# ASSESSMENT OF THE PROPERTIES OF SILK FIBRE AND FABRIC PRODUCED BY BIVOLTINE SILKWORM, *Bombyx mori* L. (LEPIDOPTERA: BOMBYCIDAE) IN NAIROBI, KENYA.

**By**

**EVERLYN K. NGUKU**
**B.Ed. Arts (Fine Art), M.A. (Fine Art), Kenyatta University**
**H87/7717/2001**

**A RESEARCH THESIS SUBMITTED IN FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY IN THE SCHOOL OF APPLIED HUMAN SCIENCES OF KENYATTA UNIVERSITY**

**JUNE, 2010**

## DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

Signature: …………………….……………………….Date: …………….………….

Everlyn K. Nguku. - H87/7717/2001

This thesis has been submitted for Examination with our approval as Supervisors.

Signature: …………………….……………………….Date: …………….………….

Prof. Keren G. Mburugu,

Dean, School of Applied Human Sciences,

Department of Fashion Design and Marketing,

Kenyatta, University,

Nairobi, Kenya.

Signature: …………………….……………………….Date: …………….………….

Prof. Olive M. Mugenda,

Vice Chancellor,

Kenyatta University,

Nairobi, Kenya.

Signature: …………………….……………………….Date: …………….………….

Prof. Suresh K. Raina,

Commercial Insects Programme,

The International Center of Insect Physiology and Ecology (*icipe*),

Nairobi, Kenya.

## DEDICATION

This thesis is dedicated to my mum Mrs. Benes Nguku and sisters, Christine Nguku and Janice Nguku, who supported me no matter what roads of research I chose to follow.

# ACKNOWLEDGEMENT

My heartfelt appreciation goes to Prof. K. G. Mburugu and Prof. O. M. Mugenda, my university supervisors for their guidance, scholarly advice and critical review of the thesis.

My sincere thanks are due to Prof. Suresh K. Raina, my *icipe* supervisor who introduced me to the silk project. His constant moral support, valuable suggestions and critical discussions throughout the study period are highly appreciated.

I am indebted to Dr. Esther N. Kioko of the National Museums of Kenya and Dr. Vijay V. Adolkar of Ankole Western University Uganda, who provided me with a wealth of literature and made many suggestions that shaped the research methodologies.

My sincere gratitude to Messer's Katam, Khaindi and Muraya of the Kenya Bureau of Standards, Textile Laboratory for their technical assistance and guidance in the quality testing of silk fabric.

I would like to thank Dr. E. Muli and Mr. Boniface Ngoka of *icipe* for their vital suggestions and encouragement in the course of this study. My sincere appreciation to *icipe's* Commercial Insects' Programme sericulture staff for their support during my studies.

To all my friends and family members who in diverse ways encouraged me throughout the study period, **THANKYOU**. Finally, special appreciation to my mum and sisters for their love and support which enabled me go through this study successfully.

# TABLE OF CONTENTS

Page

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF PLATES

## ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| **CIP:** | Commercial Insects Programme |
| **CISEO:** | Center for Insect Science Education Outreach |
| **C X Z:** | Chun-Lei X Zheng Zhu |
| **ICIPE:** | International Centre of Insect Physiology and Ecology |
| **ISA:** | International Silk Association |
| **ITC:** | International Trade Centre |
| **JAICAF:** | Japan Association for International Collaboration of Agriculture and Forestry |
| **JHA:** | Juvenile Hormone Analogue |
| **KEBS:** | Kenya Bureau of Standards |
| **Q X B:** | QuiFeng X BaiYu |
| **Q X H:** | Quingsong X Haoyoe |
| **SSC:** | Silk Standards Committee |
| **S X M:** | Suju X Minghu |

## ABSTRACT

Concern about global warming has led to renewed interest in the more sustainable use of natural fibres. Among the natural fibres, silk indeed commands considerable respect. Silk is a proteinaceous polymer secretion in the form of a cocoon, consisting of a continuous filament. Although it has been in use for centuries worldwide, *Bombyx mori* silk is one of the least researched fibre in Kenya. It has many unique physical advantages and properties which make it the highest priced natural fibre. The purpose of this experimental study therefore, was to evaluate properties of silk fibre, fabric and cocoons produced by the *B. mori* silkworm, through the rearing of six selected silkworm strains. Two locations, the Commercial Insects Programme (CIP) laboratory (S1) and the CIP farm (S2) were set up in order to study the performance of the selected strains during two seasons, the long rains (LR) and short rains (SR). This study revealed that there was a significant difference in the means of cocoon, pupa and shell weight in the two locations and seasons. ICIPE I had the highest cocoon and pupa weight, in the two locations and the highest mean shell weight in location S1. Results established that the longest silk filament length, 1183.35m, was obtained from ICIPE I during the LR season, and weighed 0.355gms. Silk winding breaks varied amongst the different strains, with ICIPE I having the least counts. Average tenacity and elongation for the raw silk analysed was 3.93g/d and 18.5% respectively and differed between the seasons and strains. It was further observed that silkworm strains with high elongation had the least number of winding breaks due to increased elasticity. Cleanliness and neatness percentages differed among the strains, and notably ICIPE I's cleanliness and neatness percentages were higher than the other silkworm strains during the two seasons, 96 and 93% respectively. There was no significant difference in the fabric mass per unit area in the two locations at $P < 0.05$ ($P = 0.0001$) and during the two seasons ($P = 0.0001$). Evaluation of the influence of the various silkworm strains had on the breaking load revealed that there was no significant difference on the warp and weft at $P < 0.05$ ($p=0.0188$) and ($p=0.0006$) respectively amongst the six strains. Auxiliary indications established that the different silkworm strains used in this study were significant in the tearing strengths of both warp and weft ($P < 0.05$) ($p=0.989$) and ($p=0.776$) respectively. ICIPE I recorded the shortest larval development period in S1 during SR and it was significantly shorter ($F = 12.61$; $df = 71$; $P = 0.05$) compared to the other strains. From the research findings, it can be concluded that there is a link between the silkworm strains and ecological conditions during rearing, which determine the larval performance. Consequently, the larval performance characteristics significantly influence the silk cocoon, fibre and fabric properties. In addition, the cocoon properties, collectively with fibre production processes play a major role in determining the fibre properties, which when combined with fabric production processes influence and determine the fabric properties. A major outcome of the study was the establishment of a silk fibre quality control laboratory. Further ICIPE I silkworm strain was identified as having the most economical traits and most suitable for field rearing in Kenya, compared to the other five strains. This study recommends the Kenya Bureau of Standard (KEBS) together with the relevant textile stakeholders should draft a standard method against which silk fabric in Kenya can be tested and graded. In addition, further research on suitable silkworm strains and training in silk production processes at all levels for production of quality silk products.

# CHAPTER ONE

# INTRODUCTION

## 1.1 General Background Information

Despite a large number of man-made fibres overwhelming the textile arena, natural fibres are making a riposte (Ballenberger and Ballenberger, 2007). Concern about global warming has led to renewed interest in the more sustainable use of natural fibres (Pickering, 2008). Further, with new research, the rising awareness of the environmental impacts of producing and disposing of synthetic fibres, and the rising cost of petroleum-based source materials, natural fibres offer increasingly practical alternatives (Natural Fibres, 2009). For thousands of years people have been learning how to cultivate plants and animals for the fibres they produce. They are converted into yarns through spinning and other methods, and then made into fabrics through processes like weaving, knitting and felting. The fabrics are then finished off with dyeing and printing, and made into various products (Dam, 2009; Mohanty, *et al*., 2005; Natural Fibres, 2009).

Of the natural fibres, silk indeed commands considerable respect, as its emotional and prestigious aura is still incomparable (Ballenberger and Ballenberger, 2007). Silk is a proteinaceous polymer secretion in the form of a cocoon, consisting of a continuous filament. It is secreted by specialized exocrine glands in several groups of arthropods; however it is only silk from lepidopteran larvae and spiders that have reached the highest level of functional specialization (Zurovec and Sehnal, 2007).

There are two varieties of silk, domesticated and wild silk. Domesticated silk is produced by the larvae of the silkmoth *Bombyx mori*, a moth in the family Bombycidae. This silkworm spins valuable silk fibres making it one of the most beneficial insects to mankind, and is becoming an attractive multifunctional material for both textile and non-textile uses (Mondal *et al.*, 2007*;* Tsukada *et al.*, 2005). The *B. mori*, which is believed to have been derived from the original mandarins silkworm, *Bombyx mandarina*, is fully domesticated and is the most important silk-producing insect (Rao, 1997). On the other hand a variety of the wild silk insects (non mulberry) such as the Tussah, Muga, and Eri moths, and even some spiders like the golden orb web weaver *Nephila* do produce silk however commercial production is dominated by the *B. mori* (Nieuwenhuys, 2006; Elices *et al*., 2005; LDB Interior Textiles, 2002).

The *B. mori* silkworm produces probably more than 99% of the worlds' silk (Gongyin and Cui, 1995). Although in use for centuries, it is one of the least researched fibres (Kumar, 1999). The whiteness and regularity of the *B. mori* fibre make it superior to the silk fibres produced by wild silkworms (New Agriculturist, 1999). Silk has an economic value that is higher than that of other natural fibres such as cotton and wool because of its superior characteristics (Kumar, 1999). It has many unique physical advantages and the lustre and drape of silk fabrics make it the most attractive and highest priced natural fibre (Dingle *et al.*, 2005).

Cultivated silk from the *B. mori* silkworm, which is and has always been the most common type of silk used, has a number of interesting and desirable properties that have been admired for over 5,000 years (Ballenberger and Ballenberger, 2007). It has long been used for the production of luxurious textiles of the finest quality (Shelagh, 2004; Welford, 1969). One remarkable property of silk is its high tensile strength and its fibres will not easily be torn or damaged (Ballenberger and Ballenberger, 2007; Schenk, 1981). It also has natural texture and fineness; and can be stretched and will recover to its original size unless stretched beyond 20-25% of its original length. Almost as strong as cotton, it is more elastic than either cotton or linen, and has been used in the past in making ropes to take advantage of this characteristic (Ballenberger and Ballenberger, 2007). Silk has outstanding mechanical properties despite being spun at room temperature and from aqueous solution (Asakura, 2007).

In addition, silk holds its structural integrity and will not rot. It is more heat resistant than many other fabrics, including wool, and is actually rather difficult to burn. It has a beautiful natural luster and will take dye readily as well as absorb up to one third of its own weight in water without feeling wet to the touch, and is a warm fabric despite its lightness (Kadolph and Langford, 2003). For all these reasons silk has been desired for centuries.

With international demand for silk outstripping world production by 12%, the worldwide demand for silk is increasing but production is decreasing (Bafana, 2009). The world production of raw silk stands at 80,774 metric tons (Gaddum, 2006; Srinivasa *et al.*, 2005). As the leading silk consumer, Japan’s local silk production has dropped from over 20,000 tons to less than 2000 tons (ITC, 1999), leaving China and India as the major production centres, 54% and 14% respectively (Chattopadhyay *et al.*, 2005). With its recent economic reforms, the People's Republic of China has become the world's largest silk producer. In 1996 it produced 58,000 tonnes out of a world production of 81,000, followed by India at 13,000 tonnes. Japanese production is now marginal, at only 2500 tonnes. Between 1995 and 1997 Chinese silk production has steadily been going down by 40% (Gaddum, 2006).

The steadily growing demand for silk in the silk consuming countries indicates excellent opportunities for any country to increase her silk production (Kumar, 1999), an opportunity valuable for Kenya to embark on. In order to secure this opportunity, it is consequently important for production of silk products to be of utmost quality.

Africa's enormous potentials in raw silk production (Hardingham, 1996; ICIPE, 1997) are faced with some limitations, which are likely to pose a setback to local cocoon producers. Apart from the lack of infrastructure and sufficient inputs, sericulture industry in Africa lacks technical expertise at various levels of the production activities (JAICAF, 2007; Akinkunmi and Odebiyi, 2001).

Sericulture in East Africa has a history of more than 30 years, but actual conditions in each country have not been successful because sericulture and silk reeling technologies are undeveloped. Its development in Kenya has been constrained because of the insufficient technological expertise in the silk production processes and processing requirements of cocoons (JAICAF, 2007). While cocoon production is a typical farming activity, it is only part of a chain of activities that needs to be completed to produce high-value raw silk outputs.

The Japanese Government first introduced sericulture in Kenya in 1973. They assisted in the introduction and establishment of mulberry and silkworm rearing unit in Thika sericulture centre. It was introduced to cater for small–scale farmers in areas with low rainfall as a cash crop. The project provided food security and profitable employment in the rural areas. In addition the enterprise would produce raw materials for local and cottage industries as well as guarantee foreign currency through the export of silk. This initiative however was hampered by monetary limitations.

In the late 1990's, the Commercial Insects Programme (CIP) re-established this project at the International Centre of Insect Physiology and Ecology (*icipe*). *B. mori* silkworm strains were imported from China, India and Japan for the production of silk. In addition, in the course of their research, ICIPE I silkworm strain was developed through hybridization. The silk production technology was developed further by introducing post harvest technology which resulted in the production of raw silk and fabric. However for the success of this initiative, there is need to focus on the silk production process and the quality of the fibre and fabric produced by the different silkworm strains, since silk is produced by spinning, rather than by growth production (Vollrath and Porter, 2006).

The main weakness in sericulture is related to the different silkworm strains and a diverse range of practices leading to a divergence in cocoon and raw silk productivity and quality. Generally, there is weak ascend on quality and consistency in cocoon production and inadequate emphasis on quality in the commercial seed sector (Doshi, 2006). Testing of silk fibre and fabric production processes is essential for the production of quality yarn and fabric (Down, 1999; Garner, 1967). It is important to realize the market is quality-conscious and prepared to pay a premium for good quality (ITC, 1999). Yet the reeling activities and reelers have received little research attention when compared with other aspects of sericulture (Economic Development Associates, 1990).

This background thus formed the foundation of this study. Six *B. mori* silkworm strains namely Chun-Lei X Zheng Zhu (C X Z), QuiFeng X BaiYu (Q X B), Quingsong X Haoyoe (Q X H), 75xin X 7532 (75xin), Suju X Minghu (S X M) and ICIPE I were used in this study, where properties of cocoons, raw silk and fabric were established and raw silk quality determined. Further, the performance of the silkworms was studied in order to establish the strain with suitable economic traits for quality silk production.

**1.2 Problem Statement and Justification**

Sericulture development in Kenya has been constrained due to lack of sufficient technological expertise in the silk production processes and cocoon processing requirements. Further, it appears there has been no study carried out in Kenya, to evaluate the properties of raw silk and silk fabric produced by the available *B. mori* silkworm strains. Therefore there was need to carry out research and evaluate the cocoon properties, establish the raw silk and silk fabric properties and quality produced by various *B. mori* silkworm strains, in the country. This study sought to fill this gap.

There was need to also study and determine the suitability of the various *B. mori* silkworm strains available in Kenya for silk production. This would enable the improvement of certain practical aspects like silkworm rearing and mounting; and contribute to the production of quality cocoons and consequently silk fibre and fabric, hence this study. This in the long run will enable Kenyan silk to compete in the international, regional and local silk market.

## 1.3 Purpose of the Study

The main purpose of this study was to evaluate the properties of silk fibre, fabric and cocoons produced by the bivoltine *B. mori* silkworm, through the rearing of six selected silkworm strains.

## 1.4 Research Objectives

The study was guided by the following specific objectives:

1. Evaluate the cocoon properties of six *B. mori* silkworm strains, namely Chun-Lei X ZhengZhu (C X Z), QuiFeng X BaiYu (Q X B), Quingsong X Haoyoe (Q X H), 75xin X 7532, Suju X Minghu (S X M) and ICIPE I.
2. Establish the properties and quality of raw silk produced by the six *B. mori* silkworm strains.
3. Determine the properties of silk fabric produced by the six *B. mori* silkworm strains.
4. Verify if there are differences in the production performance of the six *B. mori* silkworm strains.

## 1.5 Hypotheses

1. There is a relationship between silk cocoon production and raw silk fibre qualities.
2. There is a relationship between silk processing and silk fabric properties.
3. There is a relationship between silkworm performance and silk cocoon properties.

## 1.6 Significance of the Study

In order to complete, validate and extend the sericulture initiative started by the Japanese in the 1970's there is need to focus on silk production processes and product properties. This research evaluated the raw silk and silk fabric properties produced by the *B. mori* silkworm, in order to enhance production of quality silk fibre and fabric. A silk quality control laboratory was consequently established for testing raw silk and is valuable to the country, as it will benefit the silk industry in production of quality products. This can be a significant achievement in silk production in Kenya and is important in marketing of the textile material.

Data collected from this study is useful to silk research and production centres in Kenya, as well as silk farmers undertaking sericulture as a cottage industry. From the results, ideal silkworm rearing methods and silk production processes can be formulated to ensure manufacture of quality silk textiles. Based on the findings, the study also proposes certain recommendations which when implemented will lead to improvements in silk fibre and fabric production in Kenya.

## 1.7 Limitations of the Study

The study confined itself to six selected *B. mori* strains, as they were the only available strains at *icipe's* grainage, the only major silkworm grainage in the country. As such, generalization to other strains should be done with caution.

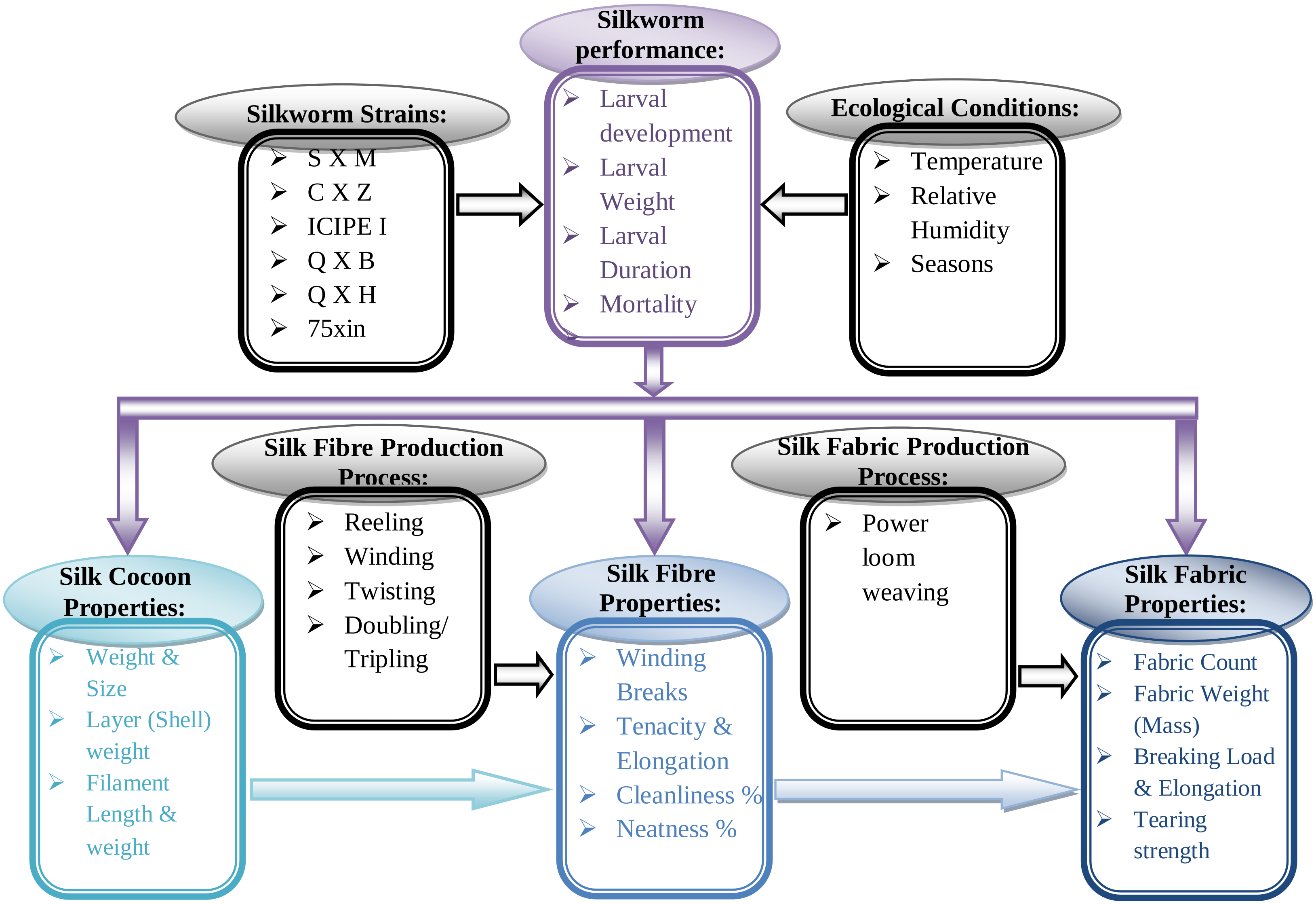
## 1.8 Conceptual Framework

Majhi *et al.*, (1994), noted that the maximum yield of raw silk from cocoons is an important aspect of sericulture and largely depends upon several factors but primarily on the quality of cocoons. They further observed that the quality of cocoons is influenced to a large extend by the rearing process and silkworm strain. Long (2001) on the other hand, outlined the setting of a grainage for potential silkworm strains in Africa. He outlined the structures and procedures for rearing and breeding. He indicated that the silkworm rearing conditions largely influence the cocoon quality and quantity. In addition, Akai *et al*., (1985), revealed that environmental conditions during rearing can directly influence the silk yield and there is need to take into account the rearing conditions.

Raina (2000) outlined the procedures for silk fibre and fabric production, from reeling, throwing, degumming and weaving. He outlined the details of each procedure and factors that affect the fibre and fabric qualities. Booth (1974) and Skinkle (1949) gave principles and methods by which the physical and mechanical properties of textile materials and products are measured and investigated. They suggested that the raw material used (silkworm cocoons), and the equipment used for manufacture influences the quality. SSC (1995) and Lee (1999), further provide a practical guide on both traditional and automated methods of raw silk testing and classification. It includes comparisons of results as well as suggestions that will permit International Silk Association (ISA) members to decide on how tests should be made and the criteria, which these must cover to meet current and future requirements.

The foregoing opinions are relevant to this study, where the quality of silk fibre and fabric formed the core objective of this study. The logical conclusion was that, with ideal silkworm strains, proper rearing procedures and appropriate fibre and fabric processing methods, production of quality cocoons, fibre and fabric is apparent. Consequently a conceptual model was formulated from these concepts, procedures and processes, by the various sericulture scholars. Dependent and independent variables were identified and a framework on the interaction of these variables formulated.

The conceptual framework for this study asserts that the silkworm strains and ecological conditions determine the rearing strategies adapted, in order to ensure proper silkworm performance and consequently quality silkworm cocoon, silk fibre and silk fabric products. It further emphasizes that the silk fibre and fabric manufacturing processes adapted ensure production of quality fibre and fabric. (Fig 1.1)




Source: Researcher, 2009

**Fig 1.1 Conceptual Model: Factors related to production of quality silk fibre and fabric**

## 1.9 Definition of Terms

**Bave**: This term is used to refer to cocoon fibre.

**Bivoltine silkworms**: Silkworms that are usually reared twice a year.

**Cultivar**: Mulberry varieties, sometimes referred by this term.

**Denier**: The unit of measuring fineness of yarn.

**Epprouvette**: Equipment used for reeling single cocoons to get their individual length.

**Filament**: A continuous fibre. Silk is the only naturally occurring single filament fibre.

**Grainage**: The establishment of healthy silkworm eggs for production

**Instar**: Larval stages of the silkworm, $1^{st}$ instar, $2^{nd}$ instar…

**Reeling**: The process of unwinding silk filaments from the cocoon and combining them together to make a thread of raw silk.

**Sericulture**: The practice of raising silkworm for production of cocoons and silk .

**Silk**: A natural protein fibre that contains fibron and sericin.

**Standard**: An identified measure of expectation set by the national agencies to allow manufacturers to measure quality.

**Silk throwing**: Twisting and doubling or tripling of one or more threads of the raw silk into a strand of the required strength and thickness for weaving or knitting.

**Quality**: The measure of excellence and performance of a product against identified Standards.

## 1.10 Definition of Operational Variables

**Ecological conditions:** The physical environment (temperature and humidity) that can affect the development of the silkworm strains and their production capacity.

**Silk cocoon properties:** The physical attributes of the silk cocoon that include cocoon weight and size, shell weight, filament length and weight.

**Silk fibre production process:** Industrial procedures involving mechanical steps that aid in the manufacture of raw silk, usually involving reeling, winding, twisting and doubling/tripling.

**Silk fibre properties:** The physical attributes of the silk fibre that include winding breaks; tenacity and elongation; cleanliness and neatness percentage.

**Silk fabric production process:** Industrial procedures involving mechanical steps that aid in the manufacture of silk fabric, usually involving weaving on a powerloom.

**Silk fabric properties:** The physical attributes of the silk fabric that include fabric count, weight (mass), breaking load and elongation; and tearing strength.

**Silkworm performance:** The characteristics of the silkworm during the larval period that include larva development, weight, duration and mortality.

**Silkworm strains:** The various *Bombyx mori* caterpillars that produce silk cocoons of fine, strong, lustrous fibres that is the source of commercial silk. These include the following hybrids Chun-Lei X ZhengZhu (C X Z), QuiFeng X BaiYu (Q X B), Quingsong X Haoyoe (Q X H), 75xin X 7532, Suju X Minghu (S X M) and ICIPE I.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.0 Introduction

This chapter highlights studies by other scholars and researchers. Literature is reviewed under the following broad subtopics:

- General Description - *S*ilk.
- *B. mori* silk cocoon production and properties.
- *B. mori* fibre and fabric production and properties.
- Silk testing and quality control.
- Related studies.

## 2.1 General Description – Silk

Silk is natural fibrous protein which is spun by Lepidoptera larvae such as silkworms, spiders, scorpions, mites and flies (Dash, 2007; Jin *et al*., 2002). In the global textile parlance, the term 'silk' refers to the mulberry silk because the bulk of world silk production, about 95%, is of mulberry origin (Mondal *et al.*, 2007). However, silk falls into two main types, besides the mulberry silkworm, there is the non-mulberry silks. This classification is based on the kind of silkworms that are used as raw materials for silk production. Insects which spin silk fibre mainly belong to two families, Saturniidae and Bombycidae.

The non-mulberry silk often called the 'Wild Silks' are derived from silkworms belonging to the Saturniidae family which are not domesticated for example the Eri, *Samia cynthia* *ricini,* Muga*, Antheraea assama,* and Tasar, *A. mylitta* and *A. paphi* (Brown *et al.,* 2007 Jolly *et al.,* 1980). Silk production from these wild silkworms is much less predictable and much more difficult to control, since these insects cannot be domesticated like the *B. mori* (Raina *et al.*, 2000). Furthermore, tusar silk is said to be somewhat more coarse than silk from *Bombyx mori.* Despite the arrival of less costly synthetic fabrics like rayon and nylon, the properties and characteristics of silk account for its continued significant demand (Ballenberger and Ballenberger, 2007).

Mulberry silk is from larvae in the family Bombycidae, which is very important economically as the producer of silk. It is entirely dependent on humans for its reproduction and no longer occurs naturally in the wild (Goldsmith *et al.,* 2004; Cherry, 1993). The history of the use of the silkworm species *Bombyx* to produce cloth, suggests that it was invented in China at least as early as the Longshan period (3500-2000 BC), and perhaps earlier. Evidence of silk for this period is only known from a few textile fragments, and textual evidence in the Shi Ji, and art depictions of garments (Hirst, 1997).

As a textile material, mulberry silk possesses a few unique properties. It is the finest animal fibre (diam.10-12 m), has no cellular structure since it is not part of body tissue and it is a continuous filament. Silk filaments are very fine and may be 900-1,300 metres long and have a high natural luster and sheen of a white or cream colour. It is a strong filament with tenacity (grams per denier) of 2.8 to 4.9 and elastic recovery of 18.7 - 20.87% (Sonwalkar, 1993). Silk yarn can be dyed before or after it has been woven into cloth (Aruga, 1994; Marsh, 1979). Recently, silk has been focused as a biotechnological and biomedical resource. This is due to its unique properties including non-toxicity, biocompatibility and biodegradability (Foo and Kaplan, 2002).

### 2.1.1 *Bombyx mori* Silkworm

The domesticated silk comes from silkworms grouped in the phylum Arthropoda, which has a complete metamorphosis and is a member of the family Bombycidae of about 300 moth species under the order Lepidoptera. It belongs in the genus 'Bombyx', the principal species of which is known as the *Bombyx mori* (Mishra, 2000).

Also referred to as the mulberry silkworm, the larvae of the domesticated silkmoth *B. mori* is very important economically as the producer of silk. This silkworm produces delicate and valuable silk filament, making it one of the most beneficial insects to mankind, and is becoming an attractive multifunctional material for both textile and non-textile uses (Mondal *et al.*, 2007; Tsukada *et al.*, 2005). The *B. mori,* which is believed to have been derived from the original mandarins silkworm, *Bombyx mandarina-moore,* is fully domesticated and is the most important silk-producing insect (Rao, 1997). Domestication of *B. mori* occurred in China about 2700 B.C (Arunkumar *et al.,* 2006; Dingle, 1998; Maekawa *et al.*, 1988).

The *B. Mori* silkworms produce silk from a pair of labial glands, each of which consists of silk-secreting posterior and middle regions, and an outlet (Sehnal and Akai, 1990). The posterior region produces fibrous silk core, while the middle region provides a sticky coating of the fibre and adds several low molecular components with presumably protective functions to the silk (Nirmala *et al.*, 2001; Zurovec *et al.*, 1998). *B. mori s*ilk is a delicate, translucent, composite fibre (bave) which is well known since the ancient times as a natural textile fibre. It has a predominantly proteinic matrix and is constituted of proteins like fibroin (Dhawan and Gopinathan, 2003; Becker *et al.*, 1995; Rudall, 1960; Lucas *et al* 1958; Howit, 1946), which represents a prevailing fraction of the fibre (70-80%), and sericin, which represents the remaining 20-30% (Prasong *et al.*, 2009; Dhawan and Gopinathan, 2003; Raina, 2000; Asakura and Kaplan, 1994; Harbone, 1977).

Both fibroin and sericin are proteins, but of very different composition and properties (Perez *et al*., 2000). The silk protein fibroin is fibrous in nature, forming the main silk filament content, while sericin is a sticky coating substance between the layers of fibroin (Singhvi and Bose, 1991). The two brins, produced and coated in separate ducts, are pressed together while still inside the insect; the sericin hardens in air and typically on the cocoon to form the con-joining bave and tough cocoon wall composite (Vollrath and Porter, 2006). Sericin belongs to a family of proteins having high content of hydroxyl amino acids. The high polarity differentiates the sericin from the fibroin and it allows the extraction of the silk from the fibre (Harbone, 1977).

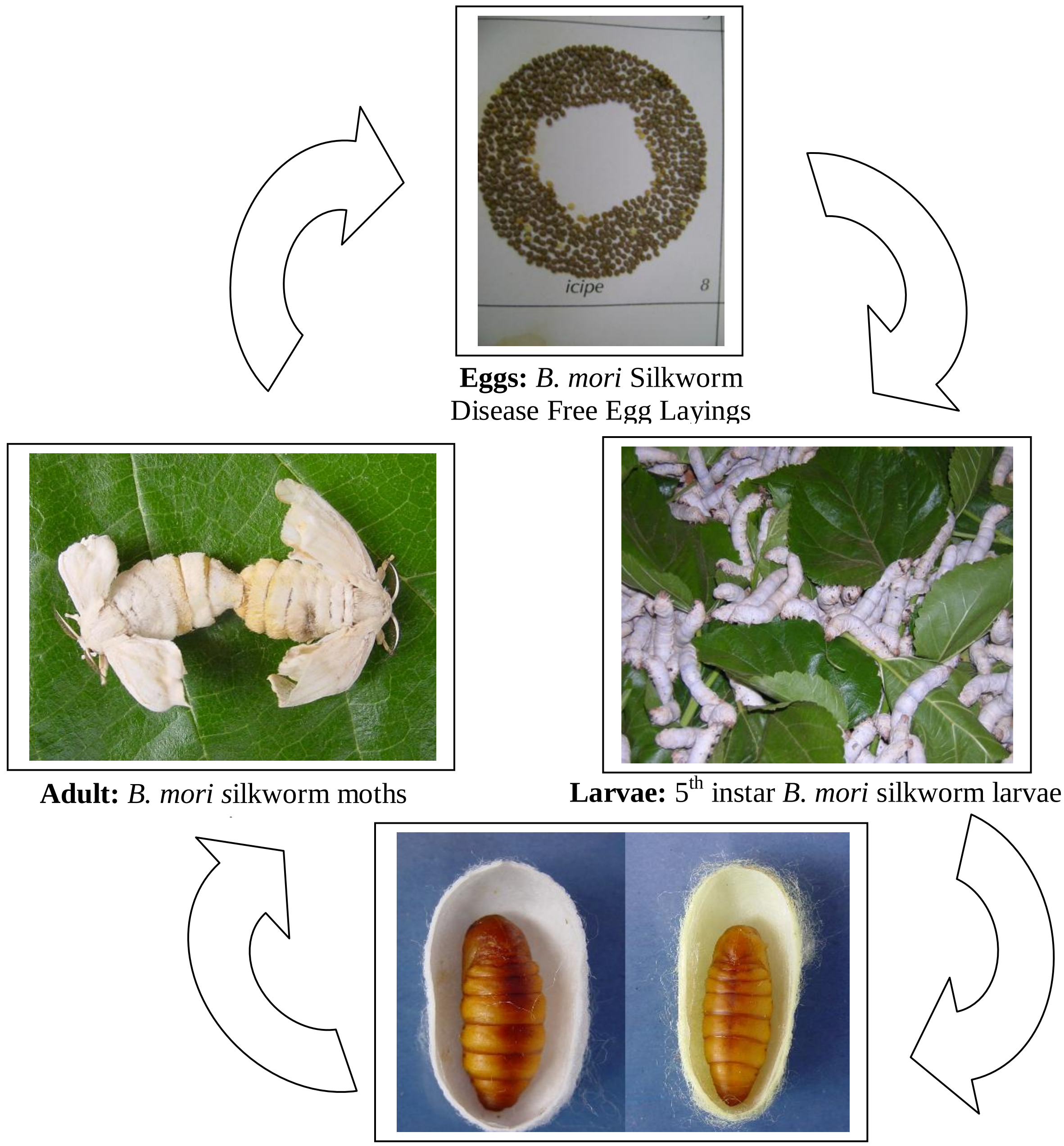
### 2.1.2 Rearing of domesticated silkworm, *B. mori* for quality cocoon production

Sericulture is the rearing of silkworms for the production of cocoons, which is the raw material for the production of silk (Donia, 2001). Silkworms have been reared for over 5000 years in China (Nagaraju and Goldsmith, 2002) for silk production purposes, and an estimated 4310 silkworm germplasm strains, comprising geographical strains, inbred lines, and mutants are thought to be available worldwide (Goldsmith *et al.*, 2004). The silk producing insect, *B. mori* is an oligophagous herbivore and depends mainly on the quality of mulberry leaves and environmental conditions for its development (Adolkar *et al.*, 2007). The rearing of the *B. mori* silkworm larvae plays an important role in the production of quality cocoons, raw silk and fabric respectively. It is a combination of three components: moriculture (mulberry farming), breeding (silkworm rearing) and silk processing (Veda *et al.*, 1997).

Termed holometabolous, the silkworm completes its life cycle through serial progression of four distinct stages of metamorphosis: egg, larvae, pupa and adult (Plate 2.1). The larvae ecdyse four times as they grow through five instar stages and the total larval duration is 25-30 days (Raina, 2000; Aruga, 1994; Lim *et al.*, 1990). The larvae of the first and second instar are called young age larvae, while those of the third, fourth and fifth instars are referred to as advance stage or late age larvae (Aruga, 1994). Upon hatching, the larvae are transferred onto the rearing bed using a small brush, a process called brushing. They are gently provided with tender finely chopped mulberry leaves.

Environmental conditions are vital for silkworm rearing. These conditions include temperature and humidity (26 – 28$^{O}$C and 80% respectively), light, air, feed and pathogens, which can exert combined effects on silkworm life (Raina, 2000; Pang-chuan *et al.*, 1988; Lim *et al.*, 1990; Aruga, 1994). Another important condition is the quality of mulberry (Raina, 2000). Rearing temperature has an important influence on the efficiency of food utilization by larvae of the silkworm *B. mori* (Muniraju *et al.,* 2004). It is therefore important that there are minimal fluctuations of temperature and humidity (Raina, 2000; Aruga, 1994).

**Plate 2.1 The *Bombyx mori* Life cycle**




**Eggs:** *B. mori* Silkworm Disease Free Egg Layings

**Larvae:** 5th instar *B. mori* silkworm larvae

**Adult:** *B. mori* silkworm moths

**Pupa:** *B. mori* silkworm cocoon cut open to show pupa

The young larvae are fed with the right quality of leaves which are highly nutritious leaves in adequate quantities at suitable intervals of time. The top 3-4 full grown leaves immediately below the growing buds are most suitable for larvae at this stage. The right environment, 26-28$^{o}$C and 80-85% RH, should be maintained to ensure proper larval growth and quality production (Raina, 2000). On the other hand, older larvae are fed on the mature mulberry leaves. Their growth is fast and their leaf consumption high. Mulberry leaves with high water and protein content should preferably be used. During the fifth instar it is important that the larvae be provided with sufficient quantity of mulberry feed when they are actively feeding. Unlike the young age larvae, they cannot withstand high temperature and humidity; temperature should be 22 – 24$^{O}$C (Raina, 2000). On the seventh to eight day, the fifth instar larvae are ready to pupate, hence they are transferred to a mountage. It takes the larvae three days to spin the cocoon and a further two to three days to moult into a pupa (Pang Chaun *et al.*, 1988; CISEO, 1997). It is important to keep the room well ventilated (I.A.R, 2000; Lim *et al.*, 1990; Krishnaswami *et al.*, 1973) in order to ensure quality cocoon formation for raw silk production.

### 2.1.3 *Bombyx mori* food plant

The *B. mori* is monophagous and survives solely on mulberry leaves (*morus* sp.) which play an important role in the nutrition of the silkworms due to the presence of morin (Nagaraju and Goldsmith, 2002; Tribhuan, *et al.*, 1989). The mulberry is a very hardy plant of the genus *Morus* under the family Moraceae (Plate 2.2).

**Plate 2.2 *Morus alba* Mulberry**

Nutritional background of the larval stage significantly influences the status of the resulting larva, pupae, adult and fibre (Rahmathulla *et al.*, 2002; Aftab *et al.*, 1999; Takano and Arai, 1978; Fakuda *et al.*, 1963). Although the mulberry leaves are a complete diet for silkworm sometimes it is possible that some deficiencies occur due to different reasons. Rahmathulla *et al.*, (2007) noted that the supplementation of extra nutrients along with mulberry leaves results in higher yield because the production of superior quality and quantity of silk depends mainly on nutritional status and healthiness of the larva.

Shekar and Hardingham (1995), state that the cocoon quality produced by the silkworm depends on the quality of mulberry leaf on which it feeds. The growth and development of larva, and subsequent cocoon production are greatly influenced by nutritional quality of mulberry leaves (Kumar *et al*., 2009; Seidavi *et al*., 2005). Further the quality of the leaves has a profound effect on the superiority of silk produced by the *B. mori*. In this regard, the production of good cocoon crop is dependent on the quality of leaves. Leaves of superior quality enhance the chances of good cocoon crop (Ravikumar, 1988). It has also been demonstrated that the dietary nutritional management has a direct influence on quality and quantity of silk production in *B. mori* (Murugan *et al*., 1998).

Research indicates that silk production of larvae reared on fresh leaves of mulberry, *Morus alba*, is greater than that of the larvae reared on artificial diets. This suggests mulberry leaves, the natural host of silkworm, have factors effective in silk production (Nakamura and Hirayama, 2000). However it is important to note that Yungen and Junliang (1999) had earlier found that the qualities of cocoons and silk fibre and fabric of artificially fed silkworms was of the same standard as that of mulberry fed silkworms.

## 2.2 *B. mori* silk cocoon production and properties

The most useful and tangible of the benefits that arise from insect activities is the utilization of the things that insects make, collect or produce such as silk. Preeminent among insects valuable in this way is the *B. mori* silkworm (Metcalf and Flint, 1962). It is of worth to note that no other species has been able to rival the *B. mori* as a commercial-silk producer. The larvae construct cocoons in order to protect their pupa against possible attacks and various other kinds of external hazardous factors (Murakami, 1996).

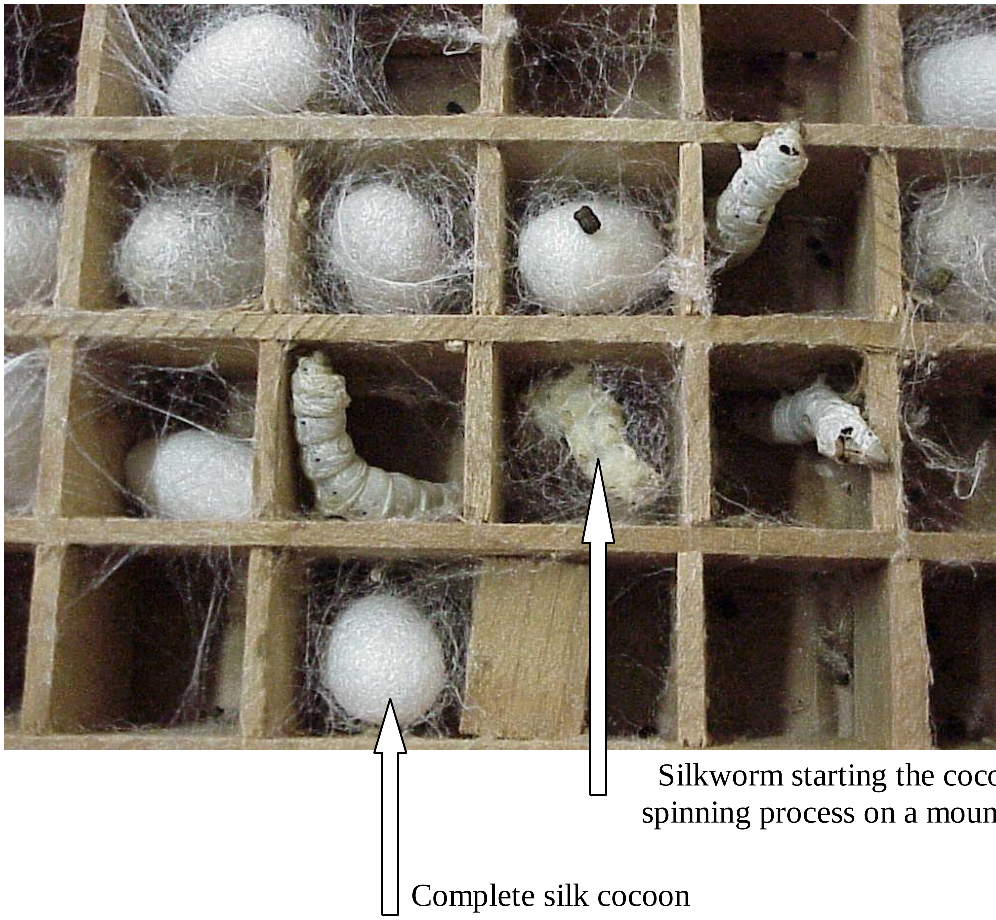
### 2.2.1 Silk cocoon production

Silkworms possess a pair of specially modified salivary glands called silk glands or sericteries, which are used for the production of silk cocoons (Microsoft® Encarta® Online Encyclopedia, 2007). These glands secrete a clear, viscous, proteinous fluid that is forced through openings called spinnerets on the mouthpart of the larva. As the fluid comes into contact with the air it hardens into filament, which is silk (Vegan Society, 2003; Aruga, 1994).

Steadily over the next four days the silkworm produces a fine thread by making a figure of eight movement some 300,000 times, constructing a cocoon in which it intends to spend the chrysalis stage where it is in a state of sleep and casting off of skin (Plate 2.3). The cocoons can be shades of white, cream and yellow depending on silkworm genetics. After a final moult inside the cocoon, the larva develops into the brown, chitin covered structure called the pupa. This is normally followed by transformation of the pupa into a moth.

The maximum yield of raw silk from cocoons is an important aspect of sericulture. To what extend this aspect is attained depends upon several factors but primarily on the quality of cocoons (Majhi *et al.*, 1994).

**Plate 2.3 *B. mori* cocoon spinning**




### 2.2.2 Silk cocoon properties

Various features of cocoons have a direct bearing on the quality of raw silk. In order to bring raw silk in competition with other fibres, particularly the synthetic and other natural organic fibres, it is absolutely essential to produce elite cocoons on a large scale. For this purpose, the silkworm eggs should be properly preserved and rearing should be carried out using excellent strains. Adequate supply of good mulberry leaves and maintenance of suitable environmental conditions during rearing and mounting are equally important. Above all, efforts should be made to minimize the incidence of silkworm diseases. All these aspects need careful consideration.

Hariraj and Somashekar, 2006). The Research indicates that the cocoon strains have significant influence on the cocoon characteristics (cocoon weight, shell weight, shell ratio percentage, average filament length), on the reeling characteristics and on quality characteristics viz. neatness, cleanness, tenacity and elongation of raw silk (quality of silk cocoons is determined by a number of characteristics and governed by several parameters, each of them being associated with a certain level of importance (Nagadevara, 2004; Anon, 1996). Each of these characteristics measures a different aspect of the quality. Some of the important quality parameters usually considered include, Shell Ratio Percentage, Defective Cocoon Percentage, Average Filament Length, Average Non Broken Filament Length, Denier, and Reelability percentage. Of these, Shell Ratio Percentage and Defective Cocoon Percentage have been identified as the most significant ones (Sonwalkar, 1982, 1993) especially because these are relatively easy to determine requiring minimum facilities, infrastructure and time.

The weight of the cocoon shell and the uniformity of the cocoon shell thickness are considered important commercial factors in raw silk reeling that are closely related to the raw silk yield to be obtained. The quality of cocoons as raw material depends mainly on the cocoon shell ratio. If the cocoon shell ratio is good, the yield and quality of raw silk improves (Datta and Nanavaty, 2007). On the other hand the filament length is as important as the shell ratio. It largely determines among things the evenness of the silk thread.

It has been established that each of the quality parameters has its own relative significance on the reeling efficiency and raw silk quality. The procedures for assessment of a few of these parameters are quite involving, while it is relatively easy for some of the others. A few tests are non destructive (as in the case of Defective Cocoon percentage), while others are destructive (as in the case of Shell Ratio Percentage). Thus, each of the parameters is associated with a certain extent of ease or difficulty in assessment (Nagadevara, 2004).

Cocoon quality parameters have an important bearing on the quality of the raw silk reeled (Vasumathi *et al.*, 2004). It has been noted that some climatic conditions affect the quality of cocoons. Temperature and humidity affects the total cocoon weight and cocoon layer weight. Relatively high temperatures of 28$^{O}$C ensures better characteristics of cocoons while high humidity during rearing of young age larvae yields better quality cocoons in terms of total cocoon weight and cocoon layer weight. On the other hand, for the advanced-stage larvae, low humidity yields better cocoons with higher weight than of high humidity (Aruga, 1994).

Various features of cocoons have a direct bearing on the quality of raw silk. In order to bring raw silk in competition with other fibres, particularly the synthetic and other natural organic fibres, it is absolutely essential to produce elite cocoons on a large scale. For this purpose, the silkworm eggs should be properly preserved and rearing should be carried out using excellent strains. Adequate supply of good mulberry leaves and maintenance of suitable environmental conditions during rearing and mounting are equally important.

Above all, efforts should be made to minimize the incidence of silkworm diseases. All these aspects need careful consideration.

### 2.3 *B. mori* fibre and fabric production and properties

Post cocoon technology plays a vital role in the production of quality silk. The Silk Standard Committee of the International Silk Association (ISA/AIS) has published a comprehensive compendium on essential raw silk quality issues (Hattenschwiller and Farber, 1999). In order to produce silk fibre and fabric, cocoons undergo various production processes, and these include silk reeling, throwing and weaving.

#### 2.3.1 Raw silk reeling process

The production of raw silk fibre from cocoons (reeling) is a crucial middle stage in the silk industry (Mayoux, 1993). Quality raw silk cannot be made just by producing good quality cocoons alone. Appropriate reeling technique is equally important for the production of good quality raw silk (Koshy, 2001).

Silk reeling is the process by which a number of cocoon baves are reeled together to produce a single thread. This is achieved by unwinding filaments collectively from a group of cooked cocoons at one end in a warm water bath and winding the resultant thread onto a fast moving reel (Lee, 1999; Corbman, 1985). There are many types of silk reeling machines in use, which include the Sitting Type Reeling Machine, the Multi-ends Reeling Machine and the Automatic Reeling Machine. However the major structural features are basically the same.

This study employed the Multi-ends Reeling Machine, which eliminates the disadvantages of the sitting type reeling machine by increasing the number of reeling thread ends per basin and reducing the reeling speed. The operator must stand when running this machine as the number of reeling threads per basin increases by twenty-fold. This is also called a "Standing type reeling machine". Reeling efficiency is unchanged and quality is better due to reduced speed (Lee, 1999).

Reeling increases filament length, non-breakable filament length and reelability percentage of the raw silk produced which are the most important commercial characters in the improvement of silk quality and yield (Kamimura and Kiuchi, 1998; Kajiura and Yamashita, 1989). The purpose of the reeling process is not only to raise the raw silk yield of cocoons and reeling efficiency, but also to improve raw silk quality.

Re-reeling process vastly improves the winding ability of silk yarn for attaining higher production and grades in the international markets. It further ensures silk is free from thin ends, neatness is improved to a certain extend and loose ends are joined to ensure continuity of the yarn (Datta and Nanavaty, 2007).

### 2.3.2 Silk Throwing

Silk throwing involves the twisting of one or more threads of the raw silk into a strand – silk yarn, sufficiently strong for weaving or knitting. The reeled silk fibres are combined, as in making tram, but they are twisted much harder than ordinary tram. Next, two of these twisted threads are combined and twisted in the direction opposite to that used in twisting the strands. Four different types of silk thread may thus be produced: organzine, crepe, tram, and thrown singles (I.S.A, 1999; Possee, 1998). The other forms of threads and yarns are all prepared on the same principle, varying only in the number of single threads, the amount and direction of twist, the number of strands used, and so on. Various machines are used in the production of silk yarn and include the winding, twisting and doubling/tripling units. Silk yarn production is done with extreme care to ensure quality is maintained.

### 2.3.3 Silk fabric production

Weaving is a process where the fabric is created by interlacing the warp yarns and the weft yarns. The warp threads are held taut and in parallel order, typically by means of a loom, though some forms of weaving may use other methods. The loom is warped (or dressed) with the warp threads passing through heddles on two or more harnesses. The warp threads are moved up or down by the harnesses creating a space called the shed. The weft thread is wound onto bobbins, which are placed in a shuttle which carries the weft thread through the shed. The raising and lowering sequence of warp threads gives rise to many possible weave structures like plain, twill, satin weaves and complex computer generated interlacing (Broudy, 1979).

Both the warp and weft can be visible in the final product. By spacing the warp more closely, it can completely cover the weft that binds it, giving a *warp-faced* textile such as rep weave. Conversely, if the warp is spread out, the weft can slide down and completely cover the warp, giving a *weft-faced* textile, such as a tapestry. There are varieties of loom styles for weaving, as well as a variety of fabrics which are produced. This requires different qualities of silk fibre.

Fabric production requires great care to ensure uniformity of weft thickness and spacing and that borders are straight. Good quality of silk begins with a warp of approximately 2,000 threads for one meter width. 1,600 threads or 1,800 threads are considered to be poor quality fabric. Loosely woven fabrics are difficult to sew.

Weaving is either done by machines or hand. Hand woven fabric is better than the machine woven. It can make delicate designs with different colored thread. Modern machines use lances, projectiles and a jet of compressed air to shoot the weft-yarn between the warp-yarns. It leads to greater yield and productivity. The powerloom was used for fabric production (Plate 2.4).

**Plate 2.4 Weaving of Silk Fabric on a Powerloom**

### 2.3.4 Silk fibre and fabric properties

The physical properties of silk like those of other natural fibres are quite variable and depend broadly on the source and growing conditions (species and sericulture) of the silkworms (Lewin and Pearce, 1998).

Compared to other natural fibres, silk has certain specific characteristics that set it apart. There are various qualities, which are tested to ascertain the quality of raw silk, and include, winding breaks, cleanliness, neatness, tenacity and elongation among others, which are used to grade raw silk (Lee, 1999).

One remarkable property of silk is its high tensile strength and its fibres will not easily be torn or damaged. It has a tenacity of 4.8g/denier slightly less than that of nylon but stronger than other natural fibres, and an elongation of 17 – 25% (dry), 30% (wet) (Ballenberger and Ballenberger, 2007; Franck, 2001). When dry, silk filaments are comparable in strength to such synthetic fibres as nylon and polyester; however, silk filaments lose some strength when they are wet (Ballenberger and Ballenberger, 2007).

The neatness and some cleanliness of the raw silk are directly influenced, whereas tenacity and cohesion of raw silk are indirectly influenced by breed characteristics of the cocoon. The minor defects in raw silk include split ends, hairiness, knots, loops and fuzziness. These defects vary in different breeds and depend almost entirely in silkworm breed/hybrid even though reeling and mounting conditions can also influence them (Datta and Nanavaty, 2007). Research indicates that cooking the cocoons to the required level is essential for producing better quality silk reeling (Naik and Somashekar, 2006).

In countries where sericulture is advanced like China, Japan and India, raw silk with neatness less than 93% is not recommended for production of quality silk. The neatness defects affect the performance of raw silk during preparatory process, weaving operations and appearance of the fabric. Further, the strength and cohesion of raw silk can be affected by low neatness. On the other hand, some cleanliness defects like slugs and long loops are influenced by the defects in the cocoon filament (Datta and Nanavaty, 2007). It has been observed that cocoon cooking condition plays a more dominant role on cohesion of raw silk.

Yarn characteristics such as size deviation and evenness variations are more depended on cocoon cooking, reelability and maintenance of appropriate number of ends during reeling (Naik and Somashekar, 2006). It has also been seen that cocoons having better filament length and reelability will have higher non broken filament length. Higher filament length helps the reeler in maintenance of required number of cocoons for a particular denier of raw silk (Datta and Nanavaty, 2007).

Amongst the animal fibres, the first place ought to be assigned to silk not only on account of the beauty of the fibre itself, but also because no other textile fabric combines such degrees the qualities of warmth, brightness, strength, firmness, and durability (Landi, 1998). Garments made from silk are lightweight but warm and absorbent. On the other hand silk fabrics have excellent draping properties and a natural resistance to creasing and wrinkling. Silk fabric is known for its softness, luster, beauty and luxurious look. It is one of the higher grade fabrics, which gives the wearer comfort in all types of weather. It keeps the body cool in summer and warm in winter. It is the strongest natural fabric in the world (Sashina *et al.*, 2006).

Silk fibres are highly receptive to dyeing, and dyed and printed silk fabrics have a richness and variety seldom found in other textiles. Silk clothing keeps one cool in the summer, and it provides surprising warmth in the winter and is often used as an insulation layer in different types of clothing or even in sleeping bags. It can absorb a fairly significant amount of moisture before it feels wet.

**2.4 Silk testing and quality control**

The textile industry is becoming an increasingly competitive environment. Differentiating products is therefore important and this can be facilitated through improving quality. Quality control has been found to be the most effective measure to maintain the prerequisite quality and quantity of any textile product either in yarn or fabric stage, further testing can be used to improve product quality and achieve compliance to international, regional or retailer specific standards (Sonwalker, 1993).

It is well known that silk textile quality control has become of increasing interest and the quality assessment of textiles is of vital importance for both manufacturers and consumers. An increased number of knowledgeable consumers with firm demands for specific performance behaviour and longer life textile goods, in combination with the numerous advances in technology have made essential the better understanding of properties of fibres, yarns and fabrics (Lee 1999).

Quality must be built into a product during manufacture and/or design stage. In raw silk production, improvement of certain practical aspects like silkworm rearing and mounting indeed follow the technical advancement and contribute to the production of quality cocoons and subsequently silk fibre and textile. Industrial raw silk users need to have the possibility of being able to rely on exact and objective identification of the qualities of raw silk, so as to permit choosing the most suitable to offer optimal efficiency on high performance machinery in throwing, weaving and knitting and leading to high quality of - the end product (SSC, 1995).

The value of silk depends on, first, lustre; second, strength; third, fineness. Its appearance under the microscope is an even, round, glasslike fibre; its strength is said to be three times that of linen. No other textile fibre can be spun to such a degree of fineness combined with elasticity (Lee, 1999).

The quality of silk cocoons is determined by a number of characteristics. Each of these characteristics measures a different aspect of the quality (Nagadevara, 2004). As a result, some form or the other of quality index as a measure of cocoon quality exists in countries more advanced in sericulture especially Japan and China (Somashekar, 1999; Nakajima, 1999). It has been established that each of the quality parameters has its own relative significance on the reeling efficiency and raw silk quality. The procedures for assessment of a few of these parameters are quite involved, while it is relatively easy for a few others. A few tests are non destructive (as in the case of Defective Cocoon percentage), while a few are destructive (as in the case of Shell Ratio percentage). Thus, each of the parameters is associated with a certain extent of ease or difficulty in assessment.

### 2.4.1 Silk tests

Quality raw silk cannot be made just by producing good quality cocoon alone. Appropriate reeling technique is equally important for the production of good quality raw silk. Introduction of silk testing and grading is a step in the right direction for bringing in quality consciousness among rearers and reelers (Koshy, 2001)

To maintain reeling thread in the required size, the average cocoon number per thread must be adjusted by a check to produce silk thread in the same size throughout all ends during reeling. If the size is different from the required size the group size controller should readjust it. This will reduce size deviation. By improving the accuracy of cocoon supply, each silk thread becomes uniform in size and different skein sizes are reduced. It can also improve the size deviation and evenness of raw silk quality through accuracy of cocoon supplying work and the improvement of cocoon reelability (Lee, 1999).

Defects in raw silk are divided into super major defects, major defects and neatness defects (Lee, 1999; SSC, 1995). Defects occur based on reeling conditions. Fibres usually experience tensile loads whether they are used for apparel or technical structures. Their form, which is long and fine, makes them some of the strongest materials available as well as very flexible (Bunsell, 2009). Good cohesion raw silk is needed for the warp of silk fabric. Factors that improve the cohesion are temperature, amount of reeling tension, sufficient croissure and good drying of raw silk. The water consistency and temperature of groping end part and reeling part affect the colour of raw silk. Therefore, the temperature control and water supply in the reeling machine should be constantly monitored to obtain a uniform colour of raw silk (Lee, 1999).

In order to support the weaving industry in the selection of the required raw silk, it must be first tested and classified. Further, the raw silk reeling industry requires well-defined standards, which can only be achieved by silk fibre testing (SSC, 1995). It is necessary that there should be industry standards for raw silk quality so as to enable buyers to purchase raw silk at internationally accepted grades. This is the reason why all raw silk produced should be classified following testing (Lee, 1999).

The unique synthesis of strength and fineness make silk very useful in certain important sectors such as surgical fields and fabrication of precision equipment. Silk fibre is also highly extensible. Therefore the determination of strength and elongation of raw silk is an important test. The breaking load, that is the load the thread can with stand just before it breaks is expressed in terms of *grams per tex* or *per denier* and is known as tenacity (Sonwalker, 1993).

The tenacity test is carried out on a serigraph strength tester or a serimeter. The tester is capacble of recording simultaneously the breaking load and the corresponding elongation of the threads. Normally the tenacity and elongation percentage of mulberry silk is in the range of 3.5 – 4.5g/d and 18 – 22% respectively (Sonwalker, 1993). Neatness indicates the frequency of short yarn lengths (approximately 3mm) which, according to their mass over step the normal cross section by 50% (Sonwalker, 1993). These are defects which as far as the naked eye is concerned are *neps*.

Silk production today is a blend of ancient techniques and modern innovations (Cherry 1993). Although none of the luxury fibres, including silk is produced in large quantities their particular and unique qualities of fineness, softness, warmth and pleasurable handle mean that they occupy a very important place in the luxury apparel and fine furnishing trades (Franck, 2001). To assure accuracy and replicability, textile testing should be carried out under carefully controlled conditions, testing equipment must conform to specifications established in testing methodology, and fabric specimen must be of uniform size (Booth, 1974; Eyre, 1956).

A common type of failure in textile fabrics and consequently a serious defect is their tendency to tear easily. It may be described as the sequential breakage of yarns or a group of yarns along a line through a fabric. The tearing strength that is usually measured as the force required to propagate a tear may often be used to give a reasonably direct assessment of serviceability and a fabric with low tearing strength is generally an inferior product (Primentas, 2001). The quite often contact of textile goods with sharp objects results in the puncture and in many cases the tear of textiles. Thus the determination of the tearing strength of textile articles occupies a very distinctive position among the various textile quality control tests (Primentas, 2001)

The testing of raw silk is based on the procedures laid down by the International Silk Association (I.S.A). However the compilation of test results and standards for various grades differs slightly from country to country. Some of the properties of raw silk and silk fabrics, which have been tested using various methods, include size and evenness, fibre fineness and defects, cohesion, colour, abrasion resistance, fabric strength and crease recovery (Booth, 1974).

Standard tests procedures administered in the laboratory provide reliable data that can be used for evaluation and in some instances, to predict fabric behaviour (Marsh, 1979). To determine whether textile products meet established standards, such products must be tested. Textile standards and textile testing are therefore closely involved.

## 2.5 Related Studies

There has been no research carried out locally on *B. mori* silk fibre and fabric qualities. Preliminary studies have however, been carried out by Adolkar *et al.*, (2007) and Raina *et al.*, (1999) on the performance of various silkworm strains fed on different mulberry cultivars, in Nairobi, Kenya.

Studies have been carried out in countries like China, Japan, India, Philippines among others, on the performance of silkworm strains, Basaen and Josue (2001) performed a comparative evaluation of cocoon properties of four bivoltine silkworm strains with the aim of determining the cocoon quality of silkworm *B. mori* in terms of cocoon weight, cocoon length and width and percent cocoon shell. Further it investigated the silk filament as to the length, weight, size, percent raw silk, non-breaking length and percent reelability. Tejano *et al.* (2002) evaluated five varieties and its reciprocal for new F1 hybrids with the objective of identifying the best silkworm hybrids for mass production and commercialisation; and increasing cocoon and raw silk production in the Philippines. Balanay (2002), has also studied the performance of various silkworm strains.

It has been known that application of hormones to *Bombyx mori* could be used to improve the quality of silk (Akai *et al.*, 1985; Ahmad *et al.,* 2007; Mamatha *et al.*, 2006). Miranda *et al*. (2002) reported that topical application of methoprene (a Juvenile Hormone Analog) prolonged larval period and caused an increase in the weight of silk gland and cocoon of *B. mori*. Further, Thyagaraja *et al.,* (1991) reported that thyroxine fed to *B. mori* larvae resulted in increased cocoon shell weight up to 150% in some cases with no loss in silk quality. Ahmad *et al.* (2007) reported that the application of thyroxine to *B. mori* larvae increased the ecdysteroid titer 33.34% higher than control; higher titer of ecdysteroid presumably would promote larval growth, as well as sericin and fibroin protein synthesis (Thagaraja *et al.,* 1991). In addition, it is known that nutrition plays a major role in improving the growth and development of *B. mori*, and the nutritive values of mulberry leaves vary by mulberry varieties (Kanafi *et al.,* 2007)

In recent years, many attempts in research have been made to improve the quality and quantity of silk (Hiware and Ambedkar, 2005), through enhancing the leaves with nutrients, spraying with antibiotics, juvenile hormone, plant products, with JH-mimic principles or using extracts of plants. Mulberry leaves have been supplemented with various nutrients for silkworm feeding to promote silk quality and quantity. The supplementation and fortification of mulberry leaves is a recent technique in sericulture research (Murugan *et. al.*, 1998). It has been reported that the vitamins of B-complex group and certain essential sugars, proteins, amino acids, minerals etc. are responsible for the proper growth and development of the silkworm, *B. mori* (Faruki, 1998).

Fortification of mulberry leaves by using supplementary nutrient and feeding to the silkworms is a useful modern technique to increase economic value of cocoon (Kumararaj et al. 1972). Supplementation with vitamin B increased the resistance against poor environmental conditions and increased body weight in silkworm (Das and Medda, 1998). Further it has been reported that supplementation of mulberry leaves with Vitamin B12 could increase the synthesis of nucleic acids and protein in the silk gland of silkworm (Das and Medda, 1998). A number of researchers have worked on the effects of vitamin-enriched food on the reproduction of *B. mori* females (Faruki *et al*., 1992; Saha and Khan, 1999).

From time to time, JHAs are being introduced into the market and many investigators have worked out their mode of action and efficacy in promoting the quality and quantity of cocoons (Asano *et al.*, 1986; Kamimura and Kiuchi, 1998; Bharathi and Yungen, 2000; Yungen and Bharathi, 2001). JHA compounds improve the overall biomass of *B. mori* larvae and these events might be responsible for improved silk quality and quantity (Mamatha *et al.,* 2006).

Currently, advanced research is focusing on genetics of silkworms and genetic engineering. Many hundreds of strains are maintained, and over 400 Mendalian mutations have been described (Goldsmith *et al.* 2004). One useful mutant for the silk industry confers the ability to feed on food besides mulberry leaves, including an artificial diet (Goldsmith *et al.* 2004). The genome has been sequenced (Mita *et al.* 2004), and many projects have worked on genetic engineering of silkworms to produce desirable proteins in the place of silk. Such proteins include human drugs (Grimaldi and Engel 2005). Biotechnological methods have also been developed for the detection of young silkworm diseases, which are being tested in the field for adoption (Nataraju *et al.,* 1994).

These studies indicate that it is necessary to carry out similar studies locally to enable for the improvement of certain practical aspects like silkworm rearing and mounting; and contribute to the production of quality cocoons and subsequently silk fibre and fabric. This will also enable for Kenyan silk to compete internationally and regionally in the silk market.

# CHAPTER THREE

# GENERAL MATERIALS AND METHODS

## 3.0 INTRODUCTION

In this chapter, methodological procedures used in this study to assess the quality of silk fibre and fabric of *B. mori* silkworms are outlined. The chapter focuses on:

- Research Design
- Study Location
- Sample Population
- Data Collection Procedures
- Data Analysis

## 3.1 Research Design

This study employed the experimental design (Ostle and Malone, 1988). The experimental design employs the (statistical) design of experiments (*DOE*), which is an efficient procedure for planning experiments so that the data obtained can be analyzed to yield valid and objective conclusions (Fig 3.1). Three basic principles were applied replication, randomization and local control. Three replications were done for the experiments mounted. Experiments were set up to establish silk fibre and fabric properties and quality assessment. In addition, observations were made on various aspects of silkworm larval development. The silkworm rearing was done during two seasons, the long rains (LR) and short rains (SR).

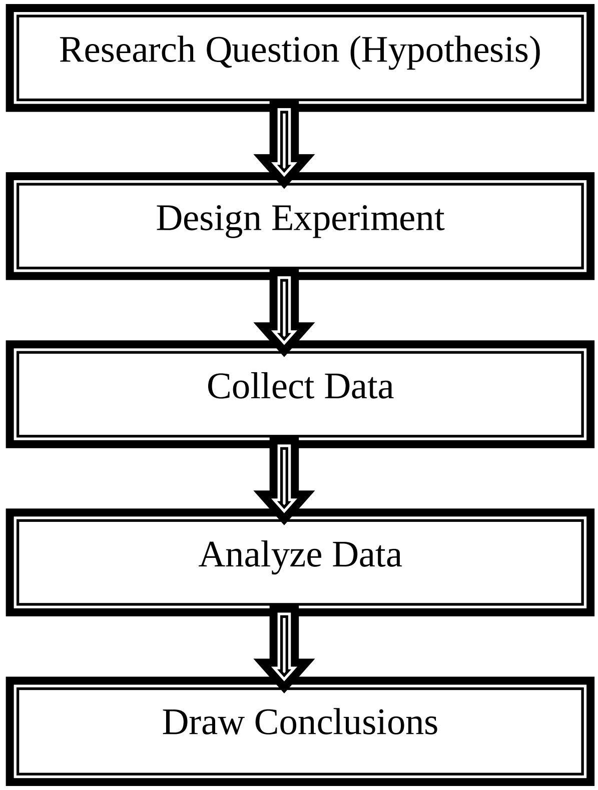



**Fig 3.1 Experimental Design Process**

### 3.2 Study Location

*icipe* Duduville Campus in Kasarani, Nairobi and the Kenya Bureau of Standards (Kebs), Nairobi were identified for the execution of this study. Nairobi is located between $1^{o}$ 18'S and $36^{o}$ 49'E, with an altitude of 1798m above sea level. These two research centres were selected as they had the facilities to carry out the necessary experiments efficiently, making them the most suitable for this research study.

At Duduville, facilities for silkworm egg production, silkworm rearing, silk fibre processing, fabric production and silk fibre quality testing were available. Further, two experimental locations in *icipe* were identified for the research. The Commercial Insects

Programme (CIP) grainage laboratories (S1), for the control sample, where conditions could be monitored and maintained at optimum, and the CIP farm (S2), for the experimental sample, where the conditions were comparable to those found in the field.

Kebs had the necessary laboratories and facilities for testing silk fibre and fabric. There were standard procedures available, with which the silk fibre and fabric quality were tested. These results made it possible for comparison purposes and evaluation of the silkworm strains.

## 3.3 Sample Population

Six bivoltine silkworm strains were reared in this study: - (C X Z), (Q X B), (Q X H), 75xin X 7532, (S X M) and ICIPE I (Appendix 1). Previous studies have shown that bivoltine silkworm *B. mori* have a high productivity rate (Tzenov *et al.,* 1999). One disease free egg laying (dfl) (≈500 eggs) of each strain was raised per rearing. Three replications were done in total, and gave sufficient comparative results and produced enough cocoons for further experimental purposes and quality testing.

## 3.4 Data Collection Procedures

### 3.4.1 Grainage and silkworm rearing

The setting of the grainage was done with specifications from the Sericultural Research Institute in China (Long, 2001). Rearing of all the silkworms was done following the procedures of Jolly, 1987; Ullal and Narasimhanna, 1987).

Silkworms in *S1* were reared under standard conditions 26 ± 2°C, 70± 5% RH and 12:12 (L:D) photoperiod, according to Raina (2000), Aruga, (1994), Lim *et al*., (1990) and Pang-chuan *et al.*,(1988). Rearing was done in trays measuring 90 x 60cm, placed on rearing racks, 150 x 75 x 200cm that could hold 24 trays each. The silkworm larvae were reared in these trays from their first instar to the fourth. At the onset of the fifth instar, 100 worms of each strain were randomly selected and monitored individually. They were placed in trays that were partitioned into small compartments that hold individual larvae, measuring 10cm by 10cm and reared under these same conditions (Plate 3.1).

**Plate 3.1 Individual Rearing of 5$^{th}$ Instar Silkworm in Location *S1***

Location *S2* was a demonstration site with facilities similar to those that would be available to the silk farmer. Temperature and humidity in the room ranged between 24 -

27 $^{O}$C and 84% - 86% respectively for young age rearing and 23 – 24 $^{O}$C and 65% - 70% respectively for late age rearing and 12:12 (L:D) photoperiod. Rearing was done in a three-tier shoot rearing rack measuring 15’ X 5’ X 8’ that accommodates up to 15,000 worms. In the fifth instar, 100 larvae of each strain were selected randomly, placed individually in permeable paper pockets, measuring 9 X 5.7 X 17.5cm, which were numbered and arranged on the rearing bed for individual monitoring and the larvae were reared under these same conditions (Plate 3.2).

**Plate 3.2 Individual Rearing of 5$^{th}$ Instar Silkworm in Location *S2***

Duration of the silkworm larval stage was noted for all the strains, mortality during each larval instar was observed and recorded and where possible, the causes were identified. Feeding was done three to four times a day as required during each larval stage. The selected larvae, which were reared individually, were weighed every day during their fifth instar stage.

### 3.4.2 *B. mori* silkworm food consumption

Mulberry leaves, which form the only feed for the silkworm larvae (Mitsuo *et al.*, 2005, Devaiah and Reddy, 1999; Miyashita, 1986), were used. The Kanva 2 variety was used for this study. These were harvested from the CIP's mulberry farm at *icipe*. For young-age rearing (first to third instar) only tender nutritious leaves were used. These were collected from the top portion of the plant and sufficiently nourished the larvae. It was ensured that the leaf quality was high and free of diseases, as this could affect growth at a later stage. For late-age rearing (fourth and fifth instar), mature mulberry leaves were used (Minamizwa, 1997).

Fifth instar silkworms in *S1* and *S2*, which were reared in isolation, were monitored on a daily basis. The larvae, faecal matter, fresh feed and unconsumed mulberry were weighed daily and recorded. A comparison of the average larval weight (LW) and average weight of the consumed food (CF) from the two locations (S1 & S2) was done. Weight of the CF was calculated as a percentage of the average LW to verify the relationship between larval weight and amount of food consumed.

Mulberry ingested by the silkworm is digested in the alimentary canal and then absorbed into the body. The amount of food not digested is discharged as faecal matter. By subtracting the amount of faeces from the mulberry leaves consumed, the amount of food ingested was estimated (Aruga, 1994).

### 3.4.3 Cocoon sorting

#### 3.4.3.1 Cocoon weight and size

Freshly spun cocoons from the two rearing sites were each randomly selected from the mountages for this study. Cocoons from each strain and location were separated. They were then numbered and weighed individually on a Kindletec electronic balance model BB 300. The length of the cocoon was also taken and comparisons were made for the different strains reared in the two locations. Cocoons from each respective strain and location were then divided into two lots ($L_i$ and $L_{ii}$). These were then used for the subsequent studies.

#### 3.4.3.2 Cocoon layer weight and layer ratio percentage

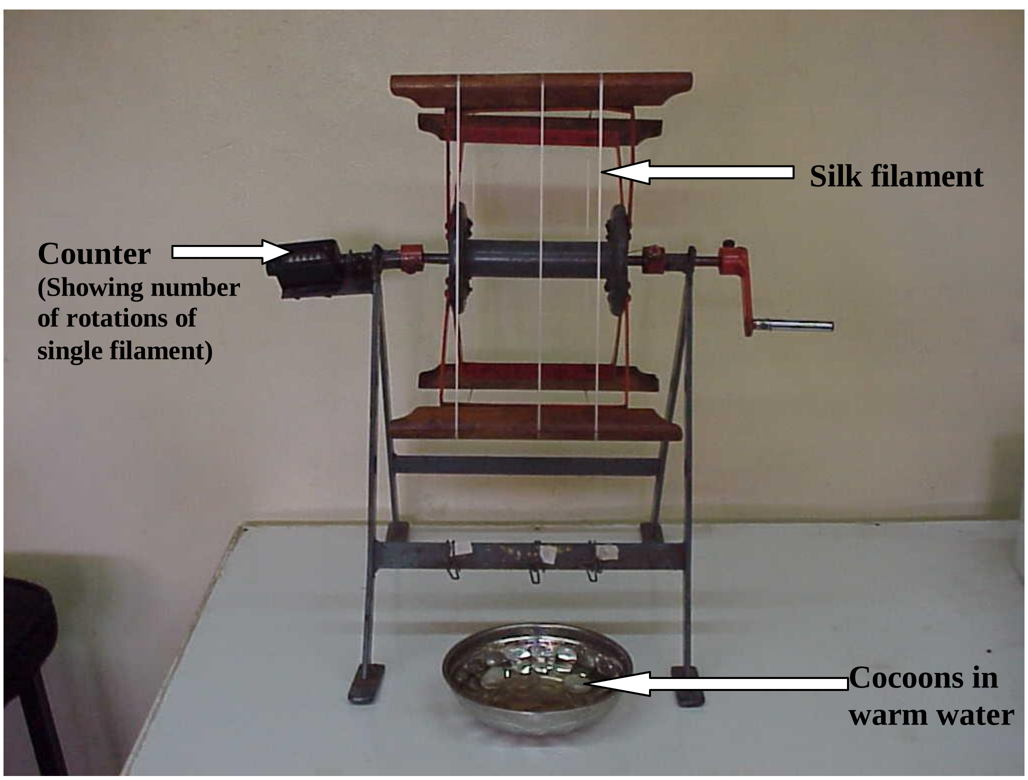
Lot $L_i$ cocoons of the different strains from the two locations were used for this parameter. They were cut open using a blade to release the pupa and the moulted skin then weighed. Weighing the cocoon shell realized the cocoon layer weight. It could also be obtained by subtracting the weight of the pupa and moulted skin from the total cocoon wet weight. The cocoon layer weight was divided by the total cocoon weight and multiplied by 100 to obtain the cocoon layer ratio as a percentage.

### 3.4.3.3 Length of the cocoon fibre (bave*)*

An epprouvette (RK Industries, India), which is a single silk cocoon reeling device fixed with a counter to measure the length of filaments per cocoon, was used to get the length of single cocoons (Plate 3.3). Lot $L_{ii}$ cocoons of the different strains from the two locations were used for this parameter. The cocoon was placed in boiling water for 5 minutes and the filament end found. This was attached to a hook on the epprouvette and the filament was reeled. An indicator counted the rotation counts and the following formula was used to calculate the filament length in meters.

***FL in meters = Number of rotations X 1.14***

**Plate 3.3 Epprouvette for single filament reeling**



#### 3.4.3.4 Thickness of cocoon fibre (Size of bave)

The thickness of the cocoon fibre was expressed in units of denier, one denier means 0.05g of fibre for a length of 450m obtained by 400 rotations per cocoon reeling. This was calculated using the following formula:

$$\textit{Size of bave} = \frac{\textit{weight of fibre (g)}}{\textit{Length of fibre (Number of rotations)}} \times \frac{400}{0.05\ (g)}$$

### 3.4.4 Cocoon processing

#### 3.4.4.1 Cocoon stifling

Cocoons of the silkworm strains were sorted and a two pan-cooking device was used to boil them (Fig 3.2).

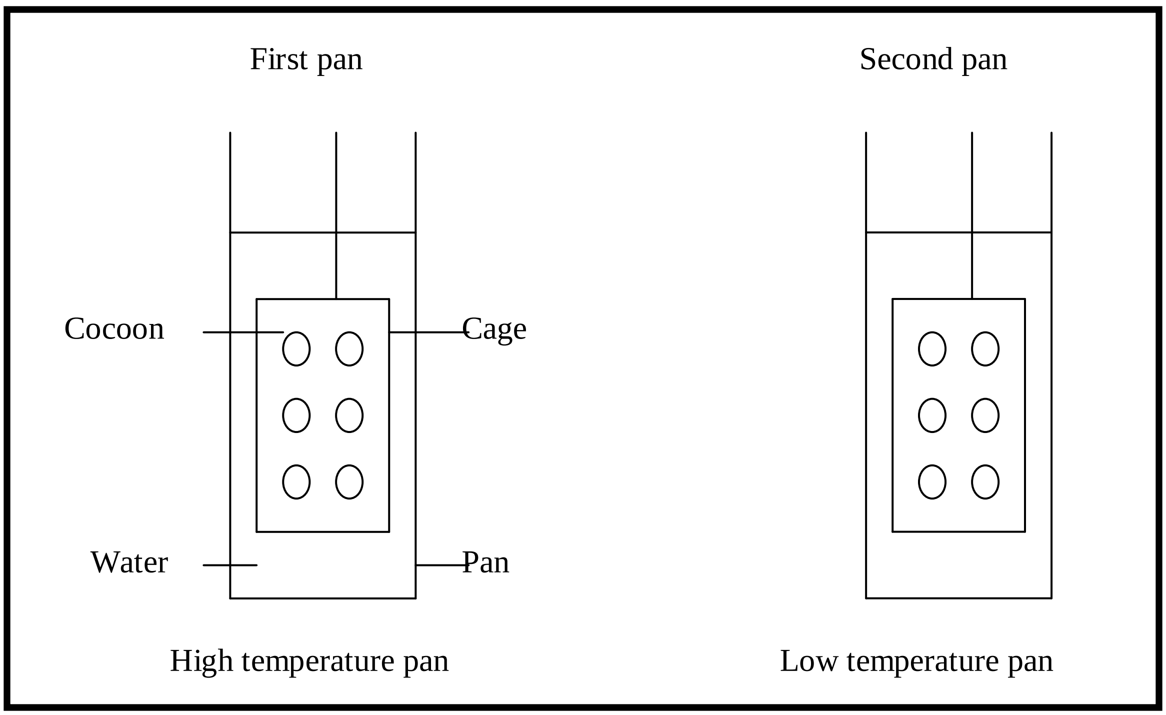



**Fig 3.2. Two pan cooking device**

Operations order was done as indicated in Table 3.1 below.

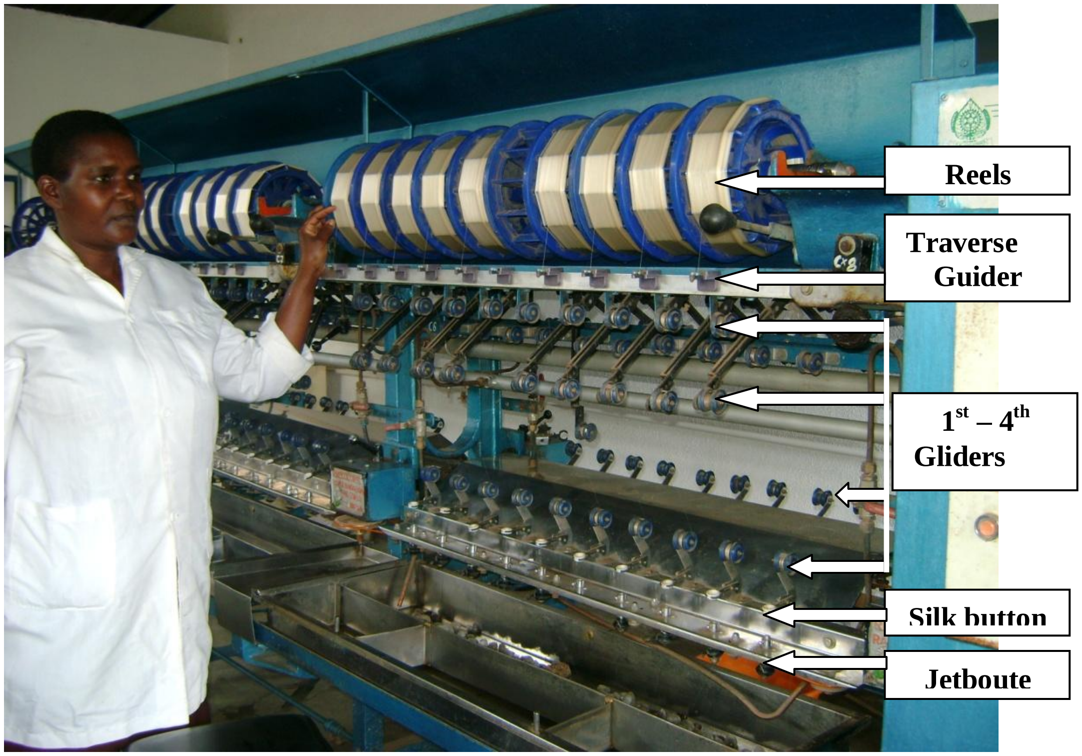
**Table 3.1: Cocoon cooking operations order**

| Operation order of cocoon cooking | Pan | Temp | Time |
|---|---|---|---|
| Low Temperature soaking | 2nd | 60°C | 1min |
| High Temperature permeation | 1st | 90 ~ 95°C | 1min |
| Low Temperature permeation | 2nd | 60 ~ 65°C | 1min |
| Cooking | 1st | 95°C | 3-4min |
| Adjusting | 1st | 95 > 50°C (gradually) | 3-4min |

**3.4.4.2 Reeling and throwing of silk**

Silk reeling is the process by which a number of cocoon baves are reeled together to produce a single thread. Reeling was then done immediately after the cocoon cooking, on a multi-end reeling machine, at a speed of 80~120m/min (Naik and Somashekar, 2005) (Plate 3.4). The direct method was used, and this was achieved by reeling a fixed number of cocoons (FN reeling). The resulting filaments were collectively wound onto a fast moving reel.

**Plate 3.4 *B. mori* silk reeling on a multi-end reeling machine**




The cooked cocoons contained in the tubs were carried into the groping ends portion of the reeling machine, and moved into the picking ends apparatus. After correctly processing, the cocoons were taken to a standby bath for cocoon feeding. They were picked up by the reeler and fed to the reeling thread. During this step 12 and 16 cocoons for the warp and weft respectively, were used. The normal speed of cocoon feeding by a skilled reeler is around 16 times per minute. The thread passes through the jetboute, silk button, first guider, second guider, third guider, fourth guider and traverse guider, in that order and then is wound onto the small reels.

The cocoons dropped during the reeling process are gathered and reprocessed starting from the groping end section. The croissure of reeling thread is made between second guider and third guider, and the length of croissure is not for twisting of thread but for cohesion of thread by rubbing of composed filament. Raw silk of 24 and 32 denier for the warp and weft respectively was produced.

The raw silk was then further subjected to the throwing process, in which the silk strands were twisted together, doubled with other silk strands and twisted again, to form a thicker, stronger, multi-threaded yarn. This was done on the winding, twisting and doubling units (Plates 3.5 – 3.7). Once the silk yarn was ready, tests were performed to certify their characteristics, performance and quality.

**Plate 3.5 Silk Winding Unit**

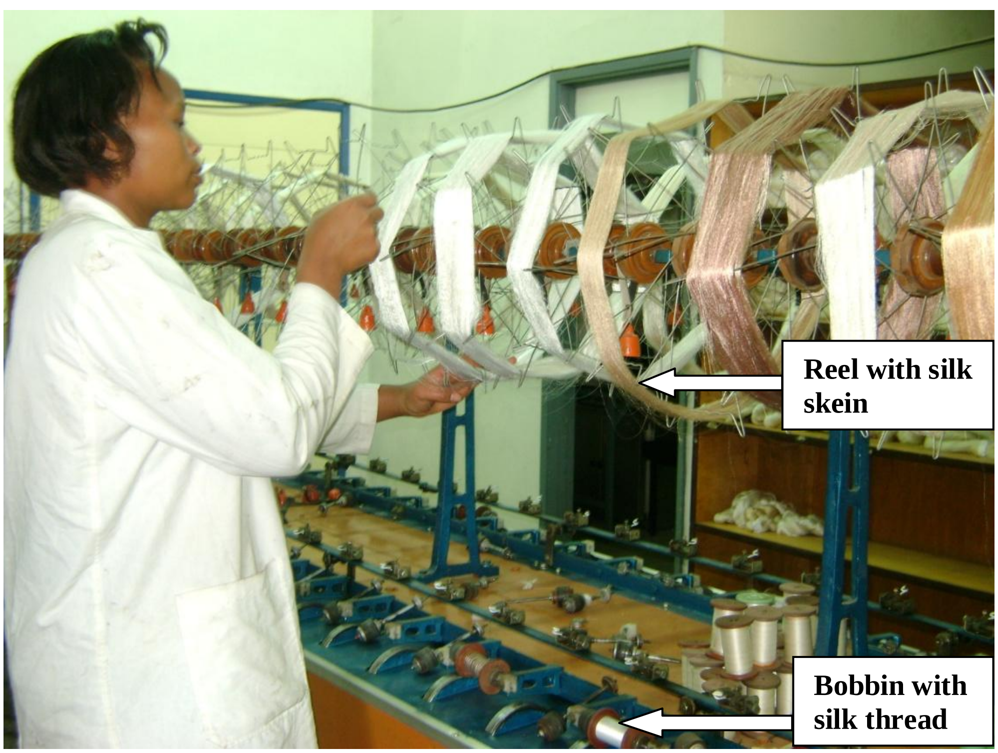


**Plate 3.6 Silk Twisting Unit**

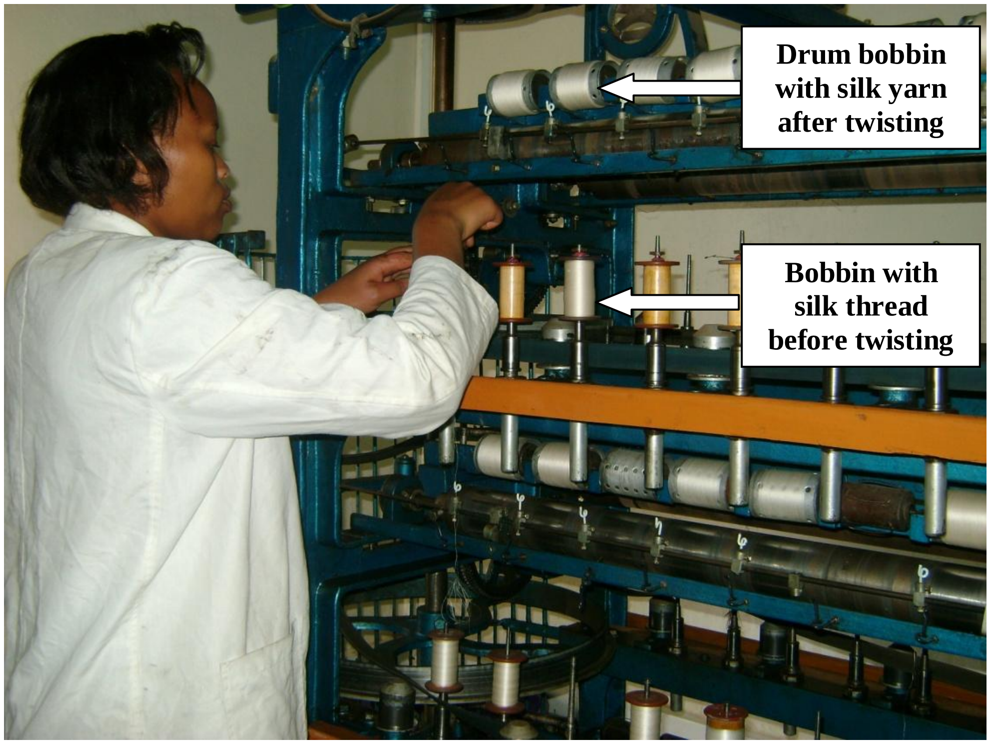



**Plate 3.7 Silk Doubling/Tripling Unit**

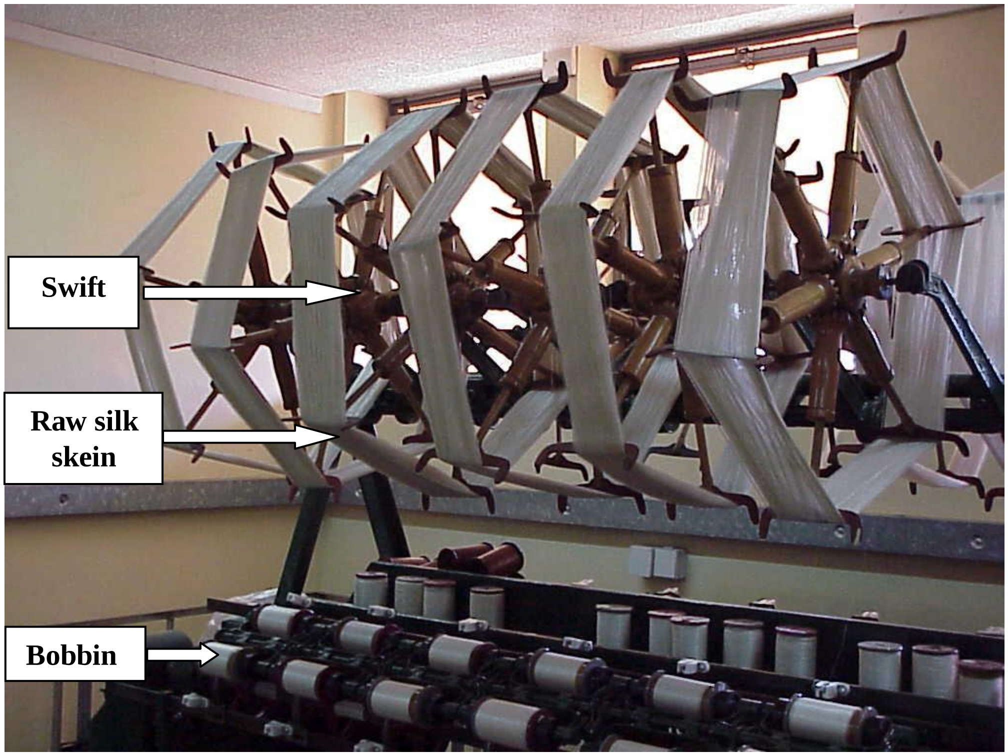
### 3.4.5 Raw silk quality testing

Quality control has been found to be the most effective measure to maintain the requisite quality and quantity of any textile product either in yarn or fabric stage. The following tests were carried out on the silk yarn.

#### 3.4.5.1 Winding breaks

In this test, the silk was tested for its winding performance. When breaks occur during winding it is necessary to note the cause of each break. Sample silk skeins were picked randomly from each strain and tested for the winding breaks. The sample skeins were fitted onto the winding frame and the end attached to a bobbin (Plate 3.8). Only the top half of the sample skein was wound, when the winding was started. Winding was carried out at a predetermined speed for a specific duration. This was adjusted according to the denier of the raw silk being tested (Appendix 2). The number of breaks that occurred were counted and noted. The cause of each break was noted and recorded

**Plate 3.8 Winding breaks unit**




### 3.4.5.2 Tenacity and Elongation percentage

The apparatus for the tenacity test and degree of elongation consisted of a serigraph (Fig 3.9 a), a tensile strength tester with an automatic attachment simultaneously recording the force and elongation of the silk. A sizing reel of 1.125m in circumference (400 revolutions equal to 450m) and a constant speed of 300 revolutions per minute were used to prepare the test sample. The sample skeins were conditioned in a room maintained at a standard temperature of $20^{O}$C and relative humidity of 65%.

**Plate 3.9 a Serigraph**


The clamp distance on the serigraph was 10cm and the extension speed 15cm per min. The sample skeins were mounted on the serigraph and testing done (Fig 3.9 b and c). The tenacity and elongation were recorded; elongation was expressed as a percentage of the total stretch of the portion tested, while tenacity was expressed in grams per denier using the following formula:

$$\textit{Tenacity in grams per denier} = \frac{Z}{n \times d}$$

**Z = Breaking load in grams of test skein**

**n = Number of strand tensioned**

**d = Denier of test skein**

**Plate 3.9 b Sample before tenacity test**

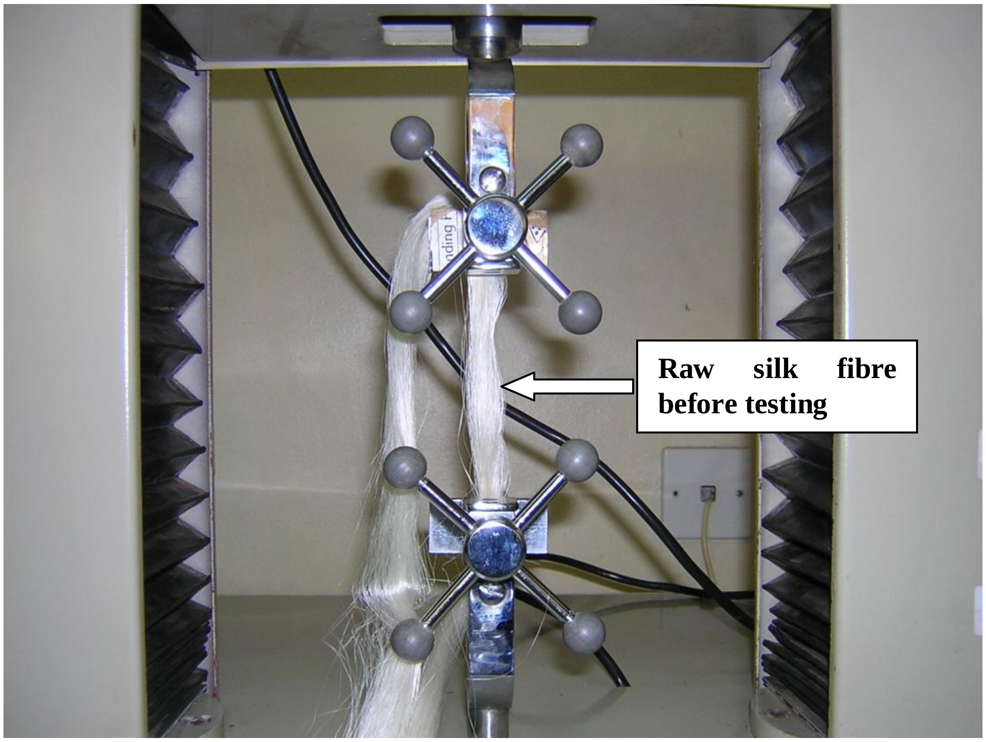
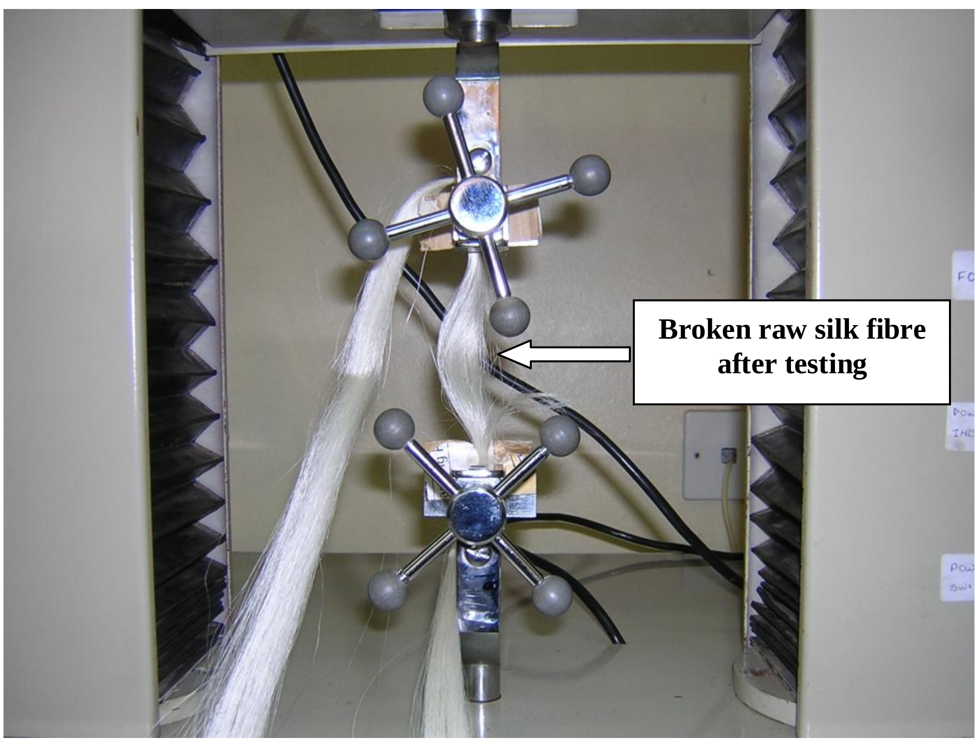


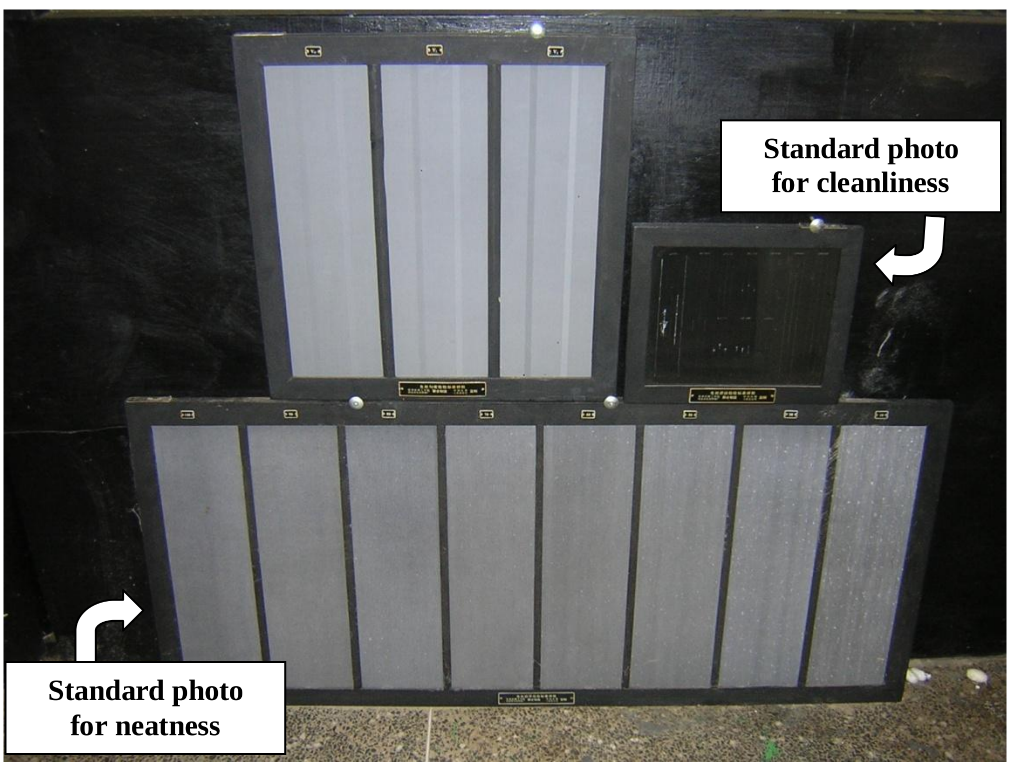

**Plate 3.9 c Sample after tenacity test**



**3.4.5.3 Cleanliness Testing**

This test is carried out to determine imperfections in the silk filament. Cleanliness defects were classified as super major defects, major defects and minor defects. Samples were drawn randomly and compared with the ISA standard photos (Plate 3.10). The cleanliness inspection was done from a position of 0.5metres (2 feet) directly infront of the seriboard inspection panels. The actual number of cleanliness defects of each class and kind were counted on the yarns on both sides of the inspection panel, omitting the parts on its edge. The kind and class to which each defect belongs was determined by comparing it with the standard photographs for cleanliness defects. Each defect carries penalty points and the difference of the total penalty points from 100 gives the test results.

**Plate 3.10 Standard photos for cleanliness and neatness in an inspection dark room**



### 3.4.5.4 Neatness test

These are imperfections in silk yarn, which are smaller than minor cleanliness defects. The inspector conducted this test from a distance of 0.5 metres (2 feet), directly infront of the inspection panels. 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. From 100 to 50 percent the estimate was made to the nearest 5 percent, while below 50 percent the estimate was made to the nearest 10 percent. The estimated neatness percentage of each panel (average neatness percentage of a total of one hundred panels), and the low neatness percentage represented by the average percentage of the low panels, (on fifth of all panels examined).

### 3.4.6 Fabric performance and testing

Silk textile samples from the six silkworm strains where subjected to various quality tests to ascertain their characteristics and quality. The following tests were carried out on the silk fabrics.

### 3.4.6.1 Fabric Count

This determination measures the number of yarns per linear inch (ends per inch or *sley*) and number of filling yarns per linear inch (picks per inch or *shot*) in a woven fabric. The textile samples were selected at random and examined with a one-inch counting glass (calibrated square magnifying glass). The glass is marked off in fractions of an inch or in centimeters, and the number of warp and filling yarns beside these calibrations can be viewed in magnified form with the glass and counted (ASTM 1424, 1944). The glass was lined up along a lengthwise yarn and a crosswise yarn. The yarns in that direction were counted and the count expressed as a whole number of warps and by a whole number of fillings.

### 3.4.6.2 Mass per unit area

Five samples of 15cm by 15cm each were prepared and conditioned to the atmosphere for testing textiles (KS 08 – 32, 1977) until they were in equilibrium with that atmosphere. A square metal plate measuring 10cm by 10cm was placed over the specimen as a guide to cut it. The resulting specimens were weighed using a precision balance to an accuracy of ± 0.001g. The mass was then calculated using the following formula and the results rounded off to the nearest gram (KS 08 – 120, 1981).

$$Mua = M \times 100$$

**Mua:** **Mass per unit area in grams per square metre of the fabric after conditioning in the standard atmosphere for testing.**

**M:** **Mass in grams of the specimen**

### 3.4.6.3 Fabric Strength

Fabric strength evaluations were made in terms of breaking load and tearing strength. The textile samples were prepared and conditions at 20$^{O}$C and relative humidity of 65% (KS 08 – 32, 1977).

### 3.4.6.3.1 Determination of breaking load and elongation

The breaking load refers to the maximum load (or force) supported by a specimen in a tensile test carried to rapture (KS08 – 119, 1981). Ten sample pieces of 350mm X 60mm were prepared for this test. Five samples were prepared with warp yarns running in the direction of stress and the other half with the stress in the filling direction. The samples were then frayed on the sides to ensure the width was 50mm. The specimens were mounted on the serigraph machine such that the longitudinal axis of the specimen was at right angle to the edge of the clamps after pre-tensioning. The tension was equal to 1 $\pm$ 0.25% of the probable breaking load. The average breaking time was 20 $\pm$ 3secs (KS 08 – 119, 1981). Average breaking strength in each direction was calculated by dividing the sum of observed values of breaking load in Newton (N) by the number of observations.

### 3.4.6.3.2 Tear Resistance

Tear testing measures the force required to continue the tearing of an initial cut. Average force required to continue a tear in a fabric was determined by measuring the work done in tearing it through a fixed distance. A representative sample was taken; five samples warp-wise and the other five weft-wise. Individual samples were punched by a cutting die as shown in (Plate 3.11).

They were conditioned in accordance with KS 08 – 32, 1977. These samples were clamped onto an ELM Series Elmendorf tear tester (Plate 3.12) and the pendulum raised to the starting point and the pointer set against its stop. A slit approximately 20mm was started on the sample specimen leaving 43.0 $\pm$ 0.15mm of fabric to be torn. The pendulum stop was depressed, releasing the pendulum (Plate 3.13). The stop was held till the tear was completed and the pendulum was caught on its return wing by the hand without disturbing the position of the pointer. The scale was read to the nearest whole scale division for the capacity used (KS 08 – 437, 1981; ASTM 1424, 1944). The tester capacity was in three ranges: 0 – 1600g, 0 – 3200g and 6400g. The two higher ranges were obtained by additional weights on the pendulum.

Average force was thus calculated as follows:

**N = kg f X 9.81**

**N: Force in Newton**

**Plate 3.11 Tear resistance sample as punched by a cutting die**

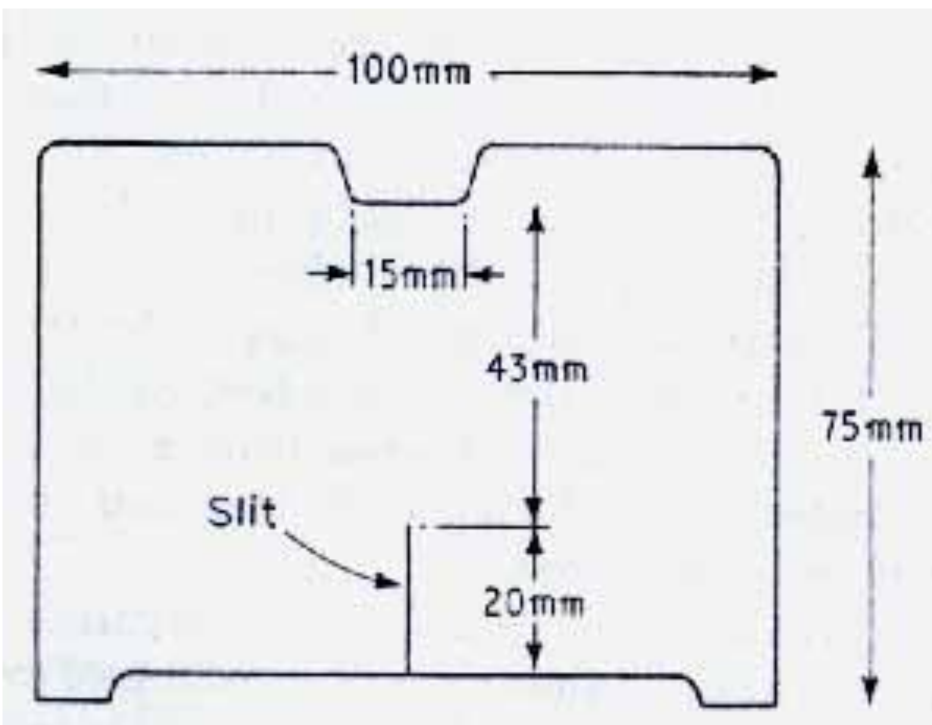
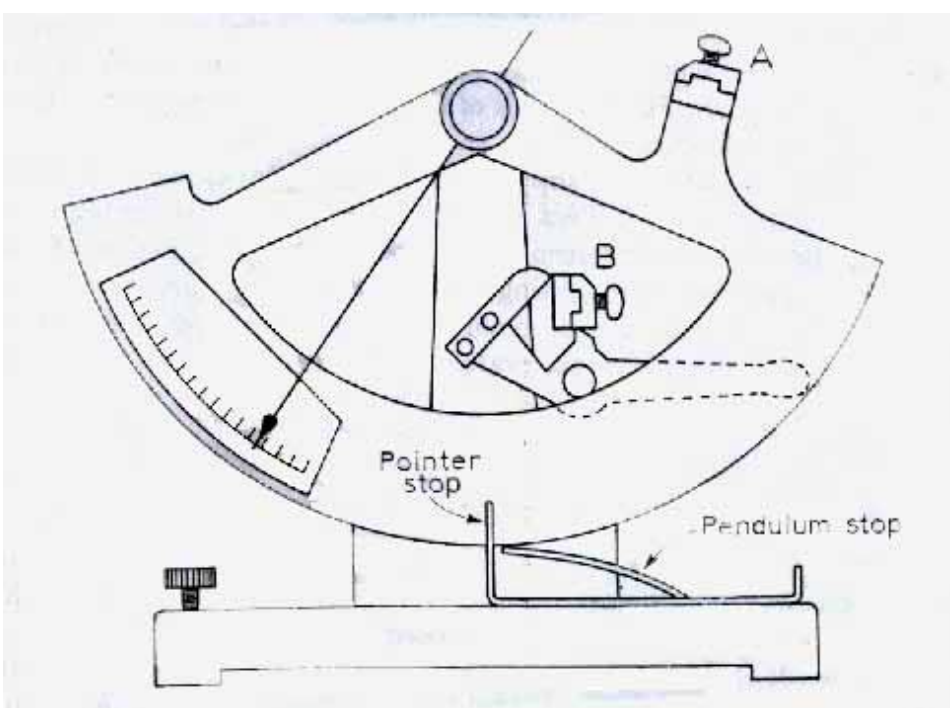


**Plate 3.12 Elmendorf Tear Tester**

**Plate 3.13 Schematic illustration of the Elmendorf Tearing Tester**



### 3.5 Data Analysis

T-test and ANOVA (SAS, 2003) were used to compare the mean biological parameters of the six silkworm strains reared in two locations during two seasons. An analysis of variance with GLM procedure statistical analysis system (SAS Institute, 2000) was used to determine the significant differences. The parameters were analysed according to silkworm strains, seasons and locations. Larval duration, mortality, cocoon, pupa and shell weight, cocoon thickness and size were analysed according to strains, locations and seasons. Data comparison among strains; Chun Lei X Zen Zhu (C X Z), Quifeng X Baiyu (Q X B), Quingsong X Haoyoe (Q X H), 75xin X 7532 (75xin), Suju X Minghu (S X M) and ICIPE I, seasons (LR and SR) and locations (S1 and S2) was done using independent T – test. In each experiment, at least thirty observations were considered for analysis.

Results have been presented in tables and graphical modes to show comparative analysis among strains, locations and seasons of filament length, raw silk winding breaks, cleanliness, neatness and elongation; and silk fabric count, mass, tears resistance and breaking load. The International Silk Association classification (ISA) standards were used for the raw silk quality analysis and Kebs procedures were used for the silk fabric examination.

# CHAPTER FOUR

# RESULTS, DATA PRESENTATION AND DISCUSSION

## 4.0 Introduction

The main purpose of this study was to determine the silkworm cocoon properties and evaluate the qualities of raw silk fibre and fabric produced by the bivoltine *B. mori* silkworms. The study, also sort to test three hypotheses; there is a relationship between cocoon production and raw silk fibre qualities; there is a relationship between silk processing and silk fabric qualities; and there is a relationship between silkworm performance and silk cocoon properties. In order to perform the above, the following bivoltine *B. mori* silkworm strains were reared Chun-Lei X ZhengZhu (C X Z), QuiFeng X BaiYu (Q X B), Quingsong X Haoyoe (Q X H), 75xin X 7532, Suju X Minghu (S X M) and ICIPE I. This chapter discusses the results of tests performed on silkworm cocoons; fibre and fabric produced by these strains to establish their qualities, as well as examines the larval performance of the six silkworm strains.

## 4.1 *B. mori* Silkworm Cocoon Qualities and Properties

The objective was to evaluate the performance of the cocoons of the selected strains and determine their suitability for quality raw silk fibre production. This study aimed at investigating the cocoon qualities of the different strains reared and evaluate their potential for silk production. The relationship between cocoon weight and size and cocoon shell percentage to silk filament length was also determined.

### 4.1.1 Cocoon weight and size

Results indicate that ICIPE I strain had the highest cocoon weight and size. A mean cocoon weight of 2.23 ± 0.015 and 2.18 ± 0.015gms and size of 3.58 ± 0.019 and 3.40 ± 0.017cm was achieved by ICIPE I, in the two locations, S1 and S2, respectively. On the other hand, 75xin had the least cocoon weight of 1.85 ± 0.018 and 1.81 ± 0.018gms and size of 3.03 ± 0.020 and 2.96 ±0.022cm respectively. It was noted that the location affected the cocoon weight significantly for all the silkworm strains apart from ICIPE I as shown in Table 4.1a.

In this study, cocoon size ranged between 3.58 – 3.03cm and 3.27 - 2.96cm in locations S1 and S2 respectively. In addition, it was noted that cocoons reared in S1 were larger in size than those reared in S2; however there was no significant difference. The study also established that rearing location had no effect on the cocoon size across the strains as indicated in Table 4.1a.

**Table 4.1a Comparison of mean cocoon weight and size of the different silkworm strains in the S1 and S2**

| | | **Cocoon Weight** | | **Cocoon Size** |
|---|---|---|---|---|
| **Strain** | **Location** | **Mean ± S.E (gms)** | **P<0.05** | **Mean ± S.E (cm)** |
| 75xin | S1 | 1.85 ± 0.018 | 0.106 * | 3.03 ± 0.020 |
| | S2 | 1.81 ± 0.018 | | 2.96 ± 0.022 |
| C X Z | S1 | 2.08 ± 0.015 | 0.228* | 3.39 ± 0.016 |
| | S2 | 2.05 ± 0.017 | | 3.27 ± 0.019 |
| ICIPE I | S1 | 2.23 ± 0.015 | 0.011 | 3.58 ± 0.019 |
| | S2 | 2.18 ± 0.015 | | 3.40 ± 0.017 |
| Q X B | S1 | 1.93 ± 0.019 | 0.101* | 3.05 ± 0.023 |
| | S2 | 1.89 ± 0.016 | | 2.96 ± 0.019 |
| Q X H | S1 | 2.00 ± 0.015 | 0.001 | 3.10 ± 0.020 |
| | S2 | 1.91 ± 0.015 | | 2.99 ± 0.020 |
| S X M | S1 | 2.01 ± 0.016 | 0.029 | 3.18 ± 0.018 |
| | S2 | 1.96 ± 0.019 | | 3.07 ± 0.019 |

*Significant at 5% SE± - Standard Error.

Results of cocoons reared during the two seasons, LR and SR, demonstrate the same trend as those reared in the two locations. ICIPE I had the highest average cocoon weight of 2.30 ± 0.012 and 2.11 ± 0.013gms during LR and SR respectively, and cocoon size of 3.57 ± 0.015 and 3.41 ± 0.022cm in the same seasons respectively. 75xin on the other hand had the least weight and size during the two seasons. The study further found that there was significant difference in the cocoon weight and no significant difference in the size during the two seasons (Table 4.1b).

**Table 4.1 b Comparison of mean cocoon weight and size of the different silkworm strains during LR and SR.**

| Strain | Season | C. W Mean ± S.E (gms) | P<0.05 | C.S Mean ± S.E (cm) |
|---|---|---|---|---|
| 75xin | LR | 1.91 ± 0.016 | 0.101* | 3.08 ± 0.015 |
| | SR | 1.75 ± 0.017 | | 2.09 ± 0.022 |
| C X Z | LR | 2.17 ± 0.012 | 0.101* | 3.41 ± 0.012 |
| | SR | 1.96 ± 0.014 | | 3.24 ± 0.002 |
| ICIPE I | LR | 2.30 ± 0.012 | 0.103* | 3.57 ± 0.015 |
| | SR | 2.11 ± 0.013 | | 3.41 ± 0.022 |
| Q X B | LR | 1.98 ± 0.014 | 0.106* | 3.08 ± 0.014 |
| | SR | 1.84 ± 0.018 | | 2.93 ± 0.025 |
| Q X H | LR | 2.02 ± 0.011 | 0.201* | 3.11 ± 0.013 |
| | SR | 1.89 ± 0.017 | | 2.99 ± 0.025 |
| S X M | LR | 2.10 ± 0.012 | 0.106* | 3.22 ± 0.012 |
| | SR | 1.87 ± 0.016 | | 3.04 ± 0.021 |

*Significant at 5% SE± - Standard Error. CW- Cocoon Weight; CS - Cocoon Shell

The difference in the cocoon weight among the strains, which were reared in similar environmental conditions in this study concur with Aruga's (1994) findings, where he reported that cocoon weight varies among different silkworm strains. This also relates to a study done by Zanatta *et al.,* (2009), where they demonstrated that strains of the same origin can have different biological and development performance resulting in cocoon weight variations.

Shekharappa *et al.,* (1993) and Hirobe, (1968), in their study noted that cocoon weight is affected by ecological conditions. Similarly, Huang *et al.,* (2008) noted that cocoon formation varies with temperature, humidity and other environmental conditions. This relates to the findings of this study, where the different environmental rearing conditions in the two locations played a significant role in the varying cocoon weight. Other significant factors that may have caused these differences include nourishment of the silkworms. Rahmathulla *et al.,* (2007), on the other hand notes that when silkworms are poorly nourished it affects the larval development and cocoon weight is low.

The findings of the cocoon sizes in this study relate to Zanatta *et al.,* (2009) study, where the average cocoon size was 2.8 – 3.7cm. Aruga (1994) notes the size of the cocoon varies with the strain of the silkworm. Even among cocoons of the same strains, depending on the conditions of rearing they influence the rate of larval growth, ultimately affecting the cocoon size.

The different environmental conditions subjected to the silkworm larvae during the two seasons (LR and SR) may have had a direct bearing on the silkworm development and consequently caused variation in the cocoon weight amongst the strains. This concurs with Aruga (1994) who notes that the cocoon weight varies considerably depending on the external conditions. It is important to note that various studies have emphasized the importance of optimum environmental conditions during rearing. Yokoyama (1962) reported that *B. mori* yields superior quality cocoons at optimum temperatures (22-23°C) and humidity (60-70%), whereas Krishnaswami *et al.* (1973) stressed the requirement of an optimum environment for maximum productivity of good quality cocoons and comparatively drier atmosphere (60-70%RH) during spinning for better cocoon yield with *B. mori.*

In related studies, Arunga (1994) notes that one could extend or delay the mounting process by raising or lowering temperature in the rearing units. The duration of mounting becomes shorter as the temperature during mounting becomes higher. However extreme high temperatures and extreme low temperatures may be harmful to the cocoon spinning process. If the temperature becomes too high, the cocoon shell becomes very loose and folded with wrinkles and knots. On the other hand, if the temperature is too low, the larvae will excrete the silk bave slowly, the cocoon will be large, and the spinning will take longer (Pang Chuan et al., 1988).

Total cocoon weight is composed of the cocoon shell, the pupa and moulted skin. For good silk cocoon harvest some factors need to be adhered to. At the outset it is important for humidity during late age rearing not to go beyond 70% (Raina 2000). It is also imperative for ventilation during spinning (Aruga 1994; Lim *et al*., 1990; Krishnaswami *et al*., 1973). This study verified that cocoon weight differed among the six silkworm strains reared despite the similar conditions. ICIPE I had the highest cocoon weight in S1 and S2 as well as during LR and SR.

Lee, (1999) appends that cocoon size is a critical characteristic when evaluating cocoons, the size of the cocoons differ according to silkworm variety as well as rearing season and harvesting conditions. These are factors that may in one way or another affect the cocoon size. However in this study the cocoon size was not affected by the silkworm variety probably due to the strains being of the same origin - Chinese, hence related characteristics (Plate 4.1).

**Plate 4.1 Cocoons of selected silkworm strains**

**4.1.2 Cocoon Layer (Shell) Weight**

Comparative performance test in the two locations showed that there was a significant difference in the means of cocoon, pupa and shell weight (CW, PW and SW). ICIPE I had the highest cocoon weight (2.14 ± 0.040gms and 2.09 ± 0.040gms) and pupa weight (1.76 ± 0.039gms and 1.74 ± 0.038gms) in S1 and S2 locations respectively. It also had the highest shell weight mean in the two locations, 0.38 ± 0.005gms and 0.36 ± 0.004gms respectively, amongst the strains. On the other hand 75xin had the lowest CW, PW and SW irrespective of the season and location (Table 4.2 a).

The results of this study relate to Liguan and Sanchez (2003) and Sanchez (2001) studies, that revealed that silkworm breeds vary significantly in terms of weight of cocoons per liter among other parameters. Results also follow Aruga's (1994) connotation that a wide variation in CW, PW and SW may occur depending on the strain of the silkworm. This may have been the contributing factor in the difference of cocoon, pupa and shell weights.

**Table 4.2 a Cocoon, pupa, shell weight performance comparison among the strains in the two locations**

| Strain | Location | CW<br>Mean + S.E | P<0.05 | PW<br>mean + S.E | P<0.05 | SW<br>Mean + S.E | P<0.05 |
|---|---|---|---|---|---|---|---|
| 75xin | S1 | 1.73 ± 0.030 | 0.101* | 1.44 ± 0.030 | 0.001 | 0.30 ± 0.004 | 0.106* |
| | S2 | 1.74 ± 0.026 | | 1.44 ± 0.027 | | 0.30 ± 0.004 | |
| C X Z | S1 | 1.95 ± 0.029 | 0.112* | 1.60 ± 0.031 | 0.097* | 0.33 ± 0.004 | 0.200* |
| | S2 | 1.89 ± 0.029 | | 1.54 ± 0.030 | | 0.31 ± 0.004 | |
| ICIPE I | S1 | 2.14 ± 0.040 | 0.116* | 1.76 ± 0.039 | 0.106* | 0.38 ± 0.005 | 0.001 |
| | S2 | 2.09 ± 0.040 | | 1.74 ± 0.038 | | 0.36 ± 0.004 | |
| Q X B | S1 | 1.84 ± 0.036 | 0.201* | 1.52 ± 0.034 | 0.111* | 0.32 ± 0.004 | 0.101* |
| | S2 | 1.83 ± 0.036 | | 1.52 ± 0.035 | | 0.31 ± 0.003 | |
| Q X H | S1 | 1.94 ± 0.028 | 0.101* | 1.60 ± 0.028 | 0.120* | 0.35 ± 0.004 | 0.100* |
| | S2 | 1.89 ± 0.028 | | 1.56 ± 0.029 | | 0.32 ± 0.004 | |
| S X M | S1 | 1.95 ± 0.029 | 0.200* | 1.61 ± 0.030 | 0.101* | 0.35 ± 0.006 | 0.101* |
| | S2 | 1.91 ± 0.029 | | 1.56 ± 0.032 | | 0.35 ± 0.005 | |

*Significant at 5% SE± - Standard Error. CW- Cocoon Weight; PW - Pupa Weight; SW - Shell Weight

A comparative study of rearing in the two locations during the two seasons revealed that C.W, P.W and S.W performance in S1 and S2 during LR had no significant difference whereas during SR there were significant differences in the two locations as shown in Table 4.2 b.

**Table 4.2 b Cocoon, pupa, shell weight performance comparison among the strains in the two locations**

| Season | Location | C.W ± S.E | P<0.05 | P.W ± S.E | P<0.05 | S.W ± S.E | P<0.05 |
|---|---|---|---|---|---|---|---|
| LR | S1 | 2.22 ± 0.010 | 0.001 | 1.89 ± 0.008 | 0.001 | 0.33 ± 0.003 | 0.001 |
| | S2 | 2.18 ± 0.009 | | 1.87 ± 0.008 | | 0.31 ± 0.002 | |
| SR | S1 | 1.63 ± 0.014 | 0.106* | 1.28 ± 0.012 | 0.101* | 0.37 ± 0.003 | 0.101* |
| | S2 | 1.60 ± 0.012 | | 1.25 ± 0.011 | | 0.35 ± 0.001 | |

*Significant at 5% SE± - Standard Error. CW- Cocoon Weight; PW - Pupa Weight; SW - Shell Weight

Results indicate that comparative performance test in the two locations showed that there was a significant difference in the means of cocoon, pupa and shell weight. The locations in which the silkworms were reared had different environmental conditions in terms of temperature and humidity. This is a factor that cannot be overlooked as it affects the cocoon crop.

It was evident from the study that environmental conditions greatly influenced cocoon production, characteristics and quality. Therefore this may have affected the cocoons in

S2 as the temperature and humidity fluctuated throughout the rearing period. The rearing of young age larvae at relatively high temperatures ensures cocoons of good characteristics, whereas low temperatures are required for late age rearing (Raina, 2000; Aruga, 1994). This is a feature that may have affected the silkworm larvae in S2, as well as the crop harvested during the two seasons, LR and SR. Relationship between humidity during rearing and the cocoon quality is similar to that of temperature.

An important factor to consider in the above study is the quality of mulberry leaves. The quality is greatly associated with the weight of the cocoons, hence cocoon layer weight. It differs with the variety and type of mulberry leaves used. The mulberry fed to the silkworms during the study was of the same variety; however differences in climatic conditions during the two seasons may have affected the mulberry quality thus affecting the cocoon, pupa and shell weight. Bharathi and Yungen, (2000) confirmed that use of high protein diet effectively increases the quality of cocoon shell. They established this in a study by use of supplemental diets besides mulberry leaf, of soy protein and blood meal. It demonstrated that the silkworm (*B. mori*) preferred mulberry leaf and that its digestibility was found to be excellent compared to other supplemental diets. Furthermore it provided the silkworm with feeding inducers (such as morin), vitamins and other growth factors (Tribhuwan, *et al*., 1989).

Quader *et al*., (1992) found out that the nutritional value of mulberry leaves was directly reflected on the larval growth and cocoon characters of *B. mori* silkworm. Significantly, it is known that there is high correlation between leaf protein level and production efficiency of cocoon shell, which means cocoon shell weight to the total amount of mulberry leaves consumed by the silkworm (Machii and Katagiri, 1991). Therefore, an increase in protein level of mulberry leaves may lead to improvements in cocoon productivity.

It is also significant to point out that the cocoon layer weight of female silkworm larvae is usually slightly higher than the male larvae for the reason that the body of the female pupa is larger than the male. Singhvi and Bose (1991) have further reported that sericin content is also a deciding factor in the quality of the cocoon and raw silk reeled.

### 4.1.3 Silk Filament Length, Weight and Cocoon Thickness

It is evident in Table 4.3, that the longest silk filament length, 1183.35m was attained during the Long Rains season (LR). ICIPE I silkworm strain produced the longest filament, 1183.35 and 1170.87m in S1and S2 respectively. Similarly, during the Short Rains (SR) ICIPE I also had the longest filament length, 1152.78 and 1135.43m in S1 and S2, during SR respectively. On the other hand the shortest filament length was produced by 75xin strain reared in S2 during SR (945.73m). These results concur with Ueda *et al's* (1969) study, which established that different seasons caused the length of silk filament to vary within strains. Basaen *et al.,* (2001) study drew similar conclusions where cocoon filament properties differed due to various environmental conditions. These factors indeed contributed to the variations of the filament lengths. It is thus significant to note that environmental conditions have a direct bearing on silk filament length variations.

**Table 4.3: Silk filament length, weight and cocoon thickness comparison**

| Strain | Season | Location | Mean Filament Length (FL) cm | Mean Filament Weight (FW) gm | Mean Cocoon Thickness (CT) |
|---|---|---|---|---|---|
| 75xin | SR | S1 | 964.12 | 0.289 | 2.400 |
| | SR | S2 | 945.73 | 0.284 | 2.399 |
| | LR | S1 | 983.97 | 0.295 | 2.398 |
| | LR | S2 | 970.33 | 0.291 | 2.404 |
| C X Z | SR | S1 | 1047.22 | 0.314 | 2.397 |
| | SR | S1 | 1035.60 | 0.311 | 2.403 |
| | LR | S2 | 1061.02 | 0.318 | 2.402 |
| | LR | S2 | 1053.93 | 0.316 | 2.400 |
| ICIPE I | SR | S1 | 1152.78 | 0.346 | 2.401 |
| | SR | S2 | 1135.43 | 0.341 | 2.403 |
| | LR | S1 | 1183.35 | 0.355 | 2.400 |
| | LR | S2 | 1170.87 | 0.351 | 2.398 |
| Q X B | SR | S1 | 990.18 | 0.297 | 2.399 |
| | SR | S2 | 964.00 | 0.289 | 2.402 |
| | LR | S1 | 1011.00 | 0.303 | 2.400 |
| | LR | S2 | 991.87 | 0.298 | 2.399 |
| Q X H | SR | S1 | 1036.77 | 0.311 | 2.398 |
| | SR | S2 | 1018.43 | 0.305 | 2.402 |
| | LR | S1 | 1061.30 | 0.318 | 2.398 |
| | LR | S2 | 1019.43 | 0.306 | 2.399 |
| S X M | SR | S1 | 984.72 | 0.295 | 2.400 |
| | SR | S2 | 965.43 | 0.290 | 2.353 |
| | LR | S1 | 999.02 | 0.300 | 2.310 |
| | LR | S2 | 983.27 | 0.295 | 2.401 |

In addition, these results relate to studies by Aruga's (1994), where he illustrated that the size of the bave varies greatly depending on the strain of the silkworm. Six silkworm strains were used in this study and their different characteristics may have contributed to the varying filament lengths. Further Sanchez's (2001) study discovered that difference in filament length among silkworm strains could be attributed to varietal inheritance.

An analysis of the size of bave revealed that the strain with the longest filament length had the heaviest filament weight. ICIPE I's filament length of 1183.35m weighed 0.355gms. Cocoon thickness ranged between 2.404 and 2.310, however there seems to be minimal relation between the cocoon thickness to the length or weight of the filament.

Results indicate that within the same strain, the size of the bave varied with the rearing season. These observations concur with Nguku *et al.*, (2009a) and Aruga's (1994) experiment, which revealed that when the environmental conditions during rearing are favourable; the thickness of cocoon fibre is more than when the rearing conditions are not so favourable. Other research works have shown that the diameter of the spinneret determines the thickness of the silk thread (Vegan Society, 2003; Lee, 1999). These factors may have influenced the results of the study.

## 4.2 Raw Silk Properties Using *B. mori* Strains in Kenya

The objectives were to establish the properties of raw silk and determine if there were significant differences in the raw silk quality among the six silkworm strains. Quality tests were performed on the raw silk, which included winding breaks, tenacity and elongation percentage, cleanliness and neatness tests. Some causes that led to silk fibre defects during production processes in this study were identified. This chapter also tried to establish the relationship between silk cocoon production and raw silk fibre qualities.

### 4.2.1 Winding Breaks counts

Upon performing winding breaks test on the raw silk, the counts indicated that 75xin had the highest number of winding breaks in both locations in the two seasons. Raw silk produced during SR in S2, recorded a total of 16 counts, the highest recorded counts for the duration of the study. ICIPE I had the least with only 6 counts, in the same setting. Winding breaks in the other strains ranged between 13 and 8 counts. It was noted that silk harvested during SR had more breaks compared to those of the LR. This tendency was also perceived in silk from the two locations. S2 location had more breaks in most strains (Fig 4.1).

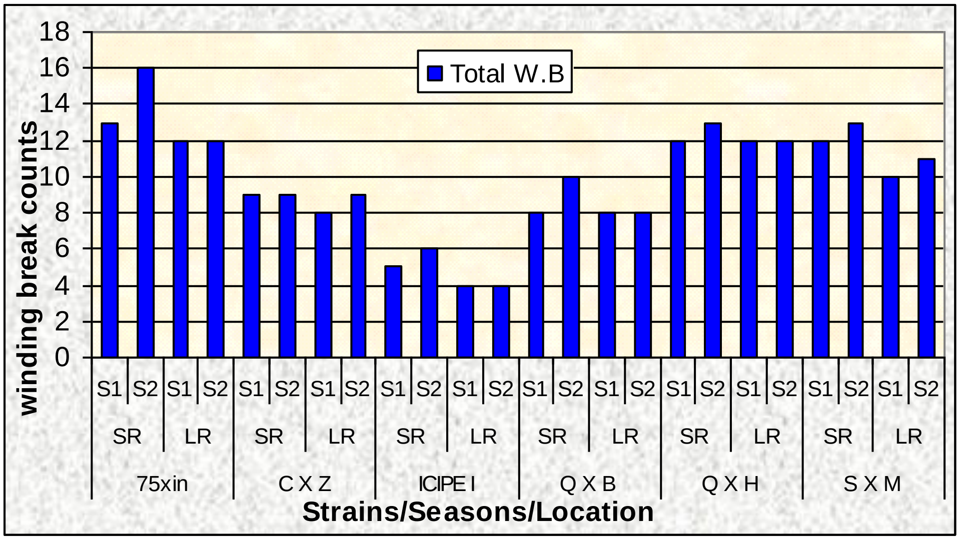



**Fig 4.1 Total Winding Breaks Count during LR & SR in S1 & S2**

The results in Fig 4.1 indicate that the raw silk winding breaks varied among the different strains. Hall (1980) observations that the silkworm is not quite perfect in its spinning of silk for the thread changes in diameter from the beginning to the end of the cocoon uncovers a possibility that may have contributed to the causes of winding breaks in this study. These results may also have been caused by the uneven thickness of the filament occasioned by silkworms of different strains as observed by Aruga (1994). He further adds that from the beginning to the end of spinning by mature larvae, the process of spinning the fibre is not uniform. These inferences relate to results of this study, where the various strains selected may have had varying characteristics in their spinning of silk thread, which could be a contributing factor to the winding breaks variation.

Environmental conditions on the other hand, have a direct impact on the development of the silkworm, its spinning abilities and hence quality of the cocoon. This trend resulted in the different strains, producing silk filaments of differing thickness, a tendency also noted by Nguku *et al.*, (2008a, b) and Aruga, (1994) in their studies.

An analysis of the two major causes of winding breaks was performed. It was apparent that the breaks were mainly caused by size deviation compared to split ends as shown in Fig 4.2). Size deviation accounted for 60 - 100% of the winding breaks counts (Appendix 3). During LR in S1, 100% of ICIPE I's winding breaks were caused by size deviation.

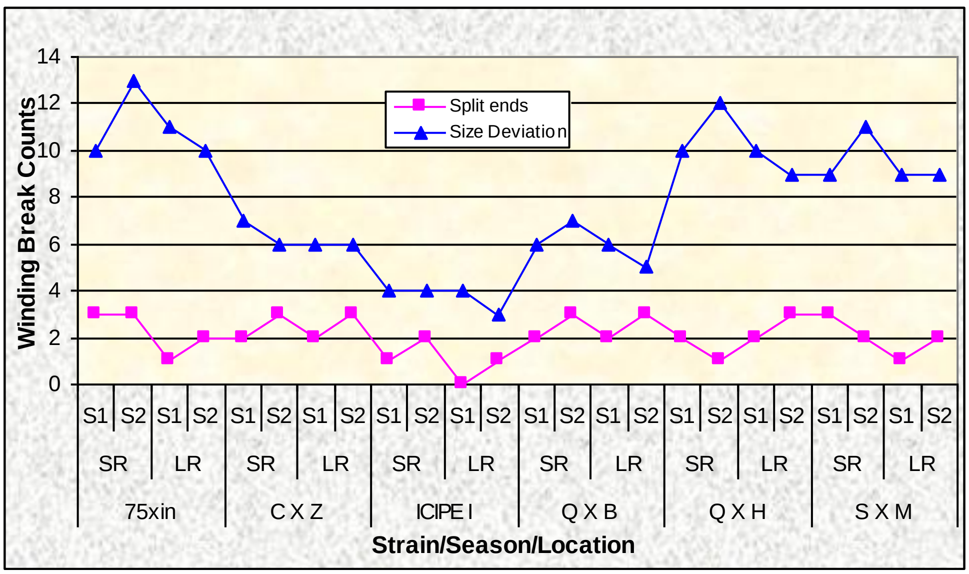



**Fig 4.2 Comparative Winding Breaks Count during LR & SR in S1 & S2**

It is important to highlight that the reeler also plays a major role in the production of raw silk. To maintain reeling thread in the required size, the average cocoon number per thread must be adjusted in order to produce silk thread in the same size throughout all ends during reeling (Lee, 1999). This is a factor that could have led to size deviation in the raw silk. Practical experience has proven that winding alters the yarn structure as noted by Vijayakumar (2003) in his study. This is a phenomenon, which may affect standard deviation of silk and increase breaking tendencies. (Economic Development Associates, 1990).

### 4.2.2 Raw silk tenacity and elongation percentage

The study revealed that average tenacity and elongation for the raw silk analysed was 3.93g/d and 18.5% respectively. ICIPE I had tenacity of between 4.25 and 3.99g/d and elongation percentages between 19 and 20%, the highest recorded percentages. The tenacity of the other strains ranged between 3.98 and 3.81g/d. On the other hand it was noted that the other strains generally had elongations of 18% apart from C X Z. It was evident from the results that silk harvested during LR had higher tenacity and average elongation percentages compared to silk harvested during SR as shown in Figure 4.3.

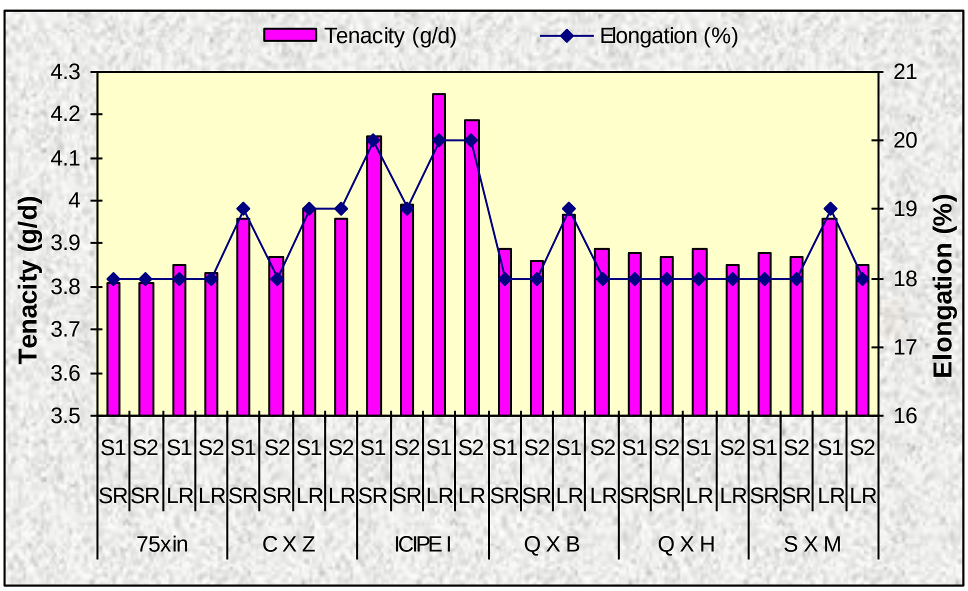



**Fig 4.3 Tenacity and Elongation during LR & SR in S1 & S2**

The raw silk tenacity results of this study concur with findings of studies conducted by various researchers. Sonwalker (1993), noted tenacity ranged between 4.28 and 3.4g/d, whereas Franck (2001) research, noted tenacity and elongation of raw silk was between 4 – 5g/d and 18% respectively. Results in this study further compare with (Lee, 1999); who states that the typical tenacity of a bave is 3.6 to 4.8 g per denier and an elongation of 18 – 23% of its original length. He adds that moisture increases the elongation of silk and decreases its tenacity. Datta and Nanavaty (2007) also noted that silk has a tenacity of about 4g/d and that it is elastic with an elongation of 20%.

The differences in tenacity and elongation noted in this study, though minimal, may have been caused by the different silkworm strains. Hariraj and Somashekar (2006), in their study noted that cocoon strains have significant influence on the 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. It is important to note that mulberry silk fibres are fine and have crystallites of small size, high molecular orientation, and compact overall packing of molecules. These structural parameters have been shown to result in relatively high initial modulus and tenacity along with superior elastic recovery behavior of mulberry silk (Rajkhowa *et al*., 2000).

A comparison of the elongation percentage and breaking counts was done and after plotting the elongation and winding graph, it was noted that silkworm strains having the highest elongation count, had the least winding breaks and vice verse as shown in Fig 4.4. ICIPE I had the highest elongation percentage with an average of 19.75% and the least number of breaking counts with an average of 5, while on the other hand 75xin had the most breaking counts, 5, with an average elongation of 18%.

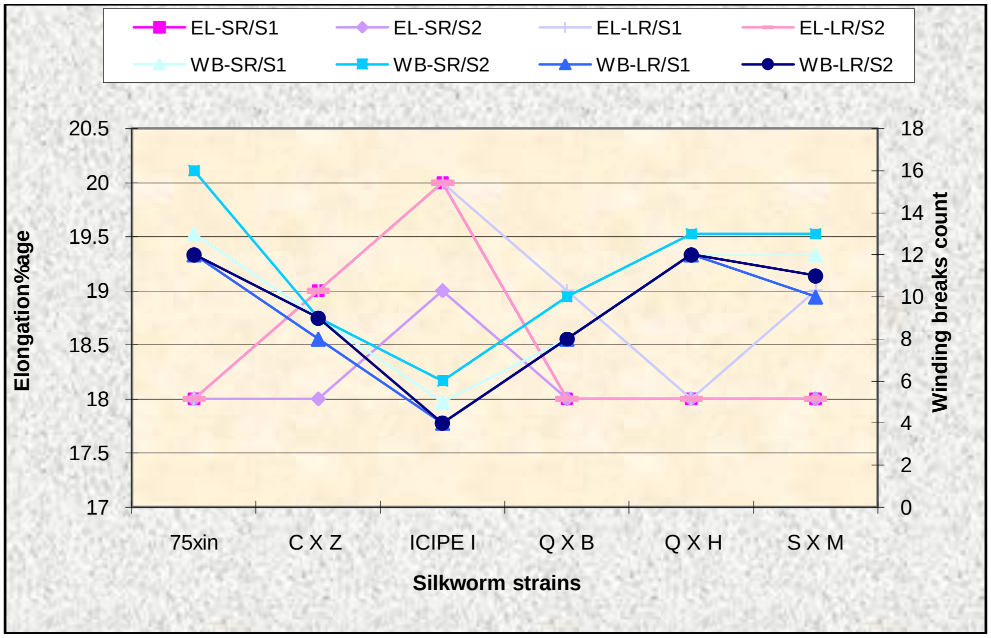



**Fig 4.4 Winding breaks and Elongation during LR & SR in S1 & S2**

The elongation percentage relates to Sonwalker, (1993) results, which demonstrated that normal silk elongation is between 18-22%. Further the Vegan Society, (2003) study indicated that when silk is dry, the elongation (elastic recovery) varies from 10-25% and when wet it will elongate as much as 33-35%. This relationship of high elongation percentage and low winding breaks could have been as a result of increased elasticity of the fibre; hence fewer breaks on the fibre occur. Raina (2000) points out that late age silkworms require 70% relative humidity and a temperature of 24$^{O}$C, he further notes that humidity that goes above 70% may give raise to breaks during reeling and decrease silk quality.

On related issues it is significant to note that Vijayakumar (2003) research indicated that if winding tension is selected properly, the following tensile properties are not affected; tenacity, elongation and breaking strength. Thus for this study, the winding tension and speed was adjusted and maintained according to denier of the raw silk (appendix 2). This ensured that during winding the required speed for respective deniers were maintained to avoid inconsistent data on winding break counts. Unsuitable tension and reeling speed for the specific deniers would result in winding break counts

### 4.2.3 Cleanliness and Neatness Percentages of *B. mori* raw silk

Cleanliness percentages were highest in ICIPE I at 97.0 ± 0.333% and 96.2 ± 0.359% during LR, S1 &S2 respectively and 96.0 ± 0.211 and 96.0 ± 0.258% during SR, S1 &S2 respectively. The lowest percentages recorded were Q X H, which had 89.9 + 0.379 and 88.3 + 0.260% during LR, S1 & S2 respectively, and 90.0 ± 0.333 and 88.0 ± 0.422% during SR, S1 &S2 respectively.

ICIPE I recorded the highest neatness percentages during LR as well as SR in both locations, S1 and S2 as follows, 93.0 ± 0.394 and 92.9 ± 0.180% respectively and 94.3 ± 0.300 and 93.3 ± 0.473% respectively. 75xin on the other hand recorded the lowest percentages. There were significant differences in cleanliness percentages in some strains during the two seasons and locations (Waller-Duncan K-ratio t - test at $\alpha = 0.05$ significant level was used). However there was no significant difference in the cleanliness percentages of ICIPE I and C X Z. In the neatness test there was no significant differences in the percentages of ICIPE I and Q X H as indicated in Table 4.4.

**Table 4.4 Mean cleanliness and neatness % in S1 & S2 during LR & SR**

| Parameter | Season | Location | ICIPEI | C X Z | S X M | Q X B | 75xin | Q X H | F value |
|---|---|---|---|---|---|---|---|---|---|
| **Mean Cleanliness** | LR | S1 | 97.0 ± 0.333 a | 94.4 ± 0.163 b | 94.1 ± 0.233 b | 92.8 ± 0.291 c | 92.8 ± 0.133 c | 89.9 ± 0.379 d | 172.96 |
| | LR | S2 | 96.2 ± 0.359 a | 94.0 ± 0.211 b | 93.0 ± 0.212 c | 92.0 ± 0.298 d | 91.0 ± 0.211 e | 88.3 ± 0.260 f | 184.21 |
| | SR | S1 | 96.0 ± 0.211 a | 94.0 ± 0.211 b | 92.9 ± 0.100 c | 92.2 ± 0.133 d | 92.0 ± 0.211 d | 90.0 ± 0.333 e | 201.58 |
| | SR | S2 | 96.0 ± 0.258 a | 92.9 ± 0.233 b | 90.8 ± 0.133 c | 90.2 ± 0.327 d | 91.2 ± 0.359 c | 88.0 ± 0.422 e | 183.34 |
| **Mean Neatness** | LR | S1 | 93.0 ± 0.394 a | 88.9 ± 0.180 c | 87.4 ± 0.400 d | 89.1 ± 0.407 b | 87.1 ± 0.180 d | 88.3 ± 0.300 c | 97.12 |
| | LR | S2 | 92.9 ± 0.180 a | 88.2 ± 0.249 b | 87.3 ± 0.396 c | 88.0 ± 0.258 b | 85.0 ± 0.211 d | 88.2 ± 0.291 b | 194.41 |
| | SR | S1 | 94.3 ± 0.300 a | 88.0 ± 0.258 b | 88.0 ± 0.333 b | 88.1 ± 0.180 b | 87.1 ± 0.379 c | 87.9 ± 0.314 b | 282.20 |
| | SR | S2 | 93.3 ± 0.473 a | 87.0 ± 0.211 b | 85.0 ± 0.258 c | 87.2 ± 0.389 b | 85.0 ± 0.258 c | 87.3 ± 0.300 b | 288.21 |

Means followed by the same letter(s) in the same row are not significantly different. Waller-Duncan K-ratio t test at $\alpha = 0.05$ significant level was used.

It is evident that location S1 was recorded as having produced better raw silk in terms of cleanliness and neatness, as opposed to S2 during the two seasons. Cleanliness and neatness percentages were within the acceptable ISA standards.

Silk neatness and cleanliness differed among the silkworm strains reared, in this study. Neatness defects are imperfections in silk yarn, which are smaller than minor cleanliness defects. On average, ICIPE I had the highest percentages of these two parameters 96 and 93% respectively, during the two seasons. On the other hand, the other strains had varied percentages. Q X H had the lowest cleanliness percentage while75xin had the lowest neatness percentage LR and SR. Hair-like projections in silk fibre called lousiness are defects that occur in silk fibre and affect neatness. Lousiness is more prevalent in baves produced by silkworms, which have been overfed in the fifth instar. Another factor promoting lousiness is mounting over mature silkworm larvae (Lee, 1999).

The personnel processing the cocoons to raw silk cannot be overlooked in this study. They can cause defects and lower the quality of the raw silk. Slubs, slugs, loops and crimps are defects found during the neatness test. They can be caused by poor workmanship of the reeler during the reeling process, as noted by Datta and Nanavaty, (2007).

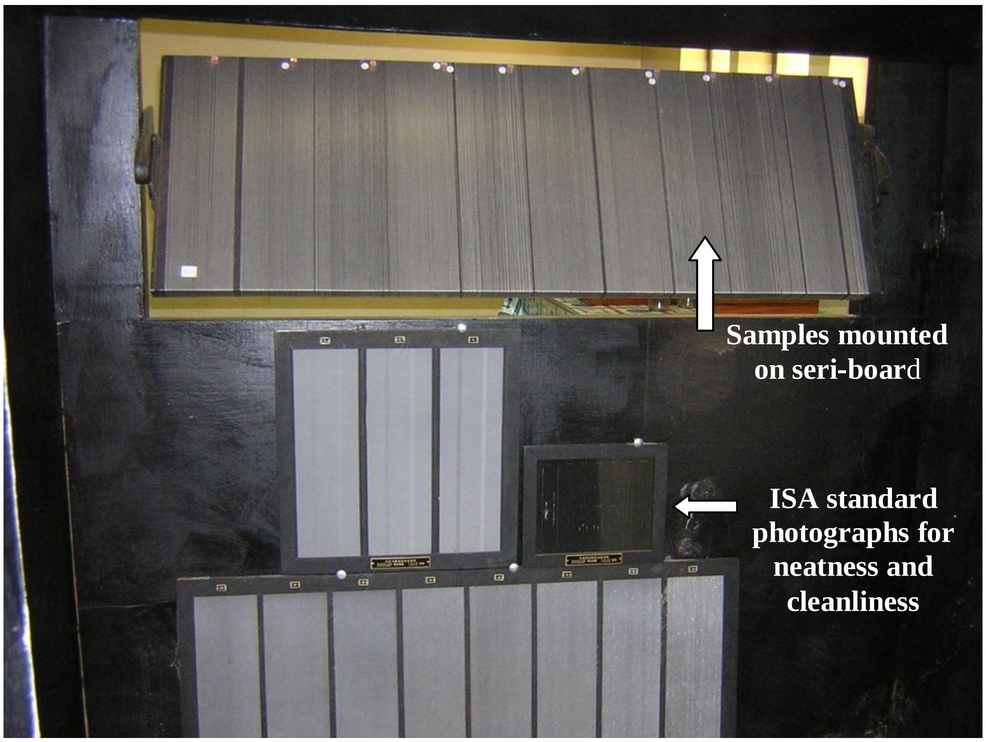
Nguku *et al.,* (2009 b) and Aruga (1994) attribute this kind of occurrence (neatness and cleanliness defects) to the technique applied in the cooking and reeling of cocoons. In this study, the two pan cooking device was used for all cocoon boiling to counter occurance of the mentioned defects. On the other hand Lee (1999) research shows that a characteristic of the silkworm strain may give rise to cleanliness and neatness defects. Results indicate that this may have contributed in the slight variations that were noted in these two parameters for the silkworm strains. In this study, it was noted that S1 produced silk of better quality in terms of neatness and cleanliness. This infers that that environmental conditions affected the development of the larvae (Aruga, 1994), which consequently gave raise to cocoons with the mentioned quality variations.

It is important to note that a study carried out by Vasumathi *et al.,* (2004), observed that the filament denier within a cocoon in addition to other cocoon parameters have significant influence on the raw silk uniformity characteristics.

It can therefore be concluded that there is a relationship between silk cocoon production and raw silk fibre quality. Results in this study indicate that raw silk qualities are affected in one way or another by cocoon production process. Environmental conditions affected the development of the larvae as noted by Aruga (1994), which consequently gave raise to cocoons with defects. Cocoon quality affected by environmental conditions has a negative effect on the quality of silk filament produced. Further, rearing of late age silkworms has a significant impact on the cocoons produced and hence raw silk quality, a factor also observed by Raina (2000). In addition, the cocoon processing procedures, cooking techniques and reeling, influence the raw silk quality. Finally the personnel doing the actual reeling of the silk contributes to the quality of raw silk as defects do occur during the process.

It is significant to point out that in this study, neatness and cleanliness for all the strains reared in S1 and S2 during LR and SR were within the acceptable international (ISA) standards (Plate 4.2 and Appendix 4).

**Plate 4.2 Samples mounted on seri-board for inspection in a dark room**



### 4.3 Characteristics and Properties of Silk Fabric of *B. mori* Silkworms in Kenya

This objective aimed to determine the characteristics and properties of silk fabric from the six bivoltine silkworm strains and determine differences in their quality standards, especially breaking load, elongation and tearing strength. Further the study sort to verify if there is a relationship between silk processing and silk fabric qualities.

#### 4.3.1 Fabric count

In this study it was important for the warp and weft silk yarn used to be of equal denier respectively. In this regard silk yarn of 24 and 32 denier for the warp and weft respectively, was used for weaving a plain weave structure. Fabric count determined the number of warp yarns and number of filling yarns per linear inch. Fig 4.5 demonstrates that the mean ends per inch and picks per inch of the fabric samples were equal, at 50 and 28 respectively. This ensured that the weave structures were uniform.

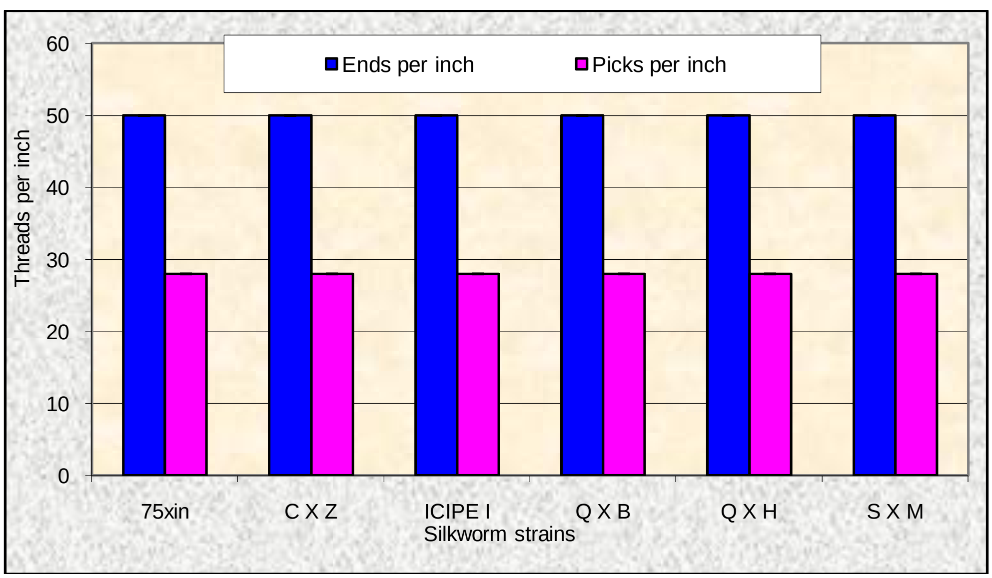



**Fig 4.5 Threads per inch**

### 4.3.2 Fabric weight (Mass per unit area)

It was established that the silk average mass per unit was 639.66g/m$^2$ for the six strains studied. ICIPE I had the highest mass of 639.90g/m$^2$ while 75xin had the least, 639.45g/m$^2$, as shown in Table 4.5.

**Table 4.5 Effect of Strains on Silk Fabric Mass**

| Strain | Mean Mass ± S.E (g/m$^2$) |
|---|---|
| 75xin | 639.45 ± 0.098 |
| C X Z | 639.73 ± 0.120 |
| ICIPE I | 639.90 ± 0.111 |
| Q X B | 639.70 ± 0.090 |
| Q X H | 639.53 ± 0.110 |
| S X M | 639.67 ± 0.109 |

Variance between the highest and lowest fabric mass was a minimal 0.45g/ m$^2$. This was a result of the denier of the warp and weft being the same respectively for all the samples. The mean picks per inch and the mean ends per inch were also equal respectively, for the six silkworm strains silk fabric samples. This being the case, the mass of the fabric samples would have been relatively the same.

A comparative study to ascertain if location and season affected the mass established that average mass was 639.86 ± 0.05 and 639.48 ± 0.062 $g/m^2$ in S1 and S2 respectively. Mass during LR and SR was 639.84 ± 0.049 and 639.49 ± 0.064 $g/m^2$ respectively. There was no significant difference in mass per unit area in the two locations (P< 0.05) (P = 0.0001) and during the two seasons (P = 0.0001) as illustrated in Table 4.6.

**Table 4.6 Comparative Study of Effect of Rearing Location and Season on Silk Mass per Unit Area**

| Location | Mean Mass per Unit Area ± S.E ($g/m^2$) | P<0.05 | Season | Mean Mass per Unit Area ± S.E ($g/m^2$) | P<0.05 |
|---|---|---|---|---|---|
| S1 | 639.86 ± 0.050 | 0.001 | LR | 639.84 ± 0.049 | 0.001 |
| S2 | 639.48 ± 0.062 | | SR | 639.49 ± 0.064 | |

*Significant at 5% SE± -Standard Error.

This study verified that there was no significant difference in the weight of the silk fabric samples tested from S1 and S2 as well as during LR and SR. During the test, conditions in the laboratory were at optimum and accuracy was of utmost importance. Conditioning of the samples was done following Kebs procedures (KS 08 – 32, 1977). The cutting and preparation of the sample was done with accuracy to ensure impeccable results. The equipment used was calibrated before test was done to ensure accuracy in the readings. All these measures ensured accurate results. It is therefore logical to conclude that since the warp and weft yarns had been of the same denier respectively, then it follows that there would be no significant difference in the fabric weight across the strains.

However a study to establish if there was an effect of the different silkworm strains on fabric mass revealed that in S1, ICIPE I and Q X B had a mass of 640.15 ± and 639.92 ± g/m$^2$ respectively, which was not significantly heavier than that in S2 (639.65 ± and 639.43 ± g/m$^2$ respectively). Results of the other strains indicated that the masses were affected by the locations, as they differed significantly. On the other hand, during LR, 75xin and Q X H strains had a mass of 639.68 ± and 639.82 ± g/m$^2$ respectively, which was not significantly heavier than that during SR (639.27 ± and 639.25 ± g/m$^2$ respectively). There were indications from the other strains that the seasons affected the masses as shown in Table 4.7.

There was a significant effect in the fabric weight among the strains in the two locations and seasons during which rearing was carried out. This may have been as a result of individual characteristics of the silkworm strains, as observed by Aruga, (1994) in his study. The thickness of the silk filament varies among different silkworm strains and this consequently affects the weight of silk yarn and accordingly the fabric (Hall, 1980).

**Table 4.7 Comparative Study of Effect of Strains on Silk Fabric Mass as per Location and Season**

| Strain | Location | Mass per Unit Area ± SE (g/m$^2$) | P<0.05 | Season | Mass per Unit Area ± SE (g/m$^2$) | P<0.05 |
|---|---|---|---|---|---|---|
| **75xin** | S1 | 639.55 ± 0.136 | 0.331* | LR | 639.68 ± 0.098 | 0.009 |
| | S2 | 639.35 ± 0.141 | | SR | 639.22 ± 0.104 | |
| **C X Z** | S1 | 639.95 ± 0.106 | 0.066* | LR | 639.90 ± 0.155 | 0.174* |
| | S2 | 639.52 ± 0.182 | | SR | 639.57 ± 0.167 | |
| **ICIPE I** | S1 | 640.15 ± 0.076 | 0.015 | LR | 640.02 ± 0.130 | 0.315* |
| | S2 | 639.65 ± 0.152 | | SR | 639.78 ± 0.179 | |
| **Q X B** | S1 | 639.92 ± 0.060 | 0.008 | LR | 639.85 ± 0.085 | 0.098* |
| | S2 | 639.48 ± 0.117 | | SR | 639.55 ± 0.141 | |
| **Q X H** | S1 | 639.73 ± 0.109 | 0.066* | LR | 639.82 ± 0.079 | 0.003 |
| | S2 | 639.33 ± 0.161 | | SR | 639.25 ± 0.123 | |
| **S X M** | S1 | 639.83 ± 0.102 | 0.155* | LR | 639.80 ± 0.151 | 0.273* |
| | S2 | 639.52 ± 0.180 | | SR | 639.55 ± 0.154 | |

*Significant at 5% SE± - Standard Error.

Shanbhag (2009), notes that the process of eliminating ‘gum’ from raw silk known as degumming of silk is synonymous to the scouring process used for purification of cotton and wool. This fibre process degrades the fibres and can have implications on the silk fabric mass per unit. She further notes that among all fibres, silk as the queen of fibres requires careful processing so as not to affect its mass, strength, feel and appearance among other properties. In addition, Hodak *et al*, (2008) notes that the finishing process in the textile industry is an ever evolving field where enhancing special fabric properties are constantly sought. However some of these processes include chemical treatments which may produce changes in the mechanical properties of the fabric making them less comfortable to wear and to some extend affect properties like mass, tenacity and breaking strength.

### 4.3.3 Determination of breaking load and elongation

In this study, the average breaking load for the 24 denier warp yarns ranged between 124.02 and 124.21N and the 32 denier weft yarns was between 256.03 and 256.46N for the six strains studied in location S1. On the other hand, the breaking load for the six strains studied in location S2 with warp and weft denier as above, ranged between 123.77 and 124.20N, and 255.06 and 256.38N respectively. Elongation was between 7.6 – 8.1cm and 3.9 – 4.3cm for warp and weft respectively in S1, and 3.7 – 4.3 for warp and weft respectively in S2 (Table 4.8).

**Table 4.8 Breaking Load and Elongation of warp and weft yarns in S1 and S2 Strain**

| Strain | S1 | | | | S2 | | | |
|---|---|---|---|---|---|---|---|---|
| | Warp | | Weft | | Warp | | Weft | |
| | Force (N) | El (cm) | Force (N) | El (cm) | Force (N) | El (cm) | Force (N) | El (cm) |
| 75xin | 124.02 | 7.6 | 256.03 | 3.9 | 123.77 | 6.7 | 255.87 | 3.7 |
| C X Z | 124.08 | 7.7 | 256.26 | 4.2 | 124.06 | 7.7 | 256.23 | 4.1 |
| ICIPE I | 124.20 | 8.1 | 256.46 | 4.3 | 124.15 | 7.9 | 256.38 | 4.3 |
| Q X B | 124.01 | 7.6 | 256.15 | 4.1 | 123.98 | 6.9 | 255.91 | 3.9 |
| Q X H | 124.15 | 7.9 | 256.16 | 4.0 | 124.10 | 8.0 | 255.95 | 3.9 |
| S X M | 124.21 | 8.1 | 256.35 | 4.2 | 124.20 | 8.0 | 256.06 | 4.0 |

Evaluation of the effect various silkworm strains had on the breaking load revealed that there was no significant difference on the warp and weft at $P < 0.05$ ($p=0.0188$) and ($p=0.0006$) respectively among the six strains. The mean warp breaking load was 124.08 ± 0.03N while the mean weft breaking load was 256.15 ± 0.036N (Table 4.9).

The strength of fibres and fibre structures is commonly regarded as the criterion of quality. The measurement of the tensile properties of textiles is an important branch of textile testing (Booth, 1974) and the strength of textiles determines the end use. This study verified that there was no significant difference among the strains in breaking load (Fig 4.9).

**Table 4.9 Comparative Study on the Effect of Strains on Breaking Load (Weft and Warp)**

| Strain | Mean Breaking Load ± SE (N) | | | |
|---|---|---|---|---|
| | **Warp** | **P<0.05** | **Weft** | **P<0.05** |
| 75xin | 123.89 ± 0.069 | 0.0188 | 255.95 ± 0.077 | 0.0006 |
| C X Z | 124.08 ± 0.055 | | 256.25 ± 0.076 | |
| ICIPE I | 124.18 ± 0.059 | | 256.43 ± 0.082 | |
| Q X B | 124.00 ± 0.078 | | 256.03 ± 0.083 | |
| Q X H | 124.13 ± 0.076 | | 256.06 ± 0.056 | |
| S X M | 124.21 ± 0.072 | | 256.21 ± 0.089 | |

*Significant at 5% SE± - Standard Error.

Further studies to verify if the location and season of rearing affected the mean warp and weft-breaking load established that the breaking load was significantly different at $P<0.05$ ($p = 0.2488$) and ($p = 0.2174$) between the two locations respectively. Location S1 had a mean warp-breaking load of 124.11 ± 0.038 while S2 had 124.04 ± 0.046N. It was noted that during the two seasons, LR and SR, there was no significant difference in the breaking load of both warp and weft (Table 4.10)

**Table 4.10 Comparative Study on the Effect of Location and Season on Breaking Load (Weft and Warp)**

| Location | Breaking Load ± SE | | | |
|---|---|---|---|---|
| | **Warp** | **P<0.05** | **Weft** | **P<0.05** |
| **S1** | 124.11 ± 0.038 | 0.2488* | 256.24 ± 0.046 | 0.2174* |
| **S2** | 124.04 ± 0.046 | | 256.07 ± 0.052 | |
| **Season** | | | | |
| **LR** | 124.27 ± 0.027 | 0.001 | 255.35 ± 0.041 | 0.001 |
| **SR** | 123.89 ± 0.03 | | 255.96 ± 0.037 | |

*Significant at 5% SE± - Standard Error.

Table 4.10 indicates the locations affected the breaking load parameter. The difference in environmental conditions in the two locations as previously seen, may have affected the silkworm larvae thus having an effect on the strength of the filament consequently produced by the silkworms. The silkworms reared at optimum conditions had superior results, an indication that it is important to maintain temperature and humidity during rearing and especially during the spinning period to ensure quality results.

A comparative study to further verify the effect of the six silkworm strains on the warp and weft-breaking load in the two locations during the two seasons revealed that there was significant differences in the warp and weft- breaking load of all six strains in the two location, whereas there was no significant difference observed during the two seasons (Table 4.11a & b).

**Table 4.11a Comparative Study of Effect of Strains on Breaking Load as per Location**

| Strain Location | | Breaking Load ± SE | | | |
|---|---|---|---|---|---|
| | | **Warp** | **P<0.05** | **Weft** | **P<0.05** |
| 75xin | S1 | 124.02 ± 0.079 | 0.066* | 256.03 ± 0.084 | 0.303* |
| | S2 | 123.77 ± 0.092 | | 255.87 ± 0.128 | |
| C X Z | S1 | 124.08 ± 0.087 | 0.888* | 256.27 ± 0.128 | 0.839* |
| | S2 | 124.07 ± 0.076 | | 256.23 ± 0.095 | |
| ICIPE I | S1 | 124.20 ± 0.097 | 0.693* | 256.47 ± 0.126 | 0.634* |
| | S2 | 124.15 ± 0.076 | | 256.38 ± 0.114 | |
| Q X B | S1 | 124.02 ± 0.095 | 0.842* | 256.15 ± 0.089 | 0.169* |
| | S2 | 123.98 ± 0.133 | | 255.92 ± 0.13 | |
| Q X H | S1 | 124.15 ± 0.076 | 0.759* | 256.17 ± 0.067 | 0.045* |
| | S2 | 124.10 ± 0.139 | | 255.95 ± 0.067 | |
| S X M | S1 | 124.22 ± 0.119 | 0.915* | 256.35 ± 0.112 | 0.115* |
| | S2 | 124.20 ± 0.093 | | 256.06 ± 0.112 | |

*Significant at 5% SE± - Standard Error.

**Table 4.11b Comparative Study of Effect of Strains on Breaking Load as per Season**

| Strain | Location | Breaking Load ± SE | | | |
|---|---|---|---|---|---|
| | | Warp | P<0.05 | Weft | P<0.05 |
| 75xin | LR | 124.07 ± 0.049 | 0.004 | 256.13 ± 0.186 | 0.009 |
| | SR | 123.72 ± 0.194 | | 255.77 ± 0.207 | |
| C X Z | LR | 124.23 ± 0.033 | 0.0001 | 256.45 ± 0.062 | 0.002 |
| | SR | 123.92 ± 0.048 | | 256.05 ± 0.076 | |
| ICIPE I | LR | 124.35 ± 0.043 | 0.0001 | 256.67 ± 0.067 | 0.001 |
| | SR | 124.00 ± 0.037 | | 256.18 ± 0.040 | |
| Q X B | LR | 124.20 ± 0.063 | 0.003 | 256.23 ± 0.061 | 0.007 |
| | SR | 123.80 ± 0.082 | | 255.83 ± 0.102 | |
| Q X H | LR | 124.32 ± 0.048 | 0.004 | 256.20 ± 0.052 | 0.004 |
| | SR | 123.93 ± 0.099 | | 255.92 ± 0.054 | |
| S X M | LR | 124.43 ± 0.042 | 0.0001 | 256.42 ± 0.098 | 0.011 |
| | SR | 124.98 ± 0.031 | | 256.00 ± 0.089 | |

*Significant at 5% SE± - Standard Error.

It is imperative to note that the strength and elongation of textiles are also affected by the regain present in the sample, which is in turn affected primarily by the relative humidity of the air and to a diminutive extend by the temperature. As a generalization one can conclude that the stretch of all textiles is increased with an increase in regain and the strength of animal fibres is decreased by an increase in regain (Skinkle, 1949). Tests in this study were carried out in conditioned laboratories where the environment was maintained at optimum hence results being uniform for all the samples.

One cannot overlook the production processes that silk undergoes. The reeling, throwing and degumming processes influence the raw silk qualities which consequently affect fabric quality. Damage may occur during the manufacturing process and hence have an effect on the strength results either by weakening or strengthening the fibres and fabric ultimately. Datta and Nanavaty, (2007) and Eyre, (1956) noted that the raw silk production processes are factors that affect textile strength.

Raw silk thread obtained from cocoon contains 20% to 30% sericin protein, which affects the luster and strength of the thread and the resultant fabric. Methods of removal of such protein has a number of disadvantages which lead to the quality of the end product being affected particularly the mulberry type of silk (Freddie *et al*., 2003).

The tensile strength of fabric is a reflection of the strength of the yarn and/or of the fabric structure. Sometimes, because of the crimp, the fabric strength is less than the strength of twisted yarns; because of the twist in the yarn, the yarn strength is less than the strength of the fibers. These attributes are caused by the personnel processing the silk. However, it is possible to increase the fabric strength over the yarn strength by means of the compacting forces developed in the woven fabric. These can prevent fibres from slipping within the yarn. Other things being equal, plain weave fabrics, which have the highest crimp, also have the lowest strength (Franck, 2001).

### 4.3.3 Tearing Strength

The tearing test in this study was performed using an Elmendorf tearing tester and the results revealed that the tearing force of the warp yarns ranged between 390.36 and 395.26N in S1 and 390.36 and 395.3N in S2. The weft yarns had a tearing force of between 311.96 and 325.03N in S1 and 311.96 and 321.76N in S2. ICIPE I and C X Z strains were recorded as having the highest tearing strength for the warp and weft yarns respectively (Table 4.12).

**Table 4.12 Tearing Strength of warp and weft yarns in S1 and S2**

| Strain | S1 | | S2 | |
|---|---|---|---|---|
| | Warp | Weft | Warp | Weft |
| | Force (N) | Force (N) | Force (N) | Force (N) |
| 75xin | 390.36 | 321.76 | 390.36 | 315.23 |
| C X Z | 392.00 | 325.03 | 392.0 | 321.76 |
| ICIPE I | 395.26 | 320.13 | 395.3 | 316.86 |
| Q X B | 393.6 | 311.96 | 393.6 | 311.96 |
| Q X H | 393.5 | 316.86 | 393.5 | 316.86 |
| S X M | 392.0 | 320.13 | 391.86 | 315.23 |

Silk is a natural fabric and for this reason some irregularities do occur. During this study it was established that there was a significant difference in the tearing strength among the silkworm strains. This may have been caused by the individual characteristics of the silkworms as noted by Hummel (2005). Gautam *et al.*, (2009), on the other hand, in his study noted and discussed the different aspect of silk processing viz degumming, bleaching, dyeing and finishing that affect silk fibre and consequently fabric properties especially tearing strength.

The quite often contact of textile goods with sharp objects, results in the puncture and in many cases the tear of the textiles. Thus, the determination of the tearing strength of textile articles occupies a very distinctive position among the various textile quality control tests. The existing device-method presupposes an initial cut in the testing area of the specimen (Perimentas, 2001). The study shows the strains differed in tearing strength. The tearing strength of the fabrics is dependent on the strength of the individual threads, concentration of threads, type of weave and the damage that the yarns may have suffered during manufacture (Eyre, 1956). The fabric samples were of uniform count and similar plain weave thus the factors could not have played a role. However the yarns may have suffered damaged during production processes.

To verify if the location and season of rearing affected the mean warp and weft-tearing strength, further experimentation was performed. It was established that the tearing strength was significantly different at $P<0.05$ between the two locations for the warp and weft. Location S1 had a mean warp tearing strength of 392.0 $\pm$ 2.842N while S2 had 392.77 $\pm$ 2.562N. It was noted that during the two seasons, LR and SR, there was no significant difference in the tearing strength of both warp and weft (Table 4.13).

**Table 4.13 Comparison between the Effect of Location and Season on Tearing Strength (Weft and Warp)**

| Location | Tearing Strength ± SE (N) | | | |
|---|---|---|---|---|
| | **Warp** | **P<0.05** | **Weft** | **P<0.05** |
| **S1** | 392.00 ± 2.842 | 0.841* | 321.22 ± 2.410 | 0.106* |
| **S2** | 392.77 ± 2.562 | | 316.33 ± 1.772 | |
| **Season** | | | | |
| **LR** | 404.21 ± 2.218 | 0.0001 | 328.57 ± 1.264 | 0.001 |
| **SR** | 380.57 ± 1.324 | | 308.97 ± 1.486 | |

*Significant at 5% SE ± - Standard Error.

A comparative experiment, to verify if the silkworm strains affected the tearing strength of the warp and weft yarns, revealed that there were significant differences in the tearing strengths of both the warp and weft ($P < 0.05$) ($p=0.989$) and ($p=0.776$) respectively (Table 4.14). This concurs with Aruga's (1994), observations that silkworm strains have different characteristics, which affect the quality of silk fibre, and consequently fabric quality and performance in terms of breaking strength and tearing load.

**Table 4.14 Comparison Study on Effect of Strains on Tearing Strength**

| Strain | Mean Tearing Strength ± SE | | | |
|---|---|---|---|---|
| | **Warp** | **P<0.05** | **Weft** | **P<0.05** |
| 75xin | 390.37 ± 5.764 | 0.989* | 318.50 ± 4.750 | 0.776* |
| C X Z | 392.00 ± 4.672 | | 323.40 ± 2.697 | |
| ICIPE I | 395.28 ± 5.444 | | 318.50 ± 4.265 | |
| Q X B | 391.98 ± 4.343 | | 315.23 ± 3.783 | |
| Q X H | 392.75 ± 3.872 | | 319.32 ± 4.083 | |
| S X M | 391.93 ± 4.487 | | 317.68 ± 2.547 | |

The study further established that in the two rearing locations, there were significant differences in the warp and weft tearing strengths across the strains (Table 4.15). Xu *et al.*, (2005) noted that the structural differences in silk yarn may occur due to diverse rearing conditions as well as degumming processes. These are conditions the yarn was exposed to and may have consequently influenced the results.

**Table 4.15 Comparison Study on Effect of Location on Tearing Strength per Strain**

| Strain | Location | Mean Tearing Strength ± SE | | | |
|---|---|---|---|---|---|
| | | **Warp** | **P<0.05** | **Weft** | **P<0.05** |
| 75xin | S1 | 390.37 ± 8.916 | 1.000* | 321.77 ± 8.916 | 0.518* |
| | S2 | 390.37± 8.165 | | 318.23 ± 3.934 | |
| C X Z | S1 | 392.00 ± 8.392 | 1.000* | 325.03 ± 3.340 | 0.570* |
| | S2 | 392.00 ± 5.060 | | 321.77 ± 3.340 | |
| ICIPE I | S1 | 395.27 ± 9.005 | 0.998* | 320.13 ± 7.006 | 0.721* |
| | S2 | 395.30 ± 7.022 | | 316.87 ± 5.466 | |
| Q X B | S1 | 390.37 ± 5.318 | 0.728* | 318.50 ± 6.068 | 0.413* |
| | S2 | 393.60 ± 7.325 | | 311.97 ± 4.677 | |
| Q X H | S1 | 392.00 ± 5.658 | 0.857* | 321.77 ± 6.410 | 0.574* |
| | S2 | 393.50 ± 5.808 | | 316.87 ± 5.476 | |
| S X M | S1 | 392.00 ± 6.694 | 0.989* | 320.13 ± 4.132 | 0.361* |
| | S2 | 391.87 ± 6.617 | | 315.23 ± 3.012 | |

*Significant at 5% SE ± - Standard Error.

On the other hand, variations in tensile strength of silk thread under various conditions have been reported (Aruga, 1994). However, during the two seasons this study verified that there was no significant difference in the tearing strengths of the warp and weft across the silkworm strains (Table 4.16). This may have been as result of the variations in climatic conditions during the two seasons not being exceptionally diverse.

**Table 4.16 Comparison Study on Effect of Season on Tearing Strength per Strain**

| Strain | Location | Mean Tearing Strength ± SE | | | |
|---|---|---|---|---|---|
| | | **Warp** | **P<0.05** | **Weft** | **P<0.05** |
| 75xin | LR | 403.43 ± 7.341 | 0.014 | 331.57 ± 4.670 | 0.001 |
| | SR | 377.30 ± 4.900 | | 305.43 ± 3.012 | |
| C X Z | LR | 403.43 ± 6.410 | 0.006 | 331.57 ± 1.633 | 0.0001 |
| | SR | 380.57 ± 1.630 | | 315.23 ± 1.633 | |
| ICIPE I | LR | 410.00 ± 6.411 | 0.001 | 329.93 ± 3.267 | 0.002 |
| | SR | 380.57 ± 1.633 | | 307.07 ± 4.132 | |
| Q X B | LR | 403.40 ± 3.921 | 0.002 | 325.03 ± 3.012 | 0.003 |
| | SR | 380.57 ± 3.934 | | 305.43 ± 3.934 | |
| Q X H | LR | 401.67 ± 4.320 | 0.012 | 329.93 ± 2.066 | 0.003 |
| | SR | 383.83 ± 3.934 | | 308.70 ± 4.900 | |
| S X M | LR | 403.30 ± 5.277 | 0.004 | 323.40 ± .530 | 0.016 |
| | SR | 380.57 ± 3.012 | | 311.98 ± 3.012 | |

*Significant at 5% SE ± - Standard Error.

Strength as a measure of uniformity is a very useful test since a change in any physical property or change in any chemical composition of a textile material will nearly always result in a change in strength (Skinkle, 1949; Eyre, 1956). Notably, silk undergoes a degumming process where chemicals are used to remove the sericin. It is therefore possible that the chemicals used may have affected the strength of the silk fibres and consequently the fabric tearing strength.

The tear strength of a woven fabric is very important, since it is more closely related to serviceability than is the tensile strength. The behavior of woven fabric under tearing loads is quite different from their behaviors under tensile loading. In the case of tensile loading, all the yarns in the direction of loading share the load: in tear loading, only one, two or at most a few yarns share the load (Dhamija and Chopra, 2007). In their study, Varma and Chakraberty, (1971) also noted that the yarn and fabric structures play very important roles in determining the fabric tear strength. The movement of a hairy weak yarn would be restricted during loading, and yarn would present to the load one by one, this resulted in a low tearing strength. Tight constructions would produce the same effect. Loose, open constructions allow more freedom for the yarns to move and group together, thus presenting bundles of yarns woven together, such as rib weaves and basket weaves would have high tear strengths.

It is important to note that strength tends to give minimum rather than average results. The principle value of the strength is its use to measure the quality of the textile material, which is dependent upon the qualities of the constituents of the material and the quality of the work done upon it. It is the result of several variables and is rather complex. Testing at standard conditions of temperature and relative humidity ($70^{O}$F and 65%) gives the most accurate results (Eyre, 1956). The tearing strength is affected by the regain present in the sample, as noted in the above, and which is in turn affected primarily by the relative humidity of the air and to a small extent by the temperature (Plaza *et al*., 2008).

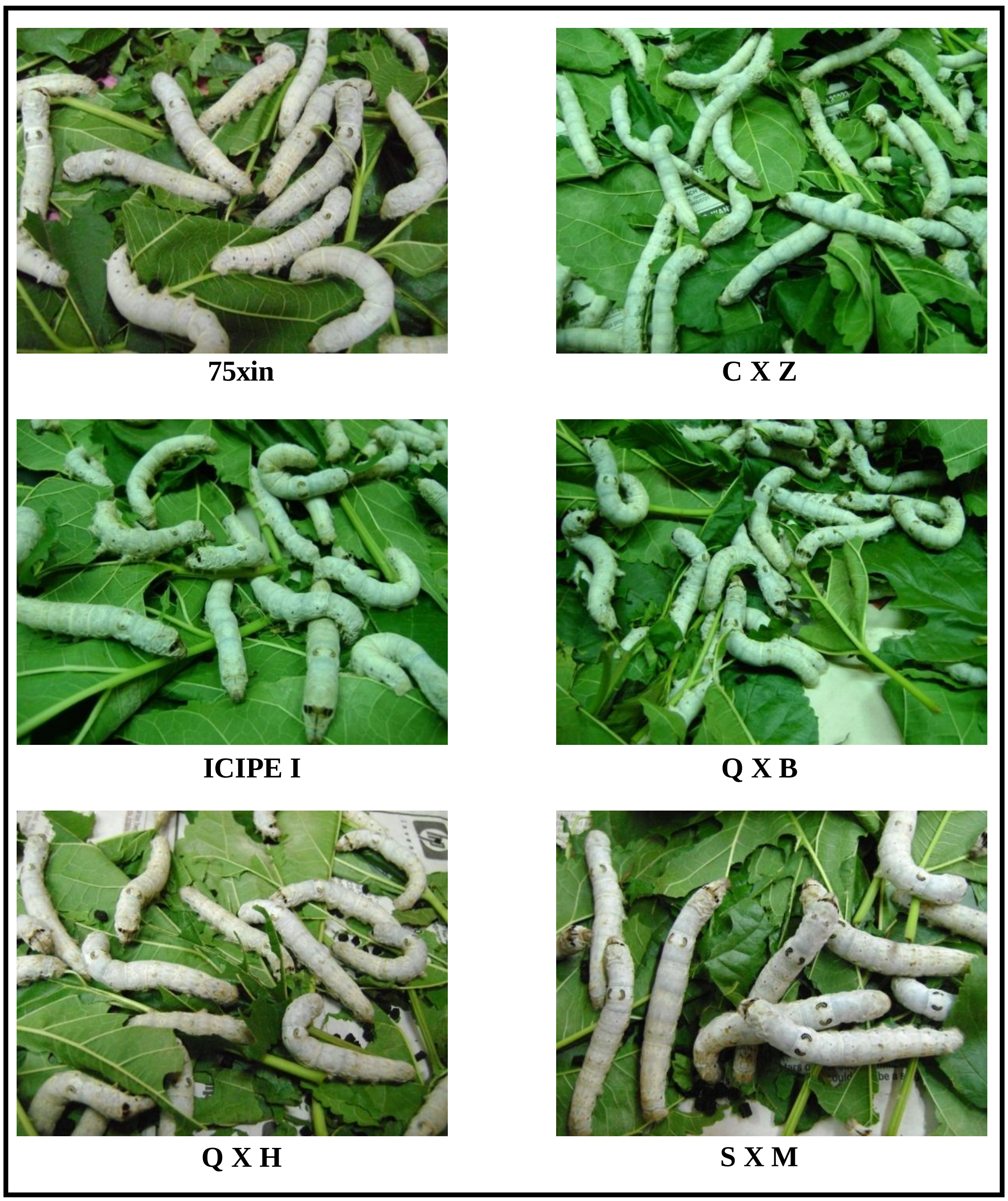
Mukhopadhyay *et al.,* (2006) in their study note that tearing strength of fabric is found to be very much susceptible to change due to the processing variation, while fabric tensile strength is relatively less sensitive. It is imperative to note that silk undergoes elaborate production processes whereby different machines and personnel are involved in the production. These different production stages may affect the silk fabric quality in more than one ways.

It can therefore be concluded that there is a relationship between silk fibre processing and silk fabric quality. During the raw silk production, the raw silk denier and structure of the yarn will determine the fabric properties and qualities. In addition, environmental factors affect the silk strength properties during testing. The personnel processing the fibre also influence its qualities consequently affecting the silk fabric quality to some extent.

## 4.4 Performance of *B. mori* Silkworm in Kenya

The specific objective was to rear six selected bivoltine silkworm strains, namely: C X Z, Q X B, Q X H, S X M, 75xin and ICIPE I (Plate 4.3), analyze their performance, identify suitable characteristics of these strains for production of silkworms of high cocoon shell ratio, filament length and low mortality.

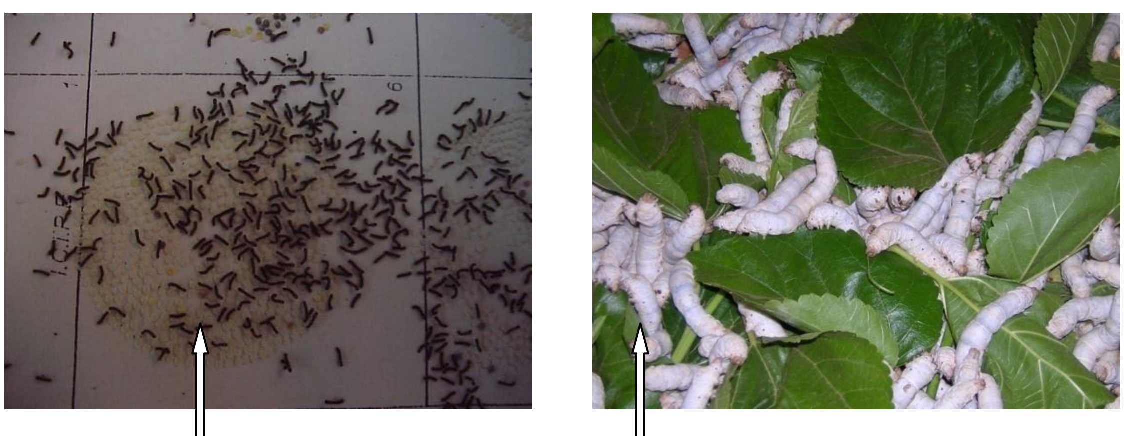
**Plate 4. 3. Fifth instar silkworm larvae of selected strains**



### 4.4.1 Larval development and characteristics

It was observed that upon hatching, the silkworm larvae of all strains were a gray-black colour, however on reaching the third instar this changed to an off white color (Plate 4.4). It was noted that the newly hatched larvae of all strains stayed close to the eggs and did not move around much after hatching. This nature persisted even in advanced stages of the larvae. These observations concur with Cappellozza (2002), who notes that silkworm races differ in certain important characteristics. Further, Nguku *et al.,* (2009a) and Aruga (1994) observed in their studies that the activities of young larvae vary with the silkworm strain. In the Chinese races, soon after hatching the young larvae do not move around but remain near the eggs. On the other hand, in the Japanese and European races, the young larvae are extremely active and move around. This feature follows the same trend even in advanced stage of the larvae.

**Plate 4. 4. Young-age and late -age silkworm larvae**



Gray/black coloured larvae before brushing

Off white coloured late – age larvae

Significant variations in larval duration were noted within the silkworm strains and rearing conditions/seasons. ICIPE I recorded the shortest larval development period in S1 during SR and it was significantly shorter (F = 12.61; df = 71; P = 0.05) compared to that of the other strains. However, it was not statistically different to that of the C X Z. Varying larval development periods were recorded in all strains during SR in S2, however the performance of the strains was not significantly different with an exception of ICIPE I and SXM. The two strains had significantly different larval periods, with ICIPE I recording the shortest and SXM the longest larval periods, 29.77 ± 5.56 and 33.30 ± 6.19 days respectively. These results relate to other studies by Singh *et al.*, (2002), who noted that under ideal conditions the silkworm completes cocoon formation in 24 -28 days from the day of hatching. Raina (2000) similarly notes that the larval lifespan of the *B. mori* is 25 – 30 days. However, variation in the larval span due to fluctuation in temperature and humidity can occur.

During LR in S1 significantly different larval periods were recorded (F= 8.54; df = 71; P = 0.05). ICIPE I and 75xin strains had significantly shorter larval periods (28.40 ± 5.27 and 28.50 ± 5.24 days) compared to QXH and SXM strain (32.37 ± 6.01 and 33.47 ± 6.21 days) respectively. All the six strains had shorter developmental larval periods in S1 compared to S2. The differences were statistically different in some cases. These results concur with Sanchez (2001) study, which revealed that silkworm breeds vary significantly in terms of hatching percentage, and larval duration. However during LR, larval development periods of all the six strains did not have statistically significant differences under S2 (Table 4.17).

**Table 4.17. Average Larval Duration in Locations S1 and S2 During Season SR and LR**

| Season/Location | Strain | | | | | |
|---|---|---|---|---|---|---|
| | **ICIPE I** | **CXZ** | **75xin** | **QXH** | **QXB** | **SXM** |
| SRS1 | 26.53 ± 5.03aA | 29.86 ± 5.55abA | 30.90 ± 5.74bA | 30.27 ± 5.62bA | 31.17 ± 5.61bA | 31.37 ± 5.84bA |
| SRS2 | 29.77 ± 5.56aB | 30.87 ± 5.73abA | 31.07 ± 5.77abA | 30.97 ± 5.74abA | 32.30 ± 5.90abA | 33.30 ± 6.19bA |
| LRS1 | 28.40 ± 5.27aA | 30.30 ± 5.63abA | 28.50 ± 5.24aA | 32.37 ± 6.01bA | 30.33 ± 5.63abA | 33.47 ± 6.21bA |
| LRS2 | 27.27 ± 5.07aA | 28.30 ± 5.25aA | 28.37 ± 5.29aA | 30.50 ± 5.63abA | 30.20 ± 5.47aA | 30.30 ± 5.63abB |

Means followed by the same small letter within rows and same capital letters within columns are not significantly different (P >0.05) by Tukey's test.

In this study, rearing of the silkworms was done in rearing trays and shoot rearing beds in both locations respectively. The temperature and humidity maintained in location S1 and S2, relate to results of a study done by Tazima (1978) that, noted temperatures in the range of 21–27$^{O}$C with relative humidity (RH) of 70–85% are required for rearing. It is worth to further note that the ability of silkworms to produce is affected by seasonal factors such as temperature and humidity, as verified by the silkworms reared in the two locations during the two seasons.

It has been well established that efficiency in silkworm production is often lower during and after the hot season. One reason for the reduction in their productive performance might be elevated ambient temperatures, which induce heat stress (Lertsatitthanakorn *et al.*, 2006). In related studies Singh *et al*, (2002), performed a research where a chawki-rearing technique named “Chawki Foam Pad Cover" developed at Central Research Station BAIF, to avoid unfavorable environmental conditions was used. This technique showed better growth, uniform moulting and better survival rate (10%) during the chawki stage and ultimately, cocoon production. Optimum temperatures of 26 ± 2$^{O}$C and humidity 80 ± 5%RH respectively were maintained.

### 4.4.2 Larval weight

During the LR season, ICIPE I had the highest larval mean weight of 4.73gms, it was noticed that during the SR season, it also had the highest larval mean weight, whereas 75xin had the least larval weight which was at 3.5gms (Fig 4.6a).

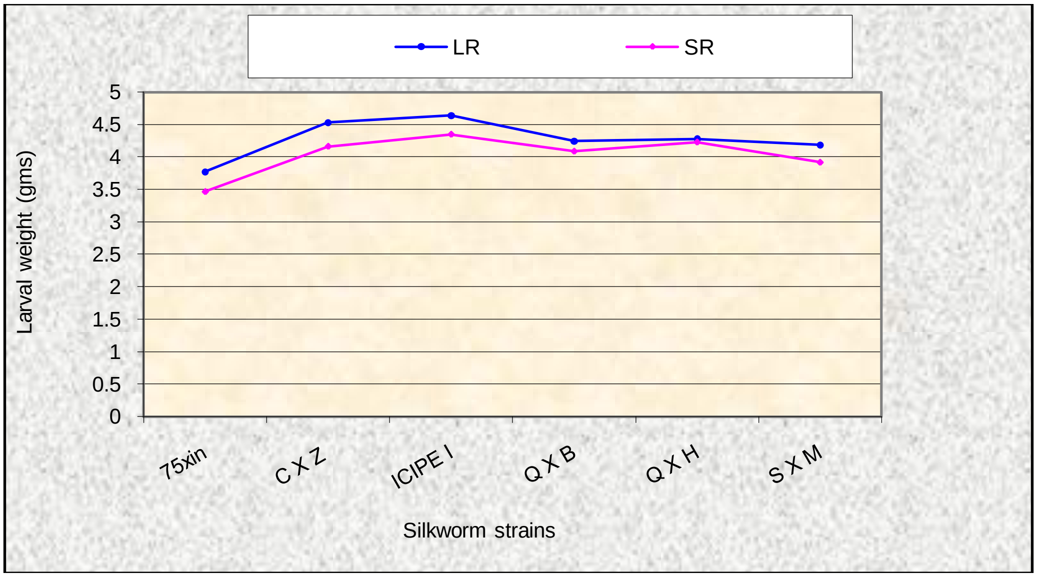



**Fig. 4.6 a. Mean larval weight during the two seasons**

Balanay (2002) cites the standard larval weight as 3.6 – 4.0 grammes per silkworm. In this study the average mean larval weight of the silkworms reared in S1was 4.21gms and 3.8gms in S2. Accordingly it was within and above the cited averages by Balanay (2002). There are various factors, which could have contributed to the results; regular feeding of the silkworm larvae with mulberry leaves of high nutritious value resulting in well-developed healthy larvae, favourable rearing conditions and hygiene during the rearing period affects the larval development and weight as a result. Quader *et al*., (1992) found out that nutritional value of mulberry leaves was directly reflected on the larval growth. Thus there is a possibility that the quality of the leaves may have influenced the silkworm larval development. In addition Rahmathulla *et al*., (2002); Aftab *et al*., (1998); Takano and Arai (1978) ascertained that nutritional background of the larval stage significantly influences the status of the resulting larva.

Rearing during the two seasons didn't reflect any significant difference in Q X B, and Q X H. On the other hand, conditions in the two locations didn't affect mean larval weight of C X Z, Q X B, Q X H and S X M (Fig 4.6 b).

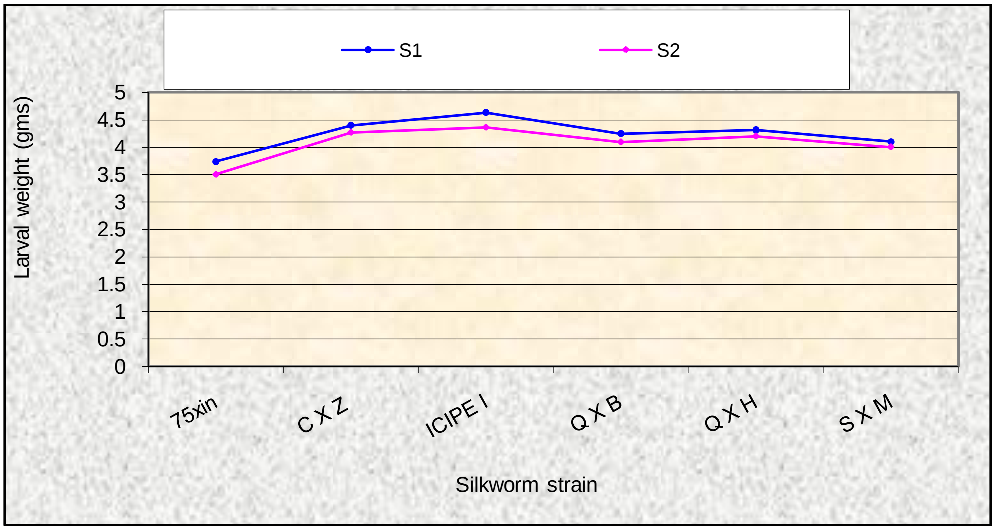



**Fig. 4.6 b. Mean larval weight in the two locations**

In this study, rearing of the silkworms was done in rearing trays and shoot rearing beds in both locations respectively. In location S1, temperature and humidity was maintained at 26$^{O}$C and 85% for young age rearing and 24$^{O}$C and 70% for late age rearing, respectively. Location S2 temperature and humidity was between 24 - 27$^{O}$C and 84 -86%, for the young age and 23-24$^{O}$C and 65 - 70%. It is feasible that the difference in larval weight in S1 and S2 was due to several factors, which include differing environmental conditions in the two locations and rearing techniques.

In contrast, difference in larval weight of silkworm reared in the same environmental conditions and techniques can be attributed to individual strain characteristics. This significant difference in weight concurs with studies done by Nguku *et al.,* (2009a; 2008b) and Sanchez (2001), where they noted that silkworm breeds vary in terms of weight. It is also important to point out that larval weight could have been affected by the ability of the different silkworm strains to assimilate consumed food in varying percentages (Aruga, 1994).

During the early age rearing, silkworms were fed on chopped leaves and as they grew during the late age rearing, they were fed on whole leaves. This was replicated in the two locations during the two seasons. The larvae showed a steady larval mean weight increase, ICIPE I gaining a maximum larval mean weight of 4.73gms. This feeding method was found most appropriate as Dhepe *et al*., (2000) found in his research. He studied the effect of different feeding methods viz. chopped leaf method, entire leaf method, chopped wet leaf method, entire wet leaf method on the growth and cocoon parameters of silkworm *B. mori*. Entire leaf method showed better performance and indicated the potential for field use. In addition Vainker (2004), notes that silkworm consume a prodigious quantity of mulberry leaves, which have to be in constant fresh supply. He adds that the best way of rearing silkworms was on large trays where both leaves and worm could be spread out in a dry ventilated environment.

Singh *et al.*, (2002) research revealed that, chawki-rearing technique named "Chawki Foam Pad Cover" developed at Central Research Station BAIF, to avoid unfavorable environmental conditions, showed better growth, uniform moulting and better survival rate (10%) during the chawki stage and ultimately, cocoon production. Optimum temperatures of 26 $\pm$ 2$^{O}$C and 80 $\pm$ 5% RH respectively, were maintained.

### 4.4.3 Larval Mortality

Mortality of the silkworm larvae was observed only during the late age rearing. ICIPE I was the only strain that had no mortalities recorded during the first to third instar. It was eminent among the strains that ICIPE I also had the lowest mortality percentage of 0.6 and 0.8% in S1 and S2 respectively, whereas Q X H had the highest of 2.6 and 3.3% in S1 and S2 respectively. Mortality increased steadily from the third instar and it was noted that it was highest during the fifth instar in all strains (Fig 4.7 a. and 4.7 b). Mortality occurred during the study at different stages and it is important to point out that it was noted only during late age rearing and reached its peak during the fifth and final instar of the silkworm larvae. Sen *et al*, (1969) reported mortality was accelerated from the third instar onwards. Similar observations by Wilson (1984) concluded that 3$^{rd}$ instar larvae and above are more susceptible.

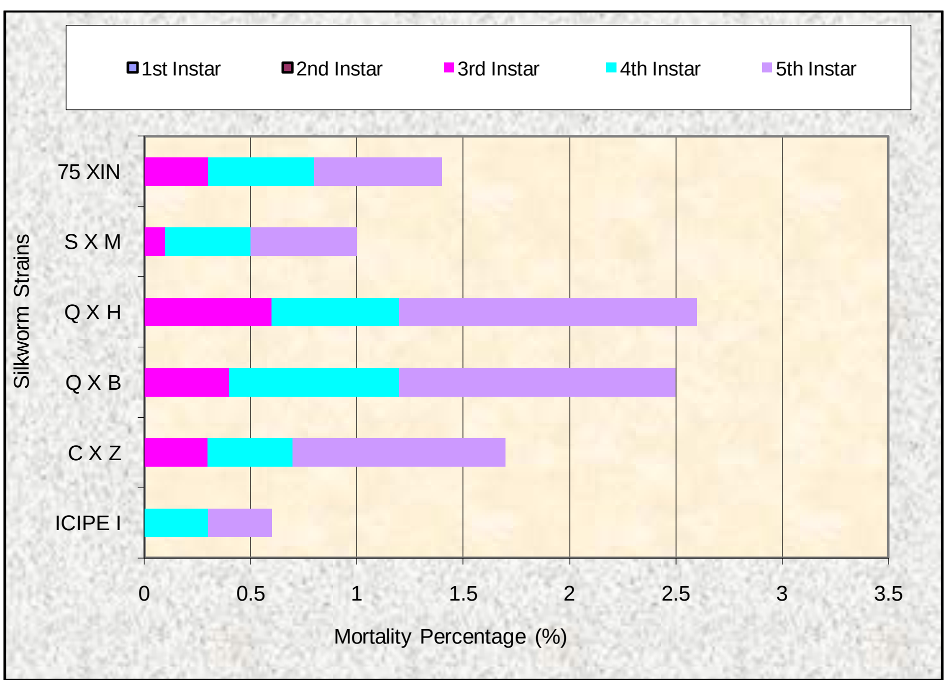



**Fig. 4. 7 a Larval mortality percentage in location S1**

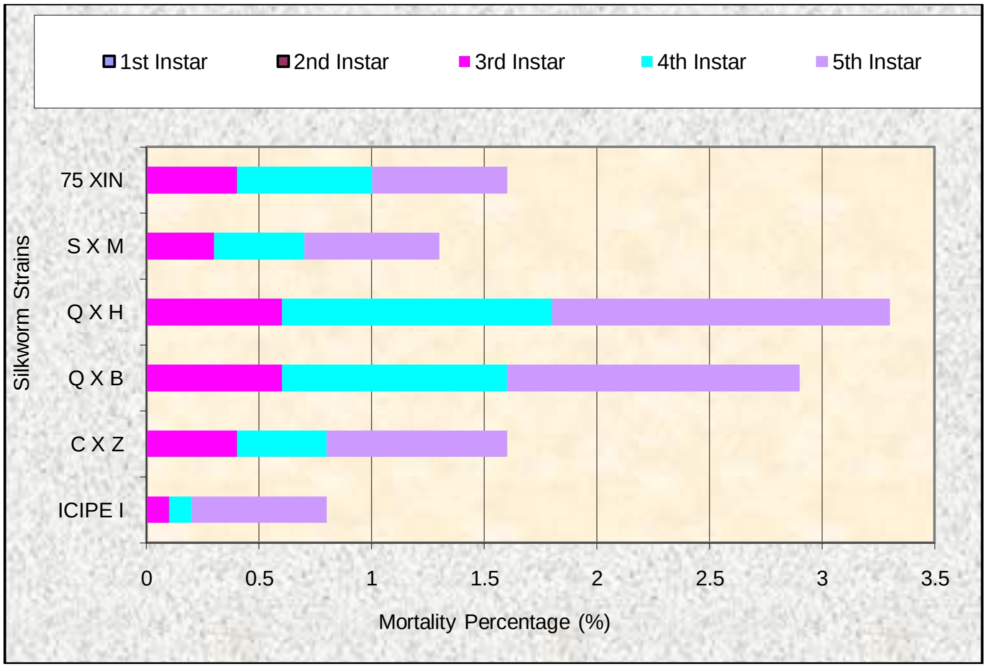



**Fig. 4.7 b Larval mortality percentage in location S2**

Mortality was noticeably higher in location S2 during fifth instar at 5.4% compared to location S1's 5.1% (Fig 4.7 c). It was also highest in the late age rearing (3rd to 5th instars) and lowest in the young age rearing (1st and 2nd instar) at 0% in both locations S1 and S2 for all strains studied. These results concur with Sen *et al.*, (1969) findings in their study.

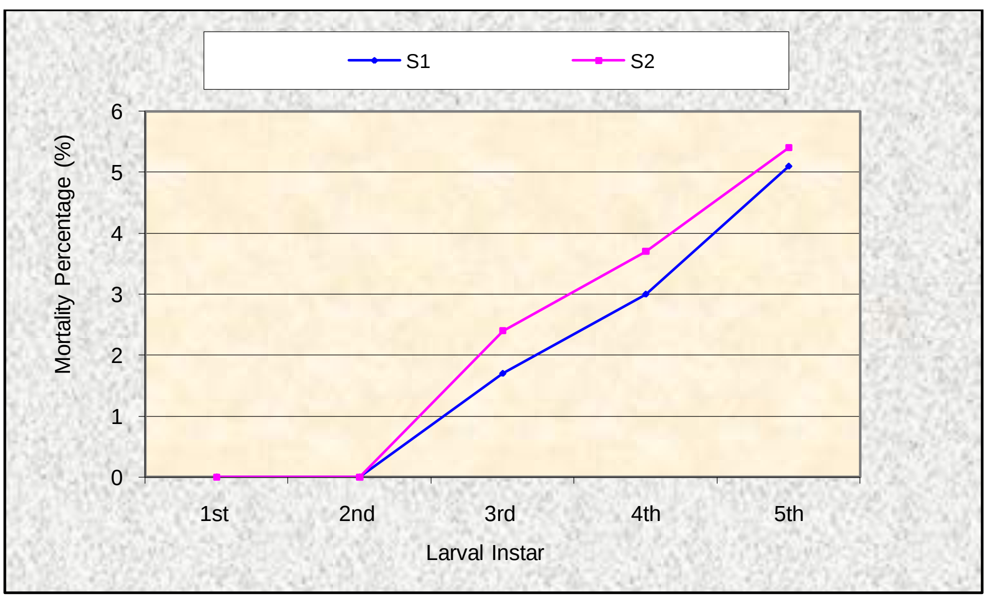



**Fig 4.7 c Comparison of mortality % in location S1 and S2**

High mortality in S2 can be attributed to the environmental conditions, which may have not been consistent with the required optimum temperatures and relative humidity. Raina, (2000) noted that for the young age rearing, temperature and humidity should be maintained at $26^{O}C$ and 85% respectively, while for the late age rearing, temperature and humidity should be $24^{O}C$ and 65 - 70% respectively. In this study it was vital to maintain conditions in S2 as normal, to enable for performance comparison to be carried out using pertinent conditions found in the farmers' field.

**4.4.4 Weight of larvae in relation to consumed food.**

The larvae of fifth instar silkworms reared in isolation were monitored on a daily basis. The waste, fresh feed and unconsumed mulberry were weighed daily and recorded. A comparison of the average larval weight (LW) and average weight of the consumed food (CF) from the two locations (S1 & S2) was done. Weight of the consumed food was calculated as a percentage of the average larval weight to establish the relationship between larval weight and amount of food consumed.

Amount of consumed food was evidently reflected in the larval weight. The silkworm larvae were able to convert high percentages of food into their own body weight. These percentages ranged between 85.21 and 88.55% in *S1* and 85.19 and 87.67% in *S2* (Table 4.18). It was also noted that in location *S1,* average amount of consumed food, as a percentage of average of average larval weight was slightly higher across the strains compared to location *S2.* It was apparent that ICIPE I was able to convert the highest percentage of consumed food into its weight, 88.55 and 87.65% for locations *S1* and *S2* respectively, while Q X H and 75xin had the least percentages in both locations.

**Table 4.18: Average weight of 5th instar larvae in relation to average amount of consumed food in Locations S1 and S2**

| Strain | Location | Ave. Amount of food consumed (dry) FC (gms) | Ave. Weight of 5th instar larvae LW (gms) | FC as % of LW |
|---|---|---|---|---|
| **75xin** | S1 | 3.17 | 3.72 | 85.21 |
| | S2 | 2.99 | 3.51 | 85.19 |
| **C X Z** | S1 | 3.84 | 4.40 | 87.27 |
| | S2 | 3.64 | 4.20 | 86.67 |
| **ICIPE I** | S1 | 4.10 | 4.63 | 88.55 |
| | S2 | 3.91 | 4.46 | 87.67 |
| **Q X H** | S1 | 3.69 | 4.31 | 85.60 |
| | S2 | 3.57 | 4.18 | 85.41 |
| **Q X B** | S1 | 3.69 | 4.25 | 86.80 |
| | S2 | 3.53 | 4.10 | 86.10 |
| **S X M** | S1 | 3.57 | 4.10 | 87.07 |
| | S2 | 3.50 | 4.04 | 86.63 |

Feeding ratio was not restricted during the study, as previous studies have shown that there is no significant difference in the parameters. Nicanora *et al*., (2002), performed an experiment to evaluate larval performance when fed on different feeding ratios. Results showed that all the parameters on the raw silk production data have no significant difference among treatments.

The relationship between larval weight and consumed food is important in sericulture for one to be able to rear economical strains in terms of food consumption. Despite differences in environmental conditions (temperature and humidity), which may affect the silkworms' appetite in one way or another, another contributing factor could have been the strains ability to assimilate consumed food. Stoyan *et al*., (1985) reported that feeding also has strong influence on larval mortality and quality cocoon production as well as their larval duration as larvae feed only during their larval period.

It has been noted in related studies that rearing temperature has an important influence on the efficiency of food utilization by larvae of the silkworm *Bombyx mori* L. During this study ICIPE I was able to convert the highest percentage of consumed food into its weight, 88.55 and 87.65% for locations S1 and S2 respectively. These percentages concur with Krishnaswami *et al*., (1973) study that revealed silkworms utilize 85-88% of total leaf consumption during 5$^{th}$ instar, ranging over a period of about 8 days. Muniraju *et al.*, (2004) performed an experiment where food intake and utilization efficiency in *B. mori* reared at different temperature combinations was assessed, viz. 26, 28, 30 and 32°C during instars I to III and combinations of these temperatures during later instars (IV and V). The amount of dry food consumed by silkworms reared at 28°C during young-age, than at the other temperatures was significantly higher, but a significant decrease in conversion efficiencies.

This study demonstrated that ICIPE I assimilated a big percentage of the consumed food compared to the other strains, thus gained more larval weight in both locations. The more the larvae consumed, the heavier they became. However it is important to note that the strains individual characteristics play an important role in deciding the ingestion behaviour. Other factors that could have influenced this behaviour include method of leaf supply and quantity of mulberry leaves supplied during rearing.

#### 4.4.5 Quantity of mulberry consumed and the amount of silk produced

Table 4.19 shows the percentages of cocoon weight (CW) and cocoon shell weight (CSW) against the quantity of consumed food (CF) by the silkworm larvae. A wide variation among the strains was noted during this study, the percentage of total cocoon weight to the amount of food consumed was between 50 –58% whereas that of the cocoon shell weight was between 9 and 10%. These results relate with Aruga's (1994) study where he noted a wide variation in a similar study, 55 – 60% and 10 – 13% respectively and observed that the amount and percentage of assimilated food differed according to different environmental conditions during rearing. It is also well known that the temperature and humidity as well as texture of the leaves have much influence on this aspect.

**Table 4.19: Relationship of cocoon weight and cocoon shell weight to the quantity of consumed food in location S1 and S2.**

| Strain | Location | CW (gms) | CF (gms) | CW as % of CF | CSW (gms) | CSW as % of CF |
|---|---|---|---|---|---|---|
| C X Z | S1 | 1.95 | 3.84 | 50.57 | 0.33 | 8.59 |
| | S2 | 1.89 | 3.64 | 51.93 | 0.31 | 8.52 |
| Q X H | S1 | 1.94 | 3.69 | 52.57 | 0.35 | 9.49 |
| | S2 | 1.89 | 3.57 | 52.94 | 0.32 | 8.93 |
| Q X B | S1 | 1.84 | 3.69 | 49.86 | 0.32 | 8.67 |
| | S2 | 1.83 | 3.53 | 51.84 | 0.31 | 8.78 |
| 75xin | S1 | 1.73 | 3.17 | 54.17 | 0.30 | 9.46 |
| | S2 | 1.74 | 2.99 | 58.19 | 0.30 | 10.03 |
| S X M | S1 | 1.80 | 3.57 | 50.42 | 0.35 | 9.80 |
| | S2 | 1.78 | 3.50 | 50.85 | 0.35 | 10.00 |
| ICIPE I | S1 | 2.14 | 4.10 | 52.20 | 0.38 | 9.27 |
| | S2 | 2.09 | 3.91 | 53.45 | 0.36 | 9.21 |

CW: Cocoon Weight; CF: Consumed Food; CSW Cocoon Shell Weight

The relationship of the weight of cocoon shell and the amount of food consumed is important in determining which strain gives better percentage of silk production to the amount of mulberry leaves actually consumed. Even while selecting the races; it is desirable to select those races, which produce higher quantity of silk per unit of feed consumed (Aruga, 1994).

It was evident that there was a link between the consumed food (CF) by the silkworms and the cocoon weight (CW). The more food consumed, the heavier the cocoon. ICIPE I had the highest CW, CF and cocoon shell weight (CSW) in locations S1 and S2. On the other hand 75xin had the least CW, CF and CSW. This relates to Machii and Katagiri (1991) research, where they noted that the there was high correlation between leaf protein level and production efficiency of cocoon shell, which means cocoon shell weight to the total amount of mulberry leaves consumed by the silkworm.

It has been documented in related studies that rearing temperature has an important influence on the efficiency of food utilization by larvae of the silkworm *Bombyx mori* L. During this study ICIPE I was able to convert the highest percentage of consumed food into its weight, 88.55 and 87.65% for locations S1 and S2 respectively. These percentages concur with results of Krishnaswami *et al.*, (1973) study that revealed silkworms utilize 85-88% of total leaf consumption during 5$^{th}$ instar, ranging over a period of about 8 days. Similarly, studies to assess food intake and utilization efficiency in *B. mori* reared at different temperature combinations viz. 26, 28, 30 and 32°C during instars I to III and combinations of these temperatures during later instars (IV and V) have been performed. They have revealed that the amount of dry food consumed by silkworms reared at 28°C during young-age, than at the other temperatures was significantly higher, but a significant decrease in conversion efficiencies (Muniraju *et al.*, 2004).

Table 4.20 shows comparative performance tests of cocoon, pupa, shell and larval weights in the two locations. Results show that there was a significant difference in the means of cocoon, pupa and shell weight across the strains. 75xin had the lowest CW, PW and SW irrespective of the season and location, on the other hand ICIPE I had the highest means in these same parameters in the two locations respectively. It is interesting to note that ICIPE I's means of cocoon, pupa and larval weight respectively, had no significant differences within the seasons and locations.

Cocoons obtained from S1 location were larger and heavier compared to those of S2 location. It has been reported that *Bombyx mori* yields superior quality cocoons at optimum temperatures (22-23°C) and humidity (60-70%) (Yokoyama, 1962). Ventilation during spinning is crucial for a good cocoon quality (Indiaagrovet, 2008; Aruga, 1994; Krishnaswami *et al.*, 1973). These observations could be as a result of the conditions, which differed in S1 and S2. These results relate to reports that high temperature followed by strong fluctuation results in poor quality cocoons of *B. mori* (Ullal and Narasimhanna, 1987).

In related studies, Rahmathulla *et al.*, (2006) noted that most of the feed conversion efficiency parameters related to digesta, such as efficiency of digested food into larvae, cocoon and shell were not significantly different between the control and the treated batches. Results indicated that higher assimilation and conversion of food was observed in silkworm treated with antibiotic. It can therefore be inferred that quantity of mulberry consumed plays an important role in silk production.

**Table 4.20: Comparative performance of cocoon, pupa, shell and larval weights**

| Strain | Season | Location | Mean CW | Mean PW | Mean SW | Mean LW |
|---|---|---|---|---|---|---|
| 75xin | LR | S1 | 2.013 ± 0.014 c | 1.731 ± 0.011 e | 0.283 ± 0.005 e | 3.869 ± 0.012 f |
| | LR | S2 | 1.971 ± 0.016 d | 1.685 ± 0.015 d | 0.284 ± 0.004 c | 3.682 ± 0.014 e |
| | SR | S1 | 1.454 ± 0.030 b | 1.142 ± 0.253 b | 0.314 ± 0.007 d | 3.608 ± 0.026 f |
| | SR | S2 | 1.517 ± 0.026 c | 1.190 ± 0.024 cd | 0.325 ± 0.005 c | 3.335 ± 0.022 e |
| C X Z | LR | S1 | 2.204 ± 0.011 b | 1.878 ± 0.010 bc | 0.324 ± 0.005 c | 4.552 ± 0.014 b |
| | LR | S2 | 2.136 ± 0.013 c | 1.831 ± 0.013 c | 0.307 ± 0.003 b | 4.455 ± 0.019 b |
| | SR | S1 | 1.705 ± 0.035 a | 1.318 ± 0.032 a | 0.338 ± 0.006 c | 4.244 ± 0.012 c |
| | SR | S2 | 1.640 ± 0.033 b | 1.260 ± 0.029 b | 0.320 ± 0.007 c | 4.088 ± 0.018 b |
| ICIPEI | LR | S1 | 2.531 ± 0.014 a | 2.150 ± 0.012 a | 0.379 ± 0.007 a | 4.725 ± 0.010 a |
| | LR | S2 | 2.458 ± 0.009 a | 2.130 ± 0.008 a | 0.331 ± 0.004 a | 4.566 ± 0.012 a |
| | SR | S1 | 1.741 ± 0.031 a | 1.369 ± 0.028 a | 0.371 ± 0.006 b | 4.539 ± 0.009 a |
| | SR | S2 | 1.728 ± 0.030 a | 1.352 ± 0.027 a | 0.387 ± 0.005 a | 4.164 ± 0.034 a |
| Q X H | LR | S1 | 2.196 ± 0.012 b | 1.851 ± 0.010 d | 0.347 ± 0.006 b | 4.345 ± 0.013 c |
| | LR | S2 | 2.142 ± 0.010 c | 1.837 ± 0.008 c | 0.303 ± 0.004 b | 4.228 ± 0.041 c |
| | SR | S1 | 1.697 ± 0.030 a | 1.340 ± 0.028 a | 0.362 ± 0.005 b | 4.286 ± 0.008 b |
| | SR | S2 | 1.636 ± 0.030 b | 1.291 ± 0.027 ab | 0.342 ± 0.005 b | 4.180 ± 0.013 a |
| Q X B | LR | S1 | 2.195 ± 0.013 b | 1.858 ± 0.011 cd | 0.328 ± 0.007 c | 4.301 ± 0.012 d |
| | LR | S2 | 2.185 ± 0.012 b | 1.878 ± 0.011 b | 0.305 ± 0.003 b | 4.201 ± 0.015 cd |
| | SR | S1 | 1.483 ± 0.027 b | 1.171 ± 0.026 b | 0.305 ± 0.005 d | 4.196 ± 0.007 d |
| | SR | S2 | 1.468 ± 0.027 c | 1.162 ± 0.024 d | 0.314 ± 0.005 c | 3.990 ± 0.019 c |
| S X M | LR | S1 | 2.195 ± 0.015 b | 1.886 ± 0.012 b | 0.301 ± 0.005 d | 4.128 ± 0.012 e |
| | LR | S2 | 2.181 ± 0.014 b | 1.873 ± 0.014 b | 0.308 ± 0.004 b | 4.159 ± 0.015 d |
| | SR | S1 | 1.712 ± 0.034 a | 1.332 ± 0.030 a | 0.390 ± 0.007 a | 3.985 ± 0.011 e |
| | SR | S2 | 1.630 ± 0.025 b | 1.240 ± 0.023 bc | 0.388 ± 0.005 a | 3.857 ± 0.015 d |
| $F_{\alpha=0.05, 7,352}$ | LR | S1 | 117.61 | 118.94 | 33.48 | 416.24 |
| $F_{\alpha=0.05, 7,352}$ | LR | S2 | 113.87 | 105.42 | 11.24 | 165.02 |
| $F_{\alpha=0.05, 7,352}$ | SR | S1 | 11.99 | 8.29 | 21.34 | 378.87 |
| $F_{\alpha=0.05, 7,352}$ | SR | S2 | 8.11 | 5.37 | 27.09 | 156.00 |

Means followed by same letters in the same column are not significantly different (t-test, $\propto = 0.05$).

CW: Cocoon Weight; PW: pupa Weight; SW: Shell Weight; LW: Larval Weight

In conclusion, there were differences in the overall performance of the silkworm strains that were reared with ICIPE I definitely having superior qualities compared to the others. It is evident from this study that the silkworm strains and environmental/rearing conditions played a major role in the overall development of the larvae. These also influenced the larval mortality and duration, which are economic traits. The environmental/rearing conditions influenced the ability of the different strains to assimilate food, which determined the larval, cocoon and cocoon shell weights. These were reflected in the silk filament length, an important cocoon property. The nutritional value of the mulberry on the other hand, plays a significant role in determining production of quality cocoons. This study verified that the overall performance of the silkworm strains reared was mainly related to the strains and environmental conditions hence it is possible to formulate appropriate silkworm rearing procedures suitable for Kenya, and advise silk farmers on the appropriate strains and rearing conditions for optimum production.

# CHAPTER FIVE

# SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

## 5.0 Introduction

This chapter highlights the summary of the study, conclusions drawn and recommendations derived from the research. In addition, suggestions for further research have been made.

## 5.1 Summary

This study sought to evaluate and establish the raw silk and silk fabric qualities, and cocoon properties produced by the bivoltine *B. mori* silkworm, through the rearing of six selected silkworm strains. The study also sought to verify if there were differences in the production performance of the silkworm strains.

### 5.1.1 Objectives

The study was guided by four specific objectives:

1. Evaluate the cocoon properties of six *B. mori* silkworm strains, namely Chun-Lei X ZhengZhu (C X Z), QuiFeng X BaiYu (Q X B), Quingsong X Haoyoe (Q X H), 75xin X 7532, Suju X Minghu (S X M) and ICIPE I.
2. Establish the properties of raw silk produced by the six *B. mori* silkworm strains.
3. Determine quality of silk fabric produced by the six *B. mori* silkworm strains.
4. Verify if there are differences in the production performance of the six *B. mori* silkworm strains

### 5.1.2 Literature Review

Literature reviewed indicated that despite the large number of man-made fibres overwhelming the textile arena, natural fibres are making a comeback. With new research, the rising awareness of the environmental impacts of producing and disposing of synthetic fibres, and the rising cost of petroleum-based source materials, natural fibres offer increasingly practical alternatives. Of the natural fibres, silk indeed commands considerable respect. The *B. mori*, which is believed to have been derived from the original mandarins silkworm, *Bombyx mandarina,* is fully domesticated and is the most important silk-producing insect and produces probably more than 99% of the worlds' silk.

With international demand for silk outstripping world production by 12%, the worldwide demand for silk is increasing. This indicates excellent opportunities for any country to increase her silk production, an opportunity valuable for Kenya to embark on. In order to secure this opportunity, it is important for production of silk products to be of utmost quality. However Africa's enormous potentials in raw silk production are faced with some limitations. Apart from the lack of infrastructure and sufficient inputs, sericulture industry in Africa faces lack of technical expertise at various levels of the production processes. The review revealed that limited study on silk quality has been carried out in Kenya.

Literature further revealed that compared to other natural fibres, silk has certain specific characteristics that set it apart. However, in order to ensure that silk meets the required standards various tests are carried out, and include, winding breaks, cleanliness and neatness, tenacity and elongation among others, which are used to grade silk. In addition, quantitative characters, such as cocoon weight, shell weight, shell ratio and filament length, are jointly controlled by multiple genes and environmental factors, and are important in ascertaining the properties of silk cocoon. The review highlighted that silkworm strains are the most important element for development of silk industry, as they are the key factors determining silk quality. Together with environmental conditions, silk fibre and fabric production processes directly influence the quality of cocoons and silk fibre and fabric.

Studies have been carried out in countries like China, Japan, India, Philippines among others, on the performance of silkworm strains. These studies indicate that it is necessary to carry out similar studies locally to enable for the improvement of certain practical aspects like silkworm rearing and mounting; and contribute to the production of quality cocoons and subsequently silk fibre and fabric. This will also enable for Kenyan silk to compete internationally and regionally in the silk market.

### 5.1.3 Methodology

An experimental design was used in this study. Six strains were reared namely; C X Z, Q X B, Q X H, 75xin X 7532, S X M and ICIPE I. Using one disease free egg laying (dfl) of each strain per rearing, data was gathered. Experiments were set up in ICIPE Duduville Campus in Kasarani, Nairobi and the Kenya Bureau of Standards (Kebs), to verify silk fibre and fabric properties and quality control assessment. Observations were made on various aspects of silkworm larval development. The silkworm rearing was done in two locations, S1 and S2, during two seasons, long rains (LR) and short rains (SR).

Statistical analysis of results was carried out using Analysis of Variance (ANOVA) (PROC GLM, 2000) and t-test. The parameters were analyzed according to silkworm strains, seasons and locations. Larval duration, mortality, cocoon, pupa and shell weight, cocoon thickness and size were analyzed according to strains, locations and seasons. Data comparison among strains, (C X Z, Q X B, Q X H, 75xin X 7532, S X M and ICIPE I), seasons (LR and SR) and locations (S1 and S2) was done using independent T – test. The International Silk Association classification (ISA) standards were used for the raw silk quality analysis and Kebs procedures were used for the silk fabric examination.

### 5.1.4 Research Findings

A brief discussion of the results is presented in this section, which summarizes the findings of the four objectives of the study as specified in 5.1.1.

#### 5.1.4.1. Objective 1

**Evaluate the cocoon properties of six *B. mori* silkworm strains, namely Chun-Lei X ZhengZhu (C X Z), QuiFeng X BaiYu (Q X B), Quingsong X Haoyoe (Q X H), 75xin X 7532, Suju X Minghu (S X M) and ICIPE I.**

This study established that the rearing location affected the cocoon weight significantly for all the silkworm strains, however on the other hand, it was noted that the cocoon size was not affected. The study further verified that there was significant difference in the cocoon weight and no significant difference in the size during the two seasons. In addition, the cocoon size was not affected by the silkworm strain during the study.

In this study, comparative performance tests in the two locations demonstrated that there was a significant difference in the means of cocoon, pupa and shell weight. The locations in which the silkworms were reared had different environmental conditions in terms of temperature and humidity. This study established that these environmental factors affected the cocoon crop.

Results in this study established that the longest silk filament length, 1183.35m was attained during the Long Rains season (LR), and weighed 0.355gms. Cocoon thickness on the other hand ranged between 2.404 and 2.310. There seems to have been no relation between the cocoon thickness; and the length and weight of the filament. Results clearly indicated that within the same strain, the size of the bave varied with the season.

Comparison of filament length of the selected strains within the two locations, S1 and S2, indicated that the heaviest cocoon weight of 2.23 and 2.18gms; and cocoon size of 3.58 and 3.40 was achieved by ICIPE I silkworm strain in both locations respectively. On the other hand, 75xin had the shortest filament length in both S1 and S2. However it is important to point out that the lengths were within acceptable standards.

An analysis of the size of bave revealed that the strain with the longest filament length had the heaviest filament weight. However there seems to be minimal relationship between the cocoon thickness to the length or weight of the cocoon. Results indicate that within the same strain, the size of the bave varied with the season of rearing. These observations may have been as a result of the environmental conditions the silkworms were subjected to. From the research findings, it is clear that the silkworm strains and ecological conditions influence the larval development and hence affect the silk cocoon properties.

This study established the cocoon properties of the six silkworm strains reared and further demonstrated that ICIPE I had superior cocoon properties among the six strains, in terms of cocoon weight, size and thickness; shell weight, filament length and weight.

The average cocoon properties of the six silkworm strains that were reared in this study are summarized in Table 5.1.

**Table 5.1: Average cocoon properties of six *B. mori* silkworm strains**

| STRAIN<br>PARAMETER | 75xin | C X Z | ICIPE I | Q X B | Q X H | S X M |
|---|---|---|---|---|---|---|
| **Cocoon weight (gms)** | 1.83 | 2.07 | 2.21 | 1.91 | 1.96 | 1.99 |
| **Cocoon Size** | 2.79 | 3.33 | 3.49 | 3.01 | 3.05 | 3.13 |
| **Cocoon Thickness** | 2.40 | 2.40 | 2.40 | 2.40 | 2.40 | 2.37 |
| **Shell Weight (gms)** | 0.30 | 0.32 | 0.37 | 0.32 | 0.34 | 0.35 |
| **Filament Length (m)** | 966.08 | 1049.44 | 1160.60 | 989.26 | 1033.98 | 983.11 |
| **Filament Weight (gms)** | 0.29 | 0.31 | 0.35 | 0.30 | 0.31 | 0.30 |

#### 5.1.4.2. Objective 2

**Establish the properties of raw silk produced by the six *B. mori* silkworm strains.**

This study established that raw silk produced during SR in S2 had the highest winding breaks recorded during the duration of the study. It further verified that silk harvested during SR had more breaks compared to those of the LR and this trend was also perceived in silk from the two locations. Raw silk produced in S2 location had more breaks in most strains compared to S1. This study established that raw silk winding breaks varied among the different strains and it was apparent that they were mainly caused by size deviation as opposed to split ends. Size deviation and split ends are defects that are caused by human error during the reeling process as well as silkworm strain characteristics to a minor percentage.

This study established that the seasons did not affect the elongation percentages of the silk. It was further illustrated that silkworm strains having the highest elongation count, had the least winding breaks and vice verse. This study verified that average tenacity and elongation for the raw silk analysed was 3.93g/d and 18.5% respectively, with ICIPE I having the highest tenacity of between 4.25 and 3.99g/d; and elongation percentages between 19 and 20%. The tenacity of the other strains ranged between 3.98 and 3.81g/d. It was evident from the results that silk harvested during LR had higher tenacity and average elongation percentages compared to silk harvested during SR.

This study established that location S1 produced better raw silk in terms of cleanliness and neatness qualities, as opposed to S2 during the two seasons. ICIPE I cleanliness and neatness percentages were higher than the other silkworm strains during the two seasons, 96 and 93% respectively. The lowest cleanliness percentage was 87% and 85% during the two seasons. The lowest neatness percentage was 87% attained by S X M strain during both seasons. Silk neatness and cleanliness differed among the silkworm strains reared in this study, further confirming that raw silk properties were influenced by the different strain characters. The same pattern as above was observed in the neatness and cleanliness qualities of larvae reared in the two locations.

This study determined the properties of raw silk produced by the six *B. mori* silkworm strains (Table 5.2). Further it was established that cocoon qualities influenced the raw silk qualities, which were within the acceptable ISA standards (Table 5.3).

**Table 5.2: Properties of raw silk produced by the six *B. mori* silkworm strains**

| STRAIN<br>PARAMETER | 75XIN | C XZ | ICIPE I | Q X B | Q X H | S X M |
|---|---|---|---|---|---|---|
| **Winding (Breaks)** | 13.25 | 8.75 | 4.75 | 8.50 | 12.25 | 11.50 |
| **Tenacity (grams)** | 3.82 | 3.94 | 4.12 | 3.88 | 3.84 | 3.86 |
| **Elongation (%)** | 18.00 | 18.75 | 19.75 | 18.25 | 18.00 | 18.25 |
| **Cleanliness (%)** | 91.75 | 93.80 | 96.50 | 91.80 | 89.05 | 92.70 |
| **Neatness (%)** | 86.00 | 88.00 | 93.40 | 87.90 | 88.00 | 86.90 |

**Table 5.3: Grading raw silk produced by the six *B. mori* silkworm strains**

| STRAIN<br>PARAMETER | 75XIN | C XZ | ICIPE I | Q X B | Q X H | S X M |
|---|---|---|---|---|---|---|
| **AUXILLIARY** | **CLASS** | | | | | |
| **Winding (Breaks)** | (3) | (2) | (2) | (2) | (3) | (3) |
| **Tenacity (grams)** | (1) | (1) | (1) | (1) | (1) | (1) |
| **Elongation (%)** | (1) | (1) | (1) | (1) | (1) | (1) |
| **MAJOR ITEMS** | **GRADE** | | | | | |
| **Cleanliness (%)** | 3A | 4A | 4A | 3A | A | 2A |
| **Average Neatness** | B | A | 3A | A | A | A |
| **Low Neatness** | 2A | 3A | 4A | 3A | 3A | 3A |

**5.1.4.3. Objective 3**

**Determine properties of silk fabric produced by the six *B. mori* silkworm strains.**

Results verified that there were no significant differences in the weight of the silk fabric samples tested from S1 and S2 as well as during LR and SR. The average mass per unit was 639.66g/$m^2$ for the six strains studied, and variance between the highest and lowest fabric mass was a minimal 0.45g/ $m^2$. Further this study established the different silkworm strains had an effect of on fabric mass. The study verified that there were differences in the masses and they differed significantly.

This study evaluated the effect various silkworm strains had on the breaking load and revealed that there was no significant difference on the warp and weft among the six strains. The mean warp breaking load was 124.08 ± 0.03N while the mean weft breaking load was 256.15 ± 0.036N. Further it was established that the breaking load was significantly different between the two locations respectively. It was verified that during the two seasons, LR and SR, there were no significant difference in the breaking load of both warp and weft. It was established that the silkworms reared at optimum conditions had superior results, an indication that it is important to maintain temperature and humidity during rearing and especially during the spinning period to ensure quality results.

This study verified that there were significant differences in the tearing strengths of the warp and weft in both locations. The tearing force of the warp yarns ranged between 390.36 and 395.26N in S1 and 390.36 and 395.3N in S2. The weft yarns had a tearing force of between 311.96 and 325.03N in S1 and 311.96 and 321.76N in S2. However on the other hand, it was established that during the two seasons there was no evident significant difference in the tearing strengths of the warp and weft.

During this study it was established that there was a significant difference in the tearing strength among the silkworm strain. It was further established that the tearing strength was significantly different between the two locations for the warp and weft. It was verified that that there was significant differences in the tearing strengths of warp and weft in both locations, whereas in contrast the seasons did not affect the tearing strength during the two seasons.

In conclusion, this study established that silk processing procedures, influenced the silk fabric qualities especially the tearing strength. From the finding, appropriate post harvest processing procedures can thus be formulated for quality production of silk fibre and fabric. The silk fabric properties established in this study are illustrated in Table 5.4.

**Table 5.4: Silk fabric properties produced by six *B. mori* silkworm**

| STRAIN<br>PARAMETER | 75XIN | | C XZ | | ICIPE I | | Q X B | | Q X H | | S X M | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fabric Weight ($g/m^2$) | 639.45 | | 639.73 | | 639.90 | | 639.70 | | 639.53 | | 639.67 | |
| | **Warp** | **Weft** | **Warp** | **Weft** | **Warp** | **Weft** | **Warp** | **Weft** | **Warp** | **Weft** | **Warp** | **Weft** |
| **Fabric Count** | 50 | 28 | 50 | 28 | 50 | 28 | 50 | 28 | 50 | 28 | 50 | 28 |
| **Breaking Load (N)** | 123.89 | 255.95 | 124.08 | 256.25 | 124.18 | 256.43 | 124.00 | 256.03 | 124.13 | 256.06 | 124.21 | 256.21 |
| **Elongation (mm)** | 7.15 | 3.80 | 7.70 | 4.15 | 8.00 | 4.30 | 7.25 | 4.00 | 7.95 | 3.95 | 8.05 | 4.10 |
| **Tearing Strength (N)** | 390.36 | 318.50 | 392.00 | 323.40 | 395.28 | 318.50 | 393.60 | 311.96 | 393.50 | 316.86 | 391.93 | 317.68 |

#### 5.1.4.4. Objective 4

**Verify if there are differences in the production performance of the six *B. mori* silkworm strains.**

This study established that there were significant variations in larval duration for the different strains. Larval duration ranged between 26.53 and 33.47days. It was further established that the duration of the second instar was the shortest and lasted two days irrespective of the strain, location or season. Ecdysis for all instars lasted 24 hours irrespective of rearing location and season. Results also verified that all the six strains had shorter developmental larval periods in S1 compared to S2.

It was established that there were various factors, which contributed to the larval development and differences in larval weight and included, regular feeding of the silkworm larvae with mulberry leaves of high nutritious value resulting in well-developed healthy larvae, favourable rearing conditions and hygiene during the rearing period.

The study further established that silkworm mortality occurred only during the late age rearing. Interestingly, ICIPE I was the only strain that had no mortalities recorded during the first to third instar. The study illustrated that high mortality especially in S2 was due to the environmental conditions, which may have not been consistent with the required optimum temperatures and relative humidity.

This study demonstrated that there was a link between the mulberry consumed by the silkworms and the cocoon weight; the more food consumed, the heavier the cocoon. It also verified that there was a wide variation in the amount of silk produced in relation to quantity of mulberry consumed amongst the strains was noted. It was established that the highest larval mean weight was achieved during the LR season. It was further demonstrated that ICIPE I strain had the highest larval mean weight during both seasons while 75xin had the least larval weight. This study established that the quality of mulberry influenced the larval development, as the nutritional value of mulberry leaves was directly reflected on the larval growth.

This study verified that the difference in larval weight in S1 and S2 was due to several factors, which include differing environmental conditions in the two locations and rearing techniques. On the other hand difference in larval weight of silkworm reared in the same environmental conditions and techniques was attributed to individual strain characteristics. Further it was verified that larval weight was affected by the ability of the different silkworm strains to assimilate consumed food in varying percentages.

This study verified that there was a link between the food consumed by the silkworms and the weight of the cocoons. The more food consumed, the heavier the cocoon. In addition ICIPE I had the highest cocoon weight (CW) and cocoon shell weight (CSW) in locations S1 and S2. Further the study established that the rearing temperature and humidity have important influence on the efficiency of food utilization by the silkworm.

This study verified that the overall performance of the silkworm strains reared was mainly influenced by the strains and environmental conditions. On the other hand the food plant and ability of the silkworm to assimilate and convert the food This forms a foundation where appropriate sericulture procedures can be formulated for silkworm rearing in Kenya. In addition, appropriate strains and rearing conditions for optimum production can be identified.

This study established that performance by the six strains differed and ICIPE I silkworm strain emerged superior in terms of larval duration, larval weight, cocoon weight, cocoon shell weight, hence more productive and suitable for commercial rearing. Further it had minimal mortality. However it was noted that it consumed more food than the other strains. On the other hand Q X H and S X M had good cocoon shell weight results which, is an important factor in commercial silk production. Of the six strains reared, 75xin had the least desirable economic traits, cocoon weight and cocoon shell weight (Table 5.5).

**Table 5.5: Average performance of six *B. mori* silkworm**

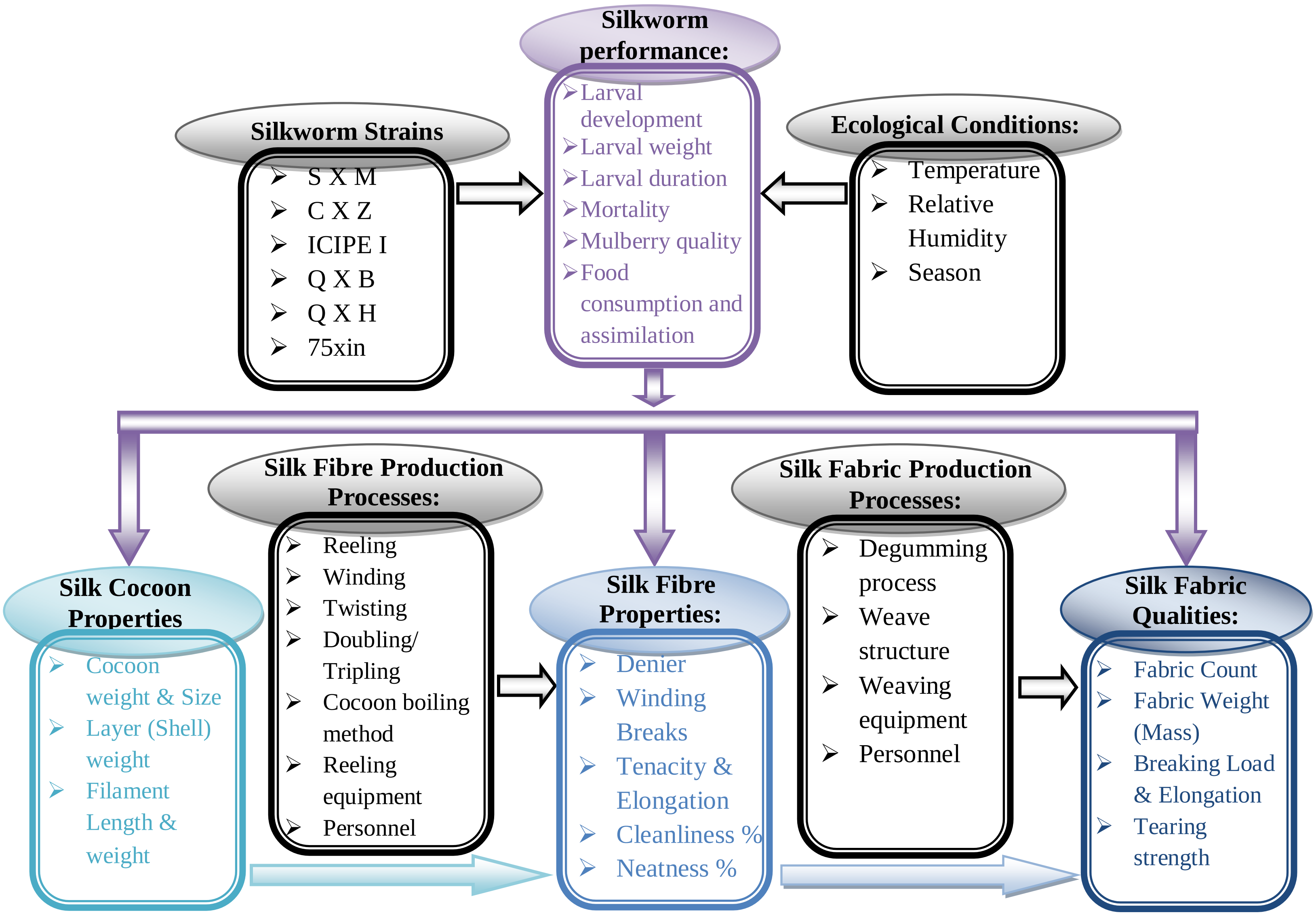
| STRAIN<br><br>PARAMETER | 75XIN | C XZ | ICIPE I | Q X B | Q X H | S X M |
|---|---|---|---|---|---|---|
| **Larval duration** | 29.71 | 29.83 | 27.77 | 31.03 | 30.00 | 32.11 |
| **Larval weight (LW)** | 3.63 | 4.33 | 4.50 | 4.18 | 4.26 | 4.06 |
| **Larval mortality (%)** | 1.15 | 1.65 | 0.70 | 2.70 | 2.95 | 1.65 |
| **CF as % of LW** | 85.20 | 86.97 | 88.11 | 86.45 | 85.50 | 86.85 |
| **Cocoon weight** | 1.74 | 1.92 | 2.11 | 1.84 | 1.92 | 1.79 |
| **Cocoon shell weight (CSW)** | 0.30 | 0.32 | 0.37 | 0.32 | 0.34 | 0.35 |
| **CSW as % of CF** | 9.75 | 8.55 | 9.24 | 8.55 | 9.21 | 9.90 |

#### 5.1.4.4. Factors related to production of quality silk fibre and fabric

The conceptual model (presented in Figure 1.1) was applicable in this study and its relevance was illustrated by the comprehensive interaction and relationship established between the independent/dependent variables and silk fibre and fabric qualities. The findings of this study relate to this conceptual model and established factors that influenced and determined the *B. mori* silk fibre and fabric properties.

The concepts illustrated in Figure 5.1 indicate that:

- There is a strong link between the silkworm strains and ecological conditions during rearing, which determine the various aspects of silkworm larval performance.
- Silkworm larval performance characteristics significantly influence the silk cocoon, fibre and fabric properties.
- Some aspects of the silk cocoon properties, collectively with silk fibre production processes play a major role in determining the silk fibre properties.
- The silk fibre properties combined with fabric production processes influence and determine the fabric properties.




Source: Researcher, 2009

**Fig 5.1 Factors related to quality silk fibre and fabric production**

## 5.2 Conclusions

The textile industry is becoming an increasingly competitive environment and the silk industry can play an important role in our economy. This can be facilitated through improving silk production and processing procedures; and silk cocoon, fibre and fabric quality. In view of the preceding findings, it can be concluded that:

1. Ecological conditions (temperature and humidity) and the silkworm strains influence larval development (larval duration, larval weight, mortality, cocoon, pupa and shell weights, filament length and weight), hence affecting the silk cocoon properties.
2. Larval mortality is minimal during young age silkworm rearing but increases steadily during late age rearing for all the strains especially those reared in the locations that lack optimum rearing conditions.
3. Consumption of mulberry leaves influences larval weight, which in turn has a significant influence on cocoon weight, cocoon shell weight and consequently the filament length.
4. The raw silk properties (winding, tenacity, elongation, cleanliness and neatness) are influenced by the different silkworm strain characteristics.
5. Some raw silk defects (winding breaks, cleanliness and neatness) are manmade and can be controlled through appropriate processing procedures for quality production of silk fibres.
6. Raw silk quality for the six strains studied ranged between Class 3 – 1 for the auxiliary parameters and grade 4A – A, for the major items.

7. Silk fibre properties and processing procedures influence the fabric qualities, especially the tearing strength.
8. Conditioning silk samples before testing is paramount for concise and accurate test results.
9. The different post harvest production processes, equipment, applications and personnel affect and influences quality of silk fibre and fabric.
10. ICIPE I silkworm strain had the most economical traits, compared to the other five strains, for field rearing in Kenya, in terms of larval duration, mortality, cocoon and shell weights and filament length. In addition it is superior to the other strains in fibre and fabric properties and quality performance.

**5.3 Outcomes**

1. A silk fibre quality control laboratory was established at *icipe*. This is the only silk quality control laboratory in East and Central Africa.
2. The study established ICIPE I as a superior strain in terms of performance and consequently suitable for commercial rearing and production of quality silk cocoons in Kenya.
3. Sericulture was identified as a viable activity for income generation that addresses the Millennium Development Goal No.1 (Eradicate extreme poverty and hunger).
4. Sericulture was recognized as an activity that offers alternative employment avenues and in so doing addresses unemployment issues, an element in Kenya's Vision 2030.

## 5.4 Recommendations

1. Quality production of silkworm cocoons, fibre and fabric needs to be combined with proper silkworm rearing and silk production practices. This therefore calls for incessant training of technicians and farmers in the silk industry in pre cocoon and post harvest technologies. *icipe*'s Commercial Insects Programme, Kenya Bureau of Standards (KEBS) and Kenya Agricultural Research Institute (KARI) are involved in some of these trainings. However there is need for the training to comprise certificate, diploma and degree levels for extension workers especially in silkworm rearing, the backbone of sericulture.

2. High-quality silkworm varieties that adapt to the local environment is an important method for increasing cocoon yield, improving cocoon, fibre and fabric quality, and enhancing profits. Hence the need for research institutions to embark on silkworm hybridization and research on adversity-resistant, high quality cocoon producing silkworm strains suitable for Kenya.

3. KEBS, KARI and *icipe* to continue participatory adaptive research based on sericulture to validate further and promote silk quality and production of silk based products. Thus improve production through the development of sericulture technologies.

4. KEBS together with the relevant textile stakeholders to draft a standard method against which silk fabric can be tested and graded.

5. There is significant potential for employment, including off farm at every stage of the sericulture process. It is practical for income generation and has the potential to address income and food security needs.

6. There is significant educational potential for farmers and research staff training. This includes strengthening of scientific staff, local and regional research capability and backstop adoption of technical packages for cooperation, which can be shared.

### 5.4.1 Suggestions for further research

Further research could be carried out as follows:

1. The properties of silk fibre and fabric of selected strains were established during this study; consequently research should be carried out to ascertain the effect silk processing personnel and equipment/machinery have on raw silk and fabric quality. This study would focus more on the equipment used in the production process and its effect on the quality of the raw silk and fabric realized as well as the personnel involved in the production.
2. The relationship between the molecular structure of silks and their mechanical and physical properties needs to be studied to verify how they influence each other in relation to quality silk production
3. A study focusing on appropriate silkworm rearing procedures needs to be carried out with a view of creating working protocols for use beyond the laboratory, in the silk industry in Kenya.

**REFERENCES**

Adolkar V.V. Raina S.K. & Kimbu D. M (2007). Evaluation of various mulberry Morus spp. (Moraceae) cultivars for the rearing of the bivoltine hybrid race Shaanshi BV-333 of the silkworm *Bombyx mori* (Lepidoptera: Bombycidae). *International Journal of Tropical Insect Science.* Vol. 27, No. 1, pp. 6–14.

Aftab, C.A. Chandrakala, M.V. Shivakumar, C. & Raghuraman, R. (1999). Food and water utilization patterns under restricted feeding durations in *Bombyx mori* of Pure Mysore race. *J. Exp. Zool.* India 129-34.

Ahmad, I. Rahayu, R. Permana, A.D. & Astari, S. (2007). Alteration of Ecdysteroid titre by Thyroxine and Juvenile Hormone Analogue (Methoprene) in *Bombyx mori* (Lepidoptera: Bombycidae). *Biota*. 12(2): 116-121.

Akai, H. Kimura, K. Kiguchi, M. & Shibukawa, K. (1985). An increase of silk production by repeated treatment with a juvenile hormone analogue. *J. Seric. Sci. Japan.* 54: 297-299.

Akinkunmi, O.A. & Odebiyi, J.A. (2001). Chemical control of *Anthrenus oceanicus* attacking stored cocoons of the silkworm with commercial formulations containing permethrin, tetramethrin, phenothrin and allethrin. *Pakistan Journal of Biological Sciences.* 4 (4): 400-401.

Anon, (1996). Manual on bivoltine silk reeling. JICA Bivoltine Sericulture Technology Development Project, CSTRI, Central Silk Board, Bangalore.

Aruga, H. (1994). Principles of sericulture. Oxford and IBH publishing Co. Pvt. Ltd, 66 Janpath New Delhi, India, pp. 376.

Arunkumar, K.P. Matta, M. & Nagaraju, J. (2006). Molecular phylogeny of silk moths reveals the origin of domesticated silkmoth, *Bombyx mori* from Chinese *Bombyx mandarina* and paternal inheritance of *Antheraea proylei* mitochondrial DNA. *Molecular Phylogenetics and Evolution*. 40 (2): 419–427. doi:10.1016/j.ympev.2006.02.023

Asakura, T. (2007). Some Observations on the Structure and Function of the Spinning Apparatus in the Silkworm *Bombyx mori*. Biomacromolecules, 8 (1), 175 -181. 10.1021/bm060874z S1525-7797(06)00874-9. Web Release Date: November 29, 2006. *American Chemical Society*.

Asakura, T. & Kaplan, D. L. (1994). Silk Production and Processing. *Encyclopedia of Agricultural Science*. C. J. Arutzen and E. M. Ritter (eds). Academic Press, London. Vol 4, 1—11.

Asano, S. Kuwano, E. & Eto, M. (1986). Anti-juvenile hormone activity of Imidazole compound (KK-22) and its dimunition by Methoprene in the 4th instar silkworm, *Bombyx mori*. L. *Applied Entomology Zoology*. 21 (1). pp 63-69.

ASTM 1424 (1944). Standard test for tear resistance by falling pendulum (Elmendorf) apparatus.

Bafana, B. (2009). Wild silk cocoons go from livestock hazard to potential new industry in rural Zimbabwe. *New Agriculturist*.

Balanay, P.G. (2002). Performance evaluation of newly F1 silkworm hybrids under laboratory condition. *PTRI TC*, Kalingagan, Phillipines.

Ballenberger, W. & Ballenberger, L. (2007). Properties and Characteristics of Silk. Retrieved June 3, 2009, from http://ezinearticles.com/Properties-and-Characteristics-of-Silk.

Basaen, A. M. & Josue, J. J. (2001). Comparative evaluation of cocoon properties of four bivoltine silkworm strains. *Samay Bulletin*, v.1, p.1.

Becker, M.A. Willman, P. & Tuross, C.N. (1995). The U.S. first ladies gowns: A biochemical study of silk preservation. *Journal of the American Institute for Conservation*. Volume 34, Number 2, Article 5 (pp. 141 to 152)

Bharathi, D. & Yungen, M. (2000). The impact of juvenile and moulting hormone analogues on silk quality of silkworm, *Bombyx mori* L. Fed on mulberry leaf and artificial diet. *Philippine Journal Science*. 129 (2): 125-130.

Booth, J.E. (1974). Principles of textile testing. 3rd Ed. An Introduction to physical methods of testing textile fibre, yarn and fabrics London, England, pp. 583.

Broudy, E. (1979). The book of looms. A history of the handloom from ancient times to the present. University Press of England. ISSN 0 – 87451-649 - 8

Brown, S.G. Boettner, G.H. & Yack, J.E. (2007). Clicking caterpillars: acoustic aposematism in Antheraea polyphemus and other Bombycoidea. *J. Exp. Biol.* 210(6): 993-1005.

Bunsell, A.R. (ed) (2009). Handbook of tensile properties of textile and technical fibres. Woodhead Textiles Series No. 91. ISBN 1 84569 387 6. Pages 664.

CISEO (Center for Insect Science Education Outreach) (1997). Silk information. The University of Arizona

Chattopadhyay, S.D.R. Gulrajani, M.L & Sen, K. (2005). Study of property and structural variants of mulberry and tasar silk filaments. *Autex Research journal*. Vol 5, No 2. http://www.autexrj.org/No2-2005/0123.pdf *81*

Cherry, R. (1993). Sericulture. *Bulletin of the Entomological Society of America*. Volume 35. Pp 83 – 84.

Corbman, B.P. (1985). Textiles: Fibre to Fabric. (6th Ed) McGraw book Company, Singapore.

Dam J.E.G (2009). Environmental benefits of natural fibre production and use. Discover natural fibres 2009. Technical Paper No. 56. In the proceedings of the symposium on natural fibres held on 20th October 2008.

Das, S. & Medda, A. (1998). Effect of cyanocobalamine on protein and nucleic acid contents of ovary of silkworm, *Bombyx mori* L. during larval, pupal and adult stages of development. *Insect Sci. Appl*. 9, 641 646.

Dash, R. Ghosh, S.K. Kaplan, D.L and Kundu, S.C (2007). Purification and biochemical characterization of a 70kDa sericin from tropical tasar silkworm *Antheraea mylitta*. *Comp. Biochem. Physiol*. Part B, 147: 129-134.

Datta, R.K. & Nanavaty, M. (2007). Global Silk Industry. A complete source book. APH Publishing Corporation. ISSN 81-313-0087-0

Devaiah, M.C. and Reddy, D.N. (1999). Sericulture an Overview. In: Advances in Mulberry Sericulture, Devaiah, M.C., K.C. Narayanaswamy and V.G. Maribashetty (Eds.). CVG. Publications, Bangalore, India.

Dhamija, S. & Choptra, M. (2007). Tearing strength of cotton fabrics in relation to certain processes and loom parameters. *Indian Journal of Fibre and Textile Research.* Vol 32. Pp 439 – 445.

Dhawan, S. & Gopinathan, K.P. (2003). Functional genomics of Silk Gland Development. Abstracts from Sixth International Workshop on the Molecular Biology and Genetics of the Lepidoptera. Journal of Insect Science, 3:36. pp16

Dhepe, V. S. Singh, K.K. Gokhale, S.B. & Jadhav, D.V. (2000). Performance of Silkworm *Bombyx mori* (L) by different feeding methods under Western Maharashtra Conditions. BAIF Development Research Foundation.

Dingle, J.G. Hassan, E. Gupta, M. George, D. Anota, L. & Begum, H. (2005). Silk Production in Australia. RIRDC Publication. No 05/145. RIRDC project No UQ-96A

Dingle, J. (1998). Silk and Silkworm Production. Commercial Production of Silk. International Centre for Training and Research in Tropical Sericulture, Central Silk Board, Mysore, India.

Donia, W. (2001). As smooth as silk. *S & T Post Feature*. Volume XIX. No. 5

Doshi, G. (2006). Indian Silk Industry. Retrieved August 17, 2009, from http://ezinearticles.com/?Indian-Silk-Industry&id=364907

Down, J. (1999). Design and technology. Textile Technology to GCSE. Oxford University Press.

Economic Development Associates, (1990). Manual silk reeling in south India. A preliminary study of technology transfer. Report by Economic Development associates.

Elices, M. Perez-Riqueiro, J. Plaza, G.R. & Guinea, G.V. (2005). Finding inspiration in *Argiope Trifasciata* Spider Silk. An article from *JOM*: A Hypertext-Enhanced Article.

Eyre, N. (1956). Testing of Yarns and fabrics: With Special reference to Viscose Rayon. The Wiliam Morris Press Limited, Manchester: Great Britain. pp.75.

Fakuda, T; Kamegama, T.; Matsuda, M. A (1963). Correlation between the mulberry leaves consumed by the silkworm larvae in different ages of the larval growth and production of the cocoon fiber spun by the silkworm larvae and the eggs laid by the silkworm. *Bull.Seric.* Exp. Stn., 18 : 165- 171

Faruki, S.I. (1998). Nutritive effects of thianomin® enriched mulberry leaves on the silkworm, *Bombyx mori* L. *Univ. J. Zool. Rajshahi Univ*. 17: 39-44.

Faruki, S.I. Khan A.R. Mannan, A. (1992). Fecundity and fertility of the silkworm, *Bombyx mori* L. fed on mulberry leaves supplemented with para-amino benzoic acid. *Bangladesh J. Zool*. 20: 351-353.

Foo, C.W.P & Kaplan, D.L (2002). Genetic engineering of fibrous proteins: *Spider Adv. Drug Deliver Rev*., 54: 1131-1143.

Franck, R. (Ed) (2001). Silk, mohair, cashmere and other luxury fibres. Woodhead Publishing Limited. 264 pages

Freddie, G. Mossotti, R. & Innocenti, R. (2003) Degumming of silk fabric with several proteases. *Journal of Biotechnology*. Volume 106, Issue 1. Pp 101 – 112.

Garner, W. (1967). Textile Lab Manual: Additional Methods. Vol 6. Cox and Wyman Limited, London

Gaddum, A.H. (2006). "Silk", Business and Industry Review. In Encyclopedia Britannica.

Gautam, M. Bhattacharya, S.K. Mazumdar, P.K & Moon, M.A. (2009). A review on chemical processing of silk Colourage. Colour Publications, Bombay, India. Vol 56. No 2, Pp 48-52. ISSN 0010-1826

Goldsmith, M.R. Shimada, T. & Abe, H. (2004). The genetics and genomics of the silkworm, *Bombyx mori*. *Annu. Rev. Entomol.* 50: 71-100. PMID 15355234. doi:10.1146/annurev.ento.50.071803.130456

Gongyin, Y and Cui H (1995). Some features of silk producing moths. *Tropicultura.* 24 1, 30 .33.

Grimaldi, D & Engel, M.S. (2005). Evolution of the Insects. Cambridge University Press. Cambridge, New York, Melbourne. XV. Pp755. ISBN 0 521 82149 5.

Harbone, J.B. (1977). Introduction to the Ecological Biochemistry. New York: Academic Press Inc.

Hardingham, M. (1996). The potentials for silk in Africa. Spore No. 61 pp5

Hariraj, G. & Somashekar, T.H (2006). Studies on reeling performance and quality characteristics of raw silk reeled from multibivoltine crossbreed and bivoltine hybrid cocoons. *The Journal of Silk Science and Technology of Japan.* Vol. 15, Pp 37-42.

Hattenschwiler, P. & Farber, C. (1999). Application: Quality Assurance and Quality Improvement. The Silk Standard Committee of the International Silk Association (ISA/AIS).

Hirst, K. K. (1997). Silkworms: Animal Domestication. About.com: Archaeology.

Hirobe, T. (1968). Characterization of silkworm races. *Proceedings of International Congress of Genetics.*

Hiware, C.J. & Ambedkar B (2005). Effect of Phytolacca Berry, Homoeopathic Drug Fortified Mulberry Leaves on V Instar Larvae, Cocoon and Post Cocoon Characters of *Bombyx Mori* L. Aurangabad-431004, (M.S.), India.

Hodak, S.K. Supasai, T. Paosawatyanyong, B. Kamlangkla, K. & Pavarajarn, V. (2008). Enhancement of the hydrophobicity of silk fabrics by SF6 plasma. *Applied Surface Science.* 254. Pp 4744–4749.

Howitt, F.O. (1946). Bibliography of the technical literature on silk. New York: Hutchinson's Scientific and Technical Publications.

Huang, S.Q. Zhao, H.P. Feng, X.Q. Cui, W. Lin, Z. & Xu, M.Q. (2008). Mechanical properties of cocoons constructed consecutively by a single silkworm caterpillar, *Bombyx mori*. *Acta Mechanica Sinica*. Volume 24, Issue 2, pp.151-160

Hummel, R.E. (2005). Understanding materials science. From natural fibers to man-made plastics. History, Properties, Applications. 2nd Ed. Springer New York. ISBN 978-0-387-26691-6. Pp 326 -365.

IAR (Indian Agricultural Resources) (2000). Management of Rearing, Mounting and production of Cocoon - Sericulture.

ICIPE (1997). Spinning a yarn from the wild. *Spore* No. 71 pp6

ITC (International Trade Centre) (1999). Silk in World Markets. International Trade Forum Issue 1/1999

JAICAF (Japan Association for International Collaboration of Agriculture and Forestry) (2007). *Sericulture in East Africa*. Tokyo , Japan.

Jin, H.J., Park J., Valluzzi, R., Cebe, P. & Kaplan, D.L. (2002). Biomaterial films of *Bombyx mori* fobroin with poly (ethylene oxide). *Biomacromolecules*, 3; 1233-1239.

Jolly, M.S. (1987). Appropriate sericulture techniques (Ed. Jolly, M.S) ICTRETS, Mysore, India, pp.75.

Jolly, M.S. Sen, S.K. Sonwalker, T.N. & Prasad, G.K. (1980). Non-Mulberry Silks. FAO. Italy Rome. ISBN 92-5-100347-5. pp178.

Kadolph, S.J. & Langford, A.L. (2003). *Textiles*. Prentice-Hall, Inc. Simon & Schuster. A Viacom Company. Upper Saddle River, New Jersey, 07458, 9th Ed pages 61-66 and 82. 356pp

Kajiura, Z. & Yamashita, O. (1989). Super growth of silk glands in the dauer larvae of silkworm, *Bombyx mori* induced by a juvenile hormone analogue. *J. Seri. Sci. Jpn*. 58 : 39-46.

Kamimura, M. & Kiuchi, M. (1998). Effect of Juvenile Hormone Analog Fenoxycarb on 5th stadium larvae of the silkworm, *Bombyx mori*. L. *Applied. Entomology and Zoology*. 33 (2): 333-338.

Kanafi, R.R., Ebadi, R., Mirhosseini, S.Z., Seidavi, R.R., Zolfaghari, & Etebari, K., (2007). A review on nutritive effect of mulberry leaves enrichment with vitamins on economic traits and biological parameters of silkworm *Bombyx mori* L. *Inv. Sur. J*. 4: 86-91.

Koshy T. D (2001) Indian silk: Challenges for the future – III. Express Textiles. India’s No 1 Weekly for Textile Industry. Mumbai, India.

Krishnaswami, S. Narasimhanna, M.N. Suryanarayan, S.K. Kumararaji, S. (1973). Manual on Sericulture. II Silkworm Rearing. *FAO Agricultural Services Bulletin Rome*, AGS 22 (15) 1-131

KS08 – 32. (1977). Kenya Standard. Conditions for Testing Textiles (1st Edition)

KS08 – 119. (1981). Kenya Standard. Method for determination of breaking load and elongation (strip method) of woven fabrics.

KS08 – 120. (1981). UDC 677.074: 677.017. 282: 513,754. -Kenya Standard: Method for determination of mass per unit length and mass per unit area of woven or knitted fabric.

KS08 – 437. Kenya Standard. Method for determination of tear resistance of woven fabrics by falling pendulum (Elmendorf) apparatus.

Kumar, R.V. Kumar, D. Kumar, A. & Dhami, S.S. (2009). Effect of blue green micro algae (spirulina) on cocoon quantitative parameters of silkworm (*Bombyx mori* L.). *ARPN Journal of Agricultural and Biological Science*. Vol. 4, No. 3. ISSN 1990-6145

Kumar, R. K. (1999). Recent Advaces in Sericulture and Seri-Biotechnology in India. Proceedings of the first international workshop on the conservation and utilization of commercial insects, 18th -21st August 1997. (Edited by Raina, S.K. Nyagode, B. Kioko, E.N. and Mwanycky S.W). *icipe* Science press, Nairobi, Kenya.Pp15 - 28.

Landi, S. (1998). The Textile Conservator’s Manual. 2nd Ed. Elsevier Science Ltd . ISBN 0 7506 3897 4. 677 pages.

Lee, Y-W. (1999). Silk reeling and testing manual. FAO Agricultural Services Bulletin No. 136. Rome, Italy.

Lertsatitthanakorn, C. Rerngwongwitaya, S. & Soponronnarit S. (2006). Field experiments and economic evaluation of an evaporative cooling system in a silkworm rearing house. Silsoe Research Institute. Elsevier Science Ltd.

Lewin, M. & Pearce, E.M. (1998). Handbook of Fiber Chemistry. 2nd Edition. Marcel Dekker, ISBN 0824794710, 9780824794712. Pp. 1083.

Liguan, R.M. & Sanchez, Z.L. (2003). Double Cross Silkworm hybrids for higher silk productivity. *NOMCARRD research*. Philippine Textile Research Institute

Lim, S.H. Kim, Y.T. Lee, S.P. Rhee, I.J. Lim, J.S. & Lim, B.H. (1990). Sericulture training manual. Rome: *FAO Agricultural Services Bulletin*. 80. Pp. 117.

Long, L. (2001). Setting of grainage for potential silkworm races in Africa. Integrating Sericulture and Apiculture Technologies with Regional Development. In the proceedings of the Trainers Course and Third International Workshop on Conservation and Utilization of Commercial Insects. 13th Nov – 8th Dec 2000. ICIPE Science Press. Pp193 -198. ISBN: 92 9064 141 X.

Lucas, F., J.T.B, Shaw, and S. G.Smith. (1958). The silk fibroins. In Advances in protein chemistry, Ed. C. B. Anfinsen Jr. *et al.* New York: Academic Press. 108–242.

Machii, H. and Katagiri, K. (1991). Varietal differences in nutritive values of mulberry leaves for rearing silkworms. *JARQ*, 25:202-208.

Maekawa, H. Takada, N. Mikitani, K. Ogura, T. Miyajima, N. Fujiwara, H. Kobayashi, M. & Ninaki, O. (1988). Nucleolus organizers in the wild silkworm *Bombyx mandarina* and the domesticated silkworm *B. mori*. *Chromosoma* 96: 263–269. doi:10.1007/BF00286912

Mamatha, D. M. Cohly, H.P.P. Raju, A.H.H. & Rao, M.R. (2006). Studies on the quantitative and qualitative characters of cocoons and silk from methoprene and fenoxycarb treated *Bombyx mori* (L) larvae. *African Journal of Biotechnology*. Vol. 5 (15), pp. 1422-1426, ISSN 1684–5315.

Marsh, J.T (1979). Textile Science: An Introductory Manual. BI Publications New Delhi, India pp. 391.

Mayoux, L. (1993). Gender and entrepreneurship: The Indian silk industry. *Dev. Policy Rev.* 11 (4):413-26

Metcalf, C.L & Flint, W.P. (1962). Destructive and Useful Insects. Their Habits and Control. McGraw-Hill Book Company, London. 4th Edition.

Microsoft® Encarta® Online Encyclopedia, (2007). Silkworm. http://ca.encarta.msn.com © 1997-2007 Microsoft Corporation.

Miranda, J.E. Bortoli, S.A. Takahashi, R. (2002). Development and Silk Production by Silkworm Larvae after Topical Application of Methoprene. *Sci. Agric.* 59(3): 585-588.

Mishra, S.P. (2000). A text book of fibre science and technology. New Age International. ISBN 8122412505, 9788122412505. Pp 363.

Mita, K. Kasahara, M. Sasaki, S. Nagayasu, Y. Yamada, T. Kanamori, H. Namiki, N. Kitagawa, M. Yamashita, H. Yasukochi, Y. Kadono-Okuda, K. Yamamoto, K. Ajimura, M. Ravikumar, G. Shimomura, M. Nagamura, Y. Shin-i, T. Abe, H. Shimada, T. Morishita, S. & Sasaki, T. (2004): The Genome Sequence of Silkworm, *Bombyx mori*. *DNA Research* 11(1): 27-35.

Mitsuo, Y. Toshiaki, S. & Tsuneo, H. (2005). Feeding response of the silkworm, *Bombyx mori*, to UV irradiation of mulberry leaves. *Journal of Chemical Ecology*. Springer Netherlands. Vol 18 No. 4. ISSN 1573-1561 Pp.561-569.

Miyashita Y. (1986). A report on mulberry cultivation and training methods suitable to bivoltine rearing in Kamataka. Central Silk Board, Bangalore, India.

Mohanty, A.K. Misra, M. & Drzal L.T. (Eds) (2005). Natural fibers, biopolymers, and biocomposites. CRC press. Taylor & Francis Group. ISBN 0-8 493-1741-X

Mondal, M. Trivedy, K. & Kumar, S.N. (2007). The silk proteins, sericin and fibroin in silkworm *Bombyx mori* Linn – a review. *Caspian J. Env Sci*. Vol 5. No 2. Pp63 – 76.

Mukhopadhyay, A. Ghosh, S. & Bhaumik, S. (2006). Tearing and tensile strength behaviour of military khaki fabrics from grey to finished process. *International Journal of Clothing Science and Technology*. Emerald Group Publishing Limited. Vol. 18. Issue. 4. Pp 247 – 264. ISSN: 0955-6222

Muniraju, E. Sekharappa, B.M. & Raghuraman, R. (2004). Food intake and utilization efficiency in silkworm *Bombyx mori* L. (Pure Mysore) reared at different temperature combinations. *International Journal of Tropical Insect Science*. 24:135-142 Cambridge University Press Copyright © ICIPE 2004. doi:10.1079/IJT200421

Murakami, K . Fukata,N., Sasaki, S. Ishioka K., Kitajima, M., Fujimura, S Kikuchi, J and Haneda H. (1996). Hydrogen Molecules in Crystalline Silicon Treated with Atomic Hydrogen. *Phys. Rev. Lett.* 77, 3161–3164.

Murugan, K., Jeyabalan, D., Kumar, S. N., Nathan, S. S; and Sivaprakasan, N. (1998) Growth promoting effects of Plant products on Silk worm. J. Sci. Ind. Res. 57: 740-745.

Nagadevara, V. (2004). Composite quality index of silk cocoons—application of discriminant analysis. *Journal of the academy of Business and economics.*

Nagaraju, J. & Goldsmith, M.R. (2002). Silkworm genomics - progress and prospects. *Current Science*. Vol. 83. Pp415-425.

Naik, S.V. & Somashekar, T.H. (2006). Studies on bivoltine cocoon reeling - Influence of cocoon cooking condition and croissure length on quality characteristics of raw silk of Indian bivoltine hybrid cocoons. *The Journal of Silk Science and Technology of Japan*, 15, 43-48.

Naik, S.V. & Somashekar, T.H. (2005). Studies on bivoltine cocoon reeling: Part I: Effect of cocoon cooking condition and reeling speed on reeling performance of Indian bivoltine hybrid cocoons. *The Journal of Silk Science and Technology of Japan*, 14, 61-65.

Nakajima, K. (1999). Report on Bivoltine Silk Reeling Technology. International Sericulture Expert Group, Indian Bivoltine Sericulture Development Project, Central Silk Board, Bangalore.

Nakamura, M. & Hirayama C. (2000). Linkage of nutrition and silk production in *Bombyx mori*. Insect physiology, neurosciences, immunity and cell biology. Symposium and Poster Session. Abstract book II – XXI-International Congress of Entomology, Brazil, August 20-26

Nataraju, B. Shivaprasad, V. Datta, R.K. Gupta, S.K. & Shamin, M. (1994). Colloidal Textile Dye Based Dipstick Immunoassay for Detection of Nuclear Polyhedrosis Virus (BmNPV) of Silkworm Bombyx mori. *J. Invertebr Pathol*. 63:135 – 139.

Natural Fibres (2009). http://www.globaleducation.edna.edu.au/globaled/go/pid/3776)-natural fibres, 2009. Accessed on 18th March 2009.

Nieuwenhuys, B. (2006). The spider. The Netherlands Internet: http://www.xs4all/~ednieuw

Nirmala, X. Kodrik, D. Žurovec, M. & Sehnal, F. (2001). Insect silk contains both a Kunitz- type and a unique Kazal-type proteinase inhibitor. *Eur. J. Biochem*. 268(7), 2064-73.

Nguku, E.K. Adolkar, V.V. Raina, S.K Mburugu, K.G. & Mugenda, O.M. (2008a). Evaluation of raw silk produced by bivoltine silkworm *Bombyx Mori* L. (Lepidoptera: Bombycidae) Races in Kenya. *Journal of Textile and Apparel, Technology and Management.* Vol 5 Issue 4. Pp1 – 9.

Nguku, E.K. Raina, S.K & Mburugu, K.G. (2008b). Quality testing of *Bombyx Mori* (Lepidotera:Bombycidae) raw silk and fabric in Kenya. In the proceedings of the 5th International Conference of Textile Research Division NRC, Cairo, Egypt, April 6 – 8, 2008.

Nguku, E.K. Adolkar, V.V. Raina, S.K Mburugu, K.G. Mugenda, O.M. & Kimbu, D.M. (2009a). Performance of six bivoltine *Bombyx Mori* (Lepidotera:Bombycidae) silkworm strains in Kenya. *The Open Entomology*. Vol 3. Pp1 – 6.

Nguku, E.K. Raina, S.K Mburugu, K.G. & Mugenda, O.M. (2009b). Evaluation of different cocoon stifling methods on raw silk quality. *African Journal of Applied Human Sciences.* Volume 1, Number 1. ISSN:2070 – 917X. Pp 61 – 64.

Ostle and Malone (1988). Statistics in research. Basic concepts and techniques for research workers. Iowa State University Press.

Pang-Chuan, W. Da-chuang, C. Zuo-pu, C. Ping-zhang, L. & He, T. (1988). *Silkworm Rearing*. FAO Agricultural Services Bulletin, 73/2.

Perez, R.J. Viney, C. Llorca, J. & Elices, M. (2000). Mechanical properties of single-brin silkworm silk. *Journal of Applied Polymer Science*. 75, 1270–1277 CODEN: JAPNAB; ISSN: 0021-8995

Perimentas, A. Ed. (2001). Puncture and Tearing of Woven Fabrics. *Journal of Textile and Apparel, Technology and Management*. Vol 1 Issue 4. Pp 1 – 8.

Pickering, K. (Ed.) (2008). Properties and performance of natural-fibre composites. Woodhead Publishing Limited. ISBN 1 84569 267 5. ISBN-13: 978 1 84569 267 4. 576 pages.

Plaza, G.R., Corsini, P., Perez-Rigueiro, J., Marsan, E., Guinea, G.V. & Elices, M. (2008). Effect of water on *Bombyx mori* regenerated silk fibres and its application in modifying their mechanical properties. *Journal of Applied Polymer Science.* Volume 109, Issue 3. Pp 1793 – 1801.

Possee, D. (1998). The weaver and the Throwster. Pp72.

Prasong, S. Yaowalak, S. & Wilaiwan, S. (2009). Characteristics of Silk Fiber with and without Sericin Component: A Comparison between *Bombyx mori* and *Philosamia ricini* Silks. *Pakistan Journal of Biological Sciences.* Volume: 12, Issue: 11, Page No.: 872-876. DOI: 10.3923/pjbs.2009.872.876.

Quader, M.A. Qaiyyum, M.A. Sarker, A.A. Rab, M.A. & Ahmed, S.U. (1992). Varietal response to NPK fertilizers in combination with foliar spray of urea on leaf yield and leaf quality of mulberry. *Bulletin of Sericulture Research,* Vol.3, Pp.64-66.

Rahmathulla, V.K. Suresh, H.M. Mathur, V.B. Geethadevi, R.G. (2002). Feed conversion efficiency of Elite bivoltine CSR hybrids silkworm *Bombyx mori* L. reared under different environmental conditions. *Sericologia.* Vol 42:197-203.

Rahmathulla, V.K. Nayak, P. Vindya, G.S. Himantharaj, M.T, & Rajan, R.K. (2006). Influence of antibiotic on feed conversion efficiency of mulberry silkworm (*Bombyx mori* L.) *Animal Biology*. Brill academic Publishers. ISSN 1570-7563. Vol 56. No.1 pp13-22

Rahmathulla, V. K. Priyabrata, D. Ramesh M. & Rajan, R. K. (2007). Growth rate pattern and economic traits of silkworm, *Bombyx mori* L under the influence of folic acid administration. *J. Appl. Sci. Environ. Manage*. December, Vol. 11(4) 81 – 84. ISSN 1119-8362.

Raina, S. K. (2000). The Economics of Sericulture and Apiculture Modules for Income Generation in Africa. IBRA Press, UK. ISBN 0 86098 236 X 86pp.

Raina, S.K. Kioko, E.N. Adolkar, V.V. Muiru, H. Nyagode, B. Kimbu, D.M. Lumumba, J. Waruiru, R. & Nguku, E. (2000). ICIPE'S Groundwork in Building African Commercial Insects for the New Millennium. Sericulture and Apiculture. Prospects of the New Millennium. Pp. 1-6. In sericulture and apiculture prospects for the new millennium. Proceedings of the second international workshop on the conservation and utilization of commercial insects, 28th November – 1st December 1999(Edited by Raina, S.K. Nyagode, B. Kioko, E.N. and Mwanycky S.W). *icipe* Science press, Nairobi, Kenya.

Raina, S.K. Kioko, E. Adolkar, V. Wei, S, Muiru, H. Kimbu, D. Lumumba, J. & Nyagode, B. (1999). A review of the commercial insects innovative research and technology development in Africa. Conservation and Utilization of Commercial Insects. Pp. 3-14. Proceedings of the first international workshop on the conservation and utilization of commercial insects, 18th -21st August 1997. (Edited by Raina, S.K. Nyagode, B. Kioko, E.N. and Mwanycky S.W). *icipe* Science press, Nairobi, Kenya.

Rajkhowa, R. Gupta, V.B. & Kothari, V.K. (2000). Tensile stress-strain and recovery behavior of Indian silk fibers and their structural dependence. *Journal of applied polymer science.* Vol. 77, No 11, Pp. 2418-2429 (27 ref). ISSN 0021-8995.

Rao, P. R. T. (1997). Genetic architecture and gene action in *Bombyx mori* L. Ph.D thesis , Department of Zoology,University of North Bengal, Darjeeling-734430, India. 191pp.

Ravikumar, C. (1988). Western ghat as a bivoltine region prospects, challenges and strategies for its development. Indian Silk, 26 (9):39-54.

Rudall, K. M. (1960). Silk and other cocoon proteins. In Comparative biochemistry, 2nd ed. Vol. 4b. M.Florkin and H. S.Mason (Eds). Pp397–433.

Saha, B.N. & Khan, A.R. (1999). The growth and development of the silkworm, *Bombyx mori* L. on feed supplemented with nicotinic acid. *Bangladesh J. Life Sci*. Vol 11: Pp103-109.

Sanchez, Z. L. (2001). Study on Cocoon Characters of F1 Single Cross (MO14 x KL81) and F1 Doube Cross (MO20 x KL81/51) of Silkworm (*Bombyx mori linn)*. PTRI TC, Kalingagan, Phillippines

SAS Institute, (2000). SAS/STAT. Users Guide. Release 6.03 Edition, Cary North Carolina USA.

Sashina, E.S. Bochek, A. M. Novoselov, N.P. & Kirichenko, D.A. (2006). Structure and solubility of natural silk fibroin. *Zhurnal Prikladnoi Khimii*. Vol. 79, No. 6, Pp. 881–888. ISSN 1608-3296

Sehnal, F. &Akai, H. (1990). Insect Silk glands. Their types, development and function, and effects of environmental factors and morphogenic hormones on them. *International Journal of Insect Morphology and Embryology*. 19, 79-132

Seidavi, A.R. Bizhannia, A.R. Sourati, R. & Mavvajpour, M. (2005). The nutritional effects of different mulberry varieties on biological characters in silkworm. *Asia Pac J Clin Nutr* . 14 (Suppl): S122.

Sen, S. K. Jolly, M. S. & Jammy, T. R. (1969). Diseases of Tasar Silkworm *A. mylitta* (saturniidae). *Indian J. Sericulture*. Vol 8. Pp 11 – 14.

Shanbhag, V. (2009). Chemical processing of 'Silk'the queen of textile fibres. Apparel Views. August issue. Pp58 -59.

Shekar, P. & Hardingham, M. (1995). Sericulture and silk production. A handbook. Intermediate Technology. Publications, London. Pp. 55

Shekharappa, B. M. Gururaj, C. S. Raghuraman, R. & Daandin, S. B. (1993). Shoot feeding for late age silkworms. Karnataka State Sericulture Development Institute, Banglore, India.

Shelagh, V. (2004). Chinese silk: A cultural history, London, British Museum Press, pp 6 – 17 ISBN 0-8135-3446-1, London.

Singh, K.K. Dhepe, V.S. Jadhav, D.V. Dusane, S.E. & Gokhale, S.B. (2002). A New Technique of summer season chawki rearing of silkworm *Bombyx mori* (L.). BAIF Development Research Foundation.

Singhvi, N. R. & Bose, P. C. (1991). Sericin – a deciding factor for the quality of cocoons and raw silk. Indian Silk. Pp 26–28.

Skinkle, J. H. (1949). Textile testing: Physical, Chemical and Microscopical. Chemical publishing Co., INC. Brooklyn N.Y. Pp 353.

Somashekar, T.H. (1999). Report on the visit to Sericultural Areas in China Central Silk Board. Bangalore.

Sonwalkar, T.N. (1982). Relationship between Shell Percentage and Renditta/Raw Silk Percentage. *Indian Silk*. XXI, 14-16.

Sonwalker, T.N (1993). Handbook of textile technology. New Age International (P) Limited Publishers. Wiley Eastern ltd. New Delhi. 336pp. ISBN 81 - 224 – 0492 – 2.

Srinivasa, G. Chengappa, P.G. Reddy, K. Achoth, L. Nagaraja, G.N. (2005). Socio-Economic Determinants of Technology Adoption in Sericulture - An Analysis. *Indian Journal of Agricultural Economics.* Vol 60. No 2. Pp264-27. ISSN 0019-5014.

SSC (Silk Standards Committee) (1995). *Raw silk. Manual for testing, classifying, quality limits, grading.* Directives, methods. Standards. Instrumentation. International Silk Association. Silk Congress Brighton. Great Britain.

Stoyan, K. Aleksandrov, K. Zakhariva, K. & Nauki, A.Y.Z. (1985). Results of raising silkworms (*Bombyx mori*) at distributed environmental factors. *Sericulture test control Stn. Bulg.* 22(3):76-81.

Takano, K. & Arai, N. (1978). Studies on the food value on the basis of feeding and cocoon productivity in the silkworm *Bombyx mori* L., Treatment of food intake and cocoon productivity. *J. Seri. Sci. J.* Pp. 47: 134, 142.

Tazima, Y. (1978). The silkworm an important laboratory tool. Kodansha Ltd. Tokyo, Japan.

Tejano, N. M. Sanchez Z. L. & Abragan H. C. (2002). Performance of F1 silkworm hybrid (Mol 251 X KI 51) to raw silk production. *NOMCARRD research*. Philippine Textile Research Institute.

Thyagaraja, B.S. Kelly, T.J. Masler, E.P. & Borkovec, A.B. (1991). Thyroid induced Haemolymph protein and ecdysteroid increases in the silkworm, *Bombyx mori* L.: Effect of larva growth and silk production. *J. Insect. Physiol*. Vol 37: 153-159.

Tribhuan, S. & Mathur, S.K. (1989). *The* morin factor in mulberry that attracted the *Bombyx mori L. Indian silk*. Vol. 28(5): 39-40.

Tsukada, M. Islam, S. Arai, T. Bosch, A. & Fred, G. (2005). Microwave irradiation technique to enhance protein fiber properties. *Autex Research Journal*. Vol. 5, No 1.

Tzenov, P. Nacheva, Y. & Petkov N. (1999). Cocoon shape inheritance in hybrids between multivoltine and uni-bivoltine silkworm, *Bombyx mori* L. Races. BJAS Archive. Vol. 5. No 3.

Ueda, S. Kimura, R. & Sujuki, K. (1969). Studies on the growth of silkworm, *Bombyx mori* (L.). II. The influence of the rearing conditions upon larval growth, productivity of silk substances, eggs and boiled off loss in the cocoon shell. *Bull. Sericulture Expt. Stn*. Japan. 23: 290-293.

Ullal, S.R. & Narasimhanna, M.N. (1987). *Handbook of practical sericulture*. Third Edition. Central Silk Board, Bangalore, India. Pp166.

Vainker, S. (2004). Chinese silk: A cultural history. London, British Museum Press. PP 6 – 17.

Varma, D.S. and Chakraberty, M. (1971). A study of tensile properties of twill-woven fabrics. Institute of Technology. Delhi, New Delhi

Vasumathi, B.V. Takabayashi, C. Nakajima, K . & Somashekar, T.H. (2004). Studies on the relationship between cocoon parameters and raw silk uniformity characteristics. *Journal of Insect Biotechnology and Sericology*. Vol. 73, pp.47-56.

Veda, K. Nagai, I & Horikomi, M. (1997). Silkworm rearing. Translated from Japanese Science Publishers Inc. New Hampshire, United States of America.

Vegan Society, (2003). Silk. Hosting by Spirit Quest. http://www.vegansociety.com/html/animals/exploitation/silk_worm.php.

Vijaykumar, T. (2003). Textile Technology. Indonesia

Vollrath, F. & Porter, D. (2006). Spider silk as archetypal protein elastomer. Royal Society of Chemistry. Soft Matter. Vol 2. Pp 377-385. DOI: 10.1039/b600098n.

Welford, T. (1969). The textile student manual. 6th Edition. Isaac Pitman and Sons Ltd. Great Britain.

Wilson, G.G. (1984). Pathogensity of nosema *distriae Pleistropha schubergi* and *varimorpha necatrix* (microsporidia) to larvae of forest tent caterpillar, *Malasocoma disstria* Zeits. *Parasit*. 70:763 – 767.

Xu, Y., Zhang, Y., Shao, H. and Hu, X. (2005). Solubility and rheological behavior of silk fibroin (*Bombyx mori*) in *N*-methyl morpholine *N*-oxide. International Journal of Bilogical Macromoleucles.Volume 35, Issuses 3 – 4, Pages 155-161

Yokoyama, T. (1962). Synthesized science of sericulture. Central Silk Board. Bombay. Pp378.

Yungen, M. & Junliang X. (1999). Effects of natural and artificial diet on the larval growth and cocoon and silk quality of the silkworm, *Bombyx Mori*.

Yungen, M. & Bharathi, D. (2001). Effect of methoprene and MH alone and in combination on the ultrastructural changes in the posterior silk gland of the silkworm, *Bombyx mori* L. *Sociologia*. 41 (2): 169-175.

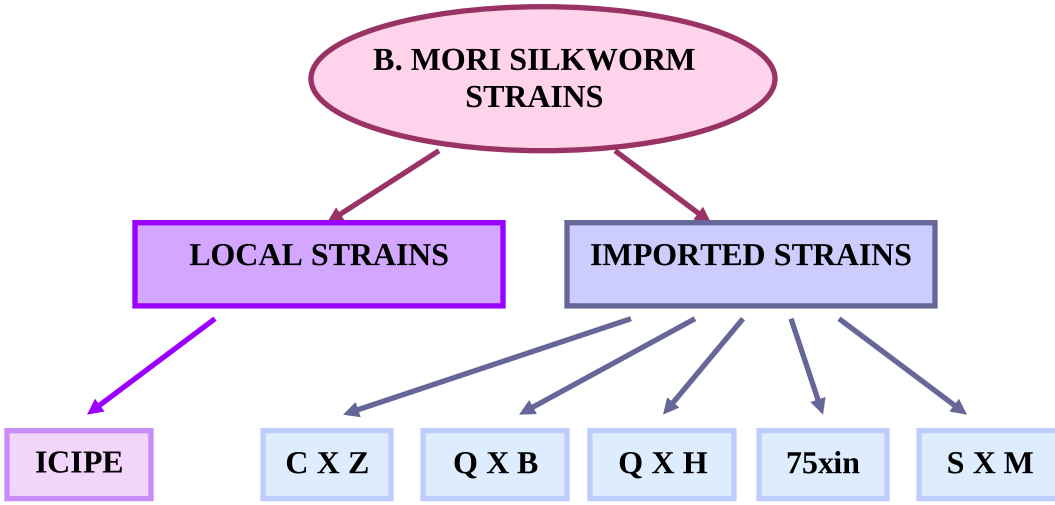
Zanatta, D.B., Bravo, J.P., Barbosa, J.F., Munhoz, R.F. Fernandez, M.A. (2009). Evaluation of Economically important traits from sixteen parental strains of the silkworm *Bombyx mori* L (Lepidoptera: Bombycidae). Ecology, behavior and bionomics. *Neotropical Entomology*. 38(3):327-331.

Zurovec, M. & Sehnal, F. (2007). Unique molecular architecture of silk fibroin in the waxmoth, Galleria mellonella. *Journal of Biological Chemistry*. Downloaded from www.jbc.org on August 13, 2007.

Zurovec, M. Yang, C. Kodrik D. & Sehnal, F. (1998). Identification of a novel type of silk protein and regulation of its expression. *Journal of Biological Chemistry*. 273(25), 15423-15428.

## APPENDICES

**Appendix 1: *Bombyx mori* Silkworm Strains used in the performance study**




C X Z: Chun Lei X Zen Zhu

Q X B: Quifeng X Baiyu

Q X H: Quingsong X Haoyoe

75xin: 75xin X 7532

S X M: Suju X Minghu

**Appendix 2: Average Speed and Winding Period for Winding Test**

| Size Under Test | Preliminary Winding | Average Speed (Metre/Min) | Winding Period (Minutes | |
|---|---|---|---|---|
| | | | 70g Skeins | 140g Skeins |
| **12 denier or finer** | 10 | 110 | 60 | 120 |
| **13 – 18** | 10 | 140 | 60 | 120 |
| **19 - 33** | 10 | 165 | 60 | 120 |
| **34 - 69** | 5 | 165 | 30 | 60 |
| **70 or coarse** | 5 | 165 | 20 | 40 |

Source Lee Y-W (1999)

**Appendix 3: Causes of Winding Breaks**

| Strain | Season | Location | CAUSES | | Total Winding breaks | %age Standard Error | Standard Deviation |
|---|---|---|---|---|---|---|---|
| | | | Split ends | Size Deviation | | | |
| 75xin | SR | S1 | 3 | 10 | 13 | 23.07 | 76.92 |
| | | S2 | 5 | 9 | 16 | 35.71 | 64.28 |
| | LR | S1 | 1 | 11 | 12 | 8.33 | 91.66 |
| | | S2 | 2 | 10 | 12 | 16.66 | 83.33 |
| C X Z | SR | S1 | 2 | 7 | 9 | 22.22 | 77.77 |
| | | S2 | 3 | 6 | 10 | 30.00 | 60.00 |
| | LR | S1 | 2 | 6 | 8 | 25.00 | 75.00 |
| | | S2 | 3 | 6 | 9 | 33.33 | 66.66 |
| ICIPE I | SR | S1 | 1 | 4 | 5 | 20.00 | 80.00 |
| | | S2 | 2 | 4 | 6 | 33.33 | 66.66 |
| | LR | S1 | 0 | 4 | 4 | 0.00 | 100.00 |
| | | S2 | 1 | 3 | 4 | 25.00 | 75.00 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Q X B | SR | S1 | 2 | 6 | 8 | 25.00 | 75.00 |
| | | S2 | 3 | 7 | 10 | 30.00 | 70.00 |
| | LR | S1 | 2 | 6 | 8 | 25.00 | 75.00 |
| | | S2 | 3 | 5 | 8 | 37.50 | 62.50 |
| Q X H | SR | S1 | 2 | 10 | 12 | 16.66 | 83.33 |
| | | S2 | 1 | 12 | 13 | 7.69 | 92.30 |
| | LR | S1 | 2 | 10 | 12 | 16.66 | 83.33 |
| | | S2 | 4 | 8 | 12 | 33.33 | 66.66 |
| S X M | SR | S1 | 3 | 9 | 12 | 25.00 | 75.00 |
| | | S2 | 2 | 11 | 13 | 15.38 | 84.61 |
| | LR | S1 | 1 | 9 | 10 | 10.00 | 90.00 |
| | | S2 | 2 | 9 | 11 | 18.18 | 81.81 |

**Appendix 4: ISA classification table for raw silk of category II (19 – 33 denier)**

| **MAJOR ITEMS** | **GRADE** | | | | |
|---|---|---|---|---|---|
| | **4A** | **3A** | **2A** | **A** | **B** |
| Cleanliness (%) | 97 | 95 | 93 | 88 | Below 88 |
| Average Neatness (%) | 94 | 92 | 90 | 87 | Below 87 |
| Low Neatness (%) | 90 | 87 | 83 | 77 | Below 77 |
| **AUXILLIARY** | **CLASS** | | | | |
| | (1) | (2) | | (3) | (4) |
| Winding (breaks) | 4 | 10 | | 18 | Above 18 |
| **AUXILLIARY** | **CLASS** | | | | |
| | (1) | | | | (2) |
| Tenacity (grams) | 3.7 | | | | Below 3.7 |
| Elongation (%) | 18 | | | | Below 18 |
| Cohesion | 60 | | | | Below 60 |

Source: Lee 1999