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Review Article

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Potential of silk proteins in cosmetics

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ABSTRACT

Synthetic and inorganic chemical ingredients in cosmetic products pose serious health impacts on skin and hair. Much emphasis has been laid on the development of cost-effective, eco-friendly and user-friendly cosmetic products from time to time. Manufacturing cosmetics using natural ingredients is considered as a viable alternative to overcome the side effects of synthetics. Silk is a natural biopolymer obtained from cocoons of sericigenous insects like silkworms. It constitutes two proteins, *viz.*, fibroin and sericin. Fibroin is the central core protein glued with sericin protein forming silken cocoons together. Both the proteins possess remarkable attributes viz, anti-microbial, anti-oxidant, anti-tyrosinase activity, efficient UV resistance, kinase activity, excellent release and absorption of moisture. The silk protein attributes are advantageous for body skin, hair and nails. It possesses a wide range of cosmetic applications such as facilitation of hair growth, improvement in softening and lustre of hair, rejuvenation of body and skin cells, UVB protection, prevention of chapping and brittleness of nails, and skin brightening. Due to its low molecular weight, easily penetrates the hair strands and skin cells, binds the keratin in hair and forms a protective layer to prevent moisture loss. A wide range of products have been developed for use in cosmetics *viz.*, SILKPRO, SILKALL, SILKPRO 1000. These products are used as natural ingredients due to their potent applications in cosmetics. The cosmetic industry can be developed by proper utilization of silk in its organic products while promoting value addition to sericulture industry.

KEYWORDS: Cosmetic, Fibroin, Sericin, SILKALL, UV-protection

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INTRODUCTION

Cosmetics may be defined as a group of health and beauty care products employed to improve the physical appearance of the skin and body (Surya & Gunasekaran, 2021). Many ingredients are added to make a product for skin care. The ingredients added should be nontoxic, harmless and safe to use (Nohynek *et al.*, 2010). Different ingredients are used for the fabrication of cosmetic formulations among which polymers are of prime importance (Alves *et al.*, 2020). Polymers are added to serve different functions in cosmetic formulations (Lochhead, 2007; Patil & Ferritto, 2013). The most widely produced cosmetic products should contain the following ingredients, which include water, emollients, Anti-oxidants, UV filters, preservatives, humectants and surfactants (Somwanshi *et al.*, 2023) The classification and function of cosmetic ingredients are mentioned in the Table 1. These basic ingredients constitute a variety of chemical compounds of synthetic nature which pose adverse effects on the skin and body (Panico *et al.*, 2019; Bilal *et al.*, 2020). Silicones and parabens are most often added as emollients and preservatives in cosmetic formulations. However, their later use poses a serious threat in topical applications (Halla *et al.*, 2018; Ahmad & Akhtar, 2023). The cosmetic ingredients and their constituents utilized in the preparation of personal care products are screened scientifically as they may pose serious safety concerns (Antignac *et al.*, 2011; Almukainzi *et al.*, 2022). Hence more emphasis is laid on the development of effective and harmless formulations free from chemicals like silicones and parabens (Bom *et al.*, 2019; Baki, 2022). The success of the cosmetic industry is highly dependent on customer acceptance because of product reactive attributes (Nohynek *et al.*, 2010; Khraim, 2011). Hence the formulation of effective and appealing aesthetic quality products with ensured sensory assessments is of prime importance in the cosmetic industry (Garrigue *et al.*, 2006; Mahesh *et al.*, 2019). The incorporation of less synthetic and more plant-based ingredients in cosmetic formulations is a prominent trend (Dodson *et al.*, 2021; Aziz & Setapar, 2022). In agriculture, different disposable byproducts with valuable chemical constituents are produced in bulk every year. These valuable products have fascinated researchers to utilize them in the beauty industry (Barbulova *et al.*, 2015). The plant-derived extracts being efficient, affordable and biodegradable are widely used in the cosmetic industry. For instance, by-product extracts or fruit extracts are always a facile choice for use in cosmetics (Michalak, 2023). The tropical fruit pineapple (*Ananas comosus* L. Merr) has been extensively used in many cosmetic products because of high ascorbic acid present in pineapple rind (Frietas *et al.*, 2015). The active compounds from dairy, meat and fish are also used in cosmetics (Barbulova *et al.*, 2015; Cristiano & Guagni,

Table 1: Role of common cosmetic ingredients (Ahmad & Akhtar, 2023)

Common ingredients	Function
Water	Primary ingredient to form semi-solid form
Emollients	Used as softener, moisturizer and conditioner
Antioxidants	Helps to prevent the skin from oxidative damage by free radicals
UV filters	Helps to protect the skin from harmful UV radiations.
Preservatives	Helps to prevent the growth of harmful micro-organisms such as bacteria, fungi and viruses.
Humectants	Helps to retain moisture in skin
Surfactants	Helps to lower the surface-tension between two immiscible compounds such as oil and water.

2022). Many macroalgal (seaweed) extracts and bioactive substances have proved promising results while treating various skin diseases (Bedoux *et al.*, 2014; Juliano & Magrini, 2018). Hence the cosmetic formulations produced from natural and organic products have provided better results. The demand for natural and safe products from consumers has also increased as well. There is a considerable increase in the consumption of agricultural products in cosmetics (Kim & Seock, 2009; Amberg & Fogarassy, 2019). Many agriculture derived products and extracts have been investigated for preparing cosmetic formulations such as, castor oil, cocoa butter, mango, coconut oil, green tea, jojoba oil, aloe vera, neem, cucumber, rosemary, henna and walnut (Aburjai & Natsheh, 2003; Desam & Al-Rajab, 2021). Silk is a natural polymer obtained from the cultivation of silkworms. It constitutes fibrous protein fibroin forming core which is glued with sericin protein, synthesized in silk gland of silkworm (Kundu *et al.*, 2008). The sole purpose of constructing silk cocoons by silkworms, mites, spiders, and scorpions relies on preying, reproduction and protection against harsh climatic conditions (Chen *et al.*, 2022). Silk is basically a large molecular weight, thermally stable, hydrophobic protein polymer (Kapoor & Kundu, 2016). The silk attributes vary greatly according to their source, environmental conditions and technology utilized for obtainment (Kundu *et al.*, 2013; Rajshree & Sahastrabuddhe, 2018). Silk is considered as an apparent class of biocompatible and green polymers because of its biodegradability, low immunogenic reactions, low toxicity and easy fabrication (Nguyen *et al.*, 2019). The silk proteins have been evaluated for many applications in biomedical engineering, electronics, textiles and cosmetics as well. Silk possesses many benefits for hair and skin care (Koh *et al.*, 2018). The silk protein derivatives are effectively utilized as an active ingredient in skin care lotions, hair dyes, facial bleaches, anti-wrinkle creams, cleansing products, hair shampoos and conditioners (Wong *et al.*, 2014; Babu & Saumte, 2024). This review is intended to throw light on the significance of silk proteins and their potent applications in the cosmetic industry.

FIBROIN PROTEIN

Fibroin is one of the core protein produced by the silkworm (Cui *et al.*, 2018). It forms the central structure, contributes to rigid structure and higher tensile strength (Koh *et al.*, 2015). It possesses higher percentage of glycine, alanine and serine (Mayen *et al.*, 2015; Rajshree & Sahastrabuddhe, 2018). The amino acid constitution of fibroin is described in Figure 1.

The combination of these amino-acids gives a promising effect on human skin (Su *et al.*, 2019; Vidya & Rajagopal, 2021). Glycine is the simple and stable amino acid constituting high collagen concentration and contributes in repair of damaged skin in addition to healing property (Mathew-Steiner *et al.*, 2021; Koczoń *et al.*, 2023). Alanine has higher combining ability with skin cells (Rajshree & Sahastrabuddhe, 2018; Louiselle *et al.*, 2022; Lujerdean *et al.*, 2022). Hence, actively used as skin conditioning and masking ingredient to fill up the creases and provides skin appearance (Alves *et al.*, 2020; Louiselle *et al.*, 2022). Silk fibroin protein has found excellence in developing contact lens material, immune-stimulant, enzyme inhibitor and controlled release of drugs in gel form (Hanawa *et al.*, 1995; Jeencham *et al.*, 2019; Chirila, 2021). The remarkable properties of fibroin protein are depicted in Figure 2. Silk fibroin reported enhanced affinity of eye shadows, reduced color bleeding of lipsticks, long lasting deodorant and excellent anti-wrinkle effect and promotes collagen formation as well (Miyashita, 1999; Daithankar *et al.*, 2005).

SERICIN PROTEIN

Sericin is the sticky protein which held the fibroin protein together (Kundu *et al.*, 2008; Aramwit *et al.*, 2012). It is composed of 18 amino acids among which lysine, serine and aspartic acid forms the major constitution as depicted in Figure 3 (Takasu *et al.*, 2002; Johnson Jr *et al.*, 2020). Sericin is highly polarized consisting of hydroxyl, carboxyl bonding which facilitate easy crosslinking (Aramwit *et al.*, 2012; Silva *et al.*, 2022). Hence sericin can be merged with other types of polymers to form biodegradable products (Barajas-Gamboa *et al.*, 2016). It has the history of being utilized in preparation of cosmetic items (Kunz *et al.*, 2016; Orlandi *et al.*, 2020). Sericin possesses biocompatibility, biodegradability and wettability (Silva *et al.*, 2022). These attributes of sericin are sufficient to develop cosmetic products for hairs, skin and nails (Padamwar & Pawar, 2004; kundu *et al.*, 2008; Silva *et al.*, 2022). The attributes of sericin protein is depicted in Figure 4. Several research works proved significant characterisctics of sericin such as, moisturizing efficiency, anti-wrinkle and diminishes signs of aging as well (Sheng *et al.*, 2013; Suryawanshi *et al.*, 2020). The sericin formulation was found to prevent nail chapping, brittleness and provide long-lasting gloss in nails (Dubey *et al.*, 2022; Babu & Sumate, 2024). Hence, sericin is most ideal ingredient for use in cosmetics.

APPLICATIONS OF SILK PROTEIN FOR HAIR AND SKIN

Skin Care

The bioactive components in silk proteins help to enhance cellular functioning of skin cells which ultimately increase collagen growth rate to produce dermal fibroblasts (Chouhan & Mandal, 2020). Silk extracts are used for topical application

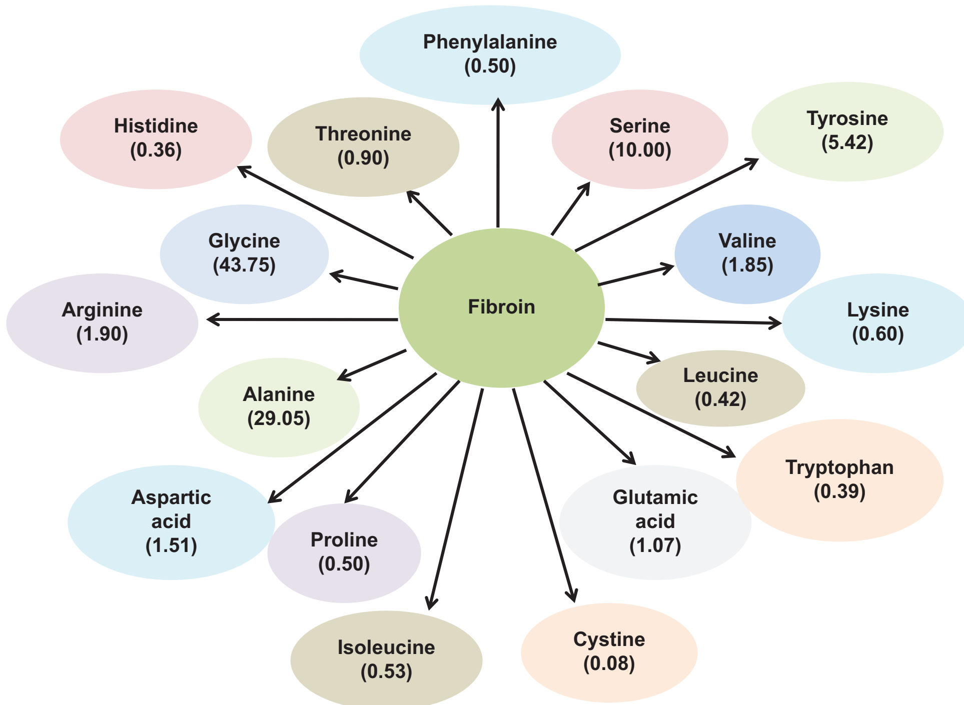

Figure 1: Amino acid composition of fibroin (Rajshree & Sahastrabuddhe, 2018)

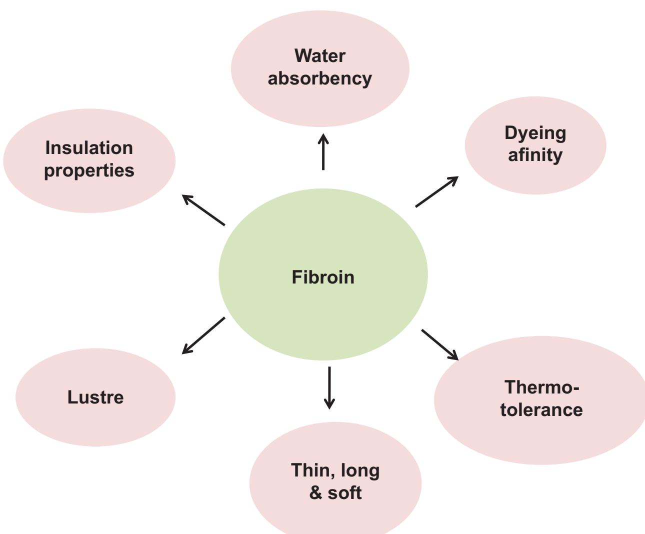

Figure 2: Properties of fibroin (Rajshree & Sahastrabuddhe, 2018)

to promote active moisturization, absorption of sebum and tightening of sagging skin in cosmetic products (Singh *et al.*, 2023b).

Silk proteins were found to help in wound healing of skin (Mazurek *et al.*, 2022). Since silk proteins are active absorbers of Ultra violet radiations at 223-400 nm (Sionkowska & Planecka, 2011). They are potent antioxidants, excellent UV protectants constituting efficient compounds of anti-tyrosinase melanin inhibition (Sinha *et al.*, 2022; Wongkrongsak *et al.*, 2022). Skin care products constituting silk proteins were found to promote fair and uniform skin complexion (Rajshree & Sahastrabuddhe, 2018). The skin care products consisting of silk protein formulations enhance skin cell regeneration, moisturization with improved efficiency of skin brightening and UVB protection (Silva *et al.*, 2022). It promotes cellular regeneration and epidermal cell thickness as well. These attributes of silk proteins can be widely exploited for developing the skin care products which can promote skin thickness and elasticity (Chouhan & Mandal, 2020). Sericin protein has excellent moisturizing ability and proved to promote skin hydration on extremely dry itchy skin (Suryawanshi *et al.*, 2020). Silk proteins possess active compounds which are used to absorb the detrimental components such as extra sebum and keratinaceous debris, thereby help to protect skin from toxins (Anonymous, 2016a; Rajshree & Sahastrabuddhe, 2018; Bernardes *et al.*, 2024). The silk based products *viz.*, sleep masks, spa-facial masks as popularly used nowadays to gain extra benefits from silk. Silk proteins promote skin brightness and reduce the problems of UVB- induced skin damage and tumor development (Zhaorigetu *et al.*, 2003). It was found to be ideal component in creams to treat hyper pigmentation of skin in clinical trials and activate collagen production (Aramwit *et al.*, 2009; Aramwit *et al.*, 2018). These skin care creams were found to enhance the appearance of skin by diminishing fine lines, reducing wrinkles and sagging of skin, thereby preventing signs of aging (Mohiuddin, 2019). Silk proteins constitute natural moisturizing factor (NMF) which enhance skin hydration and prevent formation of scars during wound healing process (Nayak & Kundu, 2016; Suryawanshi *et al.*, 2020). These proteins are anti-microbial in nature were found to inhibit the growth and development of bacteria on skin (Choudhury *et al.*, 2016; Song *et al.*, 2016).The biodegradability of silk proteins makes it excellent ingredient for manufacture of cosmetics (Rajshree & Sahastrabuddhe, 2018; Silva *et al.*, 2022). However, the potential of silk proteins in anti- tyrosinase brightening activity

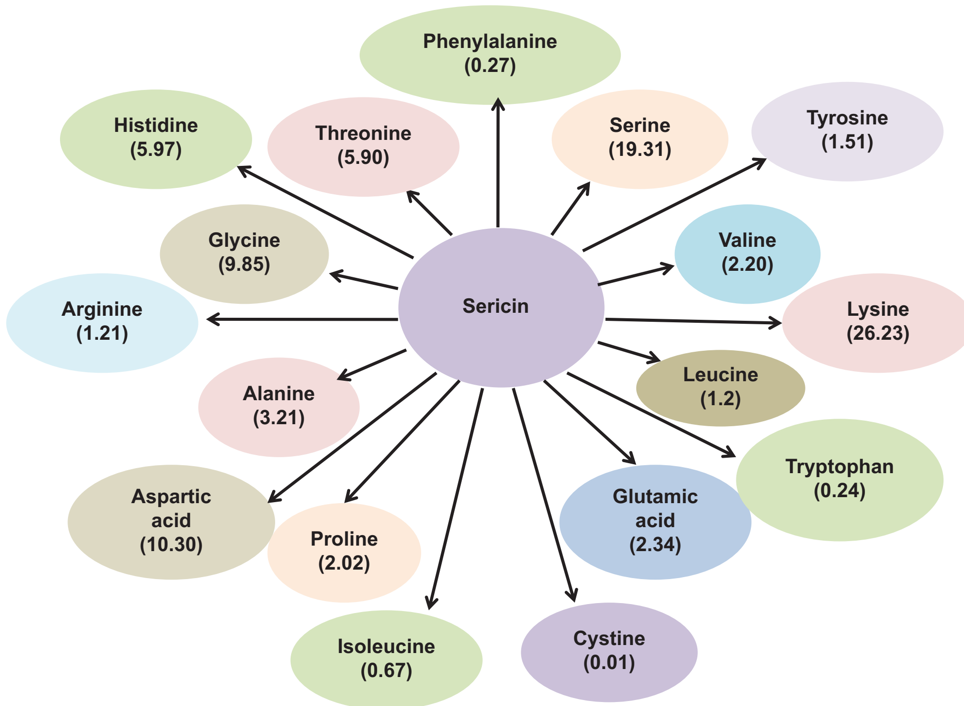

Figure 3: Amino acid composition of sericin (Rajshree & Sahastrabuddhe, 2018)

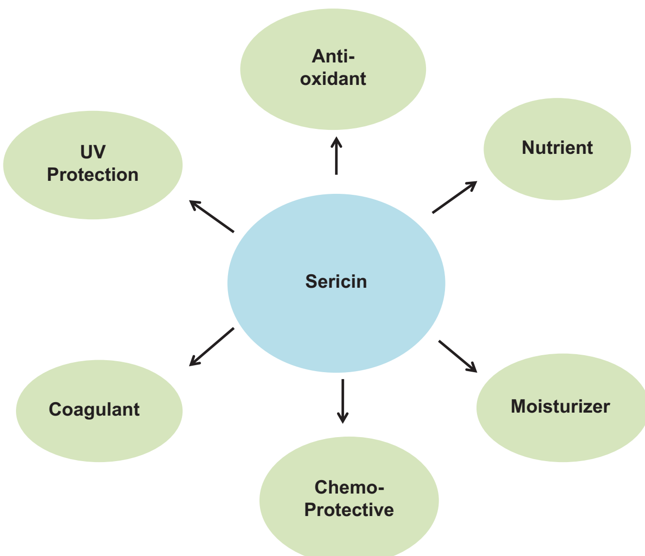

Figure 4: Properties of sericin (Rajshree & Sahastrabuddhe, 2018)

is dependent on quality and extraction technique of silk proteins (Cao & Zhang, 2016).

Hair Care

Keratin is the major protein forming hair responsible for strong locks (Velasco *et al.*, 2009; Fernandes *et al.*, 2012). Any damage in hair strands or low keratin content can be rectified by application of silk proteins (Tinoco *et al.*, 2018, 2022). Silk protein contains amino acids such as cysteine is a low molecular weight which helps to boost kertain production (Costa *et al.*, 2018). It can easily penetrate the hair strands to promote growth of hairs and makes hair strands softer (Tinoco *et al.*, 2019). Silk protein in cosmetic formulations was found to rejuvenate and strengthens the weakened hair strands (Tinoco *et al.*, 2018; Alves *et al.*, 2020). It penetrates into the bulb of hair strand and nourishes it from the roots. Therefore, forms a protective cover around the scalp which provides nourishment to each hair strand and enhances their shine as well (Anonymous, 2016a, 2016b; Reddy, 2009). It also makes hair stronger enough to retain moisture that is required to remain lustrous and soft. Hair care products containing this silk proteins as ingredient are known for reducing the dryness, repairing split ends, preventing breakage and making the hair silkier (Camargo Jr *et al.*, 2022). Silk proteins are found to prevent direct contact between hair and chemicals which ultimately prevents the hair damage from harsh chemicals or radical of environment (Khosa & Ullah, 2013). These proteins also have anti-oxidant properties indicating that they have anti-aging and anti-wrinkling properties which when applied to hair care products will give a shinier and thicker hair. Sericin hydrolysates with average molecular weight 300-3000 are used as conditioners for skin and hair (Dai & Hansenne-Cervantes, 2024). Shampoo containing sericin and pelarogenic acid of pH less than six are useful for the care and cleaning of hairs (Ghosh *et al.*, 2019; El-Sayed *et al.*, 2021). A commercial formulation named - Biosilk is used as weightless treatments suitable for all types of hair (Yanqing, 2004; Wong *et al.*, 2014).

SILK PROTEIN INGREDIENTS DEVELOPED FOR COSMETIC USE

Hydrolysed Silk

Hydrolyzed silk has good emollient and moisturizing properties which are very useful for both skin and hair care products like shampoo, skin lotion, skin cream, cleansing cream and soap (Alves *et al.*, 2020; Johnson Jr *et al.*, 2020). The excellent film making property makes it an ideal ingredient for use as a pre-treatment liquid for hair treatments (Shavandi *et al.*, 2017; Wang & Tong, 2022). The fibroin film makes a stable condition on hair, hence found more resistant and protected against chemical reactions (Wong *et al.*, 2014). Silk polypeptide is composed of a strong and elastic crystalline part and a soft and extensible non-crystalline part; it makes the film soft as well as tough. It is useful to protect hair against the mechanical action of combing and brushing (Babu, 2017). There is a great similarity between natural moisturizing factor (NMF) and silk fibroin. Thus it can be extensively utilized as a moisturizer in cosmetic products. The resemblance of amino acid and natural moisturizing factor and silk fibroin can be advantageously used as a skin moisturizer (Daithankar *et al.*, 2005). Hydrolyzed silk is marketed with different trade/product names *viz.*, SILKPRO, SILKPRO F, SILKPRO CM-1000 and SILKPRO CM-1000 SPF (Anonymous, 2016c). Silk-Pro-100 has proven excellent moisture efficiency in both *in vitro* and *in vivo* conditions ((Daithankar *et al.*, 2005). Sericin hydrolysate solution was found effective against dermatitis (Yasuda *et al.*, 1998; Ghonmode, 2016). The suggested applications of different silk products in cosmetics are described in Table 2.

Silk Ester (Hydrolyzed Silk Ethyl Ester)

Hydrolyzed protein has limited solubility in alcohol. It poses a challenge to use it in alcoholic base formulations (Li *et al.*, 2015; Wu *et al.*, 2022). However, the ethyl ester of hydrolyzed silk is completely soluble in alcohol. It increases the possibility of utilizing hydrolyzed silk in alcoholic base formulations of hair spray, and hair styling mousse with alcoholic base (Howard, 1974; Beitone *et al.*, 1986). Silk ester is marketed with the product name SILKPRO AS-A. It can be incorporated into hair spray/mousse, hair treatment/conditioner and nail enamel although the limited solubility in alcohol. However, it cannot be used for alcoholic products such as hair spray (Anonymous, 2016c).

Quaternary Silk Protein

Silk protein has improved adsorption efficiency when used for softening hairs but poses adverse effects when used in excess

Table 2: Suggested applications of different silk products in cosmetics (Anonymous, 2016c)

Product	Applications
SILKPRO	Skin care- Cream , Lotion , Liquid Soap, Cleansing Foam Hair care -Shampoo , Treatment , Conditioner
SILKPRO F	Skin care- cream, Lotion Hair care- shampoo, treatment
SILKPRO CM-1000	Skin care- cream, Lotion Hair care- shampoo, treatment
SILKPRO CM-1000 SPF	Skin care- cream, Lotion Hair care- shampoo, treatment
SILKPRO AS-A	Hair care- Hair Spray, Styling Mousse, Treatment , Conditioner Make-up – Nail enamel
SILKALL 100	Make-up- Pressed Powder, Foundation, Eye Shadow

quantity. However, the quaternary derivative of silk polypeptide with good film making features and absorbance can improve hair softening and condition (Shinde *et al.*, 2021). Quaternary silk is marketed with the trade name SILKPRO Q (Anonymous, 2016c). Nano-cellulose sericin gel forming a fibrous network like face-mask with improved moisture absorption, less adhesive and superior physical properties was developed (Singh *et al.*, 2023a). It showed no toxicity to HaCaT human keratinocyte and L929 mouse fibroblast cells (Aramwit & Bang, 2014). SILKPRO CM-1000 is the trade name of hydrolyzed silk polypeptide. It is a clear yellowish liquid developed to eliminating the product's stickiness under hot and humid conditions. SILKPRO is an aqueous silk amino acid and has been used in many hair care products on the market (Anonymous, 2016c). The damaged hairs upon treatment with silk peptides gain weight and thickness with remarkable post damage recovery (Hyun *et al.*, 2008). Silk nano-particles have also been used for drug delivery (Wongpinyochit *et al.*, 2016). Silk NPs can be effectively used for the delivery and protection of bioactive compounds in natural extracts such as guava leaf extracts. The natural extracts are extensively used in cosmetic products and can be encapsulated by silk NPs for improved protection of phenolics and persistence of anti-oxidant properties (Pham *et al.*, 2023).

Silk Powder

Silk powder is a micronized form of natural silk fibroin. This micronized silk powder has many attributes viz., smooth and glossy touch, moderate hydrophilicity, oleophilicity, and good adhesion property which makes it greater to powdery cosmetics (Chon *et al.*, 2012). Silk powder is marketed with the product name SILKALL 100 (Anonymous, 2016c). Silk fabric undergarments with the trade name - Dermasilk have proved antimicrobial effects and were found comparable with corticosteroids (topical ointments) for the treatment of atopic dermatitis (Senti *et al.*, 2006). Sericin powder in the form of hydrolysate and coated with talc, mica, titania, iron oxide and nylon has been used to formulate foundation cream and eyeliners in cosmetics (Ghonmode, 2016). The silk powder contained products always remain soft and powdery condition as its water retaining function of silk imparts the moisturizing touch to the skin (Anonymous, 2016c). Fibroin powder (70-95%) and sericin powder (5-30%) have improved moisture retaining capability (Kirikawa *et al.*, 2000). It effectively improved and detected UV filtration rates (Yoshioka *et al.*, 2001; Barajas-Gamboa *et al.*, 2016).

SAFETY ASSESSMENT OF SILK PROTEIN INGREDIENTS IN COSMETICS

According to the International Cosmetic Ingredient Dictionary and Handbook (Dictionary), silk protein ingredients are reported to function as skin, hair conditioning and bulking agents in cosmetic products (Boyer *et al.*, 2017; Johnson Jr *et al.*, 2020). Since, the safety assessment of silk proteins was necessary because of their increased utilization as one of the ingredients in cosmetics. Silk fibroin which is used as a surgical suture is an FDA-approved medical device (Wöltje & Böbel, 2017). The approval of silk as a surgical suture necessitates the demand for silk products in cosmetics as well. Many silk ingredients were assessed for safe use in cosmetics. Silk powder, hydrolyzed silk, and silk extract were found safe for use in hairspray at maximum concentration of 0.02%, 0.024% and 0.0036 % respectively. In perfumes, silk powder and hydrolyzed silk were found safe in the maximum concentrations of 0.1% and 0.000047% respectively. In face powders sericin, silk and silk powder are utilized safely in the maximum concentration of 0.00047%, 0.1-0.2% and 0.1-0.4% respectively (Rothe *et al*., 2011). Some silk ingredients were found to act as primary ingredients in cosmetics which includes hydrolyzed fibroin, hydrolyzed sericin, hydrolyzed silk, sericin, silk, silk extract, silk powder and fibroin. These ingredients were found considerably safe for use as ingredients in skin and hair care products. The use of silk fibroin in cosmetics is not yet in vogue. However, it is considered safe for use in cosmetics (Johnson Jr *et al*., 2020).

CONCLUSION AND FUTURE OUTLOOK

The cosmetic market is growing rapidly with the significant increase in demand for costeffective and eco-friendly products. The manufacture of cosmetic products relies on the utilization of low-toxic alternatives and biocompatible materials. Cosmetic products of natural origin are gaining popularity than synthetic and conventional ingredients. These commercial formulae are used for anti-aging, skin whitening and UV protection benefits with less toxicity and side effects on skin. Silk proteins are naturally originated viable alternatives to synthetic and a conventional ingredient due to their remarkable attributes viz., biocompatibility, biodegradability, wettability and stimulates collagen production. Silk proteins viz., sericin and fibroin are rich in anti-oxidants, promote skin hydration, wound healing and improved UV resistance. Many silk products have been developed for use in cosmetics. At a mass scale, the consumption of silk proteins for the manufacture of cosmetic products can be easily achieved because lot of defective cocoons which are unreelable are generated in bulk every year. These unreelable cocoons are discarded as waste usually and can be harvested for the manufacture of cosmetics. This eco-friendly innovation may evolve the cosmetic industry and promote value addition to the sericulture industry with better approach to sustainable development.

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