Scientific Research Publishing

Advances in Nanoparticles, 2020, 9, 1-22
https://www.scirp.org/journal/anp
ISSN Online: 2169-0529
ISSN Print: 2169-0510

Nanotechnology in Cosmetics: Basics, Current Trends and Safety Concerns—A Review

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How to cite this paper: Effiong, D.E., Uwah, T.O., Jumbo, E.U. and Akpabio, A.E. (2020) Nanotechnology in Cosmetics: Basics, Current Trends and Safety Concerns—A Review. *Advances in Nanoparticles*, **9**, 1-22.
https://doi.org/10.4236/anp.2020.91001

Received: August 20, 2019
Accepted: December 14, 2019
Published: December 17, 2019

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Abstract

As nanotechnology finds new applications, the formulation and use of nanoparticulate structures in the production of cosmetics and cosmeceuticals keeps increasing. Nano-sized materials such as cubosomes, nanodots, liposomes, dendrimers, nano-emulsions are now becoming regular ingredients in the cosmetic space. These nanoparticle-based cosmetics or nano-cosmeceuticals have extended the boundaries of the applications of cosmetics in managing conditions of wrinkling, dehydrated and inelastic skin associated with aging and dispersed hyperpigmentation. With so many claims by giant cosmetic manufacturers on the several possibilities achievable by such products containing these, there remain valid questions needing answers. Such includes: what are the actual facts as opposed to unfounded expectations on use of nano-materials in cosmetics? What are the peculiar properties of Nano-sized structures? Any potential or actual health risks associated with nanoparticle-incorporated cosmetic products? What roles are the regulating authorities and academic researchers playing in the light of all these developments? This review attempts to answer these questions, taking a look at the updates on nano-sized materials used in cosmetics, while presenting actual advances made in nano-cosmetics amidst the seemingly not too obvious hidden risks.

Keywords

Nanotechnology, Nanoparticles, Cosmetics, Nano-Cosmeceuticals, Safety Concerns

1. Introduction

The advent of improving technology, specifically nanotechnology, has changed the face of research in the sciences generally and in the life sciences in particular. Gone are the days when information was stored in piles of books, occupying large fraction of the space available for human habitation. Today, information storage chips as tiny as postal stamps have capacities as large as the Titanic ship and functionalities as the processing unit of a high speed computer. Thanks to nanotechnology application! In the medical and pharmaceutical sciences, for instance, nanotechnology has revolutionized diagnosis, is fine-tuning pharmacotherapy, and drug delivery, even improving the production of medical devices and accessories. Nanotechnology has come to stay!

In an attempt to satisfy the ever growing desire of consumers to look beautiful and remain youthful, the sphere of cosmetics (through its manufacturers and researchers) has imbibed nanotechnology for its potentials and is expanding its frontiers rapidly yet steadily. Dendrimers, cubosomes, nanoemulsions are good examples of nanoform particles employed in cosmetics as an application of nanotechnology in the science of cosmetics formulation and manufacture [1]. Other nanosized forms are applied in sunscreens, anti-ageing products, razors and curling tongs [2]. For the purpose of this paper, fundamentals of cosmetics and nanomaterials are covered, the peculiar properties of nanoparticles necessitating their use in cosmetics are highlighted, expounding on seemingly familiar terms for clarity. The write up will also take a look at the common current innovative nanomaterials employed in cosmetic manufacture, their unique properties, highlighting the hidden challenges associated with nanocosmeceuticals and the support necessary from regulatory authorities is not overlooked.

To gather information, a search from online sources (e.g. www.researchgate.org, and www.google.com) as well as hard copies search from the library at the Faculty of Pharmacy, University of Uyo, Nigeria was carried out. Online, three resources were used to search for articles in journals, books and websites that provide avalanche invaluable information on nanotechnology use in cosmetics in the last three decades. Key words entered during search were Nanocosmetic safety, nanotechnology in cosmetics, cosmetic history, cosmetic toxicity, cosmetic business and cosmeceuticals. The articles were evaluated and on the basis of currency of information, reputation of journals and information source, practicality of guidelines and insight on cosmetics and its use.

Highlights

The use and application of Nanomaterials is on the increase due to their great functionality. There has been a shift from use of harmful beauty products historically. Unique properties and low cost of production has aided use of nanomaterials in cosmetics. Skin care products form the largest class of cosmetic products with nanomaterial use. Researchers and regulators must have heightened interest in nanocosmetic products, provide guidelines and be proactive to prevent unsubstantiated claims of manufacturers and promoters of cosmetic products. In the end, every consumer of cosmetic product must be well-informed and be on the look-out for his own safety.

2. Cosmetics, Cosmeceuticals and Nanocosmetics

On the average, an adult uses about nine cosmetic products daily [3]. No doubt, cosmetics are probably among the most widely used products in the world. Their appeal is directly linked to their functionality in achieving man's innate desire of looking beautiful and remaining ever young. Plautus, a Roman playwright worded it this way, "A woman without paint (cosmetics) is like food without salt". How those words convey the important role of cosmetics! From imparting confidence to fine-tuning beauty, cosmetics and related materials are applicable and have been employed from time immemorial [4]. According to the Food and Drugs Act (FDA) of the United States of America (USA), cosmetic is any product/article to be rubbed, poured, sprinkled or sprayed on, introduced to or otherwise applied to the human body or part of it, except soap, intended for cleansing, beautifying, promoting attractiveness, or altering the appearance [5].

Cosmetics cover a wide range of personal care products. On the basis of body parts they are applied, cosmetics could be classified as 1) skin-care cosmetics (eg moisturizing agents, cleansing agents) 2) hair-care products eg hair colorants, styling agents, shampoos 3) face-care products eg lipsticks, mascara, powders, face foundations 4) nail-care products eg paint removers, nail vanishes, 5) fragrance products eg cologne, deodorants, aftershaves, perfumes and 6) ultraviolet (UV) light screening preparations such as sunscreens.

In the light of this definition, it is evident that cosmetics are not medicines! However some cosmetic products could contain ingredients that can elicit a biological effect, mild therapeutic action or drug-like benefit on the skin, hence such ones are described by the term "Cosmeceutical" [5]. This term though not officially catalogued by the FDA since it has no meaning in the US law, has been used by persons and researchers in the manufacture and use of cosmetics (eg skin scientists, physicians, product manufacturers skin care professionals and even authors in academic or cosmetic journals) to promote consumer patronage of marketed cosmetic products as well as distinguish cosmetics having biological effect from those without it [6]. In this article however the terms cosmetics and cosmeceutical are used interchangeably. When the ingredients of cosmeceuticals are of nanosized, then they are fittingly called nanocosmeceuticals.

2.1. Cosmetics: Brief Historical Background

It would be a tall order to attempt placing a timeline on the origin of cosmetics and its use because the quest to look good and remain as such (which is the driving force for cosmetic use) has been as old as man itself. Although in earlier times, cosmetics, medicine and religious practice were closely associated and inseparable, Henri de Mondeville and Hippocrates helped to draw the thin line between these three arts [4]. The Egyptians reportedly employed oils, creams and ointment as early as the 10,000 BCE to achieve hygiene and protect their skin from the hot sun and dry winds. Tomb paintings, frescoes, and mosaics all indicate that the use of cosmetics was widespread among people in ancient Mesopotamia and Egypt. In fact the heavily made up, almond-shaped eyes seen on images of Egyptian women and the discovery of Pharaoh Tutankhamen's tomb not only revealed cosmetic use in the ancient world but also sparked the worldwide acceptance of eyeliner products [7] [8].

As at 3000 BCE, the Chinese used brightly colored nail polishes for social class distinction, with the nobles having coloured nail whereas the poor were not allowed to do so [9]. Heang, a term describing perfume, fragrance or incense, was part of the cosmetics in Chinese T'ang upper class, which employed it lavishly whether at home or temple [10]. In fact makeup use was an Eastern habit reportedly brought to Greece by tradesmen and travellers. Grecian women then indulged in the use of facial powders and artificial eye brows to look good.

As documented, see **Table 1**, as at the fifth century B.C.E, Athenian women used lead to whiten their faces, while reddening their lips employing rouge made from either seaweed or plants' roots [8]. Eyebrows were emphasized with soot, eyelids darkened with kohl (such as powdered antimony sulfide), and mascara was made from the dung of cows or from a mixture of egg white and gum. Archaeological findings in ancient Greek palaces, cemeteries, and settlements have revealed several items related to women beautification. Some of these items include mirrors, combs, hook-shaped pins, razors, and miniature vases for perfumes, creams, and pigments [11].

Sadly, though, from the foregoing, it is evident that humans throughout history have reportedly sacrificed their health and safety in their quest for beauty with many toxic homemade cosmetics. This has been seen in some cultures, for instance particularly in the 1800 s, women used toxic materials such as lead, leeches, arsenic and mercury to give themselves the pale appearance which was seen as a beautiful look in the ancient times [12]. Many such consumers of cosmetics paid dearly.

Thankfully, the days of ignorance in using unsafe, harmful and even poisonous mixtures to enhance looks are over, but there remains the desire to look beautiful and stay young, giving way to application of verifiable science and technology to achieve this [12] [13]. One advanced technology employed in the manufacture of cosmetics is nanotechnology.

2.2. Nanotechnology: Definition and Application

In the science of Nanotechnology, atoms and molecules are formulated at the nanoscale. That means the design, production, characterization of structures, devices and systems are done at the scale of size range 1 - 100 nm(10 - 7 m). Put

Table 1. Historical development in cosmetic use.

Notable development in cosmetic use	Use of make-up & ointment common among Egyptians	Use of perfumes/& nail polishes for class distinction popular with the Chinese	Greeks(Athenian women) used lead for facial care & seaweed for lipsticks	Awareness & reduction in use of toxic/harmful cosmetics	Safety concerns regulations & proper cosmetic labeling emphasized	References
Time line:	10,000 BCE	3000 BCE	500 BCE	1800 CE	21st Century	[8] [9] [10] [11]

differently but comparatively, a nanometer globule is a size that is 80,000 times smaller than the diameter of the human hair. Application of nanotechnology has stretched across various streams of science (see **Figure 1**), from the chemical sciences to the pharmaceuticals and now has found applications in the field of cosmetics resulting in the nomenclature, nanocosmetics; scientific use of nanomaterials in cosmetic formulations.

Several surveys have revealed that the major cosmetic manufacturers now employ nanosized materials in their various products. With so much possibilities achievable with nanotechnology, to apply this science to cosmetics is to manufacture cosmetic products with elegance, conferring appeal and durability on the fragrance of perfumes, improve protection offered by sunscreen products, make hair dyes give unparalleled luster to hairs and to produce anti-ageing creams that attempts to provide resistance to progression of aging by offering prolong dermal hydration, and strengthening skin elasticity [6].

The wave of applying nanotechnology principles in cosmetic manufacture is intense. Estee Lauder(a big cosmetic manufacturer) reportedly came into the "nano cosmetic market" in 2006 with range of products containing "Nanoparticles" whereas L'Oreal, the world largest cosmetic company with headquarters in Paris, France devoted some 927 million dollars in 2011 to cosmetic and dermatological research, and has come up with patents in several cosmetic products having nanomaterials [14] [15]. Other examples of cosmetic manufacturing giants include Freeze 24/7, DDF (Doctor's Dermatologic Formula), and Colorescience; Dermaswiss, Zelens, Lancôme and Euoko, all have delved into the use of nanocosmeceuticals in the manufacture of their products, with billions of dollars as investments [15].

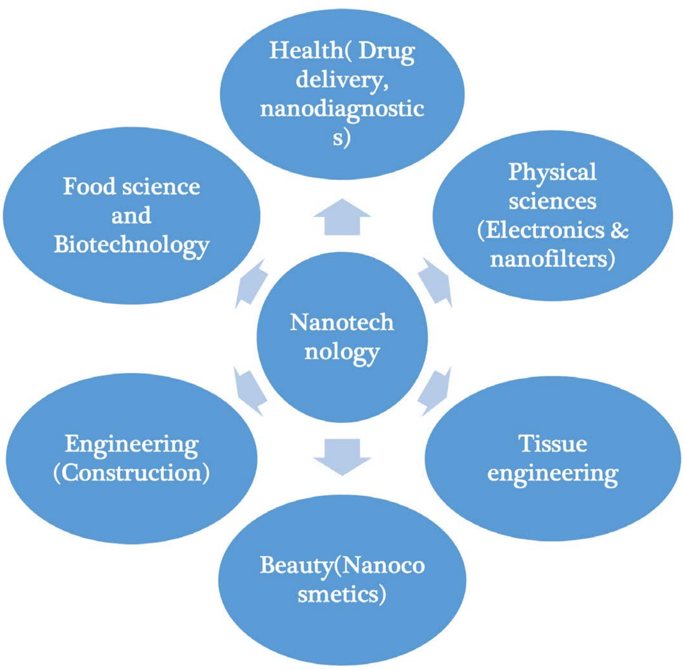

Figure 1. Some applications of nanotechnology [14] [16].

But what could possibly spark the drive for such attention and investments in the use of Nano sized ingredients in cosmetics? Unique properties and reduced production cost could be possible reasons.

2.3. Properties of Nanomaterials

One possible reason many researchers and manufacturers give for increased attention and use of nanomaterials in cosmetics is to achieve better delivery of cosmetic ingredients into the skin. This is a sound reason and a function of the perceived properties of nanomaterials. However, research results appear not to be consistent with such reason. This may be due to varying study conditions giving non reproducible results [16]. For example, the small size of lipid vesicles seen in nanoemulsions may enable cosmetic materials be absorbed more readily into skin [17].

Fellipe *et al.*, 2009 [18] on the other hand, using human skin biopsy, investigated the skin penetration of nanoparticles of Titanium dioxide and Zinc oxide used as sunscreen product and reported unlikely penetration beyond the surface of stratum corneum contrary to the claims made by manufacturers. It is, nevertheless, safe to state that nanosized materials have peculiar features that make them different from their large particle sized counterparts. **Figure 2** presents some of these features.

Particle sizes influence properties of a given material. Nanoscale particles thus possess altered properties from their parent or larger size counterparts in terms of color, structural integrity, transparency, optical activity, solubility, and chemical reactivity. For example, nanoscale materials possess the unique size which

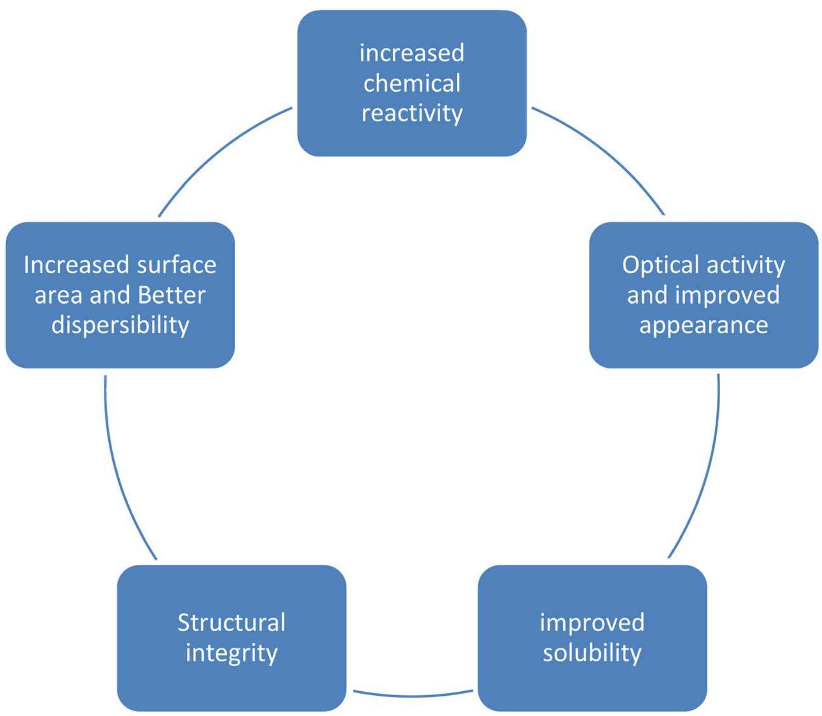

Figure 2. Properties of nanomaterials.

makes possible better solubility, size matching of cosmetic ingredients with biological structures of cells of the skin with consequent ease of interaction thereby selectively influence cellular processes at their naturally existing scale [19]. These properties of nanoparticles in cosmetics provide better UV protection, long lasting effects, better finish quality and improved penetration through the skin [1] [16].

Another invaluable property associated with nanomaterials is that they possess larger surface area to mass or volume ratio compared with larger sized particles. One of two particles with equal volume is said to have larger surface to volume ratio, if it has more numbers of molecules or atoms present on the surface of the particle than the other. Size reduction increases the surface area to volume ratio of particles.

Sivanskar and Kumar (2010) [19] had endeavored to mathematically deduce the percentage increase in the surface area of a spherical nanosized particle that is reduced from a micrometer. Improved surface area enhances dispersibility (rate of sedimentation reduced to almost zero) and dissolution rate of drug or cosmetic ingredients. Larger surface area of nanoscale materials also means more surface irregularities which promotes good adhesion due to higher number of contact points supporting van der Waals attraction. Good adhesion to the skin will achieve better cosmetic effect. More significantly is the effect of surface area on reactivity of the particles. These unique chemical properties may result in unique bioactivity and may help to predict possible biological response obtainable from nanomaterials used in cosmetics [20].

Nanosized materials even those of high solid density, when in suspension, form well dispersed systems that do not settle under the influence of Brownian motion. This implies that nanoscale ingredients in cosmetics will stay suspended longer than their micro scale counterpart. This property confers on such nanosized skin preparations a measure of stability, longer shelf life as it will take longer for features of instability such as creaming, cracking, Ostwald ripening or phase inversion to be noticed or actually occur. Little wonder then the urge to obtain and use available nanomaterials in cosmetic production. Large surface area also provides more active sites to promote chemical reaction, thus increasing reactivity of nanosized materials.

The optical activity and transparency of nanomaterials confers aesthetics to cosmetic products. This is particularly evident in many creams and sunscreens. Zinc oxide and Titanium oxide are main components of sunscreens. Their larger size particles when used leave a conspicuously white color on the skin but the Nano sized particles in similar product leave no such effect thus resulting in better aesthetics of the nanoproduct [21].

The economic advantage of nanoparticle in terms of low production cost as opposed to the large sized counterparts has also been noted as one more reason for taking the option to use nanoparticle in cosmetic products. This is especially seen many times in which nanoparticles are obtained as byproduct of diminution of larger sized particles without a determined attempt to produce them [21].

3. Identifiable Nanosized Materials Used in Cosmetics

Nanomaterials used in cosmetics are many and their unique properties vary, affecting which type of cosmetic products it will best suit. Some of these together with their composition, properties and applications are discussed below;.

3.1. Liposomes

These spherical vesicles are made of hydrophobic phospholipid bilayers enclosing an aqueous medium.

Composition: they are usually formed from cholesterol and natural phospholipids in an aqueous environment at the right ratio of lipid-to-water in the presence of heat energy.

Properties: The phospholipids could be unsaturated or saturated but non-toxic. The unsaturated are less stable but more permeable for example, egg phosphatidyl choline which is of a natural source. The saturated ones have long acyl chains, forming rigid impermeable bilayer structure eg dipalmitoyl phosphatidyl choline [22]. Liposome size ranges from 30 nm to several micrometers. Liposomes of natural or synthetic phospholipids are similar to those in cellular plasma membranes. This explains their biocompatibility, biodegradability, nontoxicity, and being flexible vesicles are readily utilized by the cells [23].

Uses and applications: These can trap cosmetic ingredients, whether hydrophilic or hydrophobic, releasing their contents at designated targeted spots. Hence even poorly soluble cosmetic ingredients can be delivered in this form. Liposomes have been used to encapsulate vitamins delivered to refresh skin epidermis. When delivered as liposomes, Vitamins A, E and carotenoids have improved stability. Little wonder the ingredients of liposomes are seen in moisturizers for skincare and shampoos for hair care [6] [24]. Liposomes however have limitation in terms of physical stability, and in large scale production [22].

3.2. Niosomes

These are nanosized vesicles made from non-ionic surfactants and cholesterol in aqueous medium.

Composition: Made up of non-ionic surfactants (the tweens and span), cholesterol and an aqueous medium. Specifically, the non-ionic surfactants form either from a mix of polysorbate 80 (HLB value = 15) and tween 20 (HLB value = 16.7) on addition of optimum level of cholesterol or from only tween 20 using same concentration of cholesterol [25] [26].

Properties: Niosomes properties are similar to those of liposomes' except for their better stability and flexibility [27]. The surfactants self-arrange as a bilayer that encloses the aqueous solution within it.

Application: Functional cosmetic ingredients can thus be dissolved or dispersed and carried in the aqueous solution within the niosomes, and delivered at intended sites (targeted delivery) or at a predetermined rate (controlled delivery). Hydrophilic drugs and lipophilic drugs are entrapped within the aqueous core and membrane bilayer of niosomes respectively.

3.3. Micelles

At the size of less than 100 nm, micelles could be used as nanosized materials in formulating drugs or cosmetic agents having low solubility as colloidal solutions.

Composition: Micelles form when surfactants self-arrange in an aqueous environment and this happens when the critical micellar concentration of the surfactant is exceeded.

Properties: Micelles are similar to liposomes but they do not have an inner hydrophilic liquid compartment. Rather they possess hydrophobic core but a hydrophilic surface which confers on them the ability to solubilize an otherwise poor soluble cosmetic ingredient.

3.4. Nanocapsules

Nanocapsules are polymeric nanoparticles consisting of a shell and a hollow space in which desired substances may be loaded and protected from the environment.

Applications: Retinol has been delivered into the deeper layers of the skin by L'Oreal (the French company and a nanotech patent holder in the US) using polymer nanocapsules [28]. Lancôme had equally manufactured a product (Primordiale Optimum Lip) using nanocapsule technology to deliver 100% botanically pure vitamin E to overcome conditions of lip bleeding and feathering that result from fine lines and wrinkles [6].

3.5. Nanoemulsions

Although emulsions are common liquid dispersed systems usually of two immiscible liquids, one being dispersed in the other, nanoemulsions are considered as one of the most advanced nanomaterials for cosmetic production [29]. Their wide application is attributed to their desirable properties.

Composition and Properties: Typically, nanoemulsions are composed of oil phase and the water phase, one dispersed as submicron droplets throughout the other and stabilized by surfactants. Nanoemulsions have so fine texture that they can be sprayed on and are relatively stable. They also possess good skin penetration and hydration power.

Uses and application: In skin creams production, ingredients are encapsulated or suspended as nanoemulsions to enhance skin penetration. Nanoemulsions are extensively used as medium for the controlled delivery of biologically active ingredients in cosmeceuticals such as lotions, shampoo, nail enamels, and hair conditioners [29]. Companies that manufacture these products claim that nanoemulsions can transport beneficial compounds deep into the skin in high concentrations. For example La Praire's product the *Dollars* 500 *skin caviar* intensive ampoule treatment uses this technology to deliver the functional ingredients into the skin at their site of action quicker to effect the claims of the product which is to minimize uneven skin pigmentation, remove lines and wrinkles.

3.6. Solid Lipid Nanoparticles (SLN)

These are made from solid lipids of nanosize dispersed in aqueous phase.

Composition: By composition, they are described as emulsions, where the solid lipids form the oil phase. Some authors designate them as solidified oil-in-water emulsion [30].

Properties: SLN is typically spherical with an average diameter of 50 - 1000 nm. They are non-toxic and bio-compatible. SLN can either be lipospheres or nanospheres. These together with nanostructured lipids can serve as carriers for drugs or cosmetic ingredients conferring good physical stability and low incidence of drug leakages. However, when storage conditions are suboptimal, SLN are subject to change into polymorphic forms, resulting in variations in the release or non-release of drugs or cosmetic ingredients in them [31].

Uses and applications; Solid lipid nanoparticles can be used as carriers for cosmetic ingredients. Such lipids carriers provide skin enhanced hydration, bioavailability, stability and controlled occlusion.

3.7. Nanocrystals

These are particles of pure active materials, reduced to nanoscale with crystallization or grinding methods. These are crystal aggregate of size range of 10 - 400 nm made up of hundreds to thousands of atoms that combine into a cluster and used for the delivery of poorly soluble actives [32].

Properties and applications: Juvena, a cosmetic company produced a nanocrystal formulation of rutin, an antioxidant, Juvedical®, in 2000. This formulation of original rutin molecule, a study revealed is 500 times more bioactive compared to the water soluble form, rutin glycoside. This comparison of rutin nanocrystal and rutin glycoside was based on its sun protective factor [33]. It was especially remarkable because the nano-crystal suspension which was less soluble had the concentration of actives formulated as nanocrystals in the skin much higher compared with the glycoside or the powder [6]. In a similar study reported by Pyo *et al.* (2016) [34], rutin nanocrystal in gel had the highest neutralizing (antioxidant) activity when compared with the commercially available form or the powder.

3.8. Nanosilver and Nanogold

Of the entire nanosized particle used worldwide in cosmetics, 12% is occupied by nanosilver [35] [36]. These metallic nanosized materials are classed as mineral nanoparticles.

Properties and applications: Silver nanoparticles, also termed nano silver or colloidal silver have been used in many personal care products as preservatives in cosmetics such as shampoos, toothpastes and in preparations for skin acne. This is not unconnected with silver nanoparticles having antibacterial activity. Silver nanoparticles have been observed to inhibit the growth of dermatophytes, making them potential anti-infective agents active against infectious organisms, including *Escherichia coli*, *Staphylococcus epididermis*, *Vibrio cholerae*, *Pseudomonas aeruginosa*, *Syphilis typhus*, and *Staphylococcus aureus* [6] [37] [38].

Published literatures have suggested that the antimicrobial activity of silver nanoparticles may be due to the release of silver ions, and similar studies have been carried out extensively on nanosilver and its products to exploit its unique antibacterial and antifungal properties [35] [39]. Gold nanoparticles on the other hand due to their unique properties for transporting and unloading the pharmaceuticals and ease of synthesis could be exploited in cosmetics. Their being readily functionalized, generally through thiol linkages makes for possible conjugation with cosmetic ingredients for improved product quality. Reportedly, nano gold has been incorporated to toothpastes producing effective oral cleansing and other marketed personal care products [40].

3.9. Dendrimers

Compositions: Dendrimers, unlike linear polymers, are monodisperse macromolecules produced by specifically controlled polymerization methods. These highly branched, star-shaped large molecules with nanometer-scale dimensions are described by three components: a central core, an interior dendritic structure (the branches), and an exterior surface having functional surface groups [41].

Properties: In several combinations of these components, different shapes and sizes of products are formed having shielded interior cores that have ideal candidates for applications in both biological and materials sciences. The interior core influences the cavity size, absorption capacity, and capture-release characteristics of dendrimers but the attached surface groups affect the solubility and ability to chelate.

Applications of dendrimers as reported in recent literature include drug delivery, gene transfection, catalysis, energy harvesting, photo activity, molecular weight and size determination, rheology modification, and nanoscale science and technology.

3.10. Cubosomes

In recent researches, cubosomes have been employed in antiperspirants and in hair care.

Composition: Cubosomes are formed from some surfactants which self-assemble when in proper ratio with water giving a microstructure of liquid crystals with unique properties. When some surfactants or polar lipid are hydrated, they form cubic phase which on dispersing into smaller particles usually form cubosomes. One such surfactant is the mono-glyceride glycerol mono-olein.

Properties: The cubic phases possess unique microstructure, biologically compatible and capable of controlled release of solubilized active ingredients like drugs and proteins or even cosmetic agents [42].

Application and Uses: Laboratory researches in collaboration with cosmetic companies such as L'Oreal and Nivea tries to use cubosome particles as oil-in-water emulsion stabilizers and pollutant absorbents in cosmeceuticals. Cubosomes are applied in varying spheres spanning the field of food science, differential geometry, biological membranes and digestive processes. Cubosomes, have the propensity for drug delivery as they can incorporate, transport and protect drugs or cosmetic ingredients of varying polar characteristics [43].

3.11. Buckyballs

Chemically named alternatively as Buckminster fullerene, buckyballs are made up of odd numbered carbon atoms arranged as rings so that they resemble the structure of some footballs but diameter is in nanometers. They are useful as anti-oxidant in mopping up radical oxygen and smoothing properties in moisturizers, hence inducing skin regeneration. Their high hydrophobicity had discouraged their use for some time but incorporating surfactants had assisted in overcoming this limitation [29]. One commercial product containing buckyball is the Zelens Fullerene C-60 night cream, an anti-aging cosmeceutical which was found to have remarkable antioxidant properties [6].

4. Selected Marketed Cosmetics Containing Nanosized Materials

UV Filters and sunscreens: As the name implies, these cosmeceuticals act to protect the skin from harmful ultraviolet rays of the sun. Titanium dioxide (TiO_2) and Zinc oxide (ZnO) are the main compounds used as nanoparticles in UV filters. Although some organic alternatives are being developed (such as those generated by ivy plants), the nanoparticles of these two oxides have been used extensively in sunscreens to prevent UV damage to the skin.

Unique merit: They are more efficient than larger particle sized counterpart in absorbing UV light while reflecting harmful ultraviolet light; the UV-A and UV-B. Sunscreen formulations with nanoparticles of TiO_2 are less greasy, transparent, less smelly and aesthetically appealing while the chalky white residue on the skin observed after using larger particle size is absent with nanosized counterparts. Research has revealed that these ivy nanoparticles are more effective; about four times better, than metallic oxide nanoparticles in blocking ultraviolet rays [44]. A good example is Sunforgettable® powder containing titanium dioxide nanoparticles a product from Colorescience [45].

Skin cleansers, Disinfectants and Antiseptics

The first defensive line of the skin (a film of sebum-sweat mix) can also be a source of harboring dirt, bacteria and their metabolic products. Such dirt are a combination of particulate matter trapped from the environment and that from desquamated stratum corneum whereas the metabolic product of the cutaneous bacteria harbored, releases unpleasant smell of body odor hence the need for cleansing to maintain a healthy skin. Soaps, toothpastes, wet wipes as well as face and body foams used in recent times for body cleansing contain nano silver.

Unique merits: Silver nanoparticles has a broad spectrum cidal antimicrobial activity especially on bacteria. Natural Korea cleanser (Cosil Nano Beauty Soap) and Evolut® hand sanitizer contain silver nanoparticles and it is claimed to be highly effective as disinfectant and for skin protection. Evolut ®is even said to be hypoallergenic yet builds immunity against airborne germs.

Moisturizing Creams

The moisturizers were introduced as cosmetic products to help overcome skin dehydration manifested by drying, scaling and breaking away of the surface skin. Moisturizers, usually containing humectants, help to retain a film of moisture on skin surface, making it look fresh, supple and smooth. Conditions of atopic dermatitis and pruritus are prevented and controlled when the skin is well hydrated and supple. Cosmetic companies started using nano-sized materials (eg liposomes) as envelopes or carriers of cosmetic ingredients to improve the solubility of ingredients and add shimmer. One such cosmetic ingredient is Vitamin E.

Unique merit: Nanostructured lipid carriers and solid lipid nanoparticles are newer nano-sized materials with better delivery and stability than the liposomes. When used in moisturizers they reflect high bioavailability and controlled occlusion, thereby providing enhanced skin hydration. Nano gold is also being used in one moisturizer available in the UK, allegedly bringing healing and anti-oxidant properties. In the market Lancôme, a cosmetic manufacturer has Hydra Flash Bronzer Daily Face moisturizer made of nanocapsules vitamin E with claims of ensuring a natural, healthy glowing skin [44].

Anti-ageing products

This is arguably the main area of application of nanomaterial in cosmetics products. Skin aging is characterized by skin thinning, loss of elasticity, dehydration, wrinkling and appearance of spots and loss of barrier function of the skin. Among other causes exposure to chemical pollutants, ultraviolet and infrared irradiations, abrasion and stress have been implicated as contributing to aging. On the contrary, skin regeneration and replenishing is hinged on the quality of collagen (a protein) in the skin. Some skin creams use such proteins derived from stem cells and enveloped in liposome nanoparticles which also carry cosmetic ingredients, to prevent aging of the skin. This allows for effective delivery of the proteins [42]. Others incorporate retinoid and botulinum toxin in fabricated nanosized materials to trigger skin rejuvenation in formulation of anti-aging products.

Unique merits: These products are claimed to reverse the conditions that characterize aging giving firmness and elasticity to the aging skin. Hydrazen cream, made up of nano-capsules of triceramides, a product of Lancôme claims to restore perfect comfort, and softness to skin giving it prolonged protection from daily stress. Vinosun® Anti-Aging Suncare, a product from Caudalie in Paris, France, combines nanosized UV filters and antioxidants for rejuvenating ageing skin and Plentitude Revitalift® from L'oreal also incorporates nanoparticles and is used as an anti-wrinkle cream [45].

Nail care products

Unlike the earlier known acrylic nail products, nail polishes impregnated with nanomaterials have been patented and reported to be tough and resistant to scratches and damage [46]. Nano lab corp has produced a nail polish with lacquer containing nanoparticles which offers ease of application yet resists shock, scratch or a crack [47]. This patent and similar marketed product offers a unique opportunity to incorporate nanoparticles (such as nanogold and nanosilver) with biocidal activities into nail care product. Hallosite Natural tubes (HNT) nail polish formula from a New Jersey cosmetic company has better polish consistency and allows for easier removal.

Unique merit: Nail care products with nanosilver and nanogold could have a dual function of aesthetics and disinfective and can be used to manage, onycholysis, onychodystrophy or onychomychosis, a fungal infection of the nail which disfigures the nails and nail bed of its sufferers.

Lip care product

Lipsticks and lip gloss meant for coating and beautifying users are now incorporated with nanoparticles to achieve bioactivity of softening and soothing the lips by preventing water loss from the lip surface. For example, silica nanoparticles in lipsticks improve homogenous spread of color pigments in lipsticks thus preventing pigment bleeding into the fine line of lips.

Unique merit: lipstick products with nanoparticles because of the very small sizes of the particles give high lustre and shine to the appearance of the lipstick improving aesthetic appeal.

5. Cosmetic Safety and Health Concerns

The unique properties of nanoparticles as used in cosmetics could be seen as a two-edge sword. On the one hand it offers appealing benefits with resultant effect of beautification but on the other, could have potential untoward effect on the body system. This brings to bear the heightened safety concerns and health risk, especially so because the known properties of particles could rapidly change when reduced to nanosize. Also the toxicity of nanomaterials is yet to be fully understood.

Thus safety concerns associated with nanosized particles in cosmetic products are mainly about whether or not they can get into the bloodstream during production or through use. If they do, what harmful effect can result. The need for safety of nanomaterials came to the fore in the USA when the Food Drug Administration (FDA) nanotechnology taskforce made recommendations for regulatory consideration with particular emphasis on the safety and non-adulteration of cosmetic products [5]. To assess safety of nanoparticles in cosmetics by the

FDA, two main pieces of information (strategies) are necessary.

One is information on the characterization of the material, particularly its nano-form used. Because nanoparticles could have altered physicochemical properties, information on such ingredients as well as finished cosmetic products will include such properties, their biological interactions and characterization of any associated impurities. Such accurate and available information can help health safety experts properly manage cases of poisoning, contamination or allergies.

The second of such information is the toxicological data of the nano sized product. Such is obtainable from assessment of the cosmetic ingredients for acute, chronic, sub-chronic systemic toxicity, skin irritation and allergy, photo irritation and photoallergy. the toxicological potential of cumulative exposure to similar products or frequent use of some products. The other necessary data will be genotoxicity, fetal toxicity, carcinogenicity evaluation as well as harm to reproductive health.

Two categories of persons get exposed to nanomaterials;

The Manufacturers: Workers in cosmetic production plants are constantly exposed to high concentrations of nanomaterials they work with through the inhalation route. This is especially so if proper safeguard measures are not in place in such working environment, or are not followed since at the production area many tiny nanoparticles will be dispersed in the air.

The Consumers: The consumers could be direct users of the product or those (secondary users) exposed as a result of contact or association with direct (or primary users). Simple actions as giving an embrace or a kiss could expose secondary users to nanoparticles in perfumes, skin care products or lipsticks. There are three possible points of entry of nanomaterials into consumers; Inhalation of sprayed products (perfumes, fragrance), ingestion whether intentionally or unintentionally of lip and near-mouth products (lip gloss, lip paints, mouth fresheners) and via the skin through application of skin care products. Inhaled nanoparticles due to their size can get into the functional unit of the respiratory tract (the alveolus), with high affinity to interact with membrane of respiratory epithelium. They likely will be absorbed through the olfactory epithelium, some quantity to nasal nerves into the brain while some others go into the circulatory system to the different organs [29]. Only small quantity of the ingested nanoparticle is reportedly absorbed into the circulatory system. The larger fraction leaves the gastrointestinal tract out of the body through fecal matter [6].

But for nanoparticles exposed to the skin, more is involved. The skin being the largest organ of the body is a primary route of exposure of cosmetic products especially by direct application. However when intact, its outermost layer serves as a functional seemingly impermeable barrier because it is lipophilic and has good cell cohesion. Although several works have been carried out to assess extent of penetration, if any, through the intact skin, there is no concrete evidence as to deeper layers of skin penetration by nanoparticles [15]. However in the presence of the following conditions, skin penetration has been documented:

1) *When nanomaterial is of low Molecular size and weight*; Nano-sized dendrimers of 2.9 nm but 3256 Da (Daltons) was observed not to penetrate intact skin while particle size of 10 nm but of lesser weight in Da have been shown to occasionally reach viable epidermal layers of the skin through the hair follicles and stratum corneum [48].

2) *When intact skin is damaged*; Cuts, burns, skin diseases and scrapes alter the barrier function of an intact skin, thus "opening the door" for entry of particles, especially nanoparticles in cosmetic product into the skin. At times stripping the upper skin surface with adhesives (such as elastoplasters) brings about the damage, removing the stratum corneum for entry of nanoparticles. The penetration profiles of the rutin nanocrystal gel on the porcine skin was carried out using tape stripping method and it was reported that the nanocrystals were found to penetrate deep to the horny layer of the skin [34].

3) *When penetration enhancers are used or the skin flexed*; Just as some chemical agents have the capacities of reversibly disrupting the intact, less permeable skin once applied, so is mechanical flexing. These enhance cutaneous absorption of active cosmeceuticals. Water, alcohol, dimethyl-sulfoxide and some other surfactants have been employed to achieve dermal penetration. For instance, Zhang and Monteiro-Riviere have reportedly compared skin penetration of quantum dots with that of quantum dot in 75% v/v glycerol. Preparation with 75% v/v glycerol gave better penetration [49]. Many of such penetration enhancers are components of cosmetics. Seventy percent of the cosmetics tested in a survey done by "friends of the earth" contained ingredients known to act as "penetration enhancers", making it more likely that nanoparticles in cosmetics will be taken up into the skin on application [35].

4) *The prevalence of appendageal pathways*; One means to circumvent the barrier of an intact skin is penetration through the appendageal route. Follicular paths through hair follicle with its associated sebaceous gland, and even the sweat pores can be means of permeation of nano-sized lipids, niosomes or nanoparticles beyond the skin surface into the viable layers [50]. However, the quantity absorbable may likely be minimal, due to the appendages occupying only a small area on the skin and some of them being already filled up by sebum or sweat respectively flowing out in opposite direction to cosmetic ingredient applied for delivery into the skin.

6. Toxicity of Nano-Sized Materials in Cosmetics

From the foregoing, it can be inferred that the safety of nanocosmetics after dermal exposure depends on condition of skin especially if intact, as the skin barrier is strong enough to prevent permeation of copious quantity of nanoparticles applied to it. But inhalation and ingestion equally can introduce nanoparticles into the blood stream. Beyond getting to the blood stream, an investigation into the level of damage or harm when in the system reveals the toxicity.

TiO_2 inhaled was reported toxic because of size and agglomeration state [51]. Several works have compared nanoparticles of different metals to their micro and large-sized counterparts systematically with results indicating greater damage to organs exposed to nanosized materials [52] [53]. However, some have inferred that the toxicity seen in nanoparticles is not a function of just the size of the particles but likely because of the nature of nanoparticles involved that is insoluble nanoparticles are usually culpable [53]. Silver nanoparticles are used in cosmetics usually for their antimicrobial effect. It is important to note, however, that the concentration of nanosilver that is bactericidal can also be lethal for body cells such as the keratinocytes and fibroblasts [54]. However, disrupted skin can only allow silver nanoparticle penetration at 0.2% - 2%. At this level, the nanoparticles is not seen to show any toxicity but smaller sizes of nanoparticle make for better skin penetration. Nanoparticles with a diameter less than 10 nm could reach the deeper layer of the stratum corneum, but sizes larger than 40 nm could only reach 5 - 8 μm into the stratum corneum Nanoparticles of chromium, silver, TiO_2, and ZnO do not penetrate deeper than the stratum corneum [48] [55]. It is because of these developments that toxicological considerations of cosmetics by some regulatory bodies now involve generating data from tests as to absorption, distribution, metabolism and excretion.

7. Regulatory Role and Responsiveness

Generally, the stringent pre-market approvals necessitated for therapeutic products before release for public consumption is not applied to cosmetic products. One major reason for this occurrence could likely be the pre-emptive conclusion that nanoparticles of a material are no different from their large size counterparts in terms of properties. Another is that cosmetics are no drugs and as such are not subjected to such "scrutiny" [5]. True, drugs and cosmetics are different however as stated in the outset, many cosmetics in the markets today elicit biological activities and are presented with penetration enhancers which can promote skin permeation of large quantities that could trigger a systemic effect. Thus, those two reasons hindering pre-market approvals could stifle research and growth in scientific understanding of nanoparticles and their possible health risk.

Without a doubt, then in line with the recommendations of the Royal Society of United Kingdom, given the evidence of serious nano-toxicity risks, nanoparticles should be treated as new chemicals requiring new safety assessments before being allowed for use in any consumer products. When implemented, this will imply that any nano-sized ingredients to be in consumer products should have appropriate detail, so that consumers have the chance to make an informed decision. Manufacturers and marketers of cosmetic products are thus by law responsible for ensuring safety and proper labeling of their product as well as any risk directly related with the changed properties of nanomaterials as against their microscopic or larger molecule counterpart.

The European commission (EC) has been proactive in this regard. In its regulation,(Regulation EC No 1223/2009) it is required that everyone responsible for production of cosmetic products register such items on the Cosmetic Products Notification Portal (CPNP) giving details of the product such as the composition, if a nano-material, their identification and any possible dangers. This notification should be made available six months earlier before the product goes into the market, thus giving sufficient time for the Scientific Committee on Consumer Safety (SCCS), of the commission make a risk assessment of the product for any concerns before being approved for market placement.

Any cosmetics with nanomaterial content must be authorized by the European Commission after opinion from the SCCS, which reviews submitted toxicological data prior to their use. Such nanomaterials must be labeled in the list of ingredients with the word "nano" in front of the substance. As a way for a sound analysis of toxicity of ingredients in cosmetics, the International Cooperation on Cosmetics Regulation (ICCR) has produced recommendations for the use of alternatives to animal test methods in cosmetics safety evaluation and resolved that in risk assessment of any cosmetics, this should start with an appropriate appraisal of any existing information on the products while any sources of constituents will be characterized and documented [56].

Post-Market Surveillance is equally essential. Once a product is in the market, consumer use is monitored and scientific data continues to be collected. New safety methods are also considered as new scientific know-how evolves. As science advances and consumers' preferences change, the industry continually innovates to ensure millions of families have the safest, highest quality yet acceptable products that help enrich their lives.

As regulatory bodies of different nations monitor and standardize nanomaterials in cosmetics to be in the markets in their locality, sharing available information and possible challenges to acquiring them, if any, will also help to bridge the gap for a concerted and committed global effort at ensuring safety in the use of cosmetic products.

8. Conclusion

With so much claimed possibilities of nanoparticles due to their improved properties, the rush to applying them in cosmetic preparation is on the increase and the market is already flooded with so much "nano-enhanced" skin formulations. There is, however, the need for further investigation into the health implications of these skin applications rather than being complacent just in the commercially viable cosmetic space. Although available knowledge in toxicity of nanoparticles is still adding up, it is essential. Regulatory bodies for cosmetic products will need to do more than providing applicable guidelines and supervision but also be proactive in screening to determine approval or not for new and existing nanosized ingredients used in cosmetics. Such authorities should raise standards for manufacturers of cosmetics in appropriate product labeling and post marketing monitoring. International collaboration of regulatory agencies in sharing information on cosmetic ingredients and their impact on health is a must to ensure global coverage. Consumers, on observing any intolerant reaction of nanocosmetic products they use, should promptly make a report to appropriate authorities. All thus have roles to play. From all indications, nanoparticles-contained cosmetics will continue to be relevant but it is important that relevance does not override health safety.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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