Available online at http://www.journalijdr.com

IJDR

International Journal of DEVELOPMENT RESEARCH

ISSN: 2230-9926

International Journal of Development Research
Vol. 06, Issue, 07, pp.8498-8502, July, 2016

Full Length Research Article

SILK PROPERTIESOF SELECTED *BOMBYX MORI (LEPIDOPTERA: BOMBYCIDAE)* STRAINS

*Everlyn Kamene Nguku, Boniface Mutua Ngoka and Suresh Kumar Raina

International Centre of Insect Physiology and Ecology, P. O. Box 30772 - 00100, Nairobi, Kenya

ARTICLE INFO

Article History:
Received 24th April, 2016
Received in revised form
18th May, 2016
Accepted 10th June, 2016
Published online 31st July, 2016

Key Words:
Bombyx mori,
Winding Breaks,
Elongation,
Neatness,
Cleanliness,
Breaking Load,
Tear Resistance.

ABSTRACT

This study assessed properties of silk produced by three selected strains of the domesticated silkworm *Bombyx mori*viz. ICIPE I, ICIPE II and Chun-Lei X Zheng Zhu reared in Kenya. Selected silk characteristics were evaluated and performance tested to determine its suitability as a textile material. The study established that winding breaks and elongation varied among the silkworm strains. The study also established that there were significant differences in the cleanliness and neatness that ranged between 97 to 94.4% and 93 to 88.9%. respectively. Tearing strength was between 393.89 to 395.30N for the warp yarns and 313.07 to 320.13 for the weft respectively. In this study ICIPE II had superior qualities compared to the other two strains.

INTRODUCTION

The finest quality raw silk and the highest fibre production come from domesticated silkworm, *Bombyx mori* (Rahmathulla, 2012). The *B. mori* silkworm is one of the most important insects which produces silk filament in the form of cocoons (Bhatia and Yousuf, 2014; Hussain *et al*., 2011); and although there are several commercial species of silkworms, it is the most widely used and intensively studied, and techniques for its rearing are the most developed (Goldsmith *et al*., 2005). This insect is the sole living species in its family, Bombycidae, and has been domesticated. Over the years, silk has become highly valued as a textile fibre because of its qualities of high strength, durability, exceptional luster and drapeability, among other unique features compared to the common cellulose and synthetic fibers in current use (Prachayawarakorn and Klairatsamee, 2005; Reddy and Yang, 2010).

Corresponding author: Everlyn Kamene Nguku,
International Centre of Insect Physiology and Ecology, P. O. Box 30772 - 00100, Nairobi, Kenya

In addition, silk has an economic value that is higher than that of other natural fibres such as cotton and wool because of its superior characteristics. Numerous studies have explored production of artificial spider silks using *Escherichia coli*, (Shimizu *et al*., 2004a; Huemmerich *et al*., 2004; Teule *et al*., 2007; Xia 2010), insect cells (Zhang *et al*., 2008; Miao *et al*., 2006; Shimizu *et al*., 2004b), plants (Scheller *et al*., 2001; Menassa *et al*., 2004), animals (Karatzas *et al*., 1999), yeasts (Fahnestock, 1997), mammalian cells (Lazaris *et al*., 2002), and silkworms (Kojima *et al*., 2007; Wen *et al*., 2010; Zhu *et al*., 2010; Teule *et al*., 2014). However, long silk fibres can be obtained only from silkworms. The *B. mori* raw silk fibre is a composite material composed of fibrous fibroin (70-75%)contained within a sericin (20-25%) protective coating (Kuwana *et al*., 2014; Ninpetch *et al*., 2015). The sericin glues the fibroin filaments and maintains the cocoon structure (Freddie *et al*., 2003; Yamada *et al*., 2003). The structure of most animal and plant-based textile fibres, including that of silk, has an effect on the physical and mechanical properties of yarn which, especially in silk, is influenced by other factors such as the strain/race, season, among others. Variations with regard to cocoons, filament denier, tenacity and elongation among others, could thus be expected.

Differences among the cocoons of different races have been noted and are more prevalent (Vasumathi *et al*., 1998). Silk has become one of the popular fabrics for apparel because of its unique properties, and besides productivity, the qualitative aspects of silk areof particular importance in making sericulture a viable enterprise. Among the various parameters that determine the quality of silk fibre, denier variation, neatness and purity are very important (Gowda *et al*., 2014). Consequently, evaluating raw silk surface appearance has become an important routine in accessing raw silk quality in the textile industry (Wang *et al*., 2016). The measurement of the yarn strength and elongation, provide numerous indications how the quality of the yarns can be improved. Other very important quality parameters for yarns are cleanliness and neatness (imperfections). "Imperfections" is used as a generic term for the number of thick places, thin places and neps per unit length. Evenness of raw silk is a fundamental quality parameter in the silk industry. If evenness testing is applied for raw silk, there are substantial possibilities for improvement, because there are ways to optimize the evenness (Camenzind *et al*., 2014). Silk production in Kenya is in the primary stages of establishment, and various silkworm breeds/hybrids have been introduced for silk production purposes. With the silkworm strains playing a significant role on the economic traits, the following investigation was therefore undertaken with the aim of assessing some selected physical/mechanical properties of silk produced by three silkworm strains.

MATERIALS AND METHODS

This study was undertaken at *icipe's* Commercial Insects Programme laboratory and the Kenya Bureau of Standards (Kebs) Textile Testing Laboratory in Nairobi, Kenya. Cocoon reeling and fibre tests were undertaken at *icipe,* while fabric tests were done at Kebs. Cocoons of three bivoltine breeds/hybrids of mulberry silkworm *Bombyx mori* L. viz. Chun-Lei X ZhengZhu (C X Z), ICIPE I and ICIPE II were selected for the present study to evaluate selected physical/mechanical properties of raw silk and fabric. The filaments were reeled off from the cocoons on a multi-end reeling unit ensuring that the filament properties are not modified by the reeling tension. The denier of the raw silk was 20/22 (dtex 23).

Silk samples representing the three strains were drawn randomly for the various tests undertaken. Winding was done according to Lee, (1999). For the cleanliness and neatness tests, the raw silk samples were wound onto a seri-board and transferred to a dark room for inspection. Inspections were done according to (Lee, 1999). The fabric breaking load and elongation, and tear resistance were carried out according to (KS08 – 119, 1981) and (KS 08 – 437, 1981; ASTM 1424, 1944) methods respectively.

RESULTS AND DISCUSSION

Winding Break counts

Results in Figure 1 show that raw silk winding breaks slightly varied among the three strains and ranged between 6 and 3 counts. C X Z strain had the highest mean number of breaks of 6 while ICIPE II had the least at 3. The winding break results from this study correspond to similar findings by Nguku *et al*. (2007), who notes that winding breaks vary amongst different *B. mori* silkworm strains, and notably, ICIPE I has an average of 4 break counts during the long rains. This variation in breaks among the strains also corroborate to similar observations made by Rahman (2004) and Aruga (1994), who observe that that the process of spinning silk fibre by mature lavae is not uniform from the beginning to the end, hence contributing to breaks.

These studies imply that the various strains selected for this study may have varying characteristics in the spinning of silk thread, which could be a contributing factor to the winding breaks variations. Practical experience has proven that winding alters the yarn structure (Vijaykumar, 2003). This is a phenomenon, which may affect standard deviation of silk and increase breaking tendencies. It is significant to note that Raina (2000) points out that late age silkworms require 70% relative humidity and a temperature of 24^{0}C. Humidity that goes above 70 may give raise to breaks during reeling and decrease silk quality.

Fig. 1. Winding Break Counts among the strains

Elongation percentage

This study revealed that elongation of the raw silk from the three silkworm strains studied ranged between 19 and 20%. Both ICIPE I and II had 20% elongation while CXZ had 19%. These results are given in Figure 2 and corroborate Lee (1999) study where the raw silk has an elongation of 18–23% of its original length before break. On the other hand, Nguku *et al*., (2007) study reveals similar results, where elongation of six silkworm strains studied is between 18 and 20%. In the same study by Nguku (2007), one of the strains used is ICIPE I and it is notable the elongation percentages are between 19 and 20%, which corroborates results of the current study. A comparison between the elongation percentage and breaking counts among the three strains revealed that ICIPE II silkworm strains which had the highest elongation percentage of 20%, had the minimum winding breaks of 6. On the other hand, C X Z had the lowest elongation percentage of 19% and the highest number of breaks. ICIPE I had an elongation of 20% and 4 winding breaks (Fig. 2). The elongation and winding curve results, where the strain with the highest elongation percentage also had the minimum winding breaks, are similar to a study by Nguku (2010).

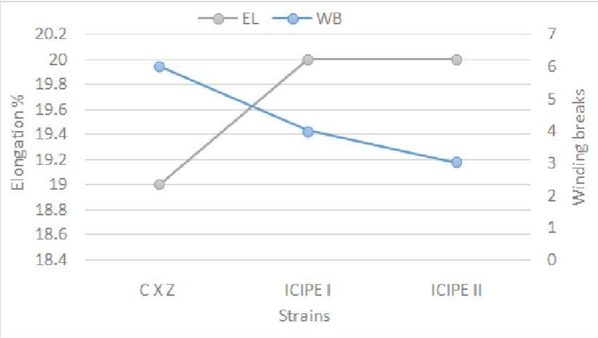

Fig. 2. Comparison of elongation and winding breaks

Cleanliness and Neatness Percentages

The mean cleanliness percentage among the strains ranged between 97 and 94.4%, with ICIPE II having the highest percentage followed by ICIPE I, while C X Z had the lowest. A similar pattern was seen in the mean neatness results, where the mean range was between 93 and 88.9%. On the other hand, there were no significant differences in the mean cleanliness and neatness of ICIPE I and ICIPE II, however C X Z was significantly different in the two parameters as seen in Table 1. Nguku *et al*., (2007) and Nguku (2010) note similar results in their studies where there are significant differences in cleanliness percentages between ICIPE I and C X Z. Datta and Nanavaty (2007) affirm that the neatness and cleanliness of raw silk is directly influenced by breed characteristics.

The resulting defects vary within different breeds and depend on the silkworm breeds/hybrids even though mounting and reeling conditions can influence them. This could also have been as a result of different strain characters, as (Lee, 1999) research shows that a characteristic of the silkworm race may give rise to cleanliness and neatness defects. This factor may have contributed in the slight variations that were noted in these two parameters within the current study. On the other hand, Aruga (1994) attributes this kind of occurrence (neatness and cleanliness defects) to the technique applied in the cooking and reeling of cocoons. This could have contributed to the differences observed in this study.

Table 1. Comparison of mean cleanliness and neatness % among the strains

Strain	Mean Cleanliness	Mean Neatness
C X Z	94.4 + 0.363 b	88.9 + 0.194 b
ICIPE I	96.2 + 0.359 a	92.9 + 0.180 a
ICIPE II	97.0 + 0.333 a	93.0 + 0.184 a

Means followed by the same letter in the same column are not significantly different (P<0.05)

Fabric breaking load and elongation

This study shows that there was no significant difference among the strains in breaking load. The mean average breaking load for warp yarns ranged between 124.08 and 124.21N and the weft yarns of the same denier was between 256.21 and 256.43N as indicated in Table 2. These results relate to observations by Nguku (2010), where the average mean warp and weft breaking load of similar fabric is 124.08 ± 0.03N and 256.15 ± 0.036N respectively. On the other hand, Nguku (2010) also notes that there are no significant differences in the breaking load of the various silkworm strains studied. It is important to note that neatness defects affect the performance of raw silk during weaving, and in addition, silk strength can be affected by low neatness (Datta and Nanavaty, 2007). In addition, one cannot overlook the production processes that silk undergoes. 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. Eyre (1956) suggests production processes as contributing factors that may affect textile strength.

Table 2. Breaking Load and Elongation per Strain

Strain	Warp		Weft	
	Force (N)	El (cm)	Force (N)	El (cm)
C X Z	124.08	7.7	256.26	4.2
ICIPE I	124.18	8.1	256.43	4.3
ICIPE II	124.21	8.0	256.21	4.3

Tearing Strength

Tearing strength ranged between 393.89 and 395.30N for the warp; and 313.07 and 320.13N for the weft respectively. There was no significant difference in the warp tearing strength among the strains, however it was noted that ICIPE II was significantly different in the weft tearing strength (Table 3). A change in any physical property and chemical composition of a textile material will nearly always result in a change in strength. In this regard, the chemicals used for degumming process may affect the strength of the silk fibres and consequently the fabric tearing strength. Gulrajani *et al*., (1998) also notes that the various methods used for degumming may cause embitterment and destruction of protein fibre by alkalis, affecting the quality and strength of silk.

Table 3. Comparison of tearing strength among the strains

Strain	Mean Tearing Strength +SE	
	Warp	Weft
C X Z	393.89 + 7.325 a	313.97 + 4.677 b
ICIPE I	394.07 +7.005 a	316.87+ 5.466b
ICIPE II	395.30 + 7.022 a	320.13 + 7.006 a

Means followed by the same letter in the same column are not significantly different (P<0.05)

Conclusion

Silk is a natural fibre and for this reason some irregularities are bound to occur. This study has established that there is a link between the silkworm strains, and the fibre and fabric qualities. The differences in the silk properties could have been caused by the individual characteristics of the silkworms. Fibre production processes also play a significant role in determining the fibre properties, which when combined with fabric production processes influence and determine the fabric properties. In this study, ICIPE II had superior qualities compared to the other two strains. Therefore, it has potential for commercial silk production in Kenya. However, overall performance of the silk from all the strains studies were within acceptable ISA standard.

Acknowledgements

The authors wish to thank the Kenya Bureau of Standards - Textile Testing Laboratory for providing equipment for testing the various silk fabric parameters, and the staff members for their assistance with the fabric measurements. We gratefully acknowledge the financial support for this research by the following organizations and agencies: International Fund for Agricultural Development (IFAD) - Grant Number 1229; UK's Department for International Development (DFID); Swedish International Development Cooperation Agency (Sida); the Swiss Agency for Development and Cooperation (SDC); and the Kenyan Government. *The views expressed herein do not necessarily reflect the official opinion of the donors.*

REFERENCES

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

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

Bhatia, N.K., Yousuf, M. 2014. Effect of rearing season, host plants and their interaction on economical traits of tropical tasar silkworm, Antheraea mylitta Drury- an overview. International Journal of Industrial Entomology, 29 (1) Korean Society of Sericultural Science. doi:10.7852/ijie.2014.29.1.93.

Camenzind, M., Freitag, R., Furter, R., Hättenschwiler, P. (eds) 2014. Raw Silk and spun silk – Quality and measurement.Pp 63.

Cherry, R. 1993. Sericulture. Bull. Entomol Soc. Am 35:83 – 84.

Datta, R.K. and Nanavaty, M. 2007. Global silk industry: A complete source book. APH Publishing Corporation ISBN 81-313-0087-0.

Eyre, N. 1956. Testing of yarns and fabrics: With special reference to viscose rayon. The William Morris Press Limited, Manchester: Great Britain. pp.75.

Fahnestock, S.R., Bedzyk, L.A. 1997. Production of synthetic spider dragline silk protein in Pichia pastoris. *Appl Microbiol Biotechnol,* 47: 33–39.

Freddi, G., Mossotti, R., Innocenti, R. 2003. Degumming of silk fabric with several protease Enzymes; *Journal of Biotechnology*. 106, 101-112.

Goldsmith, M.R., Shimada, T., Abe, H. 2005. The genetics and genomics of the silkworm, *Bombyx mori*. Annu. Rev. Entomol. 50, 71–100.

Gowda, V., Kalpana, G.V., Parthasarathy, B.A., Reddy, S.J. and Angadi, B.S. 2014. On cocoon uniformity in different crosses of bivoltine hybrids of silkworm *Bombyx mori* L. Entomol. Appl. Sci. Lett., 1 (3):13-18.

Gulrajani, M.L., Subhash, C., Agarwal, R. 1998. Method of removal of protein from silk. IIT Delhi technologies.

Huemmerich, D., Helsen, C.W., Quedzuweit, S., Oschmann, J. and Rudolph, R. 2004. Primary structure elements of spider dragline silks and their contribution to protein solubility. Biochem 43: 13604–13612.

Hussain, M., Naeem, M., Khan, S.A., Bhatti, M.F., Munawar, M. 2011. Studies on the influence of temperature and humidity on biological traits of silkworm (*Bombyx mori* L.; Bombycidae). African Journal of Biotechnology Vol. 10 (57), pp. 12368-12375. DOI: 10.5897/AJB11.1805. ISSN 1684–5315

Karatzas, C.N., Turner, J.D., Karatzas, A.L. 1999. Production of biofilaments in transgenic animals. In: WIPO, editor. WO/1999/047661.

Kojima, K., Kuwana, Y., Sezutsu, H. 2007. Secondary structure analysis of genetically modified silk with spider fiber protein. Kobunshi Ronbunshu 64: 817–819

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

KS08 – 437 1981. Kenya Standard. Method for determination of tear resistance of woven fabrics by falling pendulum (Elmendorf) apparatus.

Kuwana, Y., Sezutsu, H., Nakajima, K., Tamada, Y., Kojima, K. 2014. High-toughness silk produced by a transgenic silkworm expressing spider (*Araneus ventricosus*) dragline silk protein. PLoS ONE, 9(8), e105325.

Lazaris, A., Arcidiacono, S., Huang, Y., Zhou, J.F., Duguay, F. 2002. Spider silk fibers spun from soluble recombinant silk produced in mammalian cells. Science 295: 472–476.

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

Menassa R, Hong Z, Karatzas CN, Lazaris A, Richman A (2004) Spider dragline silk proteins in transgenic tobacco leaves: accumulation and field production. *Plant Biotechnol J.,* 2: 431–438.

Miao, Y.G., Zhang, Y.S., Nakagaki, K., Zhao, T.F., Zhao, A.C. 2006. Expression of spider flagelliform silk protein in *Bombyx mori* cell line by a novel Bac-to-Bac/BmNPV baculovirus expression system. *Appl Microbiol Biotechnol.,* 71: 192–199.

Nguku, E.K. 2010. *Bombyx mori* silk fibre and fabric properties: Assessment of the properties of silk fibre and fabric produced by bivoltine silkworm, *Bombyx mori* L. (Lepidoptera: Bombycidae) in Nairobi, Kenya. VDM Verlag Dr. Müller GmbH & Co. KG. 156 pp ISBN 363928582, 978-3-639-28258-0.

Nguku, E.K., Adolkar, V.V., Raina, S.K., Mburugu, K.G., Mugenda, O.M. 2007. Evaluation of raw silk produced by bivoltine silkworm *Bombyx mori* L. (Lepidoptera: Bombycidae) races in Kenya. *Journal of Textile and Apparel, Technology and Management*. Volume 5, Issue 4.

Ninpetch, U., Tsukada, M., Promboon, A. 2015. Mechanical properties of silk fabric degummed with bromelain. *Journal of Engineered Fibers and Fabrics*. Volume 10, Issue 3.

Prachayawarakorn, J., Klairatsamee, W. 2005. Effect of solvents on properties of *Bombyx mori* silk grafted by methyl methacrylate (MMA) and methacrylamide (MAA). Songklanakarin J. Sci. Technol. Vol.27 No.6

Rahman, K.M., Mikihiko, M.M., Hideaki, Yuichi, H., Masayuki, I. 2004. The relationship between silkworm spinneret positions during cocoon construction and movement of cocoons in the reeling bath. *Journal of Insect Biotechnology and Sericology*, Vol.73, pp.107-112.

Rahmathulla, V.K. 2012. Management of climatic factors for successful silkworm (*Bombyx mori* L.) crop and higher silk production: A Review. Psyche, Article ID 121234, 12 pages. doi:10.1155/2012/121234.

Raina, S.K. 2000. The economics of sericulture and apiculture modules for income generation in Africa. IBRA, UK, pp 86.

Reddy, N. and Yang, Y. 2010. Structure and properties of cocoons and silk fibers produced by *Hyalophora cecropia. J Mater Sci*) 45:4414–4421 DOI 10.1007/s10853-010-4523-3

Scheller, J., Guhrs, K.H., Grosse, F., Conrad, U. 2001. Production of spider silk proteins in tobacco and potato. *Nat Biotechnol.,* 19: 573–577.

Shimizu, K., Shiomi, K., Kajiura, Z. and Nakagaki, M. 2004a *Nephila clavata* flagelliform silk protein expressed in *E. coli*. *J Seric Sci Jpn.,* 73: 15–21

Shimizu, K., Shiomi, K., Kajiura, Z. and Nakagaki, M. 2004b. *Nephila clavata* flagelliform silk protein expressed in insect cells. *J Seric Sci Jpn*., 73: 23–29.

Teule, F., Furin, W.A., Cooper, A.R., Duncan, J.R., Lewis, R.V. 2007. Modifications of spider silk sequences in an attempt to control the mechanical properties of the synthetic fibers. *J Mater Sci*., 42: 8974–8985.

Teule, F., Miao, Y.G., Sohn, B.H., Kim, Y.S., Hull, J.J. 2012. Silkworms transformed with chimeric silkworm/spider silk genes spin composite silk fibers with improved mechanical properties. *Proc Natl Acad Sci.,* U S A 109: 923–928.

Vasumathi, B.V., Chilakwad, S.L., Hosur, H., Nair, B.P., Somashekar, T.H. 1999. Comparative studies on some physical and mechanical properties of mulberry silk filament. *Indian Journal of Fibre & Textile Research*. Vol. 24, pp. 167-171.

Vijaykumar, T. 2003. Textile Technology. Indonesia.

Wang, C., Junjuan Li, Chen, M., He, Z. and Zuo, B. 2016. The obtainment and recognition of raw silk defects based on machine vision and image analysis. *The Journal of the Textile Institute*. Vol. 107, No 3. 316-326,

Wen, H.X., Lan, X.Q., Zhang, Y.S., Zhao, T.F., Wang, Y.J. 2010. Transgenic silkworms (*Bombyx mori*) produce recombinant spider dragline silk in cocoons. *Mol Biol Rep.,* 37: 1815–1821.

Xia, X.X., Qian, Z.G., Ki, C.S., Park, Y.H., Kaplan, D.L. 2010. Native-sized recombinant spider silk protein produced in metabolically engineered Escherichia coli results in a strong fiber. *Proc Natl Acad Sci U* S A 107: 14059–14063.

Yamada, Y., Boo, J.S., Ozawa, R., Nagasaka, T., Okazaki, Y., Hata, K. and Ueda, M.J. 2003. Bone regeneration following injection of mesenchymal stem cells and fibrin glue with a biodegradable scaffold; *Journal of Cranio-Maxillofacial Surgery*, 31, 27- 33.

Zhang, Y.S., Hu, J.H., Miao, Y.G., Zhao, A.C., Zhao, T.F. 2008. Expression of EGFP-spider dragline silk fusion protein in BmN cells and larvae of silkworm showed the solubility is primary limit for dragline proteins yield. *Mol Biol Rep.,* 35: 329–335

Zhu, Z.H., Kikuchi, Y., Kojima, K., Tamura, T., Kuwabara, N. 2010. Mechanical properties of regenerated *Bombyx mori* silk fibers and recombinant silk fibers produced by transgenic silkworms. *J Biomater Sci Polym Ed* 21: 395–412.

****