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Review Article

A review: Application and production of nanoencapsulation in the food sector

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ABSTRACT

Particle encapsulation is a standard process within the food industry that consists of encapsulating particles within a protective layer, to shield a sensitive ingredient or nucleus from adverse reactions. This consists of encapsulating small particle cores within a protective wall this protective layer may preserve the organoleptic and physico-chemical properties of the products also on improve the palatability of volatile odorous ingredients. Encapsulation of flavors and aromas may be a rapidly expanding process within the food industry. Many aroma compounds must to be converted into solid products before its use as flavouring agents. Nano and microencapsulation technology is very promising area in food industry, which can have an excellent impact on a many category of products including functional foods, packaging, preservatives, antioxidants, flavors and fragrances. Finally, a number of the main challenges within the design and fabrication of nanocapsules & its application in food sector and characterization are highlighted.

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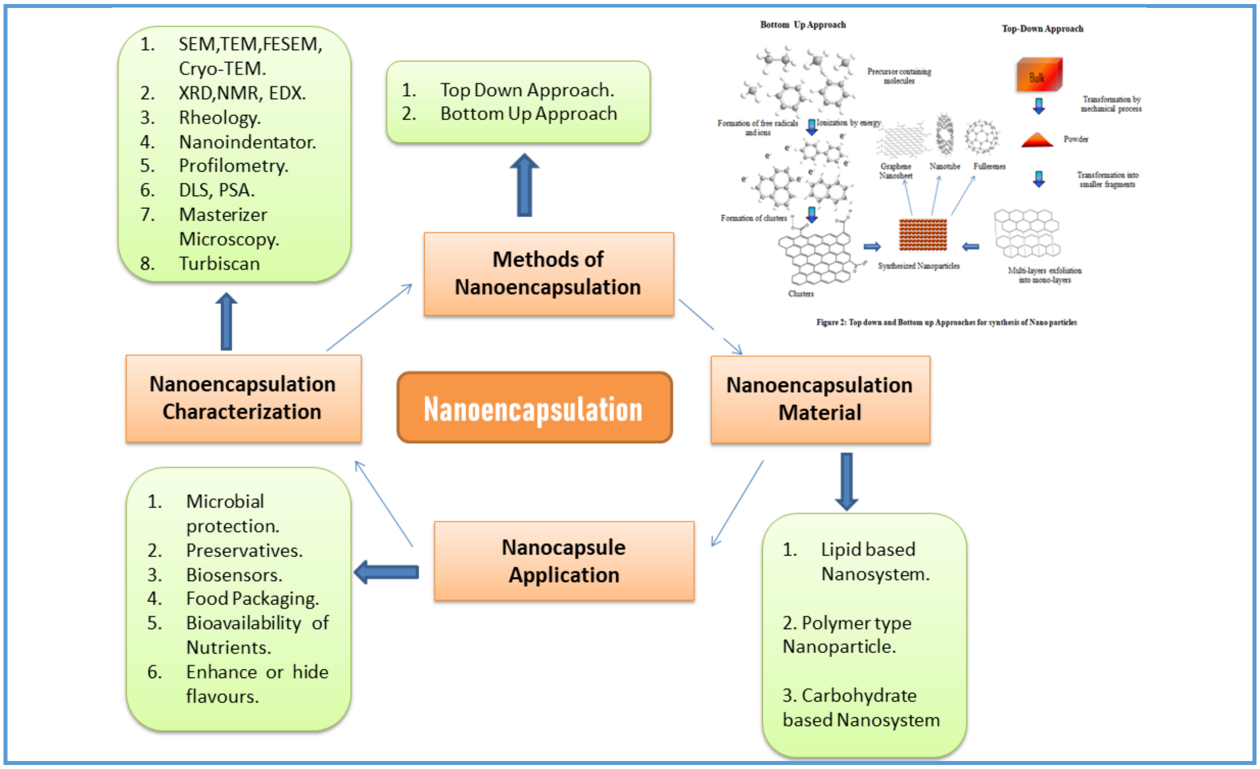
Graphical Abstract



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Introduction

The "nano" word derived from Greek language which means "dwarf" or "a tiny Particle". One nanometer is about 60,000 times smaller than a person's hair in diameter [1], or the dimensions of an virus, a typical sheet of paper is about 100,000 nm thick, a red blood corpuscle is about 2,000 to 5,000 nm in size, and therefore the diameter of DNA is within the range of 2.5 nm [1].

Nanotechnology (NT), which is a broad interdisciplinary area of research, development and industrial activity, involves the manufacture, processing and application of materials that have one or more dimensions of the order of 100 nanometers (nm) or less [2–5].

Nanotechnology in the food industries has its roots related to the process of pasteurization. Pasteurization was developed by Louis Pasteur in this process liquid food material like milk or juices are heated below 100 °C [6] to kill the spoilage bacteria (1000 nm). Louis Pasture made the primary step in the revolution of food processing and food quality improvement [6]. Despite this, within the last 20, years, the "nano-world" had grabbed the attention in the food industry, creating a replacement range of materials and processes aimed for improving not only the organoleptic characteristics of food, but also to contribute with other features like their nutritional characteristics, their safety and packaging, among others [7].

The use of nanotechnology is applicable to food packaging and surface coating with polyethylene, titanium dioxide, polyvinyl chloride. This coating ensures longer shelf life of the food products [8].

The food and beverage sector may be a global multi trillion-dollar industry. All the main food companies are consistently trying to find ways to enhance production efficiency, food safety and food characteristics. Extensive research and development projects are on-going with the last word goal of gaining competitive advantage and market share [9].

The main developments of nanotechnology, in food technology, involves altering the feel of food components, encapsulating food components or additives, developing new tastes and ambiances, controlling the discharge of flavours, and/or increasing the bioavailability of nutritional components [10]. Nanofood is additionally associated with the development of colouring, prolongation of time period and preservation, detection of microbes and antibacterial characteristics, and intelligent packaging materials. Additionally, nano-food includes not only the processed food category, but also entire areas from cultivation to packaging [11].

Encapsulation may be a technique by which the vulnerable materials are covered within a coating or wall substances. The wall material protects these ingredients against adverse reaction and controls release of the ingredients [12]. Additionally, encapsulation process can convert liquid into powder, which is easy to handle.

The aspect of nanoencapsulation represents important beginning for industries, which might undertake new natural and safe materials or systems of packaging capable to prolong the shelf life of foods, such as highly perishable fresh foods (vegetables, fruits and meat.), while not drop-off their characteristics in terms of quality and hygiene. Nanoencapsulation can be considered as a true resource for food packaging also to mask unpleasant flavors and odors, or to produce barriers between the sensitive bioactive materials and the atmosphere (represented by food or oxygen). Many encapsulations have antimicrobial properties against many foodborne pathogens and can be potentially used in different food matrices, as well as meat product [13].

Nanoencapsulation

The term nanoencapsulation explained the appliance of encapsulation process on the nanometer (nm) scale with films, layers, coverings, or just micro-dispersion. The encapsulating layer is distinctly of nanometer scale forming a protective layer on the food or flavour molecules/ingredients. Often the active ingredient is within the molecule or nano state. The main benefit is that the homogeneity imparts, resulting in better encapsulation efficiency, also as physical and chemical properties. The protection of bioactive compounds, like vitamins, antioxidants, proteins, and carbohydrates, could also be achieved using this system for the assembly of functional foods with enhanced functionality and stability [1].

The major benefits of nanotechnology for food ingredient microencapsulation are [14]: An increase in area may cause the development in bioavailability of flavors and food ingredients: this is often especially important for flavour ingredients that have low solubility and/or low flavor and odour detection thresholds.

Improvement in solubility of less water soluble ingredients: for instance, omega solubilization employing a micelle-based system.

Optically transparent (important in beverage application): Nanoemulsions and microemulsions that have oil droplet sizes of but 100 nm are optically transparent.

Higher ingredient retention during processing (volatile organic carbon reduction) during spray drying.

Closer to true molecular solution (homogeneity in system properties, like density): for instance, molecular inclusion complexes supported amylose and cyclo-dextrins.

Higher activity levels of encapsulated ingredient, e.g., antimicrobials in nanoemulsion/microemulsion forms.

Production method of nanoencapsulation

In general, the assembly of nanoparticles are often performed by both the "top-bottom up" method and nanocapsules are not an exception. For the previous approach, the nanonization is achieved by the appliance of energy, while for the latter; the aggregation of molecules, monomers, ions, or maybe atoms is controlled Physico-chemically to make the nanocapsule (Figure 1 & 2) [7].

Emulsification

The emulsification process allows mixing two liquids which are normally immiscible using an interface agent (surfactant). This process permits the incorporation of a lipid into an aqueous media or the other way around by forming droplets (dispersed phase) which remain dispersed into endless phase. The droplet size is often determined by the components, the sort production technique, among other parameters. Emulsions with droplet size within the nanometric scale (typically within the range 20 mentioned within the literature as miniemulsions, nanoemulsions, ultrafine emulsions, submicron emulsions, etc. The term nanoemulsion is preferred because, additionally to the thought that the nano scale size range of the droplets is concise, it avoids misinterpretation with the term microemulsion (which is thermodynamically stable systems) [15].

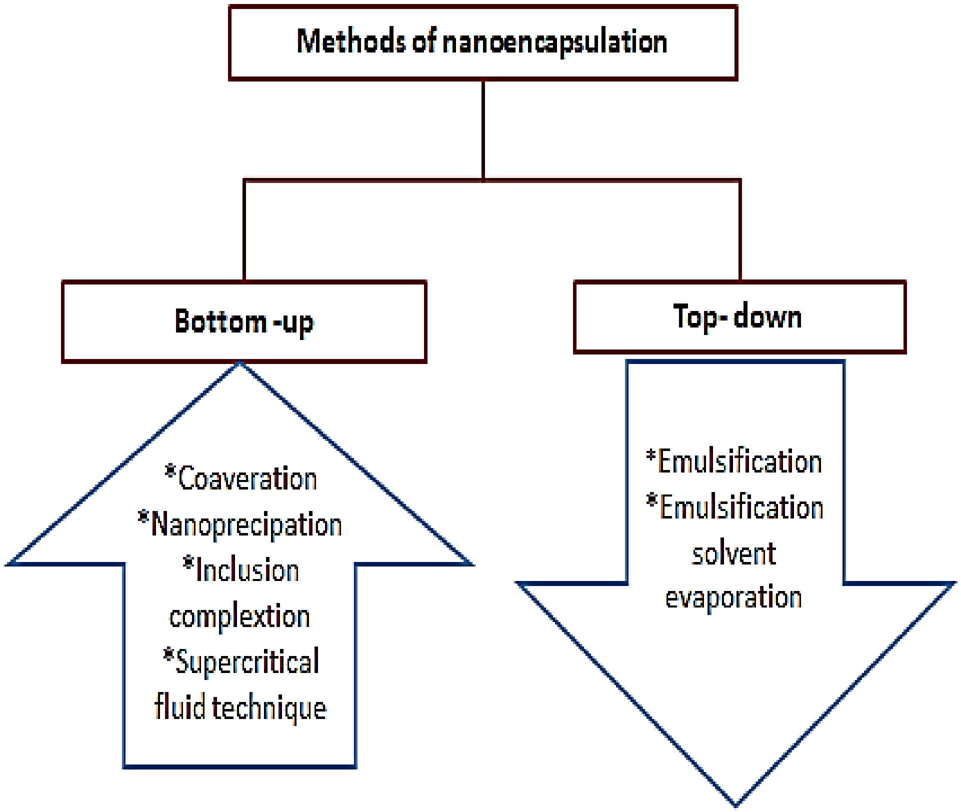

Figure 1. Top-down and bottom-up techniques for the production of nanoencapsulation

Nanoemulsion droplet sizes fall typically within the range of 20–200 nm and show narrow size distributions. Although most of the publications on either oil-in-water (O/W) or water nanoemulsions report their formation by dispersion or high-energy emulsification methods, an increased interest is observed within the study of nanoemulsion formation by condensation or low energy emulsification [16]. In contrast, low-energy emulsification methods, making use of the interior energy of the system, are often more energy efficient, as only simple stirring is required and usually allow the assembly of smaller droplet size than high-energy methods [17]. It's been also claimed that high-energy methods allow the preparing of nanoemulsions at higheroil-to-surfactant ratios than low-energy methods [18].

Nanoprecipitation

The nanoprecipitation method is additionally called solvent displacement. It's supported the spontaneous emulsification of the organic internal phase containing the dissolved polymer, drug and organic solvent into the aqueous external phase. The nanoprecipitation technique involves the precipitation of a polymer from an organic solution and therefore the diffusion of the organic solvent within the aqueous medium [19]. The solvent displacement forms both nanocapsules and nanospheres. Biodegradable polymers are commonly used, especially polycaprolactone (PCL), poly (lactide) (PLA), and poly (lactide-co-glicolide) (PLGA), Eudragit, poly (alkylcyanoacrylate) (PACA) [20, 21].

Emulsification–solvent evaporation

Emulsification–solvent evaporation technique may be a modified version of solvent evaporation method. It involves emulsification of the polymer solution into an aqueous phase and evaporation of the polymer solvent inducing polymer precipitation as nanospheres [20]. The drug is finely dispersed into the polymer matrix network. The dimensions of the capsules are often controlled by adjusting the stir rate, typeand amount of dispersing agent, viscosity of organic and aqueous phases, and temperature [22]. The foremost frequently used polymers are PLA, PLGA, ethyl cellulose, cellulose ester phthalate, PCL, and polyhydroxybutyrate (PHB) so as to supply little particle, often high-speed homogenization orultrasonication has to be used [23].

Inclusion complexation

Inclusion complexation generally refers to the encapsulation of a supramolecular association of a ligand (encapsulated ingredient) into a cavity bearing substrate (shell material) through hydrogen bonding, van der Waals force or an entropy-driven hydrophobic effect. The inclusion complexation technique is especially utilized in the encapsulation of volatile organic molecules (essential oils and vitamins); it's useful to mask odors and flavors and preserve aromas. This system yielded higher encapsulation efficiency with higher stability of the core component. However, only a couple of particular molecular compounds like ß-cyclodextrin and ßlactoglobulin are suitable for encapsulation through this method (Table 1) [21].

Solvent removal

Most of the nanocapsule production techniques are performed during a solvent media. It's documented that the presence of solvents entails variety of disadvantages, like risk of microbial contamination, increased costs and physicochemical instability. Additionally, for the organic solvents, there's a risk of explosion and toxicity (for operators and consumers). During this context, it would be necessary to eliminate the solvent to form a redispersible powdered form. To the present purpose, most popular techniques are spray drying and freeze drying [7].

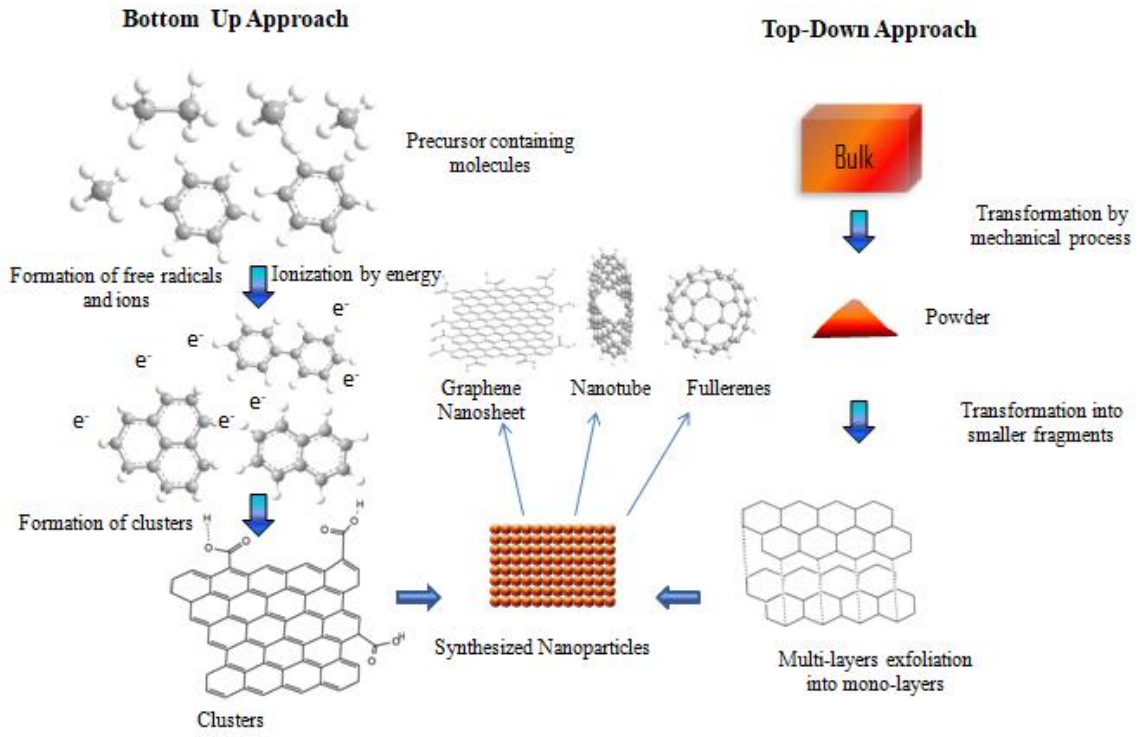

Figure 2. Top down and bottom up approach for synthesis of nanoparticles

Spray drying

Spray drying may be a rapid, continuous, cost effective, reproducible and scalable process for the assembly of dry powders from a fluid material [24]. In these devices, the liquid is sprayed through an atomizer into a hot drying gas medium, usually air. The sprayed droplets lose the solvent within the drying chamber resulting in a solid particle which is subsequently far away from the air stream and picked up.

Freeze drying

In the freeze drying method, so called lyophilisation, the fabric is firstly frozen then; the encompassing pressure is reduced to permit the frozen water within the material to sub directly from the solid phase to the gas phase. Nanocapsules present a selected problem on drying due to their fragile structure composed of a skinny envelope encapsulating an oily or aqueous core. Nanocapsules cannot withstand the freeze drying stress especially during freezing, the primary step of the method, which involves the crystallization of water and therefore the cryo-concentration of dissolved components within the formulation. Nevertheless, [25] demonstrated that the aggregation of cryo-protectants, like PVP and sucrose prevented nanocapsule destruction.

Materials used in producing nanoencapsulation

Different types of materials are often used as building blocks to make nanostructures as nanoliposomes, nanoemulsions, nanoparticles and nanofibers. Nanomaterials utilized in food applications include both inorganic and organic matter [1].

Table 1. Raw material used in different nanoencapsulation technique and particle size

Nanoencapsulation technique	Raw material used	Particle size	References
Emulsification	Wall materials: maltodextrin; emulsifiers: modified starch (Hi-Cap 100)	543–1,292 nm	[26]
	Emulsifiers: Tween-40	135 nm	[27]
	Emulsifiers: Tween-80, Span-80, and sodium dodecyl sulphate	40 nm	[28]
	Emulsifiers: Tween-20	79–618 nm	[29]
Nanoprecipitation	Wall materials: α- and β-cyclodextrin	236 nm	[30]
	Wall materials: monomethoxy poly (ethylene glycol)-poly (3-caprolactone) micelles	27 nm	[31]
	Wall materials: poly (lactide-co-glycolide); emulsifiers: polyethylene glycol-5000	81 nm	[32]
Emulsification–Solvent Evaporation	Wall materials: chitosan cross-linked with tripolyphosphate; emulsifiers: Span-80 and Tween-80; other materials: acetic acid and ethanol	254–415 nm	[33]
	Wall materials: hydroxyl propyl methyl cellulose and polyvinyl pyrrolidone; emulsifiers: D-α-Tocopheryl polyethylene glycol 1000 succinate, Tween-80, Tween-20, cremophor-RH 40, pluronic-F68, pluronic-F127	100 nm	[34]
	Wall materials: poly(D,L-lactide-co-glycolide) and polyvinyl alcohol; other materials: chloroform and ethanol	45 nm	[35]
Inclusion Complexation	Wall materials: beta-lactoglobulin and low methoxyl	100 nm	[36]
	Wall materials: carbohydrate matrix and malto dextrin; other materials: acetone	80 nm	[37]
Spray Drying	Wall materials: modified n-octenyl succinate starch; other materials: ethyl acetate	300–600 nm (droplet size); 12 um (particle size)	[38]
	Wall materials: malto dextrin; emulsifiers: Hi-Cap, whey protein concentrate, and Tween-20	0.2–1.2 µm (emulsion droplet size); 21–53 µm (dried particle size)	[39]
Freeze Drying	Wall materials: chitosan, zein; emulsifiers: Tween-20	200–800 nm	[40]
	Wall materials: polyethylene glycol; emulsifier:	164 nm	[41]

	Tween-80		
	Emulsifiers: dioctyl sodium sulfosuccinate, poloxamer 188, glycerol monostearate	450 nm	[42]
	Wall materials: chitosan and sodium tripolyphosphate	163 and 165 nm	[43]

Engineered nanomaterials (ENMs) fall under three maincategories: inorganic, surface functionalized materials, and organic engineered nanomaterials [10].

Typically, nanocarrier systems are often carbohydrate, polymer or lipid based (Figure 3). Carbohydrate and protein based nanocapsules, don't have potential of fully proportion, due to the need of complicated chemical or heat treatments. On the opposite hand, lipid based nanocarriers have the likelihood of commercial production and bear advantage of more encapsulation efficiency and low toxicity [44, 14].

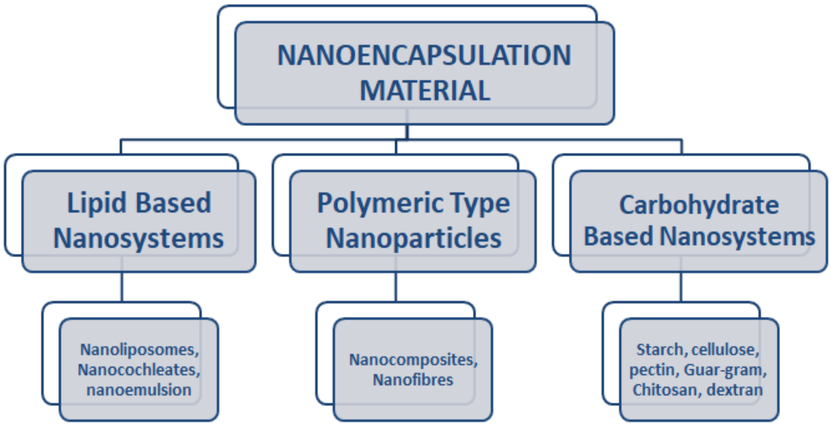

Figure 3. Types of material used in production of nanoencapsulation

Lipids based nanosystems

The main lipid nanoencapsulation systems which will be used for the protection and delivery of foods and nutraceuticals are nanoliposomes, nanocochleates, and archaeosomes [1].

Nanoliposomes

Nanoliposomes are useful in areas like encapsulation and controlled release of food Materials, also as they enhanced bioavailability, stability and time period of sensitive ingredients. Nanoliposomes are applied as carrier vehicles of nutrients, nutraceuticals, enzymes, food additives, and food antimicrobials [45]. Compared to other encapsulation technologies, liposomes can generally provide higher chemical stability and protection to sensitive bioactives, like vitamin C and glutathione at high water-activity conditions. Temperature-sensitive liposomes are often produced by the modification of the lipid bilayers with specific polymers. These kind of carriers are ideal for flavor release by increasing cocking temperature of the ready meals [44–46].

Nanocochleates

Nanocochleates are nano coiled particles that wrap around micronutrients and have ability to stabilize and protect an extended range of micronutrients and therefore the potential to extend the nutritional value of processed foods [47].

Nanoemulsions

The use of high homogenizers or microfluidizers often causes emulsions with droplet diameters of but 100 to 500 nm, these emulations are often called “nanoemulsions”. Functional food components are often incorporated within the droplets, the interfacial region, or the continual phase [48].

Nanoemulsions were developed to be used within the decontamination of food packaging equipment and within the packaging of food. However, nanoemulsions were discovered to be good candidates for delivery of poorly water-soluble food ingredients, like animal oil and lipophilic vitamins. Food-grade ingredients (such as proteins, polysaccharides, and phospholipids) and processing operations (such as homogenization and mixing) are widely utilized in the manufacture of food emulsions [44].

Polymeric type nanoparticles

Polymer based nanoparticles are unique compared to other nanoparticle systems because of their better encapsulation, sustained release and fewer toxic properties [49]. Many processes are developed to organize polymeric nanoparticles including emulsification-solvent evaporation, emulsion polymerization, spray drying and interfacial poly-condensation [50].

Nanocomposites

They are fine nanoparticulates (≤100 nm) incorporated into plastics so as to enhance the properties over those of conventional counterparts. Polymer nanocomposites are thermoplastic polymers that have nano-scale inclusions (nanoclays, carbon nanoparticles, nanoscale metals and oxides, and polymeric resins), 2%–8% by weight. The foremost widely studied sort of polymer-clay nanocomposites, a category of hybrid materials composed of organic polymer matrices and organophilic clay fillers [51], is montmorillonite (MMT).

Natural biopolymer-based nanocomposite packaging materials with bio-functional properties have an enormous potential for application within the active food packaging industry. Polymer-clay nanocomposite has emerged as a completely unique food packaging material due its benefits, like enhanced mechanical, thermal, and barrier properties [52].

Nanofibers

An emerging technology is that the production of nanofiber. These fibers have diameters of 100 nm, produced by the electrospinning process. Electrospinning is capable of manufacturing thin, solidpolymer strands from solution by applying a robust field to a spinneret with little capillary orifice. Fibers utilized in food and agriculture isn’t typically composed of biopolymers; they're made primarily from synthetic polymers. As progress within the production from food biopolymers is formed, the utilization of bio-polymeric nanofibers within the food industry will increase [48].

Carbohydrate based nanosystems

Polysaccharides, because of their huge molecular structure and skill to entrap bioactives are suitable as building blocks of delivery systems. Thus, they're widely used as safe and cheap ingredients [53].

Starch

Starch, which is that the most abundant storage polysaccharide in plants, may be a biodegradable, biocompatible, and digestible polymer, that has been accustomed to encapsulate insulin, flax seed, unsaturated fatty acids and flavors [53–55]. Naturalstarch is hydrophilic, which limits its application for encapsulating hydrophobic food bioactives. However, hydrophobic starch derivatives have therefore been developed: dialdehyde starch, propyl starch, octenyl succinic anhydride modified starches, etc. aside from the low cost of starch; it's relatively pure and doesn't need intensive purification procedures [53, 56].

Cellulose

Cellulose esters are modified celluloses that are divided into two categories: non-enteric and enteric esters. Non-enteric cellulose esters are not in water across a good range of pH values, that's why it is not suitable for encapsulation. The enteric cellulose and cellulose esters (acetate phthalate (CAP) or hydroxypropylmethyl cellulose phthalate (HPMCP)) are not soluble in acidic solutions, but soluble in mildly acidic to slightly alkaline solutions, in order that they are widely used as encapsulating agents [53, 57–59].

Pectin

Pectin may be a linear anionic polysaccharide. It's immune to enzymatic digestion within the mouth and stomach, but is degradable by the microbiome within the colon, which makes it suitable for delivery of acid sensitive food bioactives. It's usually classified consistent with the degree of esterification: low methoxyl (LM) pectin and high methoxyl (HM) pectin. LM can form gels within the presence of divalent calcium ions, whereas HM can form gels under acidic conditions in high sugar contents. An obstacle of calcium pectinate carriers is their relatively porous structure, which causes low entrapment efficiency and fast release of incorporated bioactives, especially for hydrophilic, low relative molecular mass compounds [53, 60, 61].

Guar gum

Guar gum may be a water soluble polysaccharide derived from the seeds of Guar. This biopolymer has been used as thickening, emulsification, and retrogradation retardant agent in food products. It is soluble in cold water and forms a gel-like structure in predicament. Native guar gums often form highly viscous solutions, which limits its application for encapsulating, its modification beeing necessary. It's been depolymerized to get a coffee molar mass, water-soluble fibre by different methods of hydrolysis [53].

Chitosan

Chitosan, a natural linear, cationic, biocompatible, and biodegradable polymer, is obtained by alkaline deacetylation of chitin. It also has antimicrobial and antioxidant activity [57, 62, 63]. Chitosan exhibits pH-sensitivity because it dissolves easily at acidic pH values ($pH<6.5$), but is insoluble at higher pH ranges. This polymer was also physical or chemical modified to increase or improve its functional properties [53].

Dextran

Dextran may be a bacterial polysaccharide of glucan, composed of chains of varying length of glucose. It's a linear polysaccharide containing hydroxyl groups, used for the covalent attachment of varied organic functional groups, especially hydrophobic compounds. Changing the degree of substitution, modified dextrans become water soluble or insoluble. This biopolymer could be used for self-assembled nanocarriers production to entrap active materials with different hydrophobicity. There are few reports of nanoencapsulation of food bioactives using modified dextran polymers [53].

Applications of nanocapsulation in food industry

Nowadays, nanotechnology is a huge platform technology in the area of food packaging industry. The properties of the nanomaterials offer many opportunities for food entrepreneur which incorporate increasingly powerful food colouring, flavouring, nutritive added substances and antimicrobial elements for food packaging (Figure 4) [64]. Four major areas may enjoy nanotechnology: development of latest functional materials, micro-scale and nano-scale processing, development and methods and instrumentation design for improved food safety and biosecurity [48].

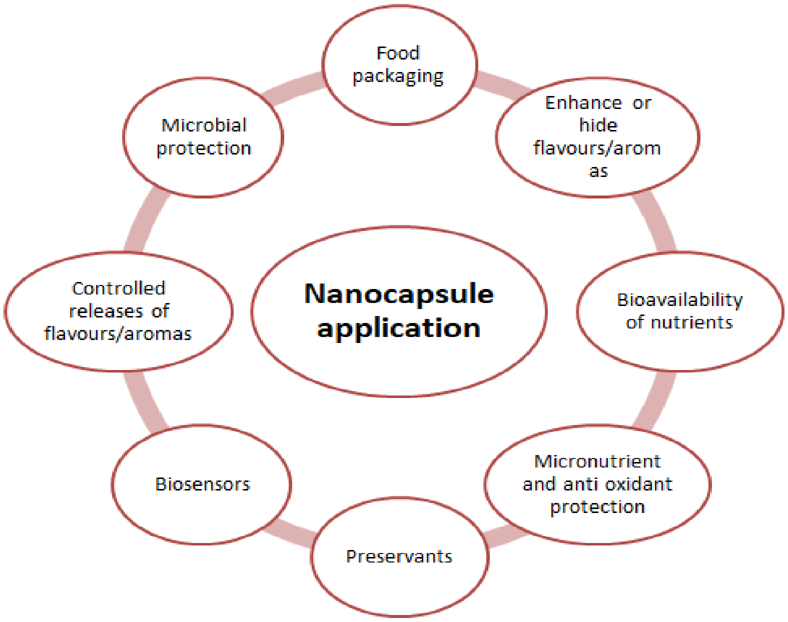

Figure 4. Application of nanoencapsulation in food sector

The main areas of application of nanocapsules include food products that contain nano-sized or nanoencapsulated ingredients, food packaging additives and food additives [1]. Example applications include food additives (benzoic acid, and ascorbic acid), dietary supplements and functional food ingredients (vitamins A and E, lipoic acid, soybean isoflavones, ß-carotene, lutein, omega-3 fatty acids, and coenzyme Q10) [21, 65]. Great developments are aimed toward altering the feel of food components, encapsulating food components or additives, developing new tastes and sensations, controlling the discharge of flavors, and/or increasing the bioavailability of nutritional components [10].

A number of Nano micellebased carriers for nutraceuticals and nutritional supplements are developed: nanocochleates (50 nm in size), supported a phosphatidylserine carrier derived from soya bean, generally considered safe (GRAS). They're obtained by the addition of calcium ions to small phosphatidylserine vesicles. The nanocochleate system is claimed to guard micronutrients and antioxidants from degradation during manufacture and storage. Another application are self-assembled nanotubes, developed from hydrolysed milk protein lactalbumin, which may offer a replacement naturally derived carrier for nanoencapsulation of nutrients, supplements and pharmaceuticals [66].

Nutraceuticals and nutritional supplements containing nano-ingredients and additives (e.g. vitamins, antimicrobials, antioxidants etc.) are currently available [65, 67, 68].

The supplementary aspect mainly involves encapsulation techniques where probiotics and other products are targeted into the human system with the assistance of iron and zinc nanostructured capsules [10]. For food packaging applications developments have led to new materials with improved mechanical, barrier and antimicrobial properties [10]. Nanotechnology derived food packaging materials are the most important category of current nanotechnology applications for the food sector [69]. These applications include incorporating nanomaterials to enhance packaging properties (flexibility, gas barrier properties, temperature/moisture stability); incorporating nanoparticles with antimicrobial or oxygen scavenging properties; 'Intelligent' food packaging with nanosensors can monitor and report the condition of the food; biodegradable polymer nanomaterial composites.

Nanocomposites are incorporated within the polymer matrix of the substances thanks to their large area which favors the filler matrix interactions and its performance. Also the nano reinforcement acts as a little barrier for gases by complicating the trail ofthe material; referred to as polymer nanocomposites [70]. Nanoclays are composite materials having complex metallic cores provide a barrier against the permeation of gases[6, 52].

Antimicrobial packaging generally includes natural nanoparticles that control the microbial growth [71]. Silver nanoparticles are utilized in all forms including biotexiles, electrical appliances, refrigerators, kitchen-wares [70].

The antibacterial activity of zinc oxides increases with the decrease in particle size; it is often stimulated by light. Titanium oxide as a coating in packing is combined with silver to enhance the disinfection process. Antimicrobial packaging would be highly healthy and consumer friendly [6].

Characterization techniques

The inclusion of nanoparticles (naturally occurring nanoparticles or engineered nanoparticles) in food or in production methods is widely studied for its implications in both, potential toxicity and functionality. Analytical methodologies are important for detecting and characterizing engineered or present nanoparticles during a wide selection of matrix types. While there are numerous techniques for the characterization of nanosystems, the methods described below are the foremost widely used routines of both developing and control of nano-scale substances utilized in food (Figure 5) [7].

Conclusions

Nanotechnology has the potential to improve the food quality either in taste, packaging and storage, making them healthier and nutritious. Nanoencapsulation specifically, permits a good variety of applications starting from increase/hide of flavors to the creation, of biosensors for food expiration. Many researchers around the world have pay attention to the use of nanoencapsulation in food and have done advances research on it.In addition many strategies to get nanocapsules are developed to different applications, complexity and scalability, with the physico chemical nature of the bioactive compound being one the foremost conditioning features on the manufacture method. Although these lines of work are in an elementary stage, nanoencapsulation is well established within the beverage segment of the food industry especially with emulsions. The research in nanotechnology applied to different fields, like pharmaceuticals, food, paint and minerals. Allowed the event of a spread of techniques for the characterization of nanoparticles. An excellent relevance think about food production is that the cost. A minimum of by now, the appliance of nanotechnology implies a high degree of investment, which is reflected within the small number of products within the foodstuff involving nanotechnology. Nanoparticles with high surface area and size modification can be used for multiple applications. They easily detect food contaminating microorganisms. Different nanoparticles like copper oxide, magnesium oxide, zinc oxide, titanium oxide are used in commercial products to control foodborne pathogens and increase the shelf life of food product up to 6 month.

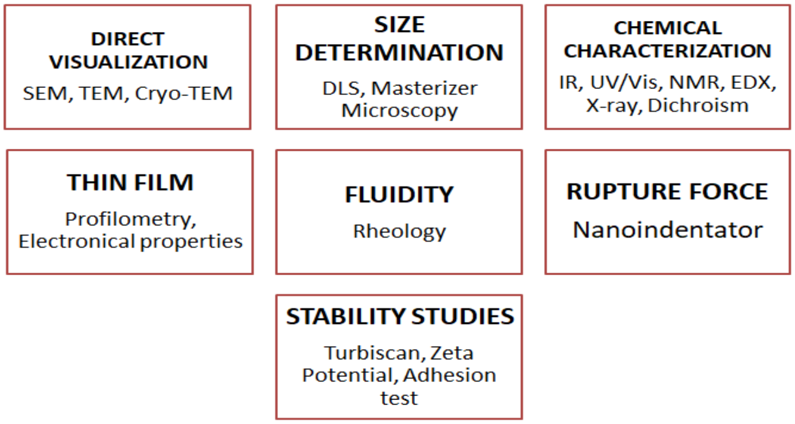

Figure 5. Various characterization techniques for nanoencapsulation

Disclosure Statement

No potential conflict of interest was reported by the authors.

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