Recent approaches for utilization of food components as nano-encapsulation: a review

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ABSTRACT
Nano-encapsulation in terms of nanotechnology is one of the wide ranging and rapid adopted technologies in food industry. Nanotechnology has modernized the whole food system from production to stored products for the improvement in quality and preservation of nutritional status. Nano-encapsulation is also known as promising technology to protect bioactive components and could be suitable for delivering such protected compounds to targeted biological systems. In this review, the recent literature highlights the formulation and fabrication of nano-encapsulation using the appropriate wall materials. Moreover, literature also focuses on different methods, which have been used for encapsulation purposes such as coacervation, inclusion complexation, nano-precipitation, emulsification, supercritical fluid technique, ultra-sonification and spray and freeze-drying. Furthermore, this review also discusses the advances in the applications of nano-encapsulation for phenolic compounds, antioxidants, natural food colorants, antimicrobial agents, essential oils, minerals, flavors and vitamins as nano-carriers in food systems. As reviewed in this study, nanotechnology have ability to improve the food properties either in sensory attributes, storage, target delivery, along with to enhance its nutrition and make it healthier. Nano-encapsulation has played a vital role in approaching the way of advancement of bioactive compounds including their therapeutic potential especially in allied fields, food, and pharmaceutical industry during last decades.

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Introduction
Nanotechnology has developed as one of the most encouraging scientific field of research over the most recent couple of decades.[1] Reduction in particles size to the nanoscale range increases the surface-to-volume proportion, which consequently enhance reactivity numerous folds with changes in mechanical, electrical, and optical characteristics. These characteristics offer numerous unique and innovative applications in different fields of science.[2] It deals with processing, production and applications of materials with a size of less than 1,000 nm .[3] The expression “Nano” refers to magnitude of $10^{-9}$ m.[4] Over last few years, research work in nanotechnology has expanded as well as various organizations represented their interest and specialized in formation of novel nano-sized materials, with anticipated applications in diagnostics, molecular computing, medical therapeutics, and structural materials.[5,6] Different research works in the field of nanotechnology emphasize on controlling the morphology,
structure, and size of nanoparticles, so enabling the tailoring of novel and desired physical characteristics of the final yield.\[7\]

Nanotechnology is a vast field of science that might be employed in all phases of food cycle as “farm to fork.” The nourishment business is confronting huge difficulties in preparing and executing frameworks that can deliver good quality, suitable safe food while being efficient and environmental-friendly.\[8\] Nanotechnology has been modernizing the whole food system form production to storage in consort with improvement of novel material/products as well as different application in food sector. It may well create advancement in the nanoscale qualities of food components, for example, sensory characteristics, color, stability of formulated particles, and a lot of other factors. Additionally, nanotechnology can likewise improve the fluid solubility, physical stability, and most important suitable bioavailability of bioactive compounds.\[3,8\]

Numerous research works have been published on the use of nanotechnology in food sector.\[8,9\] Nevertheless, just few works centered around nano-encapsulation of food components.\[10–12\] However, main purpose of this review is to talk about different nano-encapsulation techniques, wall material, applications, advantages as well as variation, just as to analyze the advanced emerging methodology and trends in field of food sciences. Current review summarizes recent data of nano-encapsulation of food ingredients that have been published majorly since 2010 until now.

**Nano-encapsulation**

In the millennia, encapsulation plays a potential application in the various fields of the science and technology especially in the food sector. In this technique, fundamental tiny particles are coated with the wall material to form capsules. In the nano-encapsulation, the bioactive substituents are confined to a cavity encircled by the unique polymer membrane, whereas nano-spheres are the matrix systems in which the bioactive components are uniformly diffused (Figure 1).\[3\] So, nano-encapsulation is elucidated as a technology to coat potential active components in the miniature and deliver final product functionality that contained controlled emancipate of the core. Nano-encapsulation technology has the ability to encounter the food industry challenges that concern

![Figure 1. Factors and process of nano-encapsulation of bioactive compounds.](image-url)
the potent delivery of the health functional substituents and also managed to release the flavors of the components.\textsuperscript{[13]}

The word encapsulation elucidates the potential applications of encapsulated material with nanometer scales like films, coverings, layers or simply microdispersions. In encapsulation, a protective nanometer scale layer is formed around the bioactive compound, flavor molecule or ingredient. Usually, the active component is in the non-scale state or molecule. Among the advantages, uniform homogeneity imparts lead to the finer encapsulation efficiency, as well as in chemical and physical aspects. In the preservation of the active ingredient, for example antioxidants, vitamins, protein, carbohydrates as well as lipids, may be accomplished by using this method for the productions of functional food that have improved functionality and stability.\textsuperscript{[9]}

Among various major nanotechnology for the food ingredient, nano-encapsulation are as described by the.\textsuperscript{[14]} It increases the solubility of the hydrophobic components for instance omega-3 fish oil is dissolved via micelle-based system. It helps to increase surface area of the ingredient, which may result in the enhancement of the flavors of the food components. This phenomenon plays a significant role for the flavor ingredients that have low flavor, low solubility, and odor detection thresholds. It generates the optically transparent (important in beverage application) nano-emulsions that have oil droplet sizes of less than 100 nm. It enhanced retention of the ingredient during the process of spray drying. This system enhances the activity of the encapsulated ingredient that is, antimicrobials in micro-emulsion/nano-emulsions. The schematic diagram of nano-encapsulation along with factor and process of release of bioactive compounds have been present in Figure 1.

\textbf{Nano-encapsulation wall material}

One of the most crucial steps in the formulation of nano-encapsulation are the proper fabrication by using the appropriate wall materials. In the formation of nano-capsules, food components and wall material impart significant role. Commonly some safety measures should be taken during the preparation of the nano-capsules: the layer coated around the food component should be orthodoxy prepared and there should be not any kind of leakage. Likewise, selection of the encapsulation material and also technique are appropriate according to the prescribed procedures. Selection of coating material should be done from the wide range of the synthetic and natural polymers, which ultimately depends on the characteristics desired in the production of final product. For the appropriate functional properties of the nano-capsule, the chemical composition imparts a significant role in the wall material. Most suitable coating materials should have better workability and good rheological characteristics at higher concentration during the encapsulation. The material should have the strength in the smooth dispersion or emulsification of the active ingredient and also in the stabilization of the emulsion synthesis. During the long-term storage and processing of the material, it should be non-reactive with the active ingredient. The coating material should have the ability, which holds and seals the active component within its structure during the long-term storage and processing. The ability to completely release the solvent or other materials used during the process of encapsulation under drying or other desolventization conditions. The material should have the strength to provide appropriate protection to the active ingredient in response to the environmental conditions, that is, heat, humidity, oxygen, and light. In addition to all these characteristics coating material, it should be inexpensive and food grade to avoid any regulatory issues.\textsuperscript{[15]} A summary of the polymer wall materials, which are commonly used in the food sector are listed in Figure 2.\textsuperscript{[16]}
Production techniques

Top-down or bottom-up approaches utilized in terms of nano-encapsulation techniques for the formulation of nanoparticles. Top-down approach includes the utilization of exact apparatuses that permit size reduction and structure forming for desired application of the nanomaterials being created. By means of bottom up approach, materials are built self-assembly and self-association of molecules, that were affected by numerous elements including pH, temperature conditions, and ionic power. For the previous approach, the nanonization is accomplished by the utilization of energy, although for the last mentioned; the accumulation of molecules, ions, monomers or even molecules are controlled physicochemically to frame the nano-encapsulation (Figure 3).[17]

Emulsification

Emulsification is a process, which deals with the mixing of two immiscible liquids by using interface agent (surfactant). This process represents that the entire lipid unifies into the aqueous media in the form of tiny droplets, which are dispersed into the continuous phase. However, size of the droplet can also be determined by components, by production techniques and the type of emulsion and many other parameters.[18] Typically, particle size of the nano-emulsion falls under range of 20 to 200 nm that indicate narrow size distribution. A lot of research works demonstrate that most of the water in oil or oil-in-water (W/O/W) Nano-emulsion reports their formation by high-energy emulsification or dispersion. Moreover, condensation and low energy emulsification has been observed more fruitful in the study of nano-emulsion formulation.[19] Nano-emulsion cannot be formed instantly since it is a non-equilibrium system. It is developed mostly via high-energy methodologies through variety of mechanical equipment strategies such
as ultrasound, high-shear stirrers as well as high-pressure homogenizers. Mentioned methods are very simple, moreover, the high-energy input yield the smaller droplet size. High amount of energy is required in the formation of nanoparticles, hence its cost-inefficient. On the other hand, small amount (approximately 0.1%) of energy is required in simple emulsification process.\[20\]

Interestingly, low-energy emulsification techniques provide smaller particle size as compared to high-energy emulsification, as it utilizes internal chemical energy of system. It has required small amount of energy along with a simple stirring is required from generation of tiny particle size.\[18\] However, smaller particle size can be attained by utilizing both techniques that depends upon composition of variables and most important on system.\[21\] It has been likewise guaranteed that high-energy techniques permit the forming of nano-emulsions at higher oil-to-surfactant proportions than low-energy strategies.\[21\]

**Coacervation**

It holds the phase separation of a single or mixture of polyelectrolyte from a solution and subsequent deposition of the newly developed coacervate phase around the active ingredient. To increase robustness of coacervate, cross-linkers shell be used like transglutaminase or glutaraldehyde.\[22\] The process can be labeled as simple (one sort of polymer) or complex (more than one polymers) coacervation, on the basis of polymer type used. The nature of complex formation depends on number of factors like type of biopolymer, ionic power, pH, concentration, and relation between complex formed along with polymer type.\[23\]

A significant contribution of hydrogen bonding and hydrophobic interactions may also have resulted as complex formation. Coacervation is a particular and promising encapsulation
innovation, as a result of the exceptionally high payloads feasible (up to 99%) and the conceivable outcomes of controlled release dependent on mechanical pressure, temperature and continued release. Major issue perceived in this strategy lies in commercializing the coacervated food components because of utilization of for cross-linking, that must be utilized according to country’s legislation. However, now such a large number of suitable enzymes are being developed for crosslinking.\cite{24}

**Inclusion complexation**

The super molecular association of ligand or encapsulated constituents into a cavity bearing substrate (wall material) through different types of bonding can be termed as inclusion complexation. These bonding forces may be hydrogen bonding, van der waals force or an entropy-driven hydrophobic influence. This technique mainly utilized in encapsulation of volatile organic molecules such as vitamins or essential oils in order to contain the unbearable odor, flavor and aroma. This type of encapsulation has high stability, efficiency, containment and preservation with wall materials. Nevertheless, a suitable encapsulation of particular components such as β-cyclodextrin and β-lactoglobulin may be possible through this technique.\cite{5}

**Nanoprecipitation**

The method in which organic internal phase spontaneously emulsified, having in it dissolved polymers, drugs and organic solvents into the aqueous external phase as well as solvent displacement is the other name of this technique. The mechanism followed in this process is that precipitation of a polymer from an organic solution and the diffusion of the organic solvent into aqueous medium.\cite{25} It is stated that nano-spheres and nano-capsules can be developed through solvent displacement. Furthermore, mostly biodegradable polymers are used such as poly (alkylcyanoacrylate), polycaprolactone, poly (lactide-co-glicolide), poly (lactide), and Eudragit.\cite{3}

**Emulsification–solvent evaporation**

In this modified form solvent evaporation process, emulsification of the polymer solution into an aqueous phase and evaporation of the polymer solvent induces polymer precipitation as nanoparticles.\cite{26} The size of the capsules can be controlled by adjusting the stir rate, temperature, type and amount of dispersing agent, viscosity of organic and aqueous phases.\cite{27} Mostly polymers are used under this technique are poly (lactide), poly (lactide-co-glicolide), cellulose acetate phthalate, cellulose, poly (hydroxybutyrate), and polycaprolactone. High-speed homogenization has to be utilized for the development of nanoparticles.\cite{28} In addition, this methodology demonstrated to be the most productive for accomplishing particle size below 250 nm.\cite{29}

**Supercritical fluid technique**

Owing to inexpensive, plentiful, and having properties in between many gases and liquids, carbon dioxide (CO\textsubscript{2}) is used in variety of chemical and industrial processes, as a solvent alternate. CO\textsubscript{2} is in the supercritical state and has gas-like viscosities and liquid-like densities above its critical temperature (31 C) and pressure (73.8 bar). With the change in temperature and pressure following parameters will also change such as density, viscosity, and dielectric properties of supercritical CO\textsubscript{2}, making it an unusually tunable, versatile, and selective solvent.\cite{30} There are some methods under supercritical fluid technology, such as rapid expansion from supercritical solution, gas antisolvent, supercritical antisolvent precipitation, aerosol solvent extraction, and precipitation with a compressed fluid antisolvent have been utilized in
recent years.\[^{31}\] Thermally sensitive compounds are encapsulated by this process, just like in spray drying. Bioactive compound and polymers are dissolved in supercritical fluid. During spraying process, the supercritical fluid was evaporated along with the particle precipitation. This technique is used usually owing to its low temperature and minimum use of organic solvents.\[^{32}\]

**Ultrasonication**

Ultrasonication is an emulsification method that includes the utilization of ultrasonic waves to deliver ultrafine emulsions. Its assistances in deagglomeration and dispersion of solid particles into fluid medium.\[^{33}\] Dispersed particles commonly bounded by molecular layers that attached with particle surface, that’s why this boundary layer should be separated or expelled for attachment of new functional group. The pressure made because of sonication assists with defeating the van der Waal’s forces of attraction and brings the functional components to the surface of the particles using Hielscher Ultrasound Technology, 2014, which gets captured by the wall material present in the solution.\[^{34}\] In an ultrasonication technique, properties of treated particles may be changed by using high intensity waves, shear forces, temperature and pressure.\[^{35}\] On the other hand, lower energy and emulsifier consumption, smaller particle size, lower polydispersity, and greater stability of nano-emulsions are among the key benefits of this technique.\[^{36}\]

**Drying techniques for nano-encapsulation**

Production of nano-suspensions (fluid or powder form) of active compounds can be possible with different encapsulated or coating wall materials via suitable encapsulation technique. Due to its stability issues, irreversible aggregation and leakage of the encapsulated active materials, it is alluring to convert over nano-capsule suspensions into dried or powder form to keep up their stability. Dried nanoparticles assist easier storage and handling as well as readily dispersible in aqueous solution. Consequently, nano-encapsulation technique along with drying technique is a fundamental approach for converting liquid nano-suspension into dried and stable form. Commonly spray-drying and freeze-drying are utilized for drying purpose of nano-suspensions and obviously both techniques have significant operating conditions for stabilization of nano-capsules. Besides, dried nanoparticles have ability to sustained and control release of encapsulated bioactive material as well as tolerate additional stress during processing.\[^{24}\]

**Nano-capsule formation via spray dryer**

Spray drying is a fast, versatile, cost-effective, flexible and continuous processing method used for development of dry powder from liquid solutions with maximum reproducibility of final product.\[^{37}\] In these gadgets, fluid solutions are sprayed through fixed narrow size atomizer into hot air chamber. These sprayed droplets separated from solution in drying chamber promoting solid particles that is expelled from air stream then collected. Low processing yield is one of the major disadvantage of traditional spray dryer on lab scale. That’s way, BÜCHI Labortechnik AG was introduced nano-spray dryer in 2009 to overcome this problem along with to enhance spray drying on submicron scale.\[^{38}\] This typical spray dryer has ability to convert aqueous solutions into fine powders with their rapid efficiency. The quick drying processing in suitable to even sensible bioactive compounds without any distractive influence.\[^{39}\] Nano-spray drying has been employed for nano-encapsulation purpose in different research areas likewise, functional food preparation, cosmetics, and pharmaceuticals.\[^{40}\] This is foremost achievement in spray drying technology, with the advantages of creating ultrafine powders with nano-size particles distribution as well as
maximum throughput. This Büchi nano-spray dryer gadget is fundamentally made spray concept, including the formation of submicron fragments from an aqueous solution such as nano-emulsions nano-suspensions.\textsuperscript{[16,41]}

**Nano-capsule formation via freeze-drying**

Freeze-drying is a drying procedure so known as lyophilization, meant for long-term preservation and stability of heat-sensitive food ingredients and biological constituents dependent on sublimation phenomena.\textsuperscript{[42]} This unique drying technique deliver high-quality final outcomes that are reconstituted without any problem. Fundamental disadvantages of freeze-drying are long processing time period (approximately 20 h or more), open porous structure and energy intensiveness. Generally, freeze drying employed to separate the nanoparticles with combination of other production techniques. Development of pores because of ice sublimation process is one of other issue related with freeze-drying. However, this procedure is a generally utilized to expel water from nano-capsules without alter their structure and shape. Conversely, spry-freeze drying procedure might be a successful option in contrast to conventional freeze-drying method as far as diminishing the pore size and drying time period.\textsuperscript{[24]}

Freeze-drying plays a vital role in exposing excellent encapsulation efficiency and stabilization of nano-capsules through their efficient productive drying process. This technique is progressively suitable for nano-encapsulation of heat-sensitive food ingredients of bioactive constituents. The attributes of formulated nanoparticles through freeze drying also rely on emulsification procedures utilized or other encapsulation strategies to decrease the droplets into Nano structure. However, aggregation of nanoparticles can be prevented during drying through cryoprotectants such as mannitol, sucrose and trehalose. In many recent studies, polymers, for example, PCL and chitosan were utilized as a wall material for encapsulation.\textsuperscript{[3]} The advantages and disadvantages of all the methods used for nano-encapsulation are presented in Table 1.

**Applications in food sector**

Food science is a high-technological discipline, which includes diversity of paraphernalia, towering biosafety demands, and well-constrained technological operations. Consequently, four major domains may assist from nanotechnology: elaboration of new functional stuff, micro-scale and Nano-scale operations, product evolution and advanced instrumentation arrangements for progressive food safety and biosecurity.\textsuperscript{[17]} In last decades, an immense growth has been observed in researches related to nano-encapsulation of food bioactive constituents by different methodologies. In terms to deliver the bioactive components and nutraceuticals into the body cells without any mischievous environmental and food operational factors, these constituents can be fixed in nano-carries which developed considering the nature of material to be deliver and targeted position, to attain a regulated release of component. In this part, current studies and developments on nano-encapsulation with different food components such as phenolic compounds and antioxidants (Table 2), fat and water soluble vitamins (Table 3), antimicrobial agents and essential/Carrier oils (Table 4), natural food colorants (Table 5), minerals ions and salts (Table 6), and some other miscellaneous food components (Table 7) have been elaborated in detail.

**Conclusion**

As reviewed in this study, nanotechnology have ability to improve the food properties either in sensory attributes, storage, target delivery, along with to enhance more nutritious and healthier. Nano-encapsulation has played a vital role in approaching the way of advancement of bioactive
Table 1. Advantages and disadvantages of all the methods used for nano-encapsulation.

| Techniques          | Advantages                                                                 | Limitations                                                                 | References |
|---------------------|-----------------------------------------------------------------------------|----------------------------------------------------------------------------|------------|
| Coacervation        | ● Environment friendly<br>● High encapsulation efficiency<br>● Increases the shelf life of sensitive food components<br>● Protect encapsulated material against nutritional losses<br>● Protect food ingredients from adverse factors, like light, heat and humidity<br>● Applicable to heat sensitive components<br>● 40–90% encapsulation efficiency | ● Many influencing variables<br>● Expensive<br>● Complex mechanisms<br>● Sensitive to the environment | [43–45]    |
| Nanoprecipitation   | ● Nanosized particles simple<br>● Low-cost equipment<br>● More facile<br>● Less complex<br>● Less energy consumption<br>● Easy and reproducible technique | ● Suitable only for organic solvents with this process,<br>● Disallowing the otherwise spontaneous release of the active compound | [46]       |
| Inclusion complexation | ● Nanosized particles masks odors/flavors<br>● Preserves aromas<br>● High encapsulation efficiency<br>● High stability | ● Suitable only for limited materials<br>● High capital investment<br>● Limited molecular compounds, like β-cyclodextrin and β-lactoglobulin are capable through this technique<br>● Required high pressure bar and low yield<br>● High costs | [17,43,46] |
| Supercritical fluid technique | ● Green, nontoxic and highly efficient technology<br>● Provide novel and reliable technique of small particle development with high surface area and free flowing characteristics<br>● This technique avoids drawbacks of traditional technique | ● Require high concentration of surfactant and cosurfactant<br>● High-melting substances cannot be solubilized easily | [43,47,48] |
| Emulsification      | ● Greater solubility,<br>● Higher kinetic stability<br>● Provide a great aqueous matrix for targeted delivery of bioactive compounds<br>● Protects the droplets from re-coalescence<br>● Improves stability of bioactive compounds | ● Low solid content of the dispersions<br>● Concentration of final formulation is needed<br>● Possible organic solvent residues in the final formulation | [43,49]    |
| Emulsification solvent evaporation | ● More efficient technique for achieving particle sizes below 250 nm<br>● Shorter process time<br>● No chemical reaction required<br>● Easily available wall materials<br>● Ability to control particle characteristics<br>● Good reproducibility<br>● Reduces mean particle size and narrow size distribution<br>● Suitable for thermosensitive drugs | ● Strong attenuation in effectiveness with distance from the ultrasound source creates the scale up problem<br>● High cost<br>● Lipid suspension may be degraded due to overheating and sonicator tips transfer metal particles into targeted sample | [47,50,51] |
| Ultrasonication     | ● Simple and fast method<br>● Highly stable emulsions, functional polymeric particles with environmental sensitivity, and nano-spheres | | [47,52]    |

(Continued)
| Techniques       | Advantages                                                                 |
|------------------|-----------------------------------------------------------------------------|
| **Spray dryer**  | • Rapid, easy, cost-effective, continuous                                   |
|                  | • Reproducible and scalable process for the nano-encapsulation              |
|                  | • Eco-friendly and efficient technique with high throughput energy          |
|                  | • 10–90% encapsulation efficiency                                           |
|                  | • High reproducibility                                                      |
|                  | • High productivity                                                        |
|                  | • Loss of nano encapsulated product in the walls of the drying chamber     |
|                  | • Low yield                                                                 |
|                  | • Viscous solutions may block the small holes in the mesh generation system, |
|                  |   so impeding the proper generation of the spray in nano spray drying      |
|                  | • High temperature may damage heat sensitive components like Vitamine C,   |
|                  |   lycopene, and β – carotene etc.                                          |
|                  | • Poor controlling system regarding droplet size as well as shape due to   |
|                  |   broad range of size distribution                                         |
| **Freeze drying**| • Improve the stability of core compound against degradation               |
|                  | • Better encapsulation efficiency of above 70%                             |
|                  | • Sterile products produced under super storage stability                   |
|                  | • Drug can be subjected to minimal thermal stress during formation          |
|                  | • Requires cryoprotectants such as sucrose, trehalose, or mannitol to      |
|                  |   conserve the particle size and to avoid aggregation during freeze-drying  |
|                  | • Requires more time                                                        |
|                  | • Low entrapment efficiency                                                 |
|                  | • High production costs                                                     |
|                  | • Expensive handling and storage in the long period                        |

References: [37, 44, 53–55, 24, 44, 47, 48]
| Phenolic compound | Purpose & characterization | References |
|-------------------|---------------------------|------------|
| Grape and apple pomace phenolic extract | Development of nano-encapsulation incorporated with phenolic extracts of grape & apple by utilizing chitosan & soy protein isolate as wall materials  
- Investigation of antioxidant activity after incorporating of formulated nanoparticles into apple & pineapple juices | [56] |
| Quercetin and curcumin | Formulation of casein-based nano-encapsulation of curcumin and quercetin with various concentrations of sodium caseinate  
- Characterization of casein nano-particles in terms of size, physical stability, aqueous solubility, loading & binding of curcumin and quercetin  
- Measurement of fluctuations in viscosity of protein dispersion  
- Investigation of fluctuations in cytotoxicity against MCF-7 human breast cancer under in vitro process by apply formulated nano-particles | [57] |
| Guabiroba phenolic extract | Preparation of guabiroba phenolic extract loaded nanoparticles by applying modified emulsion-evaporation encapsulation technique  
- Exploration of physico-chemical, antioxidant & antimicrobial activity for the measurement of encapsulation efficiency | [58] |
| Kaempferol | Preparation of kaempferol based mucoadhesive Nano-emulsion through high-pressure homogenization method  
- Examine the potential effect as delivery system to brain of rats following nasal administration as well as assessment of its activity against glioma cell line | [59] |
| Catechin | Nano-encapsulation of green tea catechin by utilizing soy protein as wall material  
- Characterization of Nano-encapsulation in terms of its physical stability, in-vitro bio accessibility and permeability | [60] |
| Olive leave extract | Creation of olive leaf extract-loaded Nano-encapsulation by utilizing whey protein concentrate and pectin with different concentrations  
- Protection & control release of olive leave extract into encapsulation system that increase antioxidant activity under internal aqueous phase of emulsions | [61] |
| Curcumin | Development of curcumin-based Nano-emulsion with utilizing milk fat & evaluate the measurement of physico-chemical as well as in vitro digestion kinetics | [62] |
| Tea polyphenol | To enhance alkaline media physical stability of tea polyphenols, for this reason a joint method (ethanol injection methods along with Dynamic high-pressure microfluidization) was adopted to formulate tea polyphenols Nano-emulsion  
- Characterization: Physicochemical properties, morphology, stability, antioxidant, antimicrobial & in vitro control drug release | [63] |
| Quercetin | Preparation of quercetin based cationic Nano-lipid carrier incorporated with soy lecithin via high pressure emulsification method  
- Investigation of its tissues distribution/circulation development in correlation with quercetin suspension for explaining tissue specific manner  
- Characterization: Morphological behavior, particle size, polydispersity index, zeta potential, efficiency, drug loading, Release assay in vitro & tissue distribution study in vivo | [64] |
| Silymarin | Silymarin-loaded Nano-carriers were devolved by utilizing egg lecithin as wall material via high-pressure homogenization technique  
- To characterized on behave of its entrapment efficiency, morphology, size, in vitro release & in vitro lipolysis  
- Evaluation of oral bioavailability of Nano-carriers in comparison with Legalon & fast control-release  
- Preparation of Nano-emulsion by applying response surface methodology (Box-behenken) with three experimental variables likewise tween-80, lecithin & sonication time and evaluate the size, polydispersity Index, efficiency & stability of Nano-emulsion under storage | [65] |
| Ferulic acid | Formulation of ferulic acid-based Nano-emulsion via ultra-sonication technique by utilizing lecithin as wall material  
- To probe the influence of chitosan coated epigallocatechin-3-gallate nano-liposoms on EGCG stability, uptake as well as viability and apoptosis of breast cancer cells (MCF7) | [66] |
| Epigallocatechin-3-gallate (EGCG) | | [67] |
Table 3. Some listed studies of nano-encapsulation with different vitamins.

| Vitamins | Purpose & characterization | References |
|----------|----------------------------|------------|
| **Water-soluble Vitamins** | | |
| Vitamin B<sub>9</sub> | • Main purpose was to prepare stable vitamin B<sub>9</sub> loaded Nano-carriers with pectin & whey protein complexes  
  • Release of vitamin B<sub>9</sub> was investigate after spray dried powder holding W<sub>1</sub>/O/W<sub>2</sub> multiple emulsion  
  • Preservation of its integrity during the shelf life under storage | [68] |
| Vitamin B<sub>12</sub> | • Vitamin B<sub>12</sub> based nano-liposomal vectors were created with good encapsulation efficiency intended for targeted as well as controlled release purpose  
  • Joint process was applied for nano-liposomal formulation such as thin film hydration process along with ultrasound assisted method  
  • Major purpose was to gain nano-liposomes in terms of maximum encapsulation efficiency and minimum particle size | [69] |
| Vitamin B<sub>1</sub> | • Formulation of vitamin B<sub>1</sub> based Nano-liposomes by utilizing phosphatidylcholine as wall material  
  • Characterization: Zeta potential, size, nano-encapsulation efficiency, physical stability & thermal behavior was investigating with respect to time, temperature & pH  
  • In addition, functional group test as well as morphological behavior was also determined | [70] |
| Vitamin C | • Stability exploration of vitamin C loaded nanofibers entrapped with soluble dietary fiber (SDF) and without SDF-nanofibers after apply UV light & heat treatment under different storage conditions  
  • Compression was done between nanofibers formulated with SDF & without SDF | [11] |
| Vitamin B<sub>6</sub> | • Development of protein-based Nano-gel incorporated with vitamin B<sub>6</sub> via probe sonicator along with to enhance the affinity between bio-crosslinker & protein  
  • Characterization: | [71] |
| Vitamin B<sub>2</sub> | • Preparation & characterization of Alginate/chitosan-based nanoparticles with respect to Nano-encapsulation of vitamin B<sub>2</sub> and analyzed the vitamin-controlled release from it under various conditions  
  • Besides, major purpose of this study to encapsulation of vitamin that pointing their applications in food industry, which might be a value-added incentive for food sector | [72] |
| Vitamins B<sub>2</sub> & C | • Formulation & characterization of cellulose acetate-based vitamins B<sub>2</sub> & C nanofibers  
  • Characterization: Screen electron microscopy, X-ray diffraction, Fourier transform infrared microscope & atomic absorption spectrometry  
  • Demonstration of two different properties of nanofiber such as antibacterial behavior & slow-release functionality of vitamins | [12] |
| **Fat-soluble Vitamins** | | |
| Vitamin E | • To comprehend the impact of Nano-encapsulation developed with vitamin E by utilizing carboxymethyl cellulose film whether this valuable change can improve film qualities  
  • Investigation of resistance against environmental changes such humidity, mechanical & thermal stability  
  • Evaluation of suitability of nano-encapsulation fortified with vitamin E | [73] |
| Vitamin D | • Production of yogurt powder enriched with vitamin D loaded Nano-encapsulation by using different wall material mixture likewise, gum Arabic, whey protein concentrate, maltodextrin & modified starch  
  • Evaluation of suitability of nano-encapsulation fortified with vitamin D | [74] |
| Vitamin D<sub>3</sub> | • Fabrication of nano-emulsion with vitamin D<sub>3</sub> combined with fish oil as capable delivery system via ultrasonication technique  
  • Characterization of its size, morphological properties & encapsulation efficiency  
  • Investigation of physical stability along with high efficiency of prepared Nano-emulsion in simulated gastro-intestinal tract | [75] |
| Vitamin A palmitate | • Preparation of formulations of nano-liposomes incorporated with vitamin A designed for enhancement of its aqueous dispensability  
  • Influence of lecithin-cholesterol concentrations was analyzed in terms of size, efficiency & physical stability of these Nano-liposome | [76] |
| Vitamin D<sub>2</sub> | Nano-encapsulation of vitamin D<sub>2</sub> by using dispersions of tripalmitin solid lipid nanoparticles  
  • Characterization of its size, phase transition as well as morphological behavior | [77] |
| Vitamin K<sub>1</sub> | • Exploration the possible preparation of Vitamin K<sub>1</sub> based Nano-emulsion via low-energy procedures without lipid excipients  
  • Principle aim of this study was to overcome industrial cost production through developing Nano-emulsion utilizing mild stirring conditions at room temperature with spontaneous emulsification | [78] |
| Vitamin A & E | • Fabrication of nano-emulsion with fat-soluble vitamin A and E powders via conventional spray-drying method  
  • Investigation of nano-emulsion on the bases of thermal stability & physicochemical properties  
  • Major purpose was to deliver valuable information as per potential methodology for development of fat-soluble vitamin-delivery systems intended for being utilized as additives in extruded food products | [79] |
| Oils                                | Purpose & characterization                                                                 | References |
|------------------------------------|-------------------------------------------------------------------------------------------|------------|
| **Essential oils**                 |                                                                                           |            |
| Cinnamon                           | • To employ Response surface methodology (Box Behnken) for production of O/W cinnamon loaded Nano-emulsion with better antimicrobial activity & stability | [80]       |
|                                   | • Examine the antimicrobial & stability test of Nano-emulsion as well as polydispersity index viscosity & droplet size |            |
|                                   | • Main focus to deliver appropriate information for the utilization of cinnamon-loaded Nano-emulsion for food susceptible to bacterial contamination |            |
| Cymbopogon citratus               | • Nano-encapsulation of hydrophilic gel combined with cymbopogon citratus oil by utilizing poly (d,l-lactide-co-glycolide) as wall material along with to determined it's in vitro anti-herpetic behavior | [81,82]   |
|                                   | • Size, zeta potential & encapsulation efficiency was measured                             |            |
|                                   | • Comparison of inhibitory activities against Herpes simplex types 1 and 2 in contrast to free oil loaded nanoparticles as well as hydrogel holding free oil |            |
|                                   | • Optimization & analyzed factors including sonication time, power & oil/polymer ratio by employing Box Behnken design |            |
|                                   | • Optimized experimental factors were utilized to gain nanoparticles with highly reduced mean hydrodynamic size & more efficient encapsulation efficiency |            |
|                                   | • Physicochemical behavior was measured plus cytotoxicity estimated in HaCat cells by WST-1 and LDH tests |            |
| Fish oil and garlic essential oil  | • Production/investigation of fish & garlic oil-loaded Nano-encapsulation utilizing persian gum & chitosan as wall material by means of electrostatic layer by layer deposition method | [83]       |
|                                   | • Physicochemical characterization: Size, stability, zeta potential, polydispersity index, surface tension, viscosity & encapsulation efficiency |            |
|                                   | • Morphology: Interactions between wall materials, Thermal & Crystalline properties         |            |
| Clove                              | • Preparation of Nano-emulsion film incorporated with clove essential oil & hazelnut meal proteins by means of ultrasonic (US) method under various time/amplitude conditions for the estimation purpose of US treatment influence on formulating/final Nano-emulsion | [84]       |
|                                   | • Characterization: Zeta potential, optical/mechanical properties, water vapor permeability, scanning electron microscopy, antioxidant & antimicrobial activity |            |
| Sage                               | • Formulation of sage based Nano-emulsion through probe sonication & estimate its effectiveness | [85]       |
|                                   | • Utilization of physical, structural, chemical & biochemical procedures to investigate the antimicrobial mode of action of Nano-emulsion against E-coli |            |
|                                   | • Infrared spectrophotometry & scanning electron microscopy was utilized to monitored the fluctuations in cell membrane composition as well as structure after antimicrobial treatment respectively |            |
| Orange peel                        | • To study the influence of different ultra-sonication factors on physical & rheological characteristics of orange peel essential oil-based nano-emulsion via different optimal combinations of response surface methodology (Box Behnken design) in consort with to formulate lowest droplet size nano-emulsion & maximum stability | [86]       |
| Thyme                              | • Preparation of Thyme oil-based Nano-emulsion with combinations of sodium caseinate & lecithin as well as investigate the antimicrobial behavior in contrast with E. coli, Salmonella enterica & Listeria monocytogenes | [87]       |
|                                   | • In addition, Compression was done between free oil and Nano-emulsion for changing of bacterial membrane permeability after treatment |            |
| Clove, cumin, caraway, marjoram,  | • To probe the antimicrobial activities of six different mentioned essential oils in contrast with S. aureus, L. monocytogenes & E. coli for selection purpose of most effective essential oils in the enrichment of nanocomposite film | [88]       |
| cinnamon, coriander                | • Preparation of alginate/clay-based films with selected most effective oils & assess the potential of formulated film against above mentioned pathogens |            |
| Rosemary                           | • To inspect the mutual effect of rosemary essential oil & montmorillonite nanoclay on the behave of physicochemical as well as antimicrobial behavior of chitosan-based film | [89]       |
|                                   | • Characterization: X-ray diffraction, Fourier transform infrared, swelling capacity, antibacterial activity, total phenolic content, measurement of film thickness, water resistance, water vapor permeability & surface color |            |

(Continued)
Moreover, the size challenge of nutraceutical compounds including their therapeutic potential specially in allied fields, food and pharmaceutical industry during last decades. This methodology especially beneficial in case of nano-size particles that can penetrate targeted object, be in the form of drugs, nutraceuticals and other functional foods. Moreover, numerous techniques to acquire nano-capsules have been created to various applications, multifaceted nature and versatility, with the physico-chemical behavior of bioactives being one of the most conditioning features on formulation strategies. Moreover, development and quality control of nano-particles formulation can be a huge challenge at large scale. This study led so far has been assessment is that in future more

Table 4. (Continued).

| Oils      | Purpose & characterization                                                                 | References |
|-----------|---------------------------------------------------------------------------------------------|------------|
| Rose      | • Evaluation the possibility of incorporation of rose essential oil into liposomes via supercritical technique & compared with formulated liposomes through thin-film dispersion  
          • Characterization: Calorimetry Analysis, transmission Electron Microscopy, measurement of entrapment efficiency & particle size | [90]       |
| Carrier oils |                                                                                           |            |
| Shrimp    | • Formulation of enriched Nano-liposomes via different preparation technique & inspect the stability of formulated enriched Nano-liposomes during storage  
          • Compared the two different formulation methods such as ultrasonication & micro-fluidization | [91]       |
| Palm (high-oleic) | • Comparison of Nano-liposomes prepared via ultrasonication & micro-fluidization techniques  
                      • Evaluation of stability as well as digestibility of Nano-liposomes by utilizing in-vitro model | [92]       |
| Fish      | • Nano-encapsulation of fish oil by using gum arabic as wall material  
          • Influence of capsulation was investigate on the characteristics of probiotic fermented milk | [93]       |
| Flaxseed  | • Encapsulation of flaxseed oil by utilizing flaxseed mucilage nanofibers  
          • To characterized the oil-loaded nanofibers in terms of oxidative stability, morphological & physicochemical properties | [94]       |
| Cumin seed | • Formulation of cumin seed-based Nano-emulsion with guar gum & whey protein isolate as wall materials  
          • To probe the preheating influence of wall materials solutions as aqueous phase of cumin seed-based Nano-emulsion  
          • To examine the physical stability, biocompatibility & antimicrobial activity | [95]       |
| Olive     | • Optimization of olive oil loaded Nano-emulsion so as to expand the bioactive compound loading such as ascorbic acid & gallic acid by means of boosting stability as well as diminishing droplet size of emulsion by minimum utilization of emulsifier | [96]       |
| Rice bran | • Preparation of potential health beneficial inulin & rice bran oil loaded Nano-emulsion  
          • To optimize & inspect the oil, inulin content along with ultrasonic power of emulsion via response surface methodology  
          • To Investigate the lipid oxidation of formulated emulsion by utilizing rosemary essential oil as potent natural antioxidant | [97]       |
| Sunflower | • To examine technological clarifications for sunflower loaded Nano-emulsion preparation to enhance the process efficiency with minimizing energy & cost  
          • Formulation/comparison of Nano-emulsion with high pressure homogenization (HPH) and ultrasonication (US) techniques  
          • Assessment of particle size, diameter, viscosity & physical stability of formulated Nano-emulsion through individual/combining of HPH & US | [98]       |
| Peppermint | • Preparation of Peppermint oil-based Nano-emulsion with modified starch along with to explore the variations of particle size & rheological characteristics under various storage conditions  
          • Exploration of antimicrobial activities of Nano-emulsion in order to antimicrobial delivery purpose | [99]       |
Table 5. Some listed studies of nano-encapsulation with different natural food colorants.

| Colorants | Purpose & characterization | References |
|-----------|----------------------------|------------|
| Astaxanthin | Preparation of astaxanthin-loaded Nano-liposomes by employing soy phosphatidylcholine | [100] |
| Lutein    | To generate lutein-based Nano-emulsion using whey protein in consort with its morphological behavior, storage conditions & stability exploration | [101] |
| Crocin    | Formulation of crocin-loaded double Nano-emulsion via angum gum, whey protein concentration & gum Arabic | [102] |
| Anthocyanin (ATC) | Stabilization/ investigate the antioxidant activity along with color of black soybean (anthocyanin) via pigmentation & nano-encapsulation systems | [103] |
| Alpha-tocopherol | Production of soluble dietary fiber-based nanofibers incorporated with alpha-tocopherol | [104] |
| Bixin     | Preparation of Bixin- loaded nano-encapsulation utilizing different concentrations of wall materials | [105] |
| β-carotene | Development of β-carotene based Nano-liposomes with novel hybrid materials | [106] |
| Lycopene  | Preparation/characterization of lycopene-loaded lipid-core Nano-capsules incorporation with poly(e-caprolactone) and sorbitan monostearate | [107,108] |
| Carotenoid | Production of carotenoid-loaded Nano-liposomes with Egg yolk phosphatidylcholine in contact with understanding how carotenoids exerted antioxidant activity after capsulation | [109] |
|           | Measurement of antioxidant activity through DPPH, FRAP and also lipid peroxidation inhibition capacity |            |
Table 6. Some listed studies of nano-encapsulation with different mineral ions/salts.

| Mineral form | Purpose & characterization | References |
|--------------|----------------------------|------------|
| Iron         | • Preparation of chitosan-based Nano-particles formulation of iron that would be increase bioavailability along with stability of iron during storage | [110] |
| FeSO₄        | • Zeta potential & size of Nano-particles measurement | [111] |
| FeSO₄        | • Investigation of iron release kinetics & in vitro stability of Nano-particles | | |
| Manganese Zinc Ferrite (MZF) | • Formulation of solid lipid based FeSO₄ nano-particles along with investigations of their size, efficiency & stability | [112] |
| Manganese Zinc Ferrite (MZF) | • Major focus to overcome the problems of marketed iron supplements pills | | |
| Na₂SeO₃      | • Synthesis the MZF loaded Nano-particles using chitosan as wall material | [113,114] |
| Na₂SeO₃      | • Characterization of coated & un-coated Nano-particles likewise X-ray diffraction, electron transmission microscopy, infrared, thermogravimetric analysis and vibrating sample magnetometry | | |
| Na₂SeO₃      | • To check the Nano-particles suspension influence and efficiency | | |
| ZnCl₂ & FeCl₃ | • Preparation of Na₂SeO₃ based nanoparticles incorporated with guar gum as wall material via nanoprecipitation technique | [115] |
| ZnCl₂ & FeCl₃ | • Physicochemical properties were examined on bases of particle size, transmission electron microscopy & X-ray diffraction | | |
| ZnCl₂ & FeCl₃ | • To inspect the interaction between nanoparticles & H9c2 cells under different factors | | |
| ZnCl₂ & FeCl₃ | • Measurement of encapsulation efficiency against in vitro cardiac ischemia, antioxidant activity as well as cellular stress indicators during reperfusion & ischemia | | |
| ZnCl₂        | • Development of Fe/Zn-loaded alginate-based Nano-encapsulation for food fortification that was utilize in ice-cream | [116] |
| ZnCl₂        | • Characterization of Nano-particles such as size, morphological behavior & FTIR evaluation | | |
| ZnCl₂        | • Further to check the sensory & rheological parameters of fortified ice-cream | | |
| Ferrous glycinate | • To explored the whey protein based ZnCl₂ nanoparticles and analysis the efficiency as well as stability of these Nano-particles | [117] |
| Ferrous glycinate | • Key fact of this study was to incorporate minerals in food items via novel techniques, enable the production of acidic dairy drinks holding nutritionally significant amount of minerals | | |
| Ferrous glycinate | • To investigate the stability & controlled release of formulated ferrous glycinate based nano-liposomes in simulated gastrointestinal tract | | |
| Ferrous glycinate | • Characterization: Encapsulation particle size, zeta potential, transmission electron microscopy | | |
### Table 7. Miscellaneous Nano-carrier applications of other important food/food related components.

| Components                        | Purpose & characterization                                                                                                                                                                                                                                                                                                                                 | References |
|-----------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| DHA/EPA                           | • Development of DHA/EPA Nano-emulsion by using EPI methodology  
• To analyze stability, size, retention rate & morphological behavior of Nano-emulsions  
• Nano-emulsion addition in apple juice and explored the stability                                                                                                           | [118]      |
| Manuka honey                      | • To fabricate honey loaded nanofiber mats  
• Identification of surface morphological behavior, mechanical behavior, size & in vitro cytocompatibility of nanofibers                                                                                                                                                                                         | [119]      |
| Alhagi honey                      | • Development/investigation of Nano-encapsulated honey within PLGA that could be improve immune-enhancement effect of honey  
• To assess the activity of Nanoparticles in vitro & antigen-specific immune responses in vivo                                                                                                                                                                                                       | [120]      |
| δ-limonene (Orange peel)          | • Production of optimized δ-limonene loaded Nano-particles within different concentration of whey protein & pectin that based on color, size, stability & viscosity  
• To investigate morphological characteristics, zeta potential along with encapsulation efficiency                                                                                                                                                                                                   | [121]      |
| Lactobacillus rhamnosus GG        | • To ensure successful probiotic Nano-encapsulation within Sodium alginate & poly vinyl alcohol  
• Investigation of morphological, molecular, colloidal & thermal characteristics of capsulation  
• Coat the fish filets & expose that which nanofiber can be utilized as functional and & natural coated material that delay fast microbial growth                                                                                                                                               | [122]      |
| Lactobacillus acidophilus         | • Development of *L. acidophilus*-based Nano-encapsulation with chitosan  
• Investigation of different concentration of chitosan on the bases of capsules size  
• To analysis the viability of probiotic cells under stimulated vivo study                                                                                                                                                                                                                 | [123]      |
| Coenzyme Q10 and vitamin E acetate | • To proposing a novel Nano-encapsulation between Q10 and vitamin E using gellan gum  
• Investigation of antioxidant, anti-edematogenic & anti-inflammatory behavior of Q10 and vitamin E associated nano-particles                                                                                                                                                                   | [124]      |
| Probiotic bitter ground juice powder | • To encapsulate the bitter taste of bitter ground with *Lactobacillus casei* via different wall materials such as starch, maltodextrin & gum arabic  
• To investigate the effect of wall materials on basis of proximate and functional characteristics as well as viability of *L. casei* under develop Nano-encapsulation                                                                                                                                 | [125]      |
| Date palm pit extract             | • Nano-encapsulation of date extract with whey protein as rich source of phenolic compound  
• To easily add in beverages without any major influences  
• Measurement of physical and morphological behavior of nanoparticles                                                                                                                                                                                                                                      | [126]      |
| Peptidic fraction from sea bream scales collagen | • Nano-encapsulation of peptide fraction with soy lecithin subjected to enzymatic hydrolysis  
• To determine entrapment efficiency, stability & size  
• Investigation of antioxidant activity and ACE-inhibitory capacity of both free & encapsulated peptide fraction                                                                                                                                                                           | [127]      |
| Saffron extract                   | • A new approach for development of saffron extract loaded Nano-encapsulation via different type of food models: (a) maltodextrin & whey protein-based model (b) single & double (W/O/W) multiple emulsion model  
• Assessment of nano-encapsulation efficiency                                                                                                                                                                                                                                                       | [128]      |
| Lactoferrin (camel milk)          | • Nano-encapsulation of lactoferrin with calcium alginate  
• To analyze physiochemical behavior as well as releasing time period of nanoparticle at different pH                                                                                                                                                                                              | [129]      |
| Cirtal (Flavor)                   | • To probe the antioxidant effect of ubiquinol-10 in O/W Nano-emulsion to protect cirtal against off-flavor & chemical deteriorations under different ubiquinol-10 concentrations                                                                                                                                                       | [130]      |
avenues of versatile techniques and applications of nano-encapsulation with explicit goals would be investigated that helps in usage of the capability of the bioactives to their best.

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