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REVIEW ARTICLE

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Some Significant Advances in Antibacterial Treatment of Textile Materials

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ABSTRACT

The article reviews some significant trends in the antibacterial treatment of textile materials. Jute-cotton blended denim is a new diversified product for the fashion and clothing sector. Chitosan was incorporated in this blend in order to improve its antimicrobial property. The incorporation of chitosan to the blended apparel was confirmed by Fourier transform infrared spectroscopy. Two microorganisms were used to create individual bacterial medium; one is the gram-positive Staphylococcus aureus and the other is the gram-negative Escherichia coli. Functional cotton with high and durable antibacterial activity by in situ formation of Ag nanoparticles (NPs) onto cotton fabric derived from phytic acid-Ag complex. The route can be divided into two simple steps, adsorption of silver ions onto cellulose matrix with phytic acid as a capture agent and subsequent reduction of Agþ to Ag NPs by sodium borohydride.

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Introduction

Natural textiles, such as cotton and silk, have been widely used in human's life because of their outstanding properties, like regeneration, softness and affinity to skin [1]. Currently, to cater to the need of market and improve human living standards, considerable efforts have been devoted to functionalization of textiles, endowing them with antimicrobial, self-cleaning, UV-blocking, and flame-retardant properties [2-16]. For cotton, which is seen as the most extensively used and abundant natural cellulose material, the antimicrobial finishing is one of the most important modifications, since the growth of microbes on cotton fabrics influenced not only their properties, but also the health of human beings. Unfortunately, warm and moist environments and nutrients attachment are usually suitable for microbe growth and reproduction on cotton fabric surface [17].

Enormous efforts and challenges are being practiced in research field and industry over the last few years, to design and develop innovative process technologies and eco-friendly materials for the intended end use of fashion products. The fashion world is thriving for new diversified products for which jute-cotton (JC) bended denim apparel and other textiles are new inclusions. Such apparel is produced by blending yarns to several ratios among which jute to cotton ratios of 30:70, 40:60 and even 50:50 ratios are growing popular as they have mostly dominated the focus of the researchers [18-20]. To ensure its suitability as human-clothing, some important criteria are also needed to be fulfilled besides the product's outer fashionable look, among which clothing fit, physical and thermo-physiological comfort, antifungal, antibacterial, etc. properties are important. In human clothing, there are several regions which are needed to be sanitized from bacterial growth, i.e. their antibacterial properties are needed to be enhanced. Mainly the clothing portions at the underarm and groin areas are prone to bacterial growth that generates bad smell and also causes several light to severe infections to human skin when these come in contact with sweat [21-24].

Cotton Fabric Coated With Silver Nano Particles

Up to now, various antimicrobial agents are applied, such as quaternary ammonium compounds, inorganic nanoparticles (NPs), triclosan, chitosan and its derivatives, to tackle this weakness of cotton [25-31]. The loading of inorganic nanoparticles, including silver, copper and some metallic oxides, has recently become a popular way to produce antimicrobial cotton fabrics [32-34]. Among all the NPs applied, Ag NPs have the advantages of low toxicity and excellent antimicrobial activities against both Gram-positive and Gram-negative bacteria [35-37]. To sum up, three methods are used to prepare Ag NPs-coated textiles, including spinning fibers with synthesized polymer-nanoparticle composites, and in situ synthesis of nanoparticles onto the fabric surfaces [38-42]. Because of the excellent stability and uniform distribution on textile as well as the eco-friendly process, in situ synthesis of Ag NPs on fabrics hence aroused attention, in which the silver ions are firstly absorbed onto the fabrics and subsequently reduced into Ag NPs [43]. And some other works presented in situ deposition of Ag NPs into cotton fibers directly in alkaline environment and high temperature, which used cellulosic groups as reducing and stabilizing agent.

These methods, however, suffer from obvious limitation of low density of loaded Ag NPs due to the limited Agþ-binding sites on the cotton fibers, meanwhile, the bonding between the hydroxyl groups and Ag NPs in the fibers is always weak that leads to poor washing durability. In order to solve the above problems,

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Rehan et al. modified cotton surface by cationization and partial carboxymethylation, and achieved formation of Ag NPs on the modified samples using trisodium citrate as both the reducer and stabilizing agent [44]. Zhang et al. used amino-terminated hyper-branched polymer (HBP-NH2) as reducer and stabilizer to prepare amino functional Ag NPs, which were then grafted onto the pre-oxidized cotton fabrics to obtain excellent antibacterial property [45]. However, these approaches may be not suitable for practical application due to their long reaction time and chemical consuming.

Moreover, some used polymers are toxic and difficult to degradation [46]. Therefore, the development of a simple and green approach for efficient formation of Ag NPs on textiles is urgent. In this study, we used phytic acid (myo-inositol 1,2,3,4,5,6-hexakisphosphate, PA) as a capture and stabilizing agent to prepare Ag NPs-coated cotton fabrics through in situ synthesis strategy. The silver ions were first adsorbed onto cellulose matrix in the presence of PA and subsequently reduced to Ag NPs by sodium borohydride. As a green and natural composition of plant, PA was widely found in nuts, pollens, fruits, legumes, oil seeds and vegetables [47]. Its six phosphate groups can provide enough binding sites for silver ions, which enhance the bonding of Agþ on cotton surface; meanwhile, the presence of PA could increase steric hindrance and electrostatic repulsion among the nanoparticles, resulting in good distribution. To the best of our knowledge, PA combined with Ag NPs used in antimicrobial finishing has not yet been reported. The antimicrobial activity against E. coli and S. aureus and durability against repetitive washing of the PA@ Ag NPs decorated cotton were well investigated [48]. This study has developed a simple, facile and time-saving route to fabricate cotton fabrics with outstanding antimicrobial activity by in situ deposition of Ag NPs into cotton fabric matrix in combination with environmental benign PA, which plays an important dual role as both capture agent for Agþ and stabilizing agent for the formed Ag NPs. The obtained fabrics exhibited excellent and durable antibacterial activities against both S. aureus and E. coli. After 10 laundering cycles, the bacterial reduction rate for CPAF was still above 99%. The results of AAS, SEM, EDS, FTIR, XRD and XPS confirmed that the silver nanoparticles have been fixed and well dispersed on the cotton fibers at the chemical state of Ag0 with size distribution between 58.6 ± 14.7 nm. The PA was of benefit to Ag distribution and bonding on the fabric with a consecutive enhancement in antibacterial properties and durability against wash.

Application of Chitosan on Jute-Cotton Blended Denim Fabric

The weather in the tropical areas persists hot and humid during maximum period of the year [49, 50]. The woven or knitted outfits such as shirts, tshirts, polo-shirts, trousers, etc. as well as undergarments are affected to a great extent in those aforementioned body-portions because of remaining moist with sweats causing undesired discoloration and bacterial growth to the garment parts in body-contact leading to bad intolerable smell. The longer the period an individual stays outdoor in these geographical locations, prolonged is the bacterial growth with the aid of sweats. In such case, anti-dermal protection by talcum-powders or deodorants are not sufficient as they are yet to achieve reliability status from experts and researchers. Hence, optimization of quality ingredients or related effective manufacturing processes are required in absence of which may lead to skin sensitization or sub-acute toxicity, irritation, allergy, carcinogenic, mutagenic or teratogenic effects to the users [51]. As a result the wearer is at a very uncomfortable and unhealthy state, which even causes discomfort for other people surrounding him [52,53]. That is why, clothing at least in the aforesaid body-portions need to possess adequate antibacterial properties so as to impart sufficient bacterial inhibition at sensitive portions which are prone to microbial growth.

It has been found from several research papers that chitosan has antibacterial properties and a promising natural eco-friendly material which is widely used to generate novel properties, chemical modifications or functional clothing applications where bacterial protection is required [54-56]. Chitosan is an environment-friendly biodegradable polysaccharide [b-(1-4)-2-amio-2-deoxy-D-glucopyranose] which is also biocompatible, antimicrobially active, chemically reactive and capable of film forming [57-59]. It can be profusely obtained from marine sources among which certain fungal cell-walls in the form of chitin, arthropods and molluscs, exoskeletons of crustaceans, etc. are worth mentioning [60-66]. It results to the yield of chitosan by means of deacetylation of chitin in the alkaline medium. Chitosan can be incorporated to cellulosic materials in several techniques [67]. Some researchers showed that Pad-dry-cure method was very effective to apply chitosan finish on cotton fabric to improve the substrate's antimicrobial property, which is at the same time an easy and economical process [68-70]. Several other researchers in their research papers have shown the treatment of cellulosic (cotton) fabric with chitosan along with different finishing agents (such as plasma, titania or silica sol-gel, etc.) which obtained remarkable achievements towards the substrate's sanitization against bacteria and some microbes [71,72]. Application of chitosan to other type of materials, such as leather, also improved its antimicrobial properties [73]. Although these antibacterial finish methods were applied to some forms of textiles in the past but the application lacked to JC blended textiles [73].

Besides, most of the studies of chitosan application to the antibacterial property improvement have complex fabrication steps, inclusion of toxic metallic components and expensive raw materials. In order to gain international acceptability, as well as for its commercial launching and global marketing, it has been deemed necessary to test and check it's every aspect to convert the combined effort into a success. A positive outcome from such experiments will boost the confidence of its entrepreneurs and manufacturers to aid for a successful launching. Besides, its market value will also rise significantly. Since, jute is the golden fibre of Bangladesh, the success and international acceptance of JC blended product will strengthen the socio-economic status of a lower-middle income country like Bangladesh.

Hence, compared to different complicated surface modification and synthetic procedures, here we introduce an eco-friendly, low cost and simple application strategy for antibacterial property improvement of fabric from a biopolymer chitosan which brings the key novelty of this research. Subsequently, this article will investigate the effect of antimicrobial treatment of chitosan for the 30/70 JC blended apparel. However, such chitosan-treatment is expected to impart both bacteriostatic and bactericidal properties to the JC blended denim fabric. The reliable test methods of AATCC 147 and ASTM E2149-01 will be followed for judging both qualitative and quantitative assessments of antimicrobial performances, respectively. The test results will evaluate the

performance standard of chitosan on diversified product such as JC blended fabric, which will add value to the substrate as well as to chitosan itself as a reliable antimicrobial agent that can be used for making skin-sensitive apparel for infants, kids or patients as well as for customers in the tropical climatic region.

A successful study was illustrated in this article regarding antibacterial property improvement of JC blended denim fabric. Incorporation of chitosan at different percentages (0% to 1.2%) showed that, chitosan is capable of reducing/growth inhibiting two different types of micro-organisms, namely S. Aureus and E. coli, which are gram-positive and gram-negative bacteria, respectively. The FTIR spectrum helped to confirm the presence of chitosan in the blends besides identifying both the blends separately. Two reliable test methods of AATCC 147 and ASTM E2149-01, which perform qualitative and quantitative antibacterial assessments on textile fabrics, respectively, were carried out successfully that added value to the study, which proved the antimicrobial efficacy of our chitosan treated JC blended denim fabric after 5 cycle of washing. This means that, chitosan has both bacteriostatic and bactericidal properties and so it is a potentially good antimicrobial agent. Because of the commercially viable antimicrobial agent and easy application techniques by pad dry cure procedure; one novelty of our proposed study is that it provides a better reasoning for industrial applications especially for JC blended apparels, fabrication of medical textiles, fundamental textiles with improved antibacterial property irrespective of climatic sensitive zone, functional requirements, gender or ages, etc. Further research is possible by finding out other antimicrobial agents' treatments to jute-blended denim fabric or mixing and blending of other type of fabric [74]. Moreover, textiles and apparel used for medical applications such as surgeons' wear (e.g. surgical gowns), wound dressing, bandaids, sutures, sanitary towels should exhibit necessary characteristics including antibacterial, non-allergic, non-toxic properties and our research concept might greatly be benefitting for such applications through further investigations.

Such treatments will open scope for the products usage in tropical humid environments, medical applications and also for skin-sensitive wearer (such as infants, children, patients, etc.), which will create diversified style and fashionable outlook supporting functional and aesthetic demand for the respective end user. However, the use of blended or modified chitosan could open the door of developing sustainable industrial practices for high end functional textiles and fashion products.

Conclusion

Qualitative and quantitative assessments were carried out to evaluate antimicrobial property of chitosan, where the results appeared in favour of chitosan's significant efficacy as an antimicrobial agent against both before-mentioned microorganisms. Because of low cost, easy application techniques and eco-friendly strategy; the success of this research will boost confidence of clothing product developers and manufacturers to use this blend as a fashionable fabric-material irrespective of climatic areas, gender or ages, that will vastly help to flourish massive scale business of major jute producing countries like Bangladesh and India. The successful deposition of Ag NPs on cotton fabric was verified by SEM, EDS and XPS. The bacterial reduction rate against E. coli and S. aureus for the as-treated fabrics was above 99%, even after 10 laundry cycles. The phytic acid was found of benefit to distribution and bonding of silver on the cotton fabric, which might lead to the enhancement of antibacterial property and durability against wash. This study may provide a green, novel and simple strategy to manufacture Ag-based antibacterial cotton for potential applications in textile industry.

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