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Silk-The Prospective and Compatible Bio-Material for Advanced Functional Applications

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ABSTRACT

The conventional approach make the insect based natural fibre, silk to create only textiles but, an insight on production pace, eco-friendliness and bio-compatibility have widen its potential for nutritional, cosmetic, pharmaceutical, bio-medical and bio-engineering functions. The promotion of silkworm as bio-factory to synthesize important bio-material (silk protein) useful for innovative and advanced functional biological applications is a big trend in modern applied research. The worth as protein-rich diet for cardiac and diabetic patients and potential ingredient for cosmetic preparations designates the nutritional and aesthetic value of silk protein. The anti-inflammatory, anti-tumefacient, anti-coagulant and bio-stability competence made silk protein a pharmaceutical, while the property of bio-resorbability serve the function of drug delivery. The bio-attuned capacity made silk fibre as an apt bio-engineering base for tissue wall and membrane repairs; muscle ligament, blood vessel and nerve gadget restoration; and tooth, cartilage and bone reconstruction. The sericin and fibroin proteins of silk are promising wound healing agents, anti-oxidant and bio-adhesive mediators, scaffolds and implants for tissue-supporting prosthetics of human body. The vital need of contemporary sericulture industry is to explore, realize and attain the comprehensive utility avenues of the silk protein to provide biological substitutes, biochemical and physical regulatory aspects for lost or damaged human functions, which simultaneously up-keep the prosperity of silk stake-holders.

Key words: Bio-factory, bio-engineering, human functions, sericulture, silk fibre

INTRODUCTION

The agro based sericulture practice is one of the oldest known textile related industries since the 27th century BC. For nearly 3000 years, silk production was kept secret in China, but gradually, the knowledge was spread to Korea, Japan, India and Southeast Asia (Devaiah and Reddy, 1999). Though, the sericulture is currently being practiced in more than fifty eight countries of temperate and tropical regions of the world, the major producers are in Asia. The China produces about 70% of the world's silk by providing employment for one million people, rest followed by India with half million people involved in the activity, while Brazil, Thailand, Viet Nam, Turkmenistan and Uzbekistan follows with little silk production and fair employment generation (Devaiah and Reddy, 1999).

The silk filament is a continuous thread of insect protein consisting fibroin and sericin with a length of 500 to 1500 m, having great tensile strength, produced by a variety of silkworm caterpillars. Technically, silk does not shrink like other fibers and is the strongest natural fiber composed of main polypeptide chains and side chains of amino acids. Over the centuries, silk has been highly valued as a textile fibre because of its qualities of unique luster, strength, excellent softness and great comfort to handle and wear. The silk has outstanding natural properties which even rival the most advanced synthetic polymers, yet its production does not require harsh processing conditions. Silk's natural beauty and soothing property in hot conditions and warmth during colder seasons have made it use in high-fashion clothing and in a range of household yard goods, including upholstery, wall coverings, rugs and carpets. In India, silk has a special significance and considered as holy fabric and a must for every special occasion. Though, the long-established application of silk felt its value and returns, the suitability potential for varied fields can substantiate its commercial sustenance over other alternative and competitive agro based practices.

PRESENT-DAY SITUATION

The sericulture practicing and silk production is just about a privilege of rural Indian farmers in view of available host plants of mulberry, Tasar, Muga and Eri silkworms as cultivated or nature grown. Also, the production of 15600 and 2760 MTs of mulberry and vanya raw silk, respectively by India during 2008-09 specify the projection of silk associated activities. The majorities of silkworm growers, though unaware of silk fibre value for other than fabric, the globalization and production economics in comparison to alternative commercial crops made them to negotiate on silk productivity and quality (Reddy *et al.*, 2009), besides the optimal applicability (Sehnal, 2008), compelling the researchers to investigate appropriately.

Though, most of the research was concentrated either on silk productivity and quality or on making silk goods and their marketing, silk still has multi-line utility potential (Reddy, 2008). Apart traditional application, ample methods are currently going on towards optimizing silk protein value and function such as animal feed, human diet for cardiacs and diabetics, automotive and building composites, interior decoration and art crafts for value addition with its flexible and eco friendly asset (Dandin and Kumar, 2007). The bio-material and compatibility values have employed silk in synthesis of artificial membranes and films, pharmaceuticals and bio-medicals, healing of wound and post-surgical trauma, anti-oxidative and bio-adhesives (Sehnal, 2008; Reddy, 2009a, b). Of late, large investigations are on for artificial synthesis of silk, besides silkworm is also being used as bio-resource to produce silk protein in bulk and to use as valuable originator of several innovative biological applications.

No doubt, the silk has been used as excellent textures for a long time, but it has been also used as suture because of the high tensile property and bio-compatibility. The silk has been involved in the medical world for centuries but it is now becoming much more concerned, especially in bio-engineering through bio-mimetics. The unique mechanical properties of silk together with excellent bio-compatibility have recently sparked interest of this protein for medical applications as bio-material and carrier for controlled drug delivery (Kundu *et al.*, 2008). Today, the development of bio-materials became an obligation to meet the rapid growing cell-engineering technique applying the appropriate bio-materials as scaffold. The silk is a mechanically robust bio-material with environmental stability, bio-compatibility and bio-degradability, which also offers a wide range of perfunctory and practical properties for bio-medical applications.

SILK PROTEIN, THE COMPATIBLE BIO-MATERIAL

The term bio-material is difficult to define, however, it can be said as a material, natural or man-made, that comprises whole or part of a living structure or biomedical device which performs, augments, or replaces a natural function. The material should have appropriate mechanical properties for the indicated application and any variation in such properties with degradation should be compatible with the healing process. The material should not evoke toxic response upon *in vivo* implantation; have acceptable shelf life with matching degradation time and process, the degraded products should be non-toxic and easily metabolized from the host body and should have appropriate permeability for the intended application.

The bio-material research and the development of innovative composites is not a new area of science as it is a provocative field with many agencies investigating wide range of products suitable for advanced biological applications. The bio-material science encompasses elements of medicine, biology, chemistry and tissue-engineering and the invented composites are being used in joint replacements, bone plating and cementing, artificial ligaments and tendons, dental implants, blood vessel prostheses, heart valves, skin repair and wound healing devices, cochlear replacements and contact lenses.

Consequent upon wider application avenues, a variety of natural and synthetic bio-degradable polymers have been investigated for biological, medical and pharmaceutical applications. In recent years, artificial bio-materials gain importance in the fields of medicine and biology through tissue-engineering to provide functional substitutes for lost or damaged, through cell integration, scaffolds and biochemical and physical regulatory aspects. The natural bio-degradable polymers like collagen, gelatin, chitosan and silk protein have promising functional and mechanical advantages over synthetic polymers with better bio-compatibility, bio-degradability, bio-resorbability and environmental stability. These properties can be easily modified to achieve desirable mechanical, compatible and degradation characteristics.

The silk fiber has a long history of use in medicine since decades because of its non-septicity and degradability. Further, the silkworms efficiently converts the plant nutrients consumed by its larvae in to silk protein, a major advantage of producing such high value protein at cheaper cost in shorter span of time. Hence, the silk can be used as a bio-material in various forms, such as films, membranes, gels, sponges, powders, artificial ligaments and scaffolds. The silk applications also include the burn-wound dressings for faster healing, enzyme immobilization matrices, nets, vascular prostheses and structural implants (Cao and Wang, 2009). The silk fibroin, a natural protein of domestic silkworm, *Bombyx mori*, provides an important set of options for bio-materials and scaffolds because of its high tensile strength, controllable bio-degradability, haemostatic properties, non-cyto toxicity, low anti-genicity and non-inflammatory characteristics (Li *et al.*, 2003; Jin *et al.*, 2004; Mauney *et al.*, 2007).

BIOLOGICAL APPLICATIONS OF SILK PROTEIN

Millions of patients suffer from end-stage organ failure or tissue loss each year and the tissue-engineering has been recognized as an alternative technique to tissue transplantation for such people with diseased or malfunctioned organs. Scaffolds play a critical role in tissue engineering. The function of scaffolds is to direct the growth of cells either seeded within the porous structure of the scaffold or migrating from surrounding tissue. The majority of mammalian cell types are anchorage-dependent, meaning they will die if an adhesion substrate is not provided. Scaffold matrices can be used to achieve cell delivery with high loading and efficiency to specific sites. Therefore, the scaffold must provide a suitable substrate for cell attachment, cell proliferation, differentiated function and cell migration.

The prime requirement of bio-materials is bio-compatibility; as like silk fibres, which can perform phenomenal mechanical properties as bio-polymers suitable for medical uses. The properties of high oxygen and vapor permeability makes silk fibre ideal for soft tissue applications and in spite of its higher adhering ability to tissue cells, still be biodegradable. The silk fibre shows no toxicity to living bodies during degradation because it is composed of amino acids similar to those found in humans (Sehnal, 2008) as like silk sutures have lesser incidence of swelling and infection than any other material. The additional applications of silk bio-materials include new generation soft contact lenses, artificial corneas, skin grafts and epilepsy drug permeable devices (Dalpra *et al*., 2005).

The scaffold requirement in tissue engineering of surface for cell attachment, a structural and logistical template for tissue formation and its subsequent integration with the host tissues found in silk. The adequate mechanical properties supporting mechano-transduction during cultivation and load bearing of the tissue engineered graft made silk a competent scaffold material (Mauney *et al*., 2007). Therefore, alternative bio-materials are required to meet a challenging combination of biological, mechanical and degradation features for tissue-engineering. In the field of tissue-engineering, the use of silk fibre based bio-degradable and bio-resorbable polymers as body joints, cartilage and bone fixtures to alleviate pain for patients (Wang *et al*., 2006). Even the silk waste, which is available at lower cost can be transformed and utilized as bio-stabilities and enhanced mechanical bio-performers. The lower inflammatory properties of transformed silk fibres are currently becoming a promising candidate for ligament tissue engineering (Liu *et al*., 2007). The silk fibre on eliminating immunogenic components (particularly sericin), can be used as implants in tissue-supporting prosthetic devices (Chitrangada *et al*., 2008). The immune-neutral properties of silk suits for other tissue engineering applications like hernia repair, tissue wall reconstruction and organ support as bladder slings The sericin can polymerize to fibres, films and 3-D structures that provide scaffolds for complex tissue reconstructions (Makaya *et al*., 2009).

The silk is one of the most demanded bio-material because of its unique properties and practical applications that can create opportunities for medical advancements. One such important focal point and area of application of silk is the repair of damaged or destroyed nerves. The silk fibroin has been used extensively in the bio-medical field with a novel bio-mimetic design of Silk Fibroin-Nerve Guidance Conduit (SF-NGC) used for peripheral nerve regeneration (Yan *et al*., 2009). The fibroin powder is known for wound dressing by regulating exudates of wound providing moist environment facilitate re-epithelialization, re-modeling of connective tissues and collagenization (Teramoto *et al*., 2008) and controlled release drug delivery vehicles (Wenk *et al*., 2008). The other promising medical applications of silk are bio-degradable micro tubes for repair of blood vessels (Lovett *et al*., 2007), as the tenacity and gum-like quality of sericin makes silk fibre a good entrant for bio-medical joining and sealing applications.

The silk sericin is a natural macromolecular protein derived from silk is useful because of its resisting oxidation and UV rays, antibacterial and moisture absorption and moisture release properties (Dandin and Kumar, 2007). The sericin protein of silk can easily be cross-linked, co-polymerized and blended with other macromolecular materials, especially artificial polymers, to produce bio-compatible medical and mechanical gadgets of improved properties for various applications. In recent years, silk has been widely applied in native and reconstituted forms such as nano fibre, film, membranes, hydro gel (Li *et al*., 2003), sponge and particles for targeted bio-technological and bio-engineering applications (Fini *et al*., 2005). The commercial production of sericin hydrolyzates as components of tissue culture media will probably expand with the use of stem cells for tissue repair (Jin *et al.*, 2004). The Silk Fibroin (SF) is a highly promising protein due to its structural properties and ability to promote cell adhesion. The silk fibroin has been the object of increasing interest as a potential bio-material for tissue regeneration, repair and artificial ligaments. It has been shown to be a mechanically superior natural polymer for ligament tissue engineering applications for the Anterior Cruciate Ligament (ACL) found in the knee. A tissue engineered silk-fiber matrix has been successfully designed to mimic the native ACL with matched mechanical properties of ligament when tested using *in vitro* tissue culturing conditions (Altman *et al.*, 2002).

The silk bio-polymer used in tissue regeneration for treating burn victims and as matrix of burnt tissue healing (Teramoto *et al.*, 2008). The silk fibroin peptides are used in cosmetics due to their glossy, flexible, elastic coating power, easy spreading and adhesion characters. The saturation and revitalization properties of sericin has got potential as skin moisturizer, anti-irritant, anti-wrinkle and sun protector in addition to shaping hair by making it soft and flexible (Hino *et al.*, 2003). The extracts of silk fibre protein like hydrolyzed silk, silk amino acids, silk powder and raw silk fibre are used in soap making, personal care and cosmetic products. The silk protein contains eighteen amino acids, among which glycine, alanine, serine and tyrosine are of vital importance in skin nourishment (Reddy, 2008, 2009a, b) and as liquid, the silk is easily absorbed in to skin adding silkiness and is widely used in shampoo and luxurious hair and facial treatments. The silk powder is touted and relieves from sunburns, due to crystalline structure it reflects UV radiation and as demulcent protective buffer between human skin and environment. The lower micron silk powder and water dispersible finer grade silk powder is used as an ingredient of liquid cosmetic preparations (Acharya *et al.*, 2008). The silk is used in anti-hay fever masks, catheters, bandages to treat dermatological disorders (Kundu *et al.*, 2008), support cell proliferation providing basic matrix at the required biological reconstruction site.

The silk is used to fight impotence, edema, cystitis, adenosine augmentation therapy, epididymitis and cancer, while, the glucosamine extracted from silk is used for treating osteoarthritis (Dash *et al.*, 2008). The silk protein derivative, Serratio peptidase is used as anti-inflammatory, anti-tumefacient for treating acute sinusitis, tonsillectomy, oral surgery, during filling, cleaning and extraction of teeth. The derivatives of silk fibre were used as non-steroidal anti-inflammatory agents for treating rheumatoid arthritis and anti-coagulants during surgeries (Dandin and Kuamr, 2007). The sericin is reported to suppress tumor promotion, provide protection against ulcers and exert other health supporting effects. The use of silk to guide light opens up new opportunities in biologically based modulation and sensing along with an opportunity to integrate light delivery within living tissue (Altman *et al.*, 2003). The silk is well suited for this purpose, being a bio-compatible, bio-degradable and toughest natural polymer.

EPILOGUE

The faster production rate, economical availability and the bio-application values of silk can effectively substitute the defunct human systems through bio-medical and bio-engineering approach. The application demand of silk for such bio-composites will create extra employment through allied industries and added revenue to the seri-stakeholders. The applied and inter-disciplinary research will further enlarge the silk usage to help mankind, besides protecting environmental safety and seri bio-diversity, a must for current and future world.

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