

FUTURISTIC TRENDS IN NANOTECHNOLOGY

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I. INTRODUCTION

Nanotechnology is one of the propitious technologies of the 21st century. It is the competency to convert the theory of nanoscience to most beneficial applications by measuring, observing, manipulating, controlling and manufacturing particles at the nanometer regime. The potential assistances are breath-taking and brain enhancing. But just like many of the great discoveries on the earth, it is not without risk. Scientists believe that nanotechnology can be used to support human health now and in the future through various applications like improved filters for enhancing water purification, better beneficial methods of drug delivering in the field of medicine and modern ways of refurbishing damaged organs and tissues. Nano technology holds great potential for India and a multi pronged arrival will assure that this is fully capitalized. Nanotechnology is applauded as having the capacity to enhance the effectiveness of energy consumption, support clean the environment, and solve major health issues. It is found to be capable to enhance manufacturing production at markedly reduced costs. In the course of time, nano-technology will influence the life of almost every individual on the planet. In the future, nanotechnology might help us make electrical lines, solar cells, and biofuels more efficient, and make nuclear reactors safer. According to the latest report on global nanotechnology market, the industry is estimated to grow at a CAGR of 18.2% between 2016 and 2021.

1. Emerging trends in food industry: A thrust on nanotechnology : Nanotechnology, to be an increasing extend is been regarded as a hot topic, that has revolutionized food industry. The aids of nanotechnology in food sector is expected to provide complete food solution. This rapidly developing technology on the nanometer scale, educe and exercise materials with unique and novel properties, influence every aspects of food system starting from seed germination, nutrition profile, cultivation, production, processing, packaging, transportation and to shelf life. The mounting costumer demand for quality food with health benefits are triggering the research community in search of nanoparticle based materials for commercial applications. These materials bring about great divergence not only in food safety and quality, but also in bioavailability of nutrients and health benefits that food concedes. Thereupon, human exposure to nanoscience is exponentially escalating with time, so that, the health impact, hygiene and safety of nano products are of great public concern and an internationally accepted uniform regulatory framework is necessary for nanotechnology in food industry.

The U.S. National Nanotechnology Initiative defines nanotechnology as “The science and engineering of understanding and control of matter at a nanoscale where unique phenomena enable novel applications” [1]. Nanomaterials are further stated as substances with size 1 nm to 100 nm, showing physical-chemical-biological properties that are incomparable from their macroscale counterparts due to their extremely small size, high surface to volume ratio, strength, colour, solubility, greater bio-chemical activities, diffusivity and other magnetic, optical and thermodynamic properties [2]. Nanotechnology enable the development of potential materials in consumer, medical, commercial and industrial applications [1]. As nanoscience is only at its infancy stage, only limited information in the field is currently available. Nanotechnology unfold the door to a whole new set of food products, which was limited to one’s imagination at some point in the past. The applications of nanotechnology in food industry can be grouped into two major heads – food nanostructured ingredients and food nano sensing (*figure 1*). The

former comprises area from food processing to packaging, where nanoparticles are used as food additives, agents of nutrition delivery, antimicrobial agent, anti-cracking carrier, cartridge for mechanical strength, filler to improve durability of packing and doer for smart shelf life. Food sensing cover better quality food and safety standards [3]. Foodborne diseases and mal-nutrition are like extremes of a single coin, that are always a nightmare to food and health sector. Processed food such as vegetables, fruits, meat and poultry products are potential vehicles for human pathogen outbreaks [4], leading to severe ill health that chattel the entire population. On the other hand, deficiency of required nutrition distort the well-being of the country. At this point, we utilize the antimicrobial properties of nanomaterials, which draw stoned public attention to ensure food safety. Nano-antimicrobial agents that are added directly to food or through antimicrobial packaging is an effective approach at this context [5,6]. Based on the scenario, role of nanotechnology in food engineering is a crucial point of discussion.

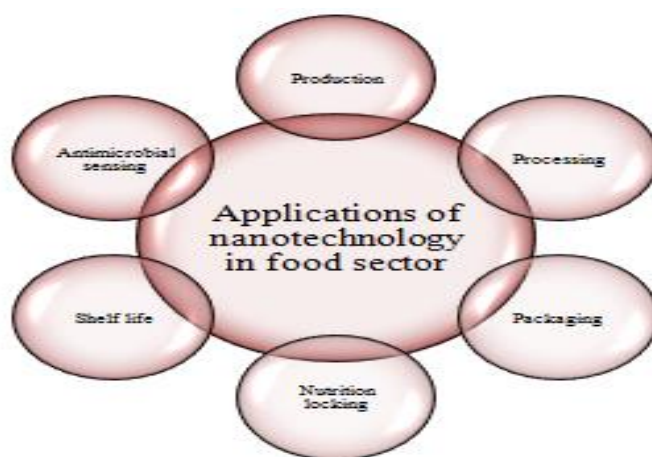


Figure 1: Applications of nanotechnology

- **Food ingredients for colour, texture and flavour:** Nanotechnology claim to develop nano sized food ingredients with refined texture, better taste, enhanced colour, improved consistency and savour flavour [7]. With nanotechnology, the wastage of large quantity of food due to microbial invasion can also be brought down to an extent. Titanium dioxide (TiO_2) and silicon dioxide (SiO_2) nanoparticles [8,9], amorphous silica [8,10] are used as food additives that can extend the shelf life of different food products. SiO_2 nanoparticles are frequently consumed as carriers of flavour and aroma in food products. TiO_2 nanoparticles can also be used as colouring agents and flow agents in the powdered sugar. These additives enhance the food delivery, without disturbing the basic morphology of the food. Nano-encapsulation techniques have been extensively utilized to retain freshness, better flavour release and to deliver culinary balance [11]. Large food molecules generally release energy slowly and require longer period to release nutrients. Coming to nanostructures, due to their subcellular size, rapid and sudden bioavailability of nutraceutical compounds is possible [2].
- **Food production and packaging:** Desirable production and packing materials must have improved mechanical strength, moisture permeability, pathogen detection, biodegradability, detection of microbial contaminations and alerting consumers about

the safety status of the food (*figure2*) [12]. Apart from conventional packing, nano based improved, active and smart packing possess these advantages. Nano-based packing is called ‘improved’ as it uses nanoparticles to improve physical performance of the food, ‘active’ since nanoparticles are used as antimicrobial agent and ‘smart’ as it consists of nano biosensors for pathogen detection [2]. A number of nanocomposites, nano-laminates, inorganic nanoparticles and nano-polymers are used by the food industry for food processing and packaging as they provide good resistance to mechanical and thermal shocks, and are cost effective [13]. For instance, ZnO and MgO nanoparticles [14] are extensively used as they crew strong antibacterial activity. Amorphous silica is used in food containers as they are stable at extreme atmospheric conditions [3,7,8]. In addition, nano silver, copper, TiO₂, chitosan has been reported to have efficient anti-bacterial property. Aerosols, engineered water nanostructures, are very effective at killing infectious pathogens such as *Escherichia coli*, *Listeria* and *Salmonella* that are seen largely on food production surfaces [10]. Such nanomaterials may have the potential of migrating from package into food. Thereupon, this innovative technology must meet regulatory standards before it gains wide-spread commercial acceptance.

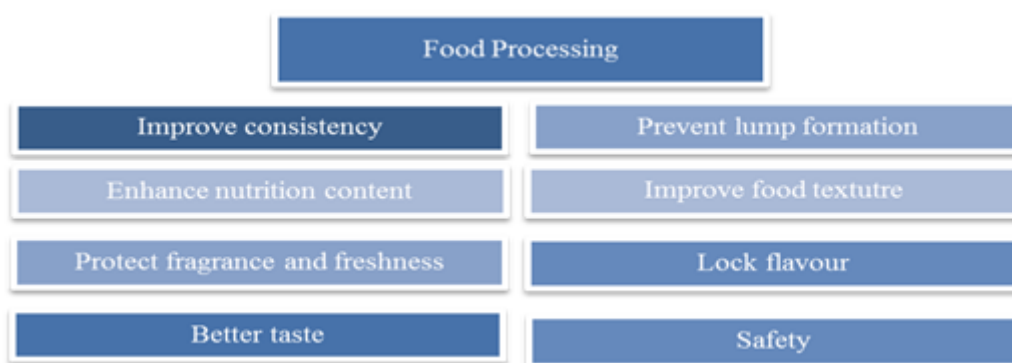
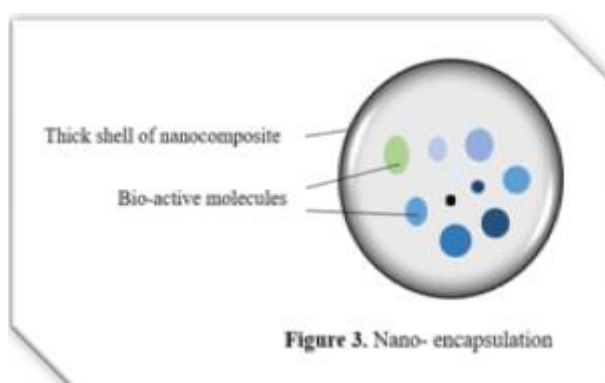


Figure 2: Applications of nanotechnology in food processing

- **Nutrients and dietary supplements:** Nano-particle based tiny edible capsules aiming at competent delivery of vitamins, bioactive compounds, micronutrients, antimicrobials and antioxidants are used as ingredients health supplements for bioavailability of required salts and their enhanced absorption [11]. Nano-emulsification, nanocomposite and nano-structuration, are different modes adopted to encapsulate nutrients and dietary supplements to miniature form for effective delivery of bioactive compounds aiming at health benefits [2].



Food Storage: Natural food elements get degraded with time, which in turn causes wastage of food resources, leading to natural food scarcity. At this point, the Nano-encapsulation technique paves a relief. It is a technique based on wrapping the bioactive compounds in food materials like lipids, proteins, carbohydrates, vitamins and minerals; within an inert matrix of edible nanocomposite, with an aim of preserving it by reducing degradation (*figure 3*). The flavour, aroma, ingredients, bio-active compounds and freshness of the liquid, solid or gaseous food stuff is locked with this process, delivering the product to target site [a]. The anti-microbial properties of nanomaterials facilitate them to preserve food during the entire chain of storage and transport, improving their shelf life [15,16]. There are different encapsulation techniques employed for bio active molecules and essential oils. A few of them are listed below.

Edible coating: The bioactive molecules are coated with edible nanocomposites in order to preserve its colour, odour and flavour. These nanocomposites can be gelatine based, lysozyme nano-laminates or SiO₂ nanoparticles.

Sol-gel method: This technique is based on preparation of solution, followed by solidification and heat treatment, forming hydrogels. These hydrogels can be placed easily inside capsules for efficient drug delivery.

Polymeric micelles: Water insoluble bio molecules are dissolve in a hydrophobic interior, formed by amphiphilic copolymers, which makes them well suited for drug delivery.

Nano emulsion: Two immiscible liquids are variegated in an inert atmosphere to form nano sized emulsion. Such emulsion has greater oral bioavailability which frame it active pharmaceutical ingredient.

- **Nano based food sensors;** Nanomaterials are used as sensors that could detect and identify contamination, regulate and sense the food environment during the entire term of processing and packing. They can detect microbial contaminants, monitor the of food atmosphere during transportation and storage [15,16], can detect nutrient deficiency, identification of foodborne germs, pesticides, waterborne toxins and pathogen sensing through ‘tracking - tracing – monitoring chain’[2]. These sensors (*figure 4*) in the form of thin films, particles, rods, chips, fibre, or polymers; act as indicators that react according to variations in food conditions, such as pH, temperature, humidity, degradation, contaminants, toxicity etc. sensors grounded on Graphene oxides and carbon nanotubes were successfully utilized for rapid detection of toxin in food and beverages [17]. on the other hand, electronic tongue or electronic nose that relay on matrix of nano structured sensors to detect odour, tang and presence of gases are extensively used in wine and beverages industry. Therefore, nanomaterials can be utilized as nano-sensors and nano-tracers with utmost unlimited potential by the food and beverages sector [18].

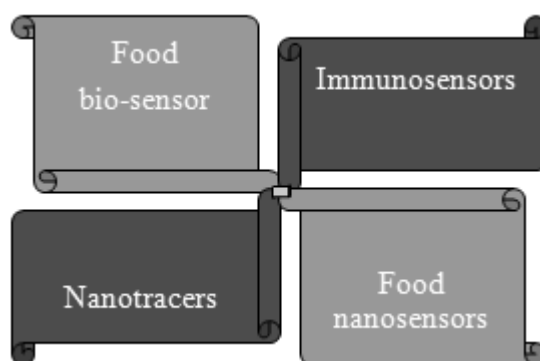


Figure 4: Fields of nano food sensing

- **Food safety:** Even though nanotechnology serves as an irreplaceable agent in food industry, the safety issues of nano based composite materials must also be taken into consideration. For consumers who are exposed to the highly reactive area of these extremely small particles, need to address the safety issues entangled. Chances of nanoparticle migration from food packing material to food articles and their hit on consumer's health cannot be neglected. Beside nanoparticles are considered generally as safe in food sector, studies are essential to evaluate the impact of such nanocomposites in human body. Once these particles get absorbed in the human gastrointestinal system, they get accumulated in various organs, leading to potentially adverse health conditions. Thus, exercise of nanotechnology in food sector is of great public concern. For instance, the silica nanoparticles that are used as anti-cracking agents to maintain the texture of food items has the potential to cause sever lung diseases. An editorial entitled "Nano-food for Thought" in the journal *Nature Nanotechnology* says, "The food industry will only reap the benefits of nanotechnology if issues related to safety are addressed and companies are more open about what they are doing" [14].

The scientific committee of the European Food Safety Agency, in March 2009, put out a notion on nanoscience in league to food and animal feed safety, with a guidance letter on how to deal with the potential risks of food-related exercise of nanotechnology [19]. In May 2011, practical recommendations to monitor how to use engineered nanomaterials in food additives, enzymes, flavourings, food packing materials, novel food ingredients and diet supplements; was provided. The U.S. Food and Drug Administration (FDA) has broadcasted guidance for practical industrial use of nanomaterials in animal feeds [20]. However, more studies are required to determine the potential of nanomaterial based food on human health, to ensure public safety and to improve public awareness of 'safe' nano food and diet supplements. Certain criterion has been reported to assess nanomaterial safety [21,22]. However, no wide accepted standards for toxicity testing of nanocomposites is recently available. Protocols are in progression stage by organizations such as the International Alliance for Nano Environment, Human Health and Safety Harmonization [23] and the U.S. National Research Council . An internationally accepted regulatory framework is a necessity for nano based food and animal feed, to ensure food quality, health issues, safety, environmental precepts and innovations.

The benefits of nanotechnology in food and beverages sector are many and is expected to hike with time. This facile, rapidly developing novel technology hits every

aspect of food industry from production, processing, packing, transporting, shelf life and bio-availability. Commercial applications of nanomaterials and nanocomposites based food grow exponentially because of their unique properties. The exposure to nanomaterials will continue to rise. Thereupon, the health impact of nanomaterials in food is of prime public concern. The capability to quantify nanomaterials throughout the 'food-life cycle' is crucial for manufacturing hygienic, consistent, safe and potential consumable products. Public acceptance of such products rely on their quality, safety, cost effectiveness, availability and environmental friendliness. An international regulatory framework for nanotechnology in food engineering is an utmost requirement.

- 2. Nanotechnology in health sector - Facts and figures:** The science of extremely small matters - nanotechnology, holds eminent potential in the healthcare sector. Developing devices with size invisible to human eye, often many hundred times thinner than normal human hair, is the foremost intent of nano-medicine. The physical-chemical and biological properties of materials are different when reduced to the nanoscale. They show radical difference in their strength, conductivity, reactivity, morphology and properties; exploiting which could revolutionize pharmaceuticals with innovative high-quality, on-time, acceptable and affordable health care facilities. Effective drug delivery, rapid disease diagnosis, sensitive delivery of vaccines is few of such interesting field (*figure 4*).

The practise of nanotechnology and its associated nano-carriers or nano-systems in medicine is known as nano-medicine, which brought countless boon to disease identification, diagnosis, treatment and prevention [2]. For instance, one among the major challenge of modern medicine is that, our body may absorb the entire drug dose efficiently, for a particular cure. Using nano-medicine, precise absorption of drugs by the body is wholly ensured. In addition, the required measure of drug is solely phrased so that active ingredients better saturate the cell membrane, reducing dosage frequency.

For economic progression, investment on nano-medicine and nano-biotechnology is benevolent. The chief generation of cancer drugs grounded on nanoparticles, for example, has already been approved by the US Food and Drug Administration (FDA). Many emerging economies have ambitious Research and Development (R&D) blueprint for nano-medicine. Reviews reveal that nanotechnology could meet the Millennium Development Goals for health, specifically, the goals to reduce child and maternal mortality, battle HIV/AIDS, cancer, malaria and other deadly diseases and to improve the holistic well-being of the society [5]. However, it is still the early premature days for nanotechnology in health sector, and is yet to be exploited. Experts are also concerned with the toxicity and ludicrous waste of such nanoparticles to human health and the environment. For example, a 2004 report by the UK Royal Society and Royal Academy of Engineering recommended that nanoparticles and nanotubes are hazardous waste [4].



Figure 4: Application of nanotechnology in health care

- Diagnosis and screening:** Nanotechnology offers a multitude of options for detecting disease, medical imaging, synthesis of diagnostic kits, biological sensors, sterilization of medical devices and gene inactivation [3]. Advances in nanomedicines and nanodevices to develop nanomaterials and nanosystems is getting crucial in the near future. One way of achieving this is by quantum dots (QDs). They are synthetic nano-sized semiconductors ranging between 1.5–10 nm, that allow to transport electrons. When excited by suitable wavelength, these electrons also get excited. As electrons come back to their ground state, they emit light. QDs emit different colours depending upon their size and properties [7]. As their luminescence can be tuned to range of frequencies and degradation in body is much slower, QDs have significant boon over conventional organic dyes. Fluorescent QDs can identify antibodies of cancerous cells, tuberculosis (TB), malaria or HIV [4]. When fluorescent QDs interact with protein of normal human blood, they form a mesh in the inner cell membrane. The protein network changes shape, when infected with malaria, spotting which can easily diagnose malaria [6].

Similarly, carbon nanotubes, nanowires and nanofilms have been successfully practised as biosensors to detect HIV and Cancers. Biosensors are designed by attaching nucleic acid probes at the ends of nanowire, that can interact with mutated RNA, during which electric currents are induced, detected by the silicon chip present in the sensor [7].

Dendrimers are naturally biodegradable nanoparticles with three dimensional globular shape. Their globular structure, small size (1–10 nm) and well penetration ability makes them ideal for healthcare in gene and drug delivery purposes [11]. Nano-diamonds with single diamond crystal and sp^3 configuration, have tuneable large surface area to which drugs can easily conjugate. The fluorescence character executes it as useful in-vivo imaging probes [17]. The major applications of nanoparticles in health sector is summarized in the table below (*table 1*) [2].

Moreover, advances in nanotechnology are often combined information technology and biotechnology. One example is computer-controlled molecular tools,

which doesn't require any direct medical practitioner. Nano-sensors that measure and store medical information, also belong to this category.

Sl no	Nanoparticles	Application
1	Carbon nanotubes	<ul style="list-style-type: none"> • Used in detection and treatment of cancer • Act as biosensors to detect diseased areas • Used for delivery of proteins to cells
2	Quantum dots	<ul style="list-style-type: none"> • In vivo bio-imaging • Used for intracellular tracking • Therapeutic drug delivery • Early detection of diseases
3	Dendrimers	<ul style="list-style-type: none"> • Used for gene delivery • drug delivery • Diagnostic application • Act as carriers of vaccines
4	Nano diamonds	<ul style="list-style-type: none"> • Useful imaging probes for diagnosis
5	Nanowires and nano-films	<ul style="list-style-type: none"> • Used for controlled drug delivery • Used as biological sensors • Used as nanopatches to close incisions after open surgery
6	Liposomes	<ul style="list-style-type: none"> • Capable of coating with hydrophobic and hydrophilic drugs • Protect drugs from environmental, chemical and enzyme degradation

Further applications of nano-medicines in diagnosis and screening include,

- Using biological fluids at nano litre scale, life process can be computerized (Nanolitre systems).
 - Magnetic nanoparticles are effectively practised as nano-sensors.
 - Nano-sensor arrays are grids of carbon nanotubes that can be used as biological sensors to detect infirmity.
 - Antibody-dendrimer conjugates are used for HIV and cancer diagnosis.
 - Mutated RNA can be identified by flatter nanobelts or nanowires.
 - Nanoparticles are capable of giving sharper medical images, making easier disease identification.
- **Drug delivery:** Nanotechnology could revolutionize drug absorption by overcoming challenges to sustain drug release, improve bio-availability and enhanced penetration of drugs. Liposomes can deliver drugs by fusing with cell membranes, is used to encapsulate HIV drugs (stavudine and zidovudine) in nano-vehicles [7]. These drugs have short half-lives; the liposome coating make them active for longer periods. Other nano based drug delivery systems include fullerenes, buckyballs [8] and dendrimers. The choice of system depends on the type of drug treatment.

- Nano-capsules: Encapsulate drugs, which release drugs more slowly and steadily in the body.
 - Liposomes: Lipid bilayer artificial vesicles which fuse and penetrate with membranes easily. Liposomes are exercised to treat diseases such as fungal infections, cancer, hepatitis A and influenza.
 - Dendrimers: Synthetic nano sized molecules that are practised to carry drugs.
 - Buckyballs: These nanoparticles can carry more than one drug at a time.
 - Nano-biomagnets: Carry drugs into the body and are held at the target site by an external magnet, aiming to concentrate drug at the tumour site for effective absorption.
 - Attapulgite clays with pores are ideal for filtering out harmful bacteria from water.
 - Alternatives to injectable vaccines is also provided by nano-medicine.
- **Health monitoring:** Nanotubes, nanostructures and nanoparticles can be used as carbohydrate, carbon dioxide and cholesterol sensors that could monitor body metabolic equilibrium. At the same time, studies are undergoing to exploit nanotechnology to fight against infectious diseases such as HIV and TB. Nanotechnology-based skin patch against West Nile Virus and Chikungunya virus is also under investigation [12]. Cancer is one of the top listed diseases being targeted for nano-medical treatment. According to WHO, cancer prevalence is showing a shooting rise.

Could nano-medicine cure cancer? : Nanotechnology approaches heavily focus on cancer treatment, mainly on diagnosis and drug intake. Polymer-coated nanoparticles are used extensively to treat multidrug-resistant breast and ovarian cancer, along with chemotherapies and lonidamine, that suppress energy metabolism in cancerous cells. Early detection, prevention and controlling further spreading of cancer can make a significant change in the survival rate. Studies witness that with the aid of magnetic nanoparticles in a resonance sensor, cancer cells can be detected even from a microlitre of a bio-sample, which enhances early detection possibility [10]. An interesting study from Stanford University in the United States employ inserting carbon nanotubes into cancer cells, exposing the tissue to near-infrared laser, heating up the nanotubes and killing the cancer cells while leaving the healthy cells intact [11]. This in fact, is use of nanotechnology to devise a precise specific method of killing cancerous cells.

Tuberculosis and nanotechnology: The existing tuberculosis (TB) treatment requires a complex drug intake over a period of time. Degradation of drugs based on nano-science is merely slow, allowing more active ingredient to be absorbed, in fewer doses. The Central Scientific Instruments Organisation of India has designed a nano TB diagnostic kit, recently undergoing clinical trials. This kit with minimal blood samples, would cut down both cost and time required for TB analysis. At the same time, the drugs are encapsulated in bio-degradable polymer microspheres, which ensure sustained medicine delivery at the target site. For instance, nanoparticles of polylactide co-glycolide, is often used to deliver TB drugs, as it degrades slowly and doesn't cause other immune reaction. Nanotechnology could also be the basis for delivering an aerosol TB vaccine that is needle-free and stable at room temperature.

Vaccines: Injectable vaccines need trained healthcare professionals for administration, need reliable refrigeration and sanitization along the delivery chain and the accessibility is minimal for common people. Nanotechnology, at this point, could host a new age of immunization by providing replacement to injectable vaccines. This method is being used to devise a vaccine against pandemic influenza [13].

- **Public acceptance:** What is technically feasible, logically possible and ethically appropriate is a matter of star debate. Studies on legal, technical, ethical, environmental and social issues of nano-medicine are lagging behind scientific edges. The invisible nature of nanotechnology makes it easier to 'hide' its products, there upon violate other's privacy or to carry out procedures without proper consent; including diagnosis to clinical trials of nano-drugs. Ethical clinical trials, lack of expertise, consent, cultural aspects etc are of prime discussion [2]. There is nothing intrinsically good or bad about nanotechnology. It will depend on how we execute and exercise.
- 2. Promise of nanotechnology in dermatology and cosmetics:** The incorporation of Nanotechnology in cosmetic articulation has become one of the hottest and modern technology accessible. The Cosmetic producers make use of nano size particles to assure improved protection from UV rays, deeper skin penetration, enduring effects, enhanced color, finish quality, better hydration and many more. Nanotechnology also permits the "packaging" of many constituents in semi-soluble packets that breakdown as the product is being applied, not before. Nano materials which are not soluble in cosmetic products are necessarily used as preservatives or UV-filters . Nanoparticles are capable of changing the properties of cosmetic products such as transparency, color, chemical reactivity and solubility .

Different kinds of nanoparticles used in cosmetics are Nanoemulsions, Liposomes, Solid lipid nanoparticles, Nanocapsules, Nanosilver and Nanogold, Nanocrystals, Cubosomes and Dendrimers. Already Sunscreen make use of two different types of nanoparticles namely zinc oxide (ZnO) and titanium dioxide (TiO₂). Applications of Nanotechnology in skin care and cosmetics involve: zinc oxide in sunscreen block ultraviolet rays while minimizing the white coating on the skin. Titanium Dioxide in sunscreen is usually ground into tiny particles. This enhances its capability to protect against UVB rays. Some cosmetics use Pigment-grade titanium dioxide to boost in hiding blemishes and skin brightening. Titanium dioxide permits for the use of delicate coatings of make-up material for the same pertinent effect. In the recent past, there arises anxiety regarding nanoparticles in sunscreens. This connects specifically to titanium dioxide (TiO₂) and zinc oxide (ZnO) nanoparticles and their potential to penetrate deep into the skin and toxicity put out by these chemicals. Sunscreens also use "micronised" or "microfine" particles, that are bigger than nanoparticles. The particles having the size range 1-100nm comes under nanoparticlea and are not visible to the human eye. Nanocream is a high fastidious, waterproof and dirt appalling cream on the basis of revolutionary Nanotechnology. It contains 31% beeswax. Highly suggested for smooth High-Tech Leathers as it does not influence breathability and provides greater protection. Fluid colourless cream. Companies make use of mercury in their products because mercury salts impede the melanin formation , resulting in light toned skin, giving

it a skin lightening effect with the vow of pigmentation reduction, freckles and dark spots. It can also be seen in antiseptic soaps! Silver nanoparticles exhibit the properties of antibiotic, because they can destroy fungi and bacteria. This property ensures the use of silver nanoparticles wound dressings and deodorants.

The interconnection of Nanoparticles with the skin is quiet a matter of inquisition by researchers, since it has been established that some Nanoparticles can penetrate the outer stratum corneum layer of the skin, while others can penetrate deep into the dermal layer, reaching the systemic circulation. Those proteins usually behave as doormans that adjudge which molecules to pass through the skin and into the body, and which molecules to hinder. When the proteins chilled out, they become less selective than normal, perhaps giving opportunity to nanoparticles to pass through the barrier. Normally Sunscreen nanomaterials like zinc oxide or titanium dioxide (inorganic uv-blockers) and organic UV-blockers are incapable to cross a healthy skin barrier and penetrate into the human body if applied correctly.

In humans, it has been connected to damage of liver and perhaps affect the immune system. In short, applications of nanoparticles in skincare and cosmetics seem to be very dangerous, and these consumers should be aware of the products they use.

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