A COMPARATIVE STUDY OF REGENERATED BAMBOO, COTTON AND VISCOSE RAYON FABRICS. PART 2: ANTIMICROBIAL PROPERTIES

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OPSOMMING

Sedert geregenereerde bamboesvesels ŉ paar jaar gelede op die mark verskyn het, word verbruikers gebombardeer met inligting – soms teenstrydig – oor hierdie vesels, die produkte wat daarvan vervaardig word en die eienskappe wat daarmee geassosieer word. Vervaardigers en verspreiders maak stellings (veral op die internet) oor die antimikrobiese en omgewingsvriendelike eienskappe daarvan, maar terselfdertyd is daar luide protes van verbruikerswaghonde dat baie min van hierdie stellings wetenskaplik bewys is. Inligtingsbronne verwar ook dikwels natuurlike bamboesvesels (wat inherente antimikrobiese eienskappe besit) met die nuwe geregenereerde bamboesvesels.

Geregenereerde bamboesvesels word vervaardig van natuurlike bamboesvesel as roumateriaal. Gedurende die regenerasieproses word die bamboespulp verwerk of verfyn in ŉ hidrolise-alkalinisasieproses, waartydens sterk chemikalieë soos natriumhidroksied en koolstofdisulfied gebruik word. Die vesels word in ŉ verdunde swawelsuurbad gespin. Die proses stem ooreen met die viskose rayon spinproses – vandaar die gebruik van name soos bamboesviskose of bamboesrayon vir geregenereerde rayon. Die houtpulp wat gebruik word in die vervaardiging van viskose rayonvesels bevat egter geen antimikrobiese agense nie. Die strawwe chemiese aard van die vervaardigingsproses het skeptiese vrae laat ontstaan oor of dit moontlik is dat die bamboeskun, wat verantwoordelik is vir die antimikrobiese eienskappe van natuurlike bamboesvesels, behoue kan bly in die geregenereerde bamboesvesels. Die moontlikheid bestaan ook dat agtergeblewe chemikalieë (bv swawel) op die gespinde vesels die antimikrobiese eienskappe kan veroorsaak.

Die hoofdoel van die studie was om die stelling te ondersoek dat geregenereerde bamboesvesels inherente antimikrobiese eienskappe besit as gevolg van die teenwoordigheid van bamboeskun in die rou materiaal waarvan dit vervaardig word (natuurlike bamboesvesels). Die antimikrobiese eienskappe van tekstielstowwe van geregenereerde bamboesvesels is vir die doel vergelyk met dié van viskose rayon en katoenveselstowwe. Katoenstof is as kontrole gebruik, aangesien dit bekend is dat hierdie vesels geen antimikrobiese eienskappe openbaar nie. In ŉ voorloperstudie is daar trouens bevind dat katoenstowwe met ŉ antimikrobiese behandeling mikrobegroei ten volle onderdruk.

Die resultate van hierdie studie wys duidelik dat die katoenstof sonder antimikrobiese bahandeling geen antimikrobiese aktiwiteit getoon het nie. Die antimikrobiese eienskappe van die geregenereerde bamboesvesel- en viskose rayonstowwe was egter beduidend hoër as dié van katoen vir beide Grampositiewe en Gram-negatiewe bakterieë. In beide gevalle was die antimikrobiese effek egter gedeeltelik en nie so effektief soos daar van behandelde katoenstowwe verwag is nie. ŉ Vergelyking van die twee geregenereerde sellulose weefstowwe het egter geen statisties beduidende verskille in antimikrobiese aktiwiteit aangetoon nie.

Die stelling rakende die antimikrobiese eienskappe van geregenereerde bamboesvesel kon dus nie verkeerd bewys word nie. Geen bewyse kon ook gevind word dat die antimikrobiese eienskappe van die geregenereerde bamboesvesels in enige opsig beter as dié van viskose rayonvesels is nie. Die rede vir dié ooreenstemming is onbekend. Aangesien die rou materiaal wesenlik verskil (bamboesvesel teenoor houtpulp), kan die antimikrobiese effek in die geval van geregenereerde bamboesvesels nie noodwendig toegeskryf word aan die teenwoodigheid van onveranderde bamboeskun in die vesels nie.

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INTRODUCTION AND BACKGROUND

The inherent antimicrobial properties of natural bamboo are undisputed. Natural bamboo contains bamboo kun, a bacteriostatic agent unique to bamboo plants, which gives these fibres properties found in none of the other cellulosic fibres. But is the same true of the new regenerated bamboo fibres that have recently reached the consumer market?

Since the "new" regenerated bamboo fibres (also referred to as bamboo viscose) became commercially available in 2006, consumers have been bombarded with contradictory information regarding products made of these fibres, their potential end-uses and their properties. On the one hand, the manufacturers and marketers of regenerated bamboo fibres and fabrics make broad claims about the environmentally friendly and "green" characteristics of the production processes and of bamboo fibres having antimicrobial properties and even "particular and natural functions of antibacteria, bacteriostatic and deodorization" (China Bambro Textile Co. Ltd., 2003; Shanghai Tenbro Bamboo Textile Co. Ltd., 2007; Swicofil AG Textile Services, 2007). On the other hand, there is an outcry that many of these claims are false and not properly proved (Bamboo fibre claims discouraged, 2009; Hardin et al., 2009).

Very little information regarding the validation of these properties through scientific research studies is available. A closer look reveals that most of the claims have their origin in information from one large Chinese company. It is also noticeable that information regarding natural bamboo and regenerated bamboo fibre products is often confusing.

Two studies on the validation of the "anti-bacteria, bacteriostatic and deodorization" properties of "bamboo fibre" are reported on a number of websites of companies that market bamboo products; although it seems that they all originate from the Shanghai Tenbro Co., one of the first and largest suppliers of regenerated bamboo in China. By implication, it would seem as if the studies were done on regenerated bamboo fibres but this is not specifically stated (in both studies, the fabrics are described as "100% bamboo").

In the first study, the Japan Textile Inspection Association (JTIA) reported a 70% elimination rate after live bacteria were incubated on bamboo fibre fabric – even after 50 washes. However, no information could be found regarding the JTIA or whether this is an accredited testing facility.

The other study was done on socks by a final-year student in textile technology (textile chemistry) at the SSM College of Engineering, Komarapayalam, India. He used a "sample swatch survival test" and found that *Escherichia coli* and *Staphylococcus aureus* bacteria survived longer on cotton and viscose rayon fabrics than on 100% bamboo and 50% bamboo/50% cotton fabrics. He concluded that the 100% bamboo and 50% bamboo/50% cotton fabrics potentially resist the colonisation of bacteria after the second day of incubation (*Bamboo – Is it antimicrobial?,* 2010; *Gomati, 2010, Tenbro bamboo fibre*, 2010). It should be noted, however, that the cotton samples also showed the elimination of bacterial growth after more than two days.

Cotton fabrics do not usually have antimicrobial properties. Studies have shown that *S. aureus* can survive up to two weeks in cotton fabrics, depending on fabric design and inoculum size (Hatch, 1993:168; Neely & Maley, 2000). Hardin et al. (2009) found a study done on 100% natural bamboo bast fibres (manufactured by Litrax GmbH in Switzerland); in this study, the bamboo fibre (from the stem of the plant) eliminated *S. aureus* in an antibacterial test. None of the above was reported in scientific publications.

David Vladeck, director of the US Federal Trade Commission (FTC), has stressed the importance of the accurate labelling and advertisement of textile products, both with respect to fibre content and properties, to ensure that consumers can trust that the products that they buy have the attributes that they require. The FTC has, in fact, taken action against three companies that were making unsubstantiated claims. An example of such claims is that the regenerated bamboo products that were being marketed were "100% bamboo fibre", that they "retain[ed] their antimicrobial properties", that they were "biodegradable" and that they were "manufactured by using environmentally friendly processes"; according to these companies, regenerated bamboo is "technically rayon". The companies were charged in accordance with the FTC's Rules and Regulations under the Textile Fiber Products Identification Act. Subsequent settlements forbade them to continue making any claims "about the benefits, performance or efficacy of any clothing or textile product they sell, unless backed by reliable evidence" (Bamboo fibre claims discouraged, 2009; Hardin et al., 2009). In August 2009, the FTC issued two publications on its website aimed at consumers and businesses, respectively, to prevent misinformation (Have you been bamboozled by bamboo fabrics?, 2009; How to avoid bamboozling your customers, 2009).

Biodeterioration refers to any undesirable change in the properties of a material caused by the vital activities of micro-organisms. Under suitable conditions, micro-organisms, including micro-fungi, bacteria and algae, can develop and proliferate on textile material. The textile fibres are attacked chemically by the action of extra-cellular enzymes produced by micro-organisms for the purpose of obtaining food (Hamlyn, 1983; Hamlyn, 1990). The effect on textile fabrics can range from mild surface growth, which can lead to unwanted pigmentation (and cause products to look unattractive), to heavy infestation, which results in physical changes, such as loss in strength or flexibility. Another problem is the development of unpleasant odours when bacteria convert human perspiration into substances such as carboxylic acid, aldehydes and amines. Microbial textile infestation can also result in disease. Bacteria such as Staphylococcus on underwear can cause odours and purulence on the skin surface and *E. coli* can lead to odour and ulcers on the skin (Montazer & Afjeh, 2007).

Microbial growth occurs on textiles under suitable conditions, such as the availability of sufficient water, air and nutrients. Under such conditions, sensitive fabrics are rapidly colonised by bacteria and micro-fungi and are eventually metabolised by them as part of their food-chain. Natural fibres are more susceptible to biodeterioration than synthetic or artificial fibres; cellulose fibres are particularly liable to microbial attack, especially under hot, humid conditions. In clothing, fabric structure forms a moist and warm environment, allowing excellent growth conditions for micro-organisms. Clothing such as shoes and socks, underwear and sportswear, as well as hospital health care textiles such as bedding, curtains, gowns, uniforms, towels, gloves and gauze are good examples of products where microbial infestation has several unpleasant consequences. Micro-organisms can also grow on accumulated dirt on fabric surfaces or attack the finishing materials applied to textiles, resulting in colour changes and a loss of mechanical properties. Starches, protein derivatives, fats and oils used during finishing also promote microbial growth on textile fabrics (Hamlyn, 1983; Hamlyn, 1990; Montazer & Afjeh, 2007).

Although complex, the reactions involved in the deterioration of fibres through microbial growth are basically a form of hydrolysis. The organisms secrete enzymes, which have the ability to catalyse the hydrolytic process by which the polymer backbone of cellulose fibres is progressively hydrolysed to fragments of lower molecular weight, which eventually leads to a loss in mechanical properties (Holker, 1988).

A growing concern about the dangers of microbial and viral contamination and the spreading of disease has lead to the development of new markets for antimicrobial textiles, particularly in institutional environments and in skin-contact products (Hatch, 1993:398). Functional fabrics with antimicrobial properties are generally regarded as valuable for two reasons: because they serve as a prophylactic measure to reduce the risk of infection or the spreading of disease and because they serve as a preventative measure against the development of odours (Horrocks & Anand, 2000:171).

Cotton is a natural cellulose fibre applied in a variety of end-uses. Cotton fibres are particularly prone to bacterial infestation as a result of their porous hydrophilic structure, which retains water, oxygen and nutrients, thereby providing a perfect environment for microbial growth should conditions during use and care be suitable. In cases where antimicrobial properties are required in an end-product, the fabric therefore has to be treated with a suitable finish (Montazer & Afjeh, 2007).

Antimicrobial-finished fabrics are described as fabrics that inhibit the growth of bacteria or germs, control the spreading of disease and reduce the chances that a wound might become infected after injury due to the presence of antimicrobial chemicals on the fabric (Kadolph & Langford, 2007:375). Such finishes (or treatments) can reduce microbial counts by as much as 75% to 99% (Hatch, 1993:397).

Antimicrobial finishes can be divided into two main groups based on their functionality. The first group comprises bacteriostatic finishes, which contain chemicals that inhibit bacterial growth, eventually causing them to die. The second group comprises fungistatic finishes, which work in the same way except against fungi. Bactericidal, fungicidal and microbicidal all mean that the chemicals kill the micro-organisms concerned on contact (Horrocks & Anand, 2000:172; Kadolph & Langford, 2007:374; Rouette, 2000:87).

Antimicrobial finishes can also be divided into two categories based on the mode of attack. The first category operates by a controlled-release mechanism, which means that the antimicrobial chemical is slowly released over time from a reservoir either on the fabric surface or in the fibre. The problem with this type of finish, however, is that the antimicrobial chemical is depleted after a while and that the fabric then has no further antimicrobial properties. The second category consists of antimicrobial molecules that are chemically bound to the fibre surfaces. These finishes, however, are effective only on microbes that are physically on the fibre surfaces (Schindler & Hauser, 2004:166). Hatch (1993:399) compared the functionality of these bound antimicrobials with that of a sword, having an unlimited capacity to kill, whereas the unbound antimicrobials function like a gun, which has limited ammunition.

Additional finishes add extra costs, can cause allergic reactions in some cases or involve chemicals of which the safety and toxicity may vary. Depending on the type of finish, antimicrobial agents may also leach from the finished fabric and become depleted with time, losing their functionality (Hatch, 1993:398).

Fibre or textile-fabric surfaces that are inherently antimicrobial implies that microbial growth on such fibre or textile-fabric surfaces will be inhibited or that live bacteria will be killed. In the case of fibres that possess this property, the use of expensive chemical antimicrobial finishes that are potentially harmful to nature are unnecessary, resulting in a more environmentally friendly product and a substantial decrease in cost. It can be expected that a fabric with such inherent antimicrobial properties would be favoured by consumers, which makes it even more important that false claims in this regard should not be allowed. This was confirmed by the strong action taken by the FTC against the companies that used unsubstantiated claims for marketing purposes regarding bamboo fabrics (Hardin et al, 2009).

Regenerated bamboo (also referred to as bamboo viscose or bamboo rayon) is manufactured from natural bamboo fibres in a regeneration process by which the bamboo pulp is refined from the stems of the bamboo plant in a hydrolysis-alkalisation process, followed by multi-phase bleaching. This process is also referred to as the viscose process and comprises the soaking of crushed bamboo cellulose (from the leaves and the soft inner pith of the bamboo trunk) in sodium hydroxide to form alkali cellulose, followed by drying and ageing. This cellulose is then sulphurised by the addition of carbon disulphide, causing the compound to take on a gel-like consistency. Any remaining carbon disulphide is removed by evaporation, leaving cellulose sodium zanthogenate as a result. This is dissolved by the addition of a diluted solution of sodium hydroxide to create a viscose solution from which the bamboo cellulose fibre filaments are spun in a diluted sulphuric-acid solution (China Bambro Textile Co. Ltd., 2003; Erdumlu & Ozipek, 2008; Sui et al., 2003). The similarities between this process and that by which viscose rayon fibres are spun were compared and discussed in Part 1 of this article (Gericke & Van der Pol, 2010).

The above led to the question of whether the antimicrobial properties of the bamboo kun remain unchanged in the regenerated bamboo fibres after exposure to the relatively severe regeneration process. It is the opinion of the FTC that the harsh chemicals used in the spinning process would nullify any natural antimicrobial functions (US Federal Trade Commission acts on bamboo fibre claims, 2009).

Another concern raised by experts in the field of textile science is the presence of residual sulphur that might still remain in or on the spun fibres. Sulphur and sulphur-containing compounds are regarded as some of the oldest antimicrobial substances (Sulfur dioxide: Science behind this anti-microbial, anti-oxidant, wine additive, 2010; Taj & Baqai, 2007; Usseglio-Tomasset, 2010). Although the process allows for the removal of sulphur in the final phase, it is possible that traces of sulphur could remain on or in the fibres (Angelini & Paoletti, 1983). If the sulphur is not thoroughly removed from the fibres during after-treatments, the possibility exists that this could cause an antimicrobial effect. If this is true, it would be expected that viscose rayon fibres would also exhibit antimicrobial properties.

The Oeko-Tex® standard is a globally uniform testing and certification system for textiles, through which products can be certified as not containing any harmful substances prohibited or regulated by law. The modular principle of the standard ensures that products can be tested and certified at all stages of the processing chain. The problem is that sulphur is not specified as a harmful substance and is thus not regulated under this standard (*Oeko-Tex® Standard 100*, 2010).

Viscose rayon, like regenerated bamboo, is a regenerated cellulose fibre and is known for its soft, cool hand and sheen. The most important difference is that regenerated bamboo fibres are manufactured from bamboo pulp and viscose rayon fibres from wood pulp. As mentioned above, natural bamboo (the source of bamboo pulp) is inherently antimicrobial. The wood pulp from which viscose rayon is made, however, does not contain bamboo kun or any other similar substance that possess antimicrobial properties. Wood pulp therefore does not exhibit any antimicrobial properties in its natural form.

During the regeneration of cellulose fibres in the spinning process – be it from wood pulp in the case of viscose rayon or bamboo pulp in the case of bamboo viscose – the degree of polymerisation of the polymer backbone of the structure is lowered as the polymer is broken down into shorter pieces by exposure to a sodium-hydroxide solution (Hatch, 1993:185). The basic polymer structure of the cellulose backbone structure, however, remains unchanged, which means that the regenerated fibres are still prone to microbial attack. This can be altered only by the presence of an applied antimicrobial finish or residual chemicals (from the manufacturing process) in or on the fibres. As mentioned earlier, the possibility exists that incomplete desulphurisation before spinning could cause an antimicrobial effect. Another cause of antimicrobial activity could be bamboo kun, an ingredient in natural bamboo fibres. No proof could be found in literature that this component is still present and unchanged in the regenerated cellulose

It could therefore be argued that, if viscose rayon fabrics are compared to regenerated bamboo fabrics with regard to antimicrobial activity and bamboo fabrics perform better, the assumption could be made that this could be due to the presence of bamboo kun in the regenerated bamboo fibres. This would imply that bamboo kun retains its antimicrobial properties during cellulose regeneration. If the two fabrics perform similarly, however, this could be the result of residual chemicals (such as sulphur) from the harsh viscose process used in the manufacturing of both fibre types.

Main aim

The main aim of this study was to determine whether the claim that regenerated bamboo fibres have inherent antimicrobial properties as a result of the bamboo kun present in natural bamboo fibre (used as a raw material) can be proved.

The first objective was to investigate and compare the antimicrobial properties of 100% regenerated bamboo, 100% viscose rayon and an untreated cotton fabric (used as the control or reference) to determine whether the antimicrobial properties of the two regenerated cellulose fabrics differed from that of the cotton, a fabric well known for not having any antibacterial properties. If this were true, the second objective would be to compare the antibacterial effect measured in regenerated bamboo (allegedly containing bamboo kun) and in viscose rayon (containing no bamboo kun) to establish whether the antibacterial activity in regenerated bamboo could be ascribed to the presence of bamboo kun.

In order to cover a broad spectrum of bacteria, both gram-positive bacteria and gram-negative bacteria were included in the tests.

METHODOLOGY

Three single jersey fabrics were knitted at a local knitting mill, on the same knitting machine, for the purpose of this study. Cotton, viscose rayon and regenerated bamboo yarns of similar counts were used. The fabrics were finished to a weight of 170 (± 2) g/m^2 and bleached. No other finishes or dyes were applied. Fabric samples were analysed according to fabric weight, gauge and thickness to confirm comparability. Before testing, all the fabrics were fully conditioned according to SABS 70.

The antibacterial properties of the test fabrics were compared by measuring antimicrobial activity according to the ASTM Designation E 2149-01 test method. This test method is particularly suitable for the study of the bacteriostatic properties of a textile sample as it does not depend on the leach ability of the antimicrobial agent from the substrate to be tested. Dynamic contact is allowed between the textile fabric, fibre or substrate tested and the bacteria that it is exposed to by the constant agitation of the test specimen in a bacterial suspension during the test period.

The bacteria used in the procedure were *Staphylococcus epidermidis,* a gram-positive bacterium that is commonly found on human skin and is often responsible for endocarditis and wound infections, surgical infections and urinary tract infections in patients with low resistance (Prescott, Harley & Klein, 2005:514), and the gram-negative bacterium *E. coli*, a bacterium known to cause several intestinal and extra-intestinal infections such as urinary tract infections, meningitis, peritonitis, mastitis, septicaemia and gram-negative pneumonia. Due to the fact that different types of bacteria react differently to different antimicrobials, it is necessary that both gram-positive bacteria and gram-negative bacteria should be included when antimicrobial activity on textiles is studied and investigated (Prescott et al., 2005:136).

A microbe solution of each of the two bacteria was prepared in sterile nutrient broth and incubated for 24 hours. From each of the three test fabrics, eight test samples of 1.5 g each plus eight control samples were cut and prepared for testing.

Each 1.5 g sample was placed in 50 ml of microbe solution in an Erlenmeyer flask. The flasks were capped and mounted in a wrist shaker for one hour, after which the fabric samples were removed and a dilution series (from 10^{-1} to 10^{-8}) was prepared from the remaining microbe solution. Of each of the dilutions, 100 ml was plated out on a plate count agar in a spread plate. The spread plates were incubated for 24 hours at a temperature of 35 °C. The number of colonies of each bacterium on each plate was counted and reported, following standard plate-count techniques. An analysis of variance (anova) was done on the results to analyse statistical differences in the results obtained from the three different fabrics and the two different microbe solutions.

The same procedure was followed for each of the two microbe solutions. The rationale for the test was that a lower microbe growth count after contact with a specific sample would indicate a higher bacteriocidal effectiveness for that specific sample. To confirm the reliability of the method, a pilot study was done to compare the antimicrobial properties of a 100% cotton fabric treated with an antimicrobial (Aegis) finish with the same untreated fabric. Results showed a 100% reduction in microbial colonies in the case of the treated fabric, as opposed to no antimicrobial activity in the case of the untreated fabric.

To determine whether any residual sulphur was present on the textile fibres in the fabrics tested, the sulphur content of the fabric samples was calculated. The samples were first analysed with a Leo 1430 VP scanning electron microscope. Compositions were quantified by energy-dispersive X-ray spectroscopy analysis with an Oxford Instrument 133 KeV detector and Oxford INCA software. Beam conditions during analyses were 20 KV and approximately 1.5 nA, with a working distance of 13 mm and a specimen beam current of -3.92 nA. Traces of sulphur were found in all the samples tested but, to confirm reliability and overcome difficulties with the solubility of the samples, further analyses on an inductively coupled plasma emission (ICP) spectrophotometer were recommended. This method is suitable specifically for analysing specimens where expected sulphur content is very low (Laban & Atkin, 1999). Fibres from the sample fabrics were digested in nitric acid and analysed with an ICP spectrophotometer against suitable standards to determine the percentage sulphur present on or in the specimens.

RESULTS AND DISCUSSION

The antimicrobial activity of the three different samples was determined separately for both gram-positive bacteria (*S. epidermidis*) and gram-negative bacteria *(E. coli*). The uninhibited microbial growth of each culture on an agar plate after no contact with a fabric sample was recorded (119 colonies for *S. epidermidis* and 129 colonies for *E. coli)*. These values served as reference values for each of the two bacteria. The antibacterial properties of the fabrics tested were clearly demonstrated when the average number of colonies counted on the agar plates after incubation was compared to the reference values. A low number demonstrated a strong antibacterial effect.

The average number of *E. coli* colonies that formed after contact with the regenerated bamboo fabric was 56, while exposure to the viscose rayon fabric led to the formation of 55 and exposure to the cotton led to 164 colonies. This denoted an increase in the number of colonies after contact with the cotton (i.e. it had no antibacterial effect) and a reduction of 56.6% and 57.4% in the cases of the regenerated bamboo and viscose rayon fabrics, respectively.

The average number of *S. epidermidis* colonies counted on the agar plates after incubation following contact with the regenerated bamboo fabric was 30, while that of the viscose rayon fabric was 53 and that of the cotton fabric was 127. The cotton fabric again did not exhibit any antibacterial properties, the regen-

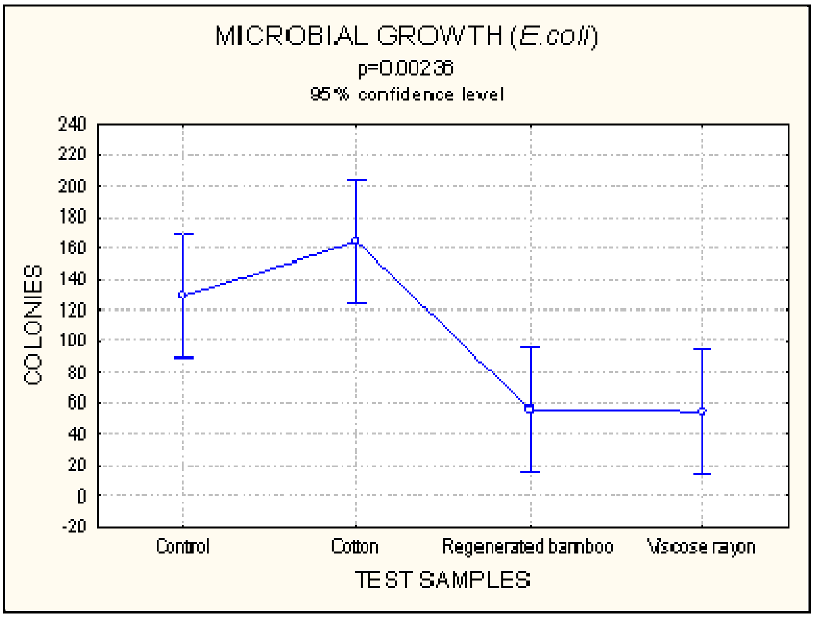

FIGURE 1: COMPARISON OF BACTERIOSTATIC EFFECT OF COTTON, REGENERATED-BAMBOO AND VISCOSE RAYON FABRICS ON *E. COLI.* GRAPH DEPICTS NUMBER OF COLONIES COUNTED 24 HOURS AFTER EXPOSURE TO FABRIC SAMPLES

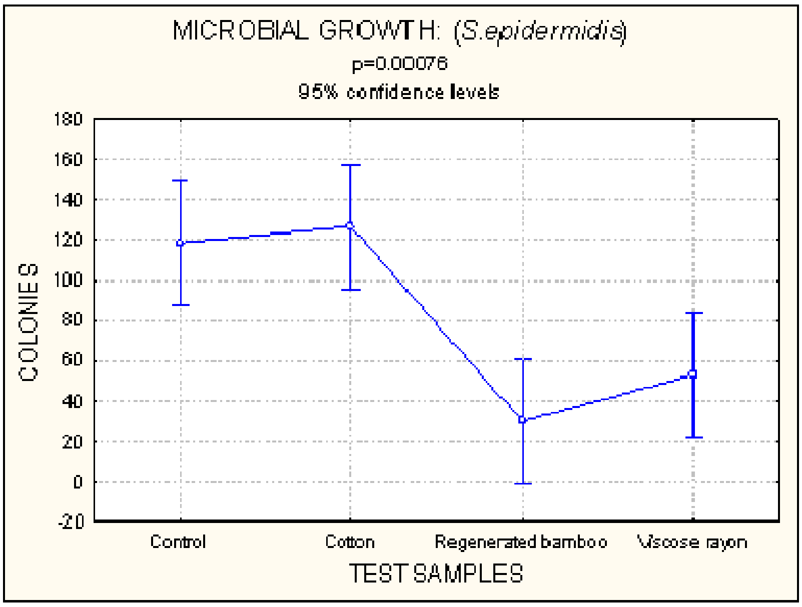

FIGURE 2: COMPARISON OF BACTERIOSTATIC EFFECT OF COTTON, REGENERATED-BAMBOO AND VISCOSE RAYON FABRICS ON *S. EPIDERMIDIS.* GRAPH DEPICTS NUMBER OF COLONIES COUNTED 24 HOURS AFTER EXPOSURE TO FABRIC SAMPLES

erated bamboo eliminated 74.8% and the viscose rayon 59.5% of the bacteria.

An anova done on the microbial growth counts indicated significant differences for both types of bacteria between the results from the tests on the cotton sample, on the one hand, and those on the regenerated bamboo and viscose rayon, on the other hand. These results were compared to the control and are illustrated graphically in Figures 1 and 2, with vertical bars denoting a 95% confidence level.

To illustrate the findings, the results for the *E. coli* and *S. epidermidis* tests were compared on a single graph (Figure 3). It is clear that, compared to the reference value, there was no significant difference (or reduction) in the number of colonies formed after exposure to the cotton fabric, indicating no sign of bacteriocidal activity on this fabric type. The numbers of colonies formed after contact with the regenerated bamboo and viscose rayon fabrics were significantly lower than those counted on the control agar plates. This confirms that both the regenerated bamboo fabric and the viscose rayon fabric have a bacteriocidal effect on the gram-positive and the gram-negative bacteria.

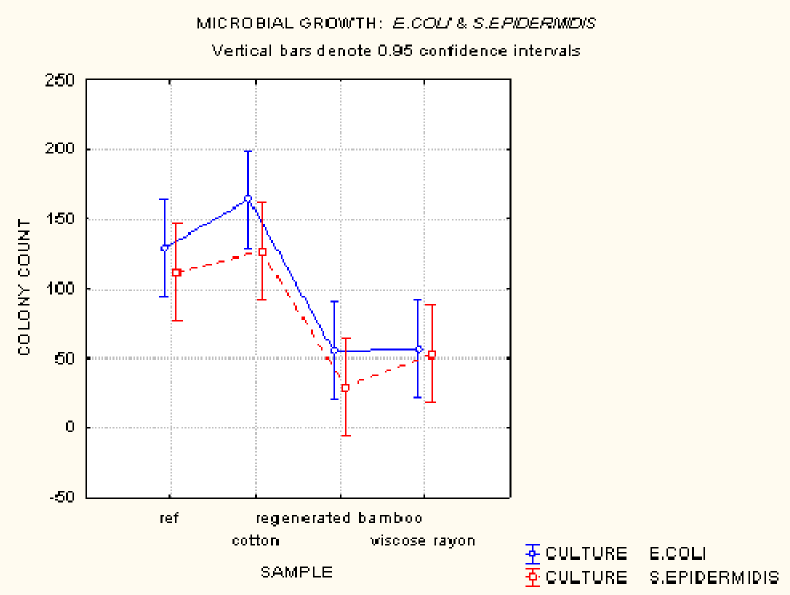

FIGURE 3: COMPARISON OF BACTERIOSTATIC EFFECT OF COTTON, REGENERATED BAMBOO AND VISCOSE RAYON FABRICS ON *S. EPIDERMIDIS* AND *E. COLI.* GRAPH DEPICTS NUMBER OF COLONIES COUNTED 24 HOURS AFTER EXPOSURE TO FABRIC SAMPLES

TABLE 1: VARIANCE ANALYSIS OF ANTI-BACTERIAL EFFECT (COLONY COUNT) MEASURED ON COTTON, REGENERATED BAMBOO AND VISCOSE AYON FABRICS ON *E. COLI* AND *S. EPIDERMIDIS*

ntercept	Sum of square	Degrees of freedom (do)	Mean square (MS)	F-ratio	P-value
Effect	263 538.0	1	263 538.0	229.5377	0.000000
Culture	3 403.1	1	3 403.1	2.9641	0.098000
Sample	60 040.7	3	20 013.6	17.4315	0.000003
Culture*sample	1 243.1	3	414.4	0.3609	0.781750
Error	27 555.0	24	1 148.1		

TABLE 2: BONFERRONI TEST ON ANALYSIS OF ANTI-BACTERIAL EFFECT (COLONY COUNT) MEASURED ON COTTON, REGENERATED BAMBOO AND VISCOSE RAYON FABRICS ON *E. COLI* AND *S. EPIDERMIDIS*

	Bonferroni test; variable colony count Probabilities for post-hoc tests error: Between MS = 1 148.1, df = 24.000									
Cell no.	Culture	Sample	{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}
1	Escherichia coli	ref		1.0000	0.1406	0.1593	1.0000	1.0000	0.0102	0.1180
2	Escherichia coli	cotton	1.0000		0.0036	0.0041	1.0000	1.0000	0.0002	0.0030
3	Escherichia coli	regenerated bamboo	0.1406	0.0036		1.0000	0.7184	0.1759	1.0000	1.0000
4	Escherichia coli	viscose rayon	0.1593	0.0041	1.0000		0.8046	0.1991	1.0000	1.0000
5	Staphylococcus epidermidis	ref	1.0000	1.0000	0.7184	0.8046		1.0000	0.0608	0.6120
6	Staphylococcus epidermidis	cotton	1.0000	1.0000	0.1759	0.1991	1.0000		0.0130	0.1478
7	Staphylococcus epidermidis	regenerated bamboo	0.0102	0.0002	1.0000	1.0000	0.0608	0.0130		1.000
8	Staphylococcus epidermidis	viscose rayon	0.118006	0.003038	1.000000	1.000000	0.612062	0.147874	1.0000	

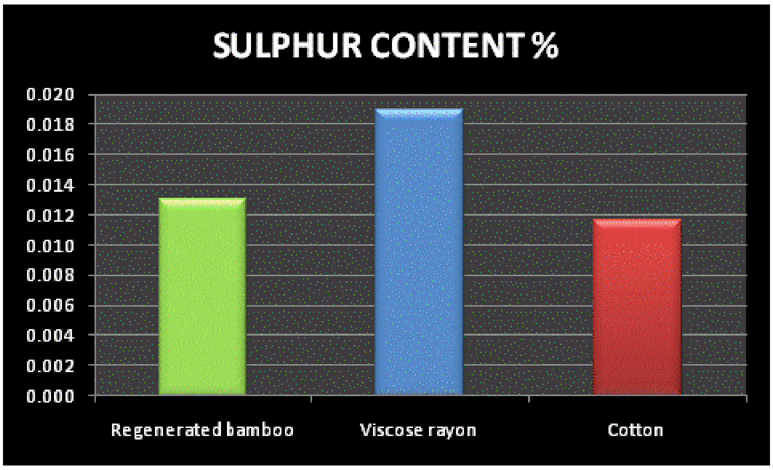

FIGURE 4: COMPARISON OF % SULPHUR CONTENT MEASURED IN COTTON, REGENERATED BAMBOO AND VISCOSE RAYON FABRIC SAMPLES

It should be noted, however, that only a percentage of the bacteria was killed and not 100%, as was found in the pilot study on antimicrobial cotton fabric. Suggestions that regenerated bamboo fibres or fabrics eliminate or prevent bacterial growth were thus not substantiated by the results obtained in this study.

The anova done on the microbial-growth counts indicated significant interactions between the factor fabric type for both the *E. coli* results and the *S. epidermidis* results (Table 1). This proved, statistically, that the results obtained for the regenerated bamboo and viscose rayon fabrics differed significantly from those obtained for the cotton fabrics. The differences between the regenerated bamboo and viscose rayon fabrics were very small and not significant, at a 95% confidence level. The significance of the differences shown in the anova was confirmed by the Bonferroni test (Table 2).

The antimicrobial properties of regenerated bamboo fabrics are said to be inherent and to be the result of bamboo kun found in the natural bamboo from which it is regenerated (China Bambro Textile Co. Ltd., 2003). Although wood, from which viscose rayon is made, does not have inherent antimicrobial properties, the antimicrobial properties of the viscose rayon fabric do not differ significantly from those of the regenerated bamboo fabric. One of the aspects that regenerated-bamboo and viscose rayon fabrics have in common is the fibre regeneration and spinning processes by which they are manufactured (Sui et al., 2003). This makes it impossible to ignore the possibility that the antimicrobial properties of these fibres can be related to residual chemicals, such as sulphur, that might still be present on the fibres after being spun in a hydrogen sulphate bath during fibre manufacturing. As mentioned, sulphur is known to have an antimicrobial effect on microbes (Sulfur dioxide: Science behind this anti-microbial, anti-oxidant, wine additive, 2010; Taj & Baqai, 2007; Usseglio-Tomasset, 2010).

Figure 4 shows a summary of the results of the analyses done on an ICP spectrophotometer to analyse the sulphur content of the samples. Although traces of sulphur were found in the cotton fibres, the amount on the viscose rayon fibres was significantly higher. The amount found on the regenerated bamboo fibres was slightly higher than on the cotton but lower than on the viscose rayon. Whether these small amounts are enough to have an antimicrobial effect is not clear and could be a subject for further research.

CONCLUSION

The main objective of this study was to investigate the claim that regenerated bamboo fibres have inherent antimicrobial properties as a result of the bamboo kun present in the raw material (natural bamboo) from which the fibres are regenerated. For this purpose, the antimicrobial properties of a regenerated bamboo fabric were compared to those of viscose rayon and cotton fabrics.

The first objective was to determine whether any difference could be found between the antimicrobial properties of cotton, on the one hand, and those of the two regenerated cellulose fabrics – the viscose rayon and regenerated bamboo – on the other hand. As was expected, the results confirmed that the cotton fabric (which was used as a control) exhibited no antimicrobial activity. The antimicrobial effect of the regenerated-bamboo and viscose-rayon samples, however, was significantly higher than that of the cotton for both gram-positive bacteria and gram-negative bacteria.

The second objective was to compare the two regenerated cellulose fabrics with each other with regard to the effect that they have on live bacteria. In contradiction with claims made by regenerated bamboo manufacturers and distributors regarding the superiority of their product, the regenerated bamboo fabrics did not perform statistically better in our tests than the viscose rayon fabrics.

These findings led to the conclusion that the claims made regarding the bacteriostatic or antimicrobial properties of regenerated bamboo cannot be proved to be false. When a broth containing bacteria was exposed to a fabric sample made of regenerated bamboo, the bacteriocidal property of the fabric led to the killing of a large percentage of the bacteria, confirmed by the lower bacterial growth observed on the agar plates after incubation. It should be noted, however, that only a percentage of the bacteria was killed and not 100%, as is often claimed in advertisements. It is generally expected that cotton fabrics with an antimicrobial finish will eliminate all bacteria, which was not found in the case of the regenerated bamboo fabrics tested.

This study did not prove that the bamboo kun in the original bamboo fibres that were used as raw material remained unchanged during the hydrolysis alkalisation and multi-phase bleaching processes used to manufacture regenerated-bamboo fibres. The fact that the viscose-rayon fabric, constructed of fibres that had gone through essentially the same process (but with a raw material that contained no bamboo kun), exhibited the same amount of bacteriostatic activity leaves the door wide open for any other explanation for the existence of this property in fabrics made of both these fibres. The presence of low amounts of sulphur (or, for that matter, any other residual substance or substances from the manufacturing process) in or on the fibres is but one possibility.

To summarise, this study confirmed that regenerated bamboo fabrics do exhibit antimicrobial behaviour but it did not prove that the fibre is superior to other regenerated cellulose fibres, such as viscose rayon, or that the antimicrobial properties of natural bamboo remain unchanged in regenerated bamboo fibres.

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