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EVALUATION OF PHYSICAL PROPERTIES OF LOCALLY PRODUCED *GONOMETA POSTICA* SILK AND WOOL FABRICS

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OPSOMMING

Sy is ‘n luukse vesel met ‘n unieke kombinasie van eienskappe. Ongelukkig lei dit en ander faktore, soos die arbeids-intensiewe produksieproses, tot die baie duur prys van sy-teksktielstowwe. Die prys is gewoonlik so hoog dat dit onbekostogbaar is vir baie verbruikers. Mengstowwe kan ‘n moontlike oplossing vir hierdie probleem bied indien die *Gonometa postica* sy met ‘n gepasde vesel gemeng kan word. Daarom is mengstowwe geskep sodat die fisiese eienskappe van die *Gonometa postica* sy tekstielstof geëvalueer kan word en dit te vergelyk met die van ‘n mengstof wat bestaan uit *Gonometa postica* sy inslag op ‘n wol skering. Die eienskappe is geëvalueer in terme van treksterkte (ISO 13934), styfheid (BM 3356), kreukelherstel (AATCC Toets Metode 66) en krimping (AATCC Toets Metode 99). Die resultate het aangedui dat die sy inslag op wol skering tekstielstof goeie kreukelherstel toon en die styfheid naby verwant is aan die van *Gonometa postica* sy tekstielstof en die treksterkte was ook toereikend. Hierdie resultate lei tot die gevolgtrekking dat wol kommersieël aanvaarbaar sal wees as ‘n menggaring stof met die *Gonometa postica* sy, aangesien dit sommige van die eienskappe verbeter sonder om ander eienskappe negatief te beïnvloed.

This study formed part of a larger project, where research was done on the properties of *Gonometa postica* silk with the aim to establish a profile of the fibre. The profile would aid in processing and developing the silk to its full potential.

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INTRODUCTION

The silk protein polymers that are produced by silkworms are classified into two general groups. These are respectively the “domestic” or cultivated varieties such as. *Bombyx mori,* and the “wild” varieties such as *Gonometa postica* (Kweon & Park, 2001). Cultivated silk is produced by a carefully controlled process in which the silkworm lives an artificial and protected life for the purpose of producing fibres. On the other hand, wild silk production is not controlled. Instead, these silkworms feed on leaves and spin cocoons in the wild under natural conditions (Hollen & Saddler, 1973:28). There are 400-500 species of silk-producing moths in the world, but only 9 species are commercially cultivated. The domesticated mulberry silk moth, *B. mori* produces 99% of the world’s silk (Dingle *et al.,* 2005: VI). “Wild” silks originate from a number of silk moth types, of which *G. postica* is a local Southern African example. *G. postica* caterpillars feed on the leaves of the Camelthorn tree (*Acacia erioloba*) (Paterson, 2002; Veldtman *et al.,* 2002).

The *G. postica* silkworm differs considerably in appearance and habits from the *B. mori.* It is usually larger and greener in colour, covered with tuffs of gingerish hair (Cooke, 1984). The coarser food that the wild silkworm eats leads to an irregular and coarse filament. The tannin in the leaves gives the wild silk a tan colour. In addition, *G. postica* leaves one end of its cocoon open and seals the hole with a layer of sericin gum before starting metamorphosis. The moth emerges from the cocoon by breaking through the sericin wall (Cooke, 1984). In doing so, the cocoons are always pierced and the fibres are shorter than reeled silk (Corbman, 1983:299). The short lengths of filaments are combed and spun to form silk thread. These threads are less lustrous, strong and elastic than reeled silk and will become fuzzy with wear (Lee, 1999). The macro structural characteristics such as denier, filament length and cross-section are different between wild and cultivated silk (Kushal & Murugesh, 2004). Cultivated silk fabrics also show lower values of stiffness, compression resilience, bending rigidity and tensile resilience (Sharma *et al.,* 2000).

Silk is the strongest natural textile fibre as a result of its molecular arrangement, which is highly oriented (Stout, 1970:129). Wet strength is about 80 to 85% of dry strength (Joseph, 1986:60). The continuous length of individual filaments provides a factor of strength, which is higher than that possible with short staple fibres (Potter & Corbman, 1967:272). The tenacity values increase along the filament length within a cocoon from the outer to the inner layers. This is true for all the silk varieties (Kushal & Murugesh, 2004).

The inherent strength of silk along with its lightness and fineness makes it desirable for sheer, yet durable fabrics. However, the strength of silk fabric is affected by its construction as well as its finish, e.g. spun silk yarn is weaker than thrown silk (Potter & Corbman, 1967:272). In addition, the harsher methods of sericin removal can cause fibre degradation and a resultant loss of strength (Freddi *et al.*, 2003).

The core filaments of silk are composed of highly organized β-sheet crystalline regions and semi-crystalline regions that are responsible for its elasticity (Altman, 2003). However, the non-mulberry silks contain more amino acid residues with bulky side groups. These enable molecular chains in non-crystalline regions of the fibre structure to slip easily when stretched and show higher elongation at break (Kushal & Murugesh, 2004).

The good absorptive property of silk contributes to its comfort in a warmer atmosphere. Silk has a moisture regain of 11% (Kadolph & Langford, 2002:64; Cowan & Jungerman, 1973:36). This property also contributes to the ease at which silk can be printed and dyed (Potter & Corbman, 1967:273). Unlike many other fibres, silk also absorbs dissolved substances (Lee, 1999) such as metal salts, which causes damage by weakening or rupturing the fibres when the fabric is not handled properly. Silk can absorb a great deal of moisture up to 30% and still feel quite dry (Cai & Qiu, 2003; Joseph, 1986:60).

Silk occupies a very special position as a textile fibre, possessing an extraordinary combination of beauty (Frank, 2000) and strength (Reddy & Yang, 2010). *Gonometa postica* has good economic potential as the larvae yield a high quality silk (Freddi *et al.,* 1993). However, the labour intensive nature and high cost of its initial production and subsequent processing make it very expensive for consumers (Miller, 1992:36). Raw *G. postica* silk was available at R550 per kilogram in 2011 (Kotze, 2011.).

Several small-scale industries have been established using the wild silk (Delport *et al.,* 2005), but new developments are restricted because the "wild silk" product range is small and unaffordable to many. A possible solution could be to create a mixed fabric to lower the cost. Wool is also a natural protein fibre (Kadolph & Langford, 2002:50) and would therefore have many of the same characteristics as silk. The mixed fabric would still be natural and could be manufactured into a sustainable fabric with commercial advantages. In 2011, raw wool was available at R86.26 per kilogram (Cape Wools, 2011). The constituent protein fibres contain many of the same characteristics as those of silk, thus making it a good candidate for use in mixed fabrics. Therefore the aim of the study was to compare the characteristics *G. postica* silk with a *G. postica* silk/wool fabric.

MATERIALS AND METHODS

Materials

All tests were conducted on two sets of hand-woven plain weave textiles. For the *G. postica* silk the weft yarns were hand spun, while the warp yarns were machine spun. The fabric contained 6 warp yarns and 5.5 weft yarns per 10 mm². For the *G. postica* silk/wool fabric the warp wool yarns were 100% machine washable, machine spun merino wool while the weft yarns were hand spun yarns from the *G. postica* silk. The fabric contained 6,5 warp yarns per $10mm^2$ and 5,5 weft yarns per 10mm². The fabrics contained the same weft yarns, while the warp yarns were both machine spun to the same diameter to ensure comparability.

Methods

Microscopic examination The characteristics of *G. postica* silk fibres and fabrics are not well documented. Therefore, the characteristics of the silk were examined microscopically (Nikon TE 2000 light microscope).

Tensile strength The maximum force required to break the samples, and elongation at maximum force, were determined using the ISO 13934 method (SABS, 1999) and the Instron Tensile Strength Tester. Eighteen 50mm x 200mm samples were taken from each of the fabrics, nine with their long side parallel to the warp yarns and the other nine with their long side parallel to their weft yarns. Samples were conditioned at 21 ± 1˚C and 65 ± 2% relative humidity for 24 hours. The gauge length of the machine was set at 100mm; (due to limited amount of available fabric), the rate of extension was set at 100 mm/min, while the ramp rate was 20 kN/min. The samples were placed to ensure that the longitudinal centre-line passed through the centre point of the front edges of the jaws of the Instron tester. The clamps were put in motion and extended the samples to the point of rupture. The following was recorded: load at rupture (N) and elongation at rupture (mm).

Stiffness A Shirley Stiffness Tester was used with the British Standards Test Method 3356 (British Standards Institution, 1990) samples (25 mm x 150 mm) were prepared accordingly. Four readings were taken from each sample, with each side up, first at the one end and then the other. The readings represented the bending length of the fabric (cm).

Crease recovery A Shirley Crease Recovery Tester was used according to the AATCC Test Method 66 (AATCC Technical Manual, 2009) and 20 (15mm x 40mm) samples were processed. The crease recovery reading (degrees recovered) was taken after five minutes.

Dimensional shrinkage (water and steam) Dimensional stability to washing was determined by measuring relaxation and progressive shrinkage using AATCC Test Method 99 (AATCC Technical Manual, 2009). Ten (50mm x 150mm) samples of each fabric were measured in both warp and weft directions.

The AATCC Test Method 99 was adjusted in order to determine shrinkage caused by steam. Ten 50mm x 150mm samples were taken from each of the fabrics in both warp and weft directions and conditioned at 21 ± 1˚C and 65 ± 2% relative humidity for 24 hours. The area was marked and samples were exposed to steam of a steam iron for 30 seconds. The samples were dried with a flat-bed press at 135-149˚C, without stretching or distorting the fibres. The area was measured after 24 hour conditioning and the relaxation shrinkage was calculated. This process was repeated to determine progressive shrinkage.

Analysis of variance (ANOVA) was used to determine any significant difference in sample means (p ≤ 0,05).

RESULTS AND DISCUSSION

Microscopic examination

A smooth surface for the silk was microscopically observed with no shadows indicative of individual filaments. One of the fibres shows a flat-

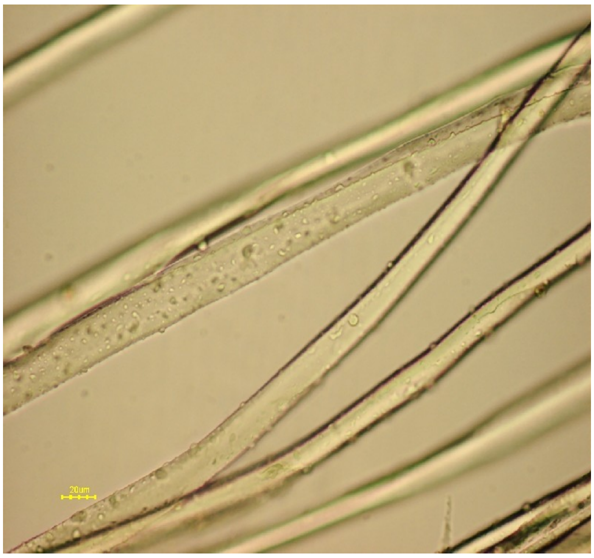

FIGURE 1: LIGHT MICROSCOPIC LONGITUDINAL VIEW OF *GONOMETA POSTICA* SILK

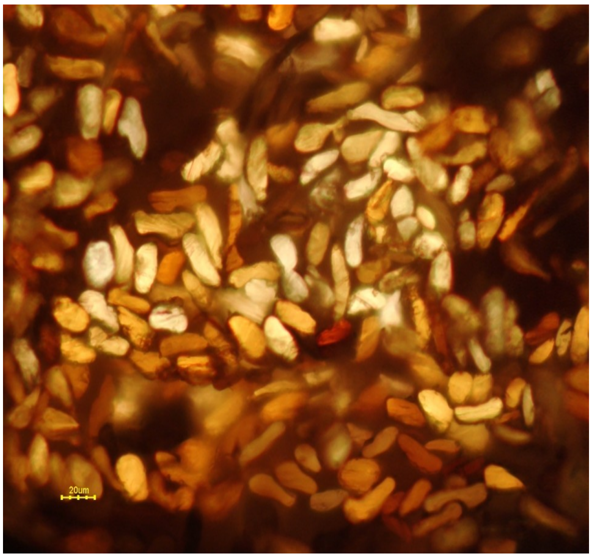

FIGURE 2: LIGHT MICROSCOPIC CROSS-SECTIONAL VIEW OF *GONOMETA POSTICA* SILK

tened area which could be due to the triangular form of the fibres. Fibres shown in Figure 1 varied in size because they were natural fibres. This concurs with the longitudinal view of wild silk, which has a slightly coarse fibre with an irregular diameter and slight striations (Liu et al., 2011; Frank, 2000). The variation in diameter (15-25 µm) could also be seen in Figure 2. A silk filament is coarser in the outer layers of the cocoon and become finer towards the inner layers and the difference can be as much as 25-40% (Sangappa, 2003). Figures 1 and 2 indicate variety of flattened and triangular shapes. Wild silk is less regular in cross-section than cultivated silks (Liu et al., 2011).

Tensile strength

Weft The mean maximum load necessary to break the silk weft yarns was 492,317 N and the mean displacement at maximum load was 39,048 mm. The mean maximum load to break the silk fabric was 412,750 N and the mean displacement was 31,764 mm. The difference between the maximum load carried by the silk weft and the silk warp is due to the fact that the weft yarns were hand spun while the warp yarns were machine spun. It is surprising that the hand spun yarns could carry a bigger load than the smooth machine spun yarns. An explanation might be that the machine spun yarn was thinner and did not contain as many fibres in the yarn cross-section as the hand spun yarn that could carry the load. The mean maximum load that the silk weft yarns of the silk/wool fabric could carry was 475,970 N and the mean maximum displacement was 39,442 mm. The statistical analysis (Table 1) indicated that there was not a significant difference between the maximum load required to break the silk fabric and the silk/wool fabric, in the weft direction (p > 0,05).

Warp The mean maximum load that the silk warp yarns could carry was 416,16 N and the mean displacement was 31,93 mm. The mean maximum load that the wool warp yarns could carry was 426,011 N and the mean displacement was 46,448 mm. There was not, however, a significant difference between the maximum loads required to break the silk fabric in warp direction compared to the silk/wool fabric in warp direction (p > 0,05) (Table 1).

The lower tenacity of wool can be explained by the large amorphous areas containing bulky molecules that cannot be packed close enough together to form strong hydrogen bonds, therefore wool has many weak bonds and less strong cystine linkages, which makes the fibre weak (Hollen & Saddler, 1973:20). Lang (1952) reports that tensile strength is independent of the shape and proportional to the size of the cross-section. Therefore, wool has a good correlation between fibre weight per unit length and breaking load.

According to Kadolph and Langford (2002:63) silk is a very strong fibre, while wool has poor tenacity. The tenacity and elongation at break of silk are different from other protein fibres because of the chemical differences. Fibroin consists mainly of four amino acids without bulky side chains, cross-linked by hydrogen bonds, structural differences, high crystallinity and orientation (Susich & Zagieboylo, 1953). Hand spun silk has a lower tenacity than filament silk (Potter & Corbman, 1967:273) and the harsh removal of sericin causes fibre degradation (Freddi *et al.,* 2003). These might be the causes of the lower tenacity of the silk weft yarns.

Stiffness

The bending length is a characteristic property of a textile and is dependent upon the energy required to produce a given bending deformation under its own weight (Brenner & Britt, 1964). Bending properties are important because they contribute towards the drape and handle of fabrics and influence the mechanisms of fabric deformation. The places where deformations occur are in the individual fibres and the yarns, which are both capable of movement within the fabric structure (Cooper, 1960).

The bending lengths of all the samples were small enough to indicate that it has good draping qualities, considering the thickness of the fabrics. The silk fabric showed less stiffness in the warp direction, possibly because it was a thinner and smoother yarn that was machine spun and therefore softer. Wool has moderate bending qualities, which could have decreased as a result of the finishing processes (Corbman, 1983:273). In this case the finishing process probably made the fibres machine washable.

There was no significant difference between the stiffness in the weft direction of the silk fabric and the silk/wool fabric (p > 0,05). There was, however, a significant difference in the warp direction of the silk fabric and the silk/wool fabric (p < 0,05) (Table 1).

Crease recovery

The ability of a fabric to recover after creasing is desirable, and wool leads among natural fibres possessing this characteristic. Recovery from creasing can be expressed by the angle to which the fabric returns after having been folded and held under a controlled pressure for a fixed period of time. Perfect recovery would be 180° (Dennison & Leach, 1952).

The silk/wool fabric exhibited the better and the silk fabric the worse crease recovery especially in the warp direction. The better crease recovery of the silk/wool fabric was expected as the warp yarn was wool, which has excellent recovery from creasing. Protein fibres are more resistant to creasing due to their flexible molecules and their existence in the form of a network, secured by strong chemical forces or primary bonds (Meredith, 1952).

According to Krasny and Sookne (1955) crease recovery is improved by the use of symmetrical weaves as the fabric construction influences the crease recovery. This could explain why the silk fabric had the smaller recovery as the weave was not balanced. The bulkiness of the wool yarn gave good crease recovery, while the warp silk yarn was machine spun and thinner than any of the other yarns that made it more difficult for these yarns to resist and recover form creasing. According to Dennison and Leach (1952) wool improves crease recovery in mixed fabrics. The small difference in crease recovery in the weft direction was expected as the weft yarns of the fabrics were hand spun silk yarns.

There was no significant difference between the crease recovery in the weft direction of the silk fabric and the silk/wool warp fabric (p > 0,05). There was, however, a significant difference in the warp direction of the silk fabric and the silk/wool fabric (p < 0,05) (Table 1).

Dimensional shrinkage

Water According to Cookson *et al*. (1991) relaxation shrinkage occurs in finished fabrics because of strain imposed during finishing processes, which is then released when the fabric is exposed to conditions of high relative humidity. The silk/wool had no shrinkage in the warp directions because the wool had a finish that made it washable. The silk fabric showed more shrinkage in the warp direction than in the weft direction. A possible explanation was that the warp yarns were machine spun and had more tension imparted that relaxed, where the weft yarns were hand spun and not twisted and stretched as much.

There was no significant difference between the shrinkage after water exposure in the weft direction of the silk fabric and the silk/wool fabric (p > 0,05). There was, however, a significant difference in the warp direction of the silk fabric and the silk/wool fabric (p < 0,05) (Table 1).

TABLE 1: ANOVA RESULTS OF THE TENSILE STRENGTH, STIFFNESS, CREASE RECOVERY AND DIMENSIONAL CHANGE OF THE *GONOMETA POSTICA* SILK AND *GONOMETA POSTICA* SILK/WOOL FABRICS

Procedure*	Unit	Fabric direction	Silk / silk			Silk / wool			P-value
			Mean	SD	Standard error	Mean	SD	Standard error	
Tensile strength	N	Warp	416,16	17,08	5,69	426,01	44,91	14,97	0,77
		Weft	486,88	17,61	5,87	475,31	52,94	17,65	0,82
Stiffness	cm	Warp	2,14	0,12	0,04	2,39	0,09	0,03	0,00**
		Weft	2,63	0,17	0,53	2,72	0,14	0,04	0,44
Crease recovery	Degrees recovered	Warp	129,50	12,60	3,98	145,70	9,04	2,86	0,006**
		Weft	133,80	10,36	3,28	139,10	7,37	2,33	0,35
Dimensional shrinkage (water)	%	Warp	16,00	4,62	1,46	0,00	0,00	0,00	0,00**
		Weft	10,80	5,01	1,58	14,80	3,29	1,04	0,09
Dimensional shrinkage (steam)	%	Warp	16,00	4,62	1,46	0,00	0,00	0,00	0,00**
		Weft	8,00	0,00	0,00	8,00	0,00	0,00	0,000

*n=10, except for Tensile strength where n=9
**statistically significant

Steam Again there was no shrinkage in the warp directions of the silk/wool fabric. It was interesting that the silk fabric showed the same amount of shrinkage in both directions with the steam. The shrinkage of 8% with exposure to steam was much less than the 15% with water.

There was no significant difference between the shrinkage after steam exposure in the weft direction of the silk fabric and the silk/wool fabric because the mean values were the same. There was, however, a significant difference in the warp direction of the silk fabric and the silk/wool fabric (p < 0,05) (Table 1).

CONCLUSION

Wild silk is an exotic fibre that creates a fabric with a unique combination of properties, which is very expensive and therefore unaffordable for many consumers. The aim of this study was to establish whether wool would create an acceptable mixed yarn fabric with the *G. postica* silk, in order to create a less expensive fabric with the same positive features as the wild silk. The results showed that the *G. postica* silk weft/wool warp mixed yarn fabric had higher tenacity and better crease recovery and also had no shrinkage in the warp direction; all favourable properties for consumer acceptance. The silk/wool fabric was more rigid than the silk fabric, but still flexible enough to ensure that the aesthetic or functional properties of the *G. postica* silk was not affected in a negative manner. Therefore Merino wool was an appropriate fibre to use in a mixed yarn fabric with the *G. postica* silk. This study was limited to hand woven fabrics and further research should be done on fabrics consisting of machine spun yarns.

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