Grafting Cosmetic Active Ingredients for the Functionalization of Cosmetotextiles

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Abstract. Consumers’ rising demands for functional fabrics have led to the burgeoning of a revolutionary type of “cosmetotextiles”, which are textile products containing various cosmetic active ingredients for energising, skincare and beautifying. Phytochemicals and/or novel formulations are required for both product development and customer attraction. Encapsulation and grafting/coating technologies have provided these cosmetic ingredients with effective stabilization, sustained dermal delivery and prolonged dermocosmetic efficiency. This article provides an overview of the development history, popular cosmetic ingredients and manufacturing techniques of cosmetotextiles.

1. Introduction
Cosmetotextiles are defined as textiles that release active ingredients at regular time intervals when in contact with the human body by the Textile Industry and Clothing Standards Agency [1]. The development of cosmetotextiles dates back to the late 80’s where a Japanese company (Tejin Co. Ltd) manufactured and sell two million of its ‘Amino Jeans’ by incorporating the amino acid arginine in the fabric for skin rejuvenation efficiency [2]. Besides functional clothing, cosmetotextiles are also emerging as a new type of pharmaceutical/cosmetic carrier (e.g. hydrogels, facial masks and healing patches) in medicinal and beautifying products. Over the past decades, many new types of cosmetotextiles have been developed and commercialized (Table 1).

1.1. Perfuming Textiles
Cosmetotextiles for perfuming are loaded with synthetic fragrances or essential oils extracted from aroma plants (e.g. clove, jasmine, lavender and orange). The incorporation of various fragrance ingredients into the textile fibers can be obtained by polymerization or doping textiles with fragrance-loaded microcapsules. For example, the Matsui Shikiso Chemical Co., Japan, have encapsulated a variety of essential oils from musk, civet, ambergris, pine and citrus and grafted the microcapsules onto the fabric fiber by interfacial or in situ polymerization techniques [3]. Encapsulation of fragrance is also a promising approach to protect the volatile components from evaporation, oxidation and
contamination [4]. In addition to sustainability, the resistance to washing and handling can be improved by incorporating fragrance in suitable textile binders and softeners [5].

1.2. Antimicrobial Textiles
With the growing public awareness of the potential threats from pathogenic bacteria, the demand for antibacterial products has grown rapidly. Finishing textiles with non-toxic and environmental friendly antimicrobial microcapsules provides a long-term-controlled release for preventing or combating the growth of harmful bacteria [6]. Bed linen can be made more comfortable and healthier using fibers coated by microcapsules with essential oils with antimicrobial properties as well as anti-mite chemicals. In a previous study, Lee et al. investigated β-cyclodextrin as a carrier for encapsulating antibacterial chemicals, benzoic acid and vanillin, and embedded them onto cellulose fibers by using N-methylol-acrylamide, and found the anti-bacterial activity was resistant to 10 laundering cycles [7].

1.3. UV-Protective Textiles
Prolonged exposure to ultraviolet light can cause skin erythema, premature aging, allergies and even skin cancer. Textiles for sun protection are coated with UV-blocking ingredients used in sunscreen cosmetics, such as zinc oxide and titanium oxide, and a sun protection factor (SPF) greater than 35 is regarded as anti-solar clothing. To enhance the absorptivity of sunscreens such as zinc oxide, textile fibers can be pretreated with plasma. Since toxicological debates on metal elements still exist, recently more natural cosmetic ingredients are stabilized in the anti-UV textiles. Lignin, a cellulose material, has exhibited dramatic synergistic effect with chemical sunscreens in developing UV-protective textiles [8]. In another study, lignin/PVA nanocomposite fibers were developed by electrospinning, an environmental-friendly technique, with not only UV protective but also antimicrobial efficiencies [9].

1.4. Moisturizing Textiles
On contact with this type of cosmotextile, moisturizing ingredients can be transferred from the fibers to hydrate the stratum corneum of skin. Commonly used moisturizing ingredients include vitamin E[10], vitamin C [11], chitosan [12] and aloe vera [13]. For example, socks and leg wear containing vitamin C or aloe vera loaded gelatin vesicles have been introduced in the U.S. and Europe for moisturizing benefits. Encapsulation of these natural ingredients can be readily achieved by an array of methods (e.g. spray-drying, sonication and complex Coacervation)[14] and the release of active ingredients from the microcapsules occurs following heat, biodegradation, friction or pressure between the body and fabric during routine usage [27]. Cognis, a spin-off from Henkel, launched the first commercial moisturizing textile by a product line called Skintex®, which is made up of microcapsules loaded with vitamin E, squalane and aloe vera [15].

1.5. Anti-ageing Textiles
Light, pollution, inflammation and other oxidative-associated stress can increase the level of oxygen free radicals in human body, which will in turn accelerate the senescence of skin. Therefore, cosmetic ingredients with strong free radical scavengering effect can be employed for the development of anti-ageing textiles, including vitamin E (α-tocopherol), hyaluronic acid [15, 16] and plant extracts from coffee, cocoa, or cinnamon [17], and animal derivatives such as collagen and chitosan [16]. EVO Care Vital, a commercial product with a finish containing a formulation of vitamin E, Aloe Vera and Jojoba oil, is devoted to improve the firmness and resilience of skin. Cosmetil and Variance co. launched “Hydrabra” which can release active agents extracted from seaweeds that can soothe skin and promote skin firmness and elasticity [18].

1.6. Wound-healing Textiles
Wound-healing textiles of gauzes, bandages and wound dressings are mainly used for hygienic and medical purposes. Ideal wound healing textiles not only provide a physical barrier to cover and protect the wound from microbial infection, but also promote healing and decrease pain. Many
pharmaceutical and antimicrobial ingredients have been employed, including chitosan, methylene blue, epidermal growth factor, HA and silver nanoparticles. On the technical side, electrospinning has attracted a lot of attention in the wound healing area due to the many promising properties (e.g. ultrafine fiber and large surface area) of the produced fabric. Miguel et al. developed a skin-like layered structure patch composed of an asymmetric electrospun membrane that displayed a porosity, wettability and mechanical properties similar to native skin. Chitosan and aloe vera were also incorporated to provide antibacterial effect [19].

2. Cosmetic Ingredients Tailored for Cosmetotextile Application
A large number of cosmetic ingredients, including minerals, synthetic chemicals, animal and plant derivatives, have been successfully grafted onto cosmetotextiles. Encapsulation has been employed as the main technique for stabilizing natural cosmetic ingredients into the textiles by which the release of active ingredients from capsules occurs following heat, biodegradation, friction, or pressure between the body and fabric during use. This section summarizes the most popular cosmetic ingredients used in cosmetotextiles.

2.1. Chitosan
Chitosan is a N-deacetylated derivative of chitin isolated from crustaceans with good antioxidant and antimicrobial activities. Chitosan has wide application in functional clothing, cosmetics and pharmaceuticals due to its ability to improve skin texture and hydration, stabilize sensitive ingredients and promote cell regeneration [20]. The presence of abundant amine groups make chitosan a biocompatible polymeric material ideal for encapsulation. For example, Cognis, a German textile company, has developed a cosmetic textile finish, Skintex®, wherein the active ingredients are encapsulated in chitosan based cosmetic microcapsules. The microcapsules can be embedded onto the fabric for products of different efficacy, including moisturizing, cooling, energizing, relaxing, anti-heavy legs and mosquito repellent benefits. Release of the active ingredients can be triggered by the gentle friction created between the microcapsules and the skin during routine use, or biodegradation of chitosan membrane by skin enzymes [21]. Despite all the benefits, the aqueous solubility of chitosan limited its application in skin delivery of lipophilic compounds.

2.2. Hyaluronic acid (HA)
HA is a natural linear polysaccharide that has been used extensively in cosmetic products to improve skin elasticity, turgor, and moisture by acting as a sponge in the skin to retain water [22]. Meryl® Hyaluronan, an anti-ageing cloth patented by NyStar was developed by incorporating HA-loaded nanoparticles in the spinning process. Medline Industries, Inc. developed Hyalomatrix®, a 3D HYAFF® (HA ester) matrix, for wound healing. The 3D scaffold facilitated an ordered reconstruction of the dermal tissues [23]. However, the clinical application of pure HA may be limited by its rapid enzymatic degradation at physiological conditions. To overcome this limitation, studies have been conducted to use covalent cross-linking of HA with polysaccharides with a slower degradation rate under the action of hyaluronidase. In a recent study, HA grafted pullulan polymers were prepared by one step esterification and demonstrated high swelling ratio and a relatively quick hemostasis ability, making it a promising wound healing dressing [24].

2.3. Essential oils
Essential oils are volatile compounds extracted from the flowers, seeds, leaves and barks of various aroma plants. Essential oils have wide applications in pharmaceutical and cosmetic industries [25]. For cosmetotextile application, essential oils of pleasant smells or cosmetic efficiencies such as antimicrobial, antioxidant, and moisturizing and cell rejuvenation are the most frequently employed functional ingredients. For example, lavender oils are favored in the manufacture of pillow fabrics because of its pleasant aroma smell and antimicrobial property [26]. Men’s slimming cloth launched by the fashion brand Legends & Heroes under the brand Ript Skinz was infused with a skincare
formula containing time-released microcapsules enriched with vitamin E, caffeine, retinol and essential oils extracted from apricot kernel (Prunus armeniaca) and rose hip (Rosa acicularis Lindl) After ever 10 washes, the garment can be re-sprayed with the formula again for continued use [13]. Recently, essential oils have been more reported in encapsulated systems, such as micro-/nano-sized capsules, to overcome their poor thermal stability as well as to improve sustainability during ordinary washing processes [27].

2.4. Peptides
Peptides exist in vivo as amino acid polymers and function in the skin only for a short period of time before decomposing into amino acids. Peptides can be subgrouped into three types (signal peptide, carrier peptides and neuro-transmitter inhibiting peptides) depending on the mechanism of action in vivo. Peptides are widely used in cosmetics however the types used in cosmetotextiles is limited to copper peptide, collagen peptide [28], and acetyl hexapeptide-3 [29]. Peptides have many functions as cosmetic ingredients including skin moisturizing, firming and elasticity-promotion, anti-wrinkle etc. Lipotec, spain, marketed an anti-wrinkle cosmetotextile containing hexapeptide (acetyl hexapeptide-3) under the name of Argireline [29]. Argireline nanoparticles have also been used to manufacture anti-ageing facial masks, including Sugar-based Frosting Sheet from Kopykake (Calif.) and Collagen Sheet from Dr. Suwelack Skin & HealthCare AG (Germany). Besides, peptides can play a role in scaffold construction for biomedical patches just like chitosan. In 2014, Loo et al. investigated the wound healing performance of peptide-nanofiber hydrogels with combined advantages of hydrogels and nanofiber scaffolds while maintaining skin hydration [30]. However, the high water content and large pore size of most peptide hydrogels may result in relatively rapid release of drug.

2.5. Aloe Vera
Aloe vera is a perennial tropical plant rich in minerals, polysaccharides, vitamins and amino acids, making it a good antimicrobial, anti-inflammatory, antioxidant and moisturizing agent used in skin care products. For cosmetotextile use, Dogi International Fabrics, Spain, launched a line of Smart Fabrics doped with aloe vera nanoparticles which provide moisturising, calming, antioxidant and anti-ageing benefits. Likewise, a cosmetically inspired fluid lingerie “Hydrabra” has also been commercialized by the incorporation of aloe vera [31]. In addition, fabrics coated with aloe vera-loaded nanoparticles have been reported with improved wash durability and antimicrobial activity [32]. Commercial microcapsules of aloe vera extracts can also be coated onto cotton/polyester fibers by using atmospheric-pressure plasma printing technique in an environmental safe and low cost manner [33]. Besides cosmetics, aloe vera gel have been extensively used as therapeutic remedies. In a recent study, Dey el al. developed a aloe vera based bio-composite hydrogel which can release UV-absorbing flavonoids that may provide better wound-healing efficacy [34].

2.6. Vitamins
Vitamin E and C are widely used in the cosmetic finish of cosmetotextiles. Vitamin E is a powerful antioxidant belonging to the lipid-soluble type, the grafting of which in microcapsules into fabrics has been reported to significantly increase skin moisture and elasticity as well as reduce skin wrinkle and roughness [35]. Coating cotton fabrics with protein-based nanoparticles containing vitamin E by a low-cost pad-cure method has shown an effective approach to impart them with antioxidant properties [10]. Besides, vitamin C, or L-ascorbic acid, is the most plentiful water-soluble antioxidant that protects the skin intracellular structures from oxidative stress [36]. Fuji Spinning, Japan, incorporated a provitamin C, which can be converted into vitamin C in the presence of sebum, on blouses and shirts [37]. Gelatin/vitamin C microcapsules have been successfully prepared using the emulsion hardening technique and grafted onto textile materials by padding [38].
3. Concluding Remarks

Functionalization of textiles for cosmetic application is a novel and rapid growing field of interests for both consumers and the cosmetic industry. Today, cosmetotextiles are emerging as high value-added products that satisfy customers’ desire for well-being, with the product form varies from functional clothing to medical dressing and specialized cosmetics. Numerous cosmetic active ingredients have been successfully grafted onto fabrics by encapsulation, plasma and sol-gel methods. Advantages of cosmetotextiles include:

- Simple and eco-friendly manufacture;
- Low water content which limit microbial contamination;
- High stability and fashion value;
- Diverse variety of cosmetic efficacy to be explored.

With the rising demands and expectations of consumers, more sustainable and cost-effective cosmetotextiles of various health benefits are being developed worldwide leading to a new era of “dermocosmetic fashion art”.

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Table 1. Commercial cosmetotextiles products and claimed dermocosmetic efficacy

| Brand name and Manufacturer | Cosmetic ingredients | Product Form | Cosmetic Efficacy | Patent No. |
|-----------------------------|----------------------|--------------|-------------------|------------|
| Amino Veil, Ajinomoto with Mizuno Corp, Japan | arginine amino acid | Tennis and golf clothes | ● Skin hydration  
● Maintain skin pH level  
● Skin rejuvenation | US3787482A |
| Skintex, Cognis Oleochemicals Corp, German | Essential oils from fruits and leaves | Clothes, innerwear | ● Skin hydration and cooling  
● Skin energizing and relaxing  
● Anti-heavy legs  
● Mosquito repellent properties | US 20070292464A1 |
| Bio cap, CPC International Inc., UK | Vitamin A, D, E and aloe vera | Bedding, underwear, T-shirts, stockings and socks | ● Skin moisturizing  
● Body cooling effect  
● Body thermal-regulating treatment | US 5660769 |
| Meryl® Hyaluronan, Nylstar, Spain | Hyaluronic acid | Innerwear | ● Promote skin elasticity, softness and firmness | CA2894370A1 |
| Solaveil™ ST-100, Croda, UK | Titanium Dioxide | UV suit | ● UV protection | US20170209350A1 |
| Skin’Up, Skin’Up Lab, France | Phyto-marine actives and safflower seed oil | Clothing, slippers, underwear, | ● Skin anti-aging  
● Skin anti-cellulite | WO 08/068418 2008  
FR2996731B1 |
| Lytess, Lytess, France | Caffeine and Shea butter | Leggings | ● Anti-cellulite | |
| Matricol®, Billerbeck, Germany | Collagen peptides | Facial mask | ● Skin anti-aging  
● Skin hydration,  
● Skin rejuvenation | US 8,358,348 B2 |
| Hydrofera Blue Dressing®, US | Methylene Blue | Wound patch | ● Antibacterial | US 2019/0224134 A1 |

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