body mass, cocoon and cocoon shell varies among the silkworm strains and mulberry varieties. Silkworms from the same genetic stock responded variedly when fed on leaves of different nutritional quality (Sabhat *et al*., 2011). Approximate digestibility was higher in ICIPE 2 and lower in Z/Y silkworm strains despite high ingestion and digestion in Z/Y strain. This observation concurs with Magadum *et al*. (1996) that higher

assimilation efficiency is a racial character, as higher food intake does not necessarily result in higher digestibility.

5.3 Effects of mulberry varieties on larval growth and development and cocoon qualities.

The larval developmental period differed significantly among the silkworm strains with the shortest duration observed among the Kenyan strains ICIPE 1 and ICIPE 2 and the longest among the Bulgarian strain M2. These findings confirm an earlier work by Nguku *et al*. (2009) who indicated ICIPE 1 strain had short larval developmental period compared to other strains. The larval developmental period in the five strains studied were shorter than what was reported by Lim *et al*. (1990) and Raina *et al.* (2000) that under ideal conditions the total larval duration was between 25 - 30 days. The Bulgarian strains had longer developmental period hence higher cocoon yield than the Kenyan strains. The current results also confirm the findings of Singh *et al*. (2002) who observed complete cocoon formation within 24 - 28 days from the day of hatching. The variations in larval developmental period may be partly due to the genetic characteristics of the different strains as the effect of the different mulberry varieties was not significant.

Larval length and width at the end of the 5^{th} instar revealed significant differences among the mulberry varieties and silkworm strains. Z/Y strain recorded the longest and widest larvae when fed on ML variety although this size did not differ significantly when fed on K2 or S36. Bose *et al*. (1989) reported that moisture content and crude fibre are maximum in S-54 genotype and minimum in Ml. Thus, the total mineral percentage is maximum in ML and minimum in S36 and K2. This may have increased the length and the width of the larvae but not the weight. Bongale and Chaluvachari (1995) indicated that lower larval weight and

moulting in ML variety were associated with lower leaf moisture content and moisture retention ability.

The larvae of Z/Y and M2 silkworm strains were heavier when fed with K2 and S36. This is in conformity with observations made by Adeduntan and Oyerinde (2010) who reported higher percentage crude protein and moisture content in S36 (21.66%, 79.35%) and K2 (21.24%, 76%). The moisture content and moisture retention capacity being relatively higher in S36 and K2 might have supported high larval weight in Z/Y and M2 strains. The significant difference in weight among the strains is in accordance with Aruga, (1994) who pointed out that larval weight could have been affected by the ability of the different silkworm strains to assimilate consumed food in varying percentages. Adolka (2007) and Seidavi (2011) also indicated that the rearing performance of silkworm strains differed significantly.

Generally, the results obtained for larval size and weight were low compared to other research work. This could be attributed to the continuous harsh weather conditions (drought) which prevailed during the rearing period, which may have influenced the quality of leaves; high evaporation, reduced protein and water content, rendering the leaves hard and unsuitable for feeding by the silkworm. This was also quite evident in the level of mortalities (3.667-14.333%) recorded for the different strains fed on the different mulberry varieties. Silkworm is prone to infections of various pathogenic organisms. ICIPE 1 strain was highly susceptible which resulted in higher mortality on K2 variety while Z/Y strain recorded a lower mortality on the same mulberry variety. Ramesh-Babu *et al*. (2009) indicated that silkworm races differ in their susceptibility or resistance to different types of diseases. The susceptibility of silkworm may also depend upon the hybrid (Baumann *et al*., 1991).

Cocoon weight and shell weight are the most important characters evaluated for productivity (Gaviria *et al.,* 2006). Significant interaction obtained for cocoon, pupal and shell weight revealed variation among the silkworm strains and mulberry varieties. The differences in the performance of silkworm strains obtained in the present study may be partly due to genotypic variability of each individual strain and the mulberry varieties. Cocoons obtained from Z/Y and M2 strains were larger and heavier than the other strains. Similar results were obtained by Nguku *et al*. (2009). Thus, quality characteristics of the silkworm cocoon depend on the silkworm strain, rearing technology and atmospheric conditions maintained during the silkworm rearing and cocoon spinning stage.

Significant effect of mulberry varieties was observed on the cocoon characters. This agrees with Qader *et al*. (1992) who investigated the nutritive effects of leaves of three mulberry varieties on larval growth and cocoon characters of three *B. mori* races. The results revealed that mature larval weight, single cocoon weight, shell percentage and the length of filament were greatly influenced by the nutritive value of different mulberry varieties. The highest cocoon, pupal and shell weight were obtained by feeding Z/Y silkworm strain with S36 variety. Ogunleye and Johnson (2012) and Saratchandra *et al*. (1992) revealed S36 mulberry variety as superior in feeding silkworms and produces high cocoon yield.

Shell ratio, expressed as percentage, indicates the amount of raw silk that can be reeled from a given fresh cocoon and this varies according to the age and breed of the silkworm (Gaviria *et al*., 2006). G2 strain obtained the highest shell ratio as this is important in selecting silkworms for increased cocoon production.

5.4 Quality control testing of raw silk.

Testing of silk yarn is essential for the production of quality yarn and fabric as it ensures efficiency in the production process (Silk Standard Committee, 1995). The results on tenacity of raw silk registered ICIPE 1 as the strain with the highest tenacity and elongation. The raw silk tenacity and elongation results from this study confirm findings from Lee (1999), who indicated the tenacity of a typical bave (filament) is 3.6 to 4.8 g per denier and an elongation of 18-23% of its original length. Nanavaty (2007) also noted that silk has a tenacity of about 4g/d and an elongation of 20%. Hariraj and Somashekar (2006) in their study noted that cocoon strains have significant influence on their silk quality characteristics which include tenacity and elongation. This may have contributed to the differences noted in the tenacities and elongation of the different silkworm strains. Since the difference in the mulberry varieties was not significant, it can be inferred that the differences in tenacity and elongation were due to the different silkworm strains.

Neatness defects are imperfections in silk yarn, which are smaller than minor cleanliness defects. G2 strain had the highest cleanliness and neatness percentages. Aruga (1994) attributed cleanliness and neatness defects to the technique applied in the cooking and reeling of the cocoon. The defects in this result may be attributed to the rough edges of the reels used during reeling causing some breakages. On the other hand, Lee (1999) reported that the characteristics of the silkworm strain may give rise to cleanliness and neatness defects. In the current study there were no differences in the cleanliness and neatness defects among the silkworm strains.

In the present study, silk filament lengths of cocoons were generally similar for most of the silkworm strains reared on the different mulberry varieties. According to FAO (1999), silk

filament length ranges from 600-1500 m out of which 80% is reelable. The results on the filament length fall within FAO range. It can be concluded that there is a relationship between silk filament length and raw silk fibre quality.

Mulberry silk production has a lot of potential in Ghana. Cocoons produced could be sold to the silk factory located at CSIR- Industrial Research Institute to be processed into yarns. The silk yarns produced could be bought by the *Kente* weavers in the Ashanti and Volta regions of Ghana as raw material for making *Kente* fabrics. The silk yarns could also be used in weaving smocks which is common in Northern Ghana. Ghana can take advantage of the African Growth and Opportunity Act (AGOA) to export Ghanaian textiles to the US market with tax exemption (Fening *et al*., 2007). Sericulture (both mulberry and wild), if properly harnessed, can offer alternative income to farmers in Ghana and Africa in general, and also help promote biodiversity and forest conservation through sustainable utilisation of biodiversity and other forest resources.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

This study has identified the presence of African wild silkmoth, *Gonometa* sp. in the Guinea Savannah Agro-Ecological zone of Ghana. This will provide baseline information necessary for future studies on *Gonometa* sp and its host plants, *Acacia* spp abundance and distribution.

In terms of raw silk yield, this study has revealed that the three silkworm strains from Bulgaria (Z/Y, G2 and M2) yielded higher than the two silkworm strains (ICIPE 1 and ICIPE 2) from Kenya. However, ICIPE 1 silkworm strain had long filament length, good tenacity and elongation which contribute to fibre quality. Leaves of S36 and K2 mulberry varieties supported good growth and development of larvae of silkworm strain Z/Y, M2 and G2 which reflected in the cocoons spun. Cocoons harvested showed significantly good yield and the silk filaments recovered from the cocoons were within International Silk Association Standards (ISA). The mulberry varieties (S36, Ml and K2) were generally good for feeding the silkworms for cocoon production. These Bulgarian silkworm strains and the three mulberry varieties can be used for silk production in Ghana. It is however recommended that the performance of these promising silkworm strains on the different mulberry plants should be tested under the different agro-ecological zones of Ghana so as to select the best for each zone.

6.2 RECOMMENDATIONS

The following recommendations on the present studies can offer useful directions for future studies.

1. There should be further studies on the diversity, abundance and distribution of wild silkmoths and their host plants in all the ecological zones of Ghana.
2. The life cycle of the F1 generation silkworm strains could be studied into details.
3. The effect of the distribution of mulberry leaves on the plant on the growth and development of the silkworm could also be studied.
4. There should be further studies on the biology of the subsequent generations (F2 and F3, etc.) of the silkworm strains in order to establish their performance. This will lay the foundation for the establishment of a silkworm grainage (egg production unit) in Ghana.

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APPENDICES

APPENDIX 1.0 ANOVA for larval length of the different silkworm strains on individual mulberry varieties

APPENDIX 1.1 ANOVA for larval length of silkworm strains fed on K2

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	2.46948552	0.61737138	4.67	0.0021
Error	70	9.25554667	0.13222210		
Corrected Total	74	11.72503219			

APPENDIX 1.2 ANOVA for larval length of silkworm strains fed on Ml

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	14.66777247	2.93355449	18.40	<.0001
Error	70	11.00006891	0.15942129		
Corrected Total	74	25.66784139			

APPENDIX 1.3 ANOVA for larval length of silkworm strains fed on S36

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	9.18163621	2.29540905	21.42	<.0001
Error	70	7.50093173	0.10715617		
Corrected Total	74	16.68256795			

APPENDIX 2.0 Analysis of variance of the individual silkworm strains on three mulberry varieties

APPENDIX 2.1 ANOVA for larval length of G2 silkworm strain fed on K2, Ml and S36

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F

Model	2	4.54757458	2.27378729	13.17	<.0001
Error	42	7.24986907	0.17261593		
Corrected Total	44	11.79744364			

APPENDIX 2.2 ANOVA for larval length of ICIPE 1 silkworm strain fed on K2, Ml and S36

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	2.28664120	1.14332060	14.69	<.0001
Error	42	3.26910080	0.07783573		
Corrected Total	44	5.55574200			

APPENDIX 2.3 ANOVA for larval length of ICIPE 2 silkworm strain fed on K2, Ml and S36

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.30615446	0.15307723	1.59	0.2167
Error	42	3.95295651	0.09641357		
Corrected Total	44	4.25911098			

APPENDIX 2.4 ANOVA for larval length of M2 silkworm strain fed on K2, Ml and S36

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	3.07663093	1.53831547	8.54	0.0008
Error	42	7.56904387	0.18021533		
Corrected Total	44	10.64567480			

APPENDIX 2.5 ANOVA for larval length of Z/Y silkworm strain fed on K2, Ml and S36

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1.31594013	0.65797007	4.83	0.0129
Error	42	5.71557707	0.13608517		
Corrected Total	44	7.03151720			

APPENDIX 3.0 ANOVA for larval weight of the different silkworm strains on individual mulberry varieties

APPENDIX 3.1 ANOVA for larval weight of silkworm strains fed on K2

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	2.22720947	0.55680237	9.20	<.0001
Error	70	4.23882720	0.06055467		
Corrected Total	74	6.46603667			

APPENDIX 3.2 ANOVA for larval weight of silkworm strains fed on Ml

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	8.81033285	1.76206657	49.59	<.0001
Error	70	2.45194230	0.03553540		
Corrected Total	74	11.26227515			

APPENDIX 3.3 ANOVA for larval weight of silkworm strains fed on S36

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	7.62929725	1.90732431	36.52	<.0001
Error	70	3.65568547	0.05222408		
Corrected Total	74	11.28498272			

APPENDIX 4.0 ANOVA for larval weight of the individual silkworm strains on different mulberry varieties

APPENDIX 4.1 ANOVA for larval weight of G2 silkworm strain on K2, Ml and S36 mulberry varieties

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.79994471	0.39997236	6.35	0.0039
Error	42	2.64730240	0.06303101		
Corrected Total	44	3.44724711			

APPENDIX 4.2 ANOVA for larval weight of ICIPE 1 silkworm strains K2, Ml and S36

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	2.95238351	1.47619176	32.06	<.0001
Error	42	1.93399093	0.04604740		
Corrected Total	44	4.88637444			

APPENDIX 4.3 ANOVA for larval weight of ICIPE 2 silkworm strains K2, Ml and S36

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.57285967	0.28642983	7.21	0.0021
Error	42	1.62936497	0.03974061		
Corrected Total	44	2.20222464			

APPENDIX 4.4 ANOVA for larval weight of M2 silkworm strains K2, Ml and S36

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.93744760	0.46872380	8.04	0.0011
Error	42	2.44901320	0.05830984		
Corrected Total	44	3.386460			

APPENDIX 4.5 ANOVA for larval weight of Z/Y silkworm strains K2, Ml and S36

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.07658364	0.03829182	0.95	0.3936
Error	42	1.68678347	0.04016151		
Corrected Total	44	1.76336711			

APPENDIX 5.0 ANOVA for cocoon weight of silkworm strains on individual mulberry variety

APPENDIX 5.1 ANOVA for cocoon weight of silkworm strains on K2 mulberry variety

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	2.28879768	0.57219942	16.21	<.0001
Error	70	2.47147387	0.03530677		
Corrected Total	74	4.76027155			

APPENDIX 5.2 ANOVA for cocoon weight of silkworm strains on Ml mulberry variety

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	4.60687832	1.15171958	26.15	<.0001
Error	70	3.08301320	0.04404305		
Corrected Total	74	7.68989152			

APPENDIX 5.3 ANOVA for cocoon weight of silkworm strains on S36 mulberry variety

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	8.88613261	2.22153315	43.72	<.0001

Error	70	3.55687187	0.05081246
Corrected Total	74	12.44300448	

APPENDIX 6.0 ANOVA for cocoon weight of individual silkworm strains fed on K2, Ml and S36 mulberry varieties

APPENDIX 6.1 ANOVA for cocoon weight of G2 silkworm strains fed on K2, Ml and S36 mulberry varieties

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.12085391	0.06042696	0.89	0.4175
Error	42	2.84529640	0.06774515		
Corrected Total	44	2.96615031			

APPENDIX 6.2 ANOVA for cocoon weight of ICIPE 1 silkworm strains fed on K2, Ml and S36 mulberry varieties

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.32035284	0.16017642	6.32	0.0040
Error	42	1.06459827	0.02534758		
Corrected Total	44	1.38495111			

APPENDIX 6.3 ANOVA for cocoon weight of ICIPE 2 silkworm strains fed on K2, Ml and S36 mulberry varieties

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.06312551	0.03156276	1.85	0.1692
Error	42	0.71509640	0.01702610		
Corrected Total	44	0.77822191			

APPENDIX 6.4 ANOVA for cocoon weight of M2 silkworm strains fed on K2, Ml and S36 mulberry varieties

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.37879480	0.18939740	2.76	0.0745
Error	42	2.87759200	0.06851410		
Corrected Total	44	3.25638680			

APPENDIX 6.5 ANOVA for cocoon weight of Z/Y silkworm strains fed on K2, Ml and S36 mulberry varieties

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1.68177204	0.84088602	21.95	<.0001
Error	42	1.60877587	0.03830419		
Corrected Total	44	3.29054791			