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NANOTECHNOLOGY IN FOOD INDUSTRY: A REVIEW OF APPLICATIONS OF NANOEMULSIONS IN FOOD PROCESSING SECTOR.

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Abstract

The rapid development of nanotechnology has transformed many scientific and industrial sectors including food industry. A wide range of nanostructured materials (NSMs), the so-called nanomaterials, including nanoencapsulated materials, nanoemulsions, nanosensors and nanoparticles have been applied in food industry including food processing packaging and preservation. This review aims at elucidating the emerging applications of nanoemulsions in food industry particularly in food processing sector. A wide range of nanoemulsions have been applied in food processing. This involves the encapsulation of some bioactive substances and nutraceuticals into nanoemulsions for various purposes such as for flavouring colouring and preservation of processed foods where they act as antimicrobials such bioactive substances and nutraceuticals including citral, ß-carotene, resveratrol, vitamins, astaxanthin, curcumin, lecithin, essential oils, capsaicin and so on. However, safety and health concerns as well as regulatory policies must be considered during nanomaterial manufacturing, use in food processing as well as the consumption of nanoprocessed foods. Extensive research must be carried out to determine the critical health and environmental impacts resulting from the use of nanotechnologies in food processing industry.

Keywords: Nanotechnology, Food Processing, Nanomaterials, Bioactives, Nanoemulsions.

Introduction

Since the emergence of life on earth, man has been making efforts to improve and device better food processing techniques to avoid rapid food spoilage and the attendant food scarcity. From the cave man trying to process and preserve the food by storing the fresh kill in carves that provided a dampened environment so as to keep it from being spoiled to the refrigeration techniques of the 21st century, man has come a long way. The methods of food processing and preservation that have been commonly used by man on a day to day basis include fermentation, salting, sundrying, roasting, oven-baking, smoking, steaming, curing, picking, canning, bottling, jellying, irradiation and carbonation as well as the use of artificial or chemical preservatives. All these methods are basically targeted at either slowing down the multiplication of pathogens in processed foods or killing the organisms in food altogether. These methods are often unable to achieve the desired goal of having processed foods that can last for longer duration which may lead to food spoilage, losses and food scarcity. Hence, there was the need for a permanent and more reliable solution to food spoilage and losses.

Researchers are now tilting towards the use of nanotechnology in food processing sector to mitigate the problems of food spoilage, food scarcity, food quality, food safety and health concerns. The panacea to these problems is sought in the use of nanotechnology in food processing. Over the past few decades, nanotechnology has increasingly been considered as to be attractive technology that can revolutionlize the food sector. Nanotechnology is a technology on the nanometer scale (nanoscale) and deals with the atoms, molecules or the macromolecules with the size of approximately 1-100mm to create and use materials that have novel properties (Roselli *et al.*, 2013) which are the so called nanomaterials (NSMs). These materials have unique properties unlike their macroscale counterparts due to the high surface to volume ratio and other physiochemical properties like colour, solubility, strength, diffusivity, toxicity, magnetic, optical, thermodynamic etc (Gupta *et al.*, 2016).

The properties of the recent nanomaterials offer many new opportunities for food industries including more potent food colouring, flavouring, nutritional activities, and antimicrobial ingredients for food processing (Alfadul and Elneshwy, 2010). Nanotechnology is now widely used in many applications in food processing, packaging and preservation as well as in agricultural sector for controlled release and delivery of nutrients, pesticides and fertilizes (Bajpai *et al.*, 2018). There are many nanomaterials used in different food applications on industrial scale including nanoencapsulations, nano-composites, nanosensors, nanoparticles, nanoemulsions and so on. Nanoemulsions are particularly utilized in food processing sector and developing countries like Nigeria can bought immensely from this technology particularly because of its cost effectiveness.

Food Processing

Food processing is the transformation of agricultural products into food or of one form of food into other forms for the purpose of toxin removal protection from pathogens, preservation, easing marketing and distribution tasks, and increasing food consistency. This is the conversion of raw ingredients into food and its other forms by making the food safe, marketable and with long shelf life. Food processing can be defined as a practice of preservation of food with the help of methods and techniques in order to transform food to a consumable state (Pradhan *et al.*, 2015). The techniques are designed such that the flavour and quality of the food are kept intact but they are also protected from infestation of micro organisms that leads to food spoilage (Pathkoti *et al.*, 2017). In addition processing increases yearly availability of many foods, enables transportation of delicate perishable foods across long distances and makes many kinds of foods safe to eat by de-activating spoilage and pathogenic microorgamisms (Smith *et al.*, 2017). Processed foods are usually less susceptible to early spoilage than fresh foods and are better suited for long distance transportation from source to the consumers (Ionescu, 2016). Some of the conventional methods of food processing include freezing, canning, pasteurization, irradiation, ohmic heating and high hydrostatic pressure (Necthirajan and Jayas, 2011). Food processing methods can be enhanced by the applications of nanosystems such as nanoemulsions, which improve the benefits of food processing.

Nanoemulsions

Generally emulsions are the dispersion of two immiscible liquids with spherical droplets forming the dispersed phase while the liquid surrounding it forms the continuous phase (Acosta, 2009). The liquids often used to form emulsions are water and oil. The oil droplets dispersed in an aqueous phase are usually regarded as oil-in-water (o/w) emulsions. These emulsion systems can be employed for the delivery of hydrophobic active substances. On the other hand, the water droplets dispersed in oil are commonly known as water-in-oil (w/o) emulsions and usually used for the delivery of hydrophilic compounds. Moreover multiple emulsion systems are equally formulated such as the water-in-oil- in water (w/o/w) and oil-in-water-in oil (o/w/o) emulsions. The w/o/w emulsions are composed of large oil droplet containing water droplets dispersed in aqueous phase while in o/w/o emulsion systems, water droplets containing oil droplets are dispersed in an oil phase (Weiss *et al.,* 2006).

Emulsions are often classified into three groups namely coarse emulsions, microemulsions, and nanoemulsions on the basis of their particle size and stability (Komaiko and McClements, 2016). The coarse emulsions, equally known as conventional emulsions or macroemulsions, have particle size of diameter 7200nm range and are thermodynamically metastable. These emulsions break down over time due to a number of destabilizing factors and are optically turbid as the dimension of the droplets is similar to the wave length of light and so scatters incident light and hence appears opaque (Jamuna and Vittal, 2019). On the contrary, the droplets in the microemulsions are <100nm in size and are thermodynamically stable. Meanwhile, their stability is affected by even slight variation in environmental conditions such as composition and temperatures (Bajpai *et al.*, 2018). Severally, microemulsions are formed spontaneously as their free energy is lower than their phase separated components and they are optically transparent as the particle size is lesser than the wave length and weakly scatters light (Anton and Vandamine, 2011).

Nanoemulsions are nano-sized emulsions, which are manufactured for improving the delivery of active nutritional and pharmaceutical ingredients (Jaiswal *et al.*, 2014). They have droplet dimensions similar to the microemulsions ranging from (200nm and in some cases <100wm (Saifullah *et al.*, 2016). Nanoemulsions are thermodynamically stable isotropic system in which two immiscible liquids are mixed to form a single phase by means of an emulsifying agent, that is, surfactant and co-surfactant. Unlike conventional emulsions, nanoemulsions are conferred with kinetic stability as there is no gravitational separation and droplet aggregation due to the reduced attractive force between the small sized droplets (Mc Clements and Rao, 2011). Also, Nanoemulsions are not affected by physical and chemical variations including temperature and pH unlike the microemulsions (Jamuna and Vittal, 2019). The Nanoemulsions require less amount of surfactants for their preparation and their droplet size apart from determining their optical property and stability equally influences their rheological and release characteristics (Pradha *et al.*, 2015). Nanoemulsions have the capacity to encapsulate functional compounds and active ingredients including antioxidants, nutraceuticals and preservatives (Jamuna and Vittal, 2019). They are employed in the controlled release of flavouring compounds in foods (McClements and Rao, 2011). Nanoemulsions encapsulation of bioactive compounds increases its solubility, controlled release and absorption in the gastro-intestinal tract, and absorption through cells (Chen *et al.,* 2006; McClements and Rao, 2011). Nanoemulsion based edible nanocoatings containing flavouring and calouring ingredients antioxidants, enzymes, anti-microbials, and anti-browning agents can be used to coat foods such as meats, dairy products (eg cheese), fresh produce, and fresh cuts including fruits and vegetables and confectioneries, to improve their shelf life. The Nanoemulsions coatings can equally prevent moisture and gas exchange, minimize moisture loss and oxidation of foods (Salvia-Trujillo *et al.,* 2017; Donsi 2018). Other advantages of nanoemulsions in food industry are that they can be used as substitute for liposomes and vesicles (Bouchemal *et al.,* 2004); improve the bioavailability of foods (Kim *et al.,* 2001), and non-toxic and non-irritant in nature (Jamuma and Vittal, 2019). They have improved physical stability, greater absorption solubilization of lipophilic nutrients and drugs, help in taste masking and less amount of energy required (Jaiswal *et al.*, 2014).

Applications of Nanoemulsions in food processing

The limitations of development of functional foods include low solubility, stability and bioavailability of the bioactive compounds. Most of the bioactive food ingredients are susceptible to degradation during food processing and oxidative deterioration during storage (Shahidi and Zhong, 2010). Some other bioactives posses low solubility but with rapid metabolism which reduces their bioavailability while some are volatile and sensitive to processing conditions (Jin *et al.,* 2016). These limitations can be mitigated by the use of nanoemulsions to encapsulate bioactive compounds for their use in food matrix. The encapsulation of bioactive compounds in an oil phase or emulsifier ensures its stability, bioavailability, and controlled rate of release (McClements *et al.*, 2007). Many lipophilic components are encapsulated with the help of nanoemulsion formulation for various functions including as flavouring and colouring agents, nutraceuticals and natural preservatives (Table 1). Some of such lipophilic components encapsulated in nanoemulsions include citral, β-carotene, resveratrol, vitamins, capsaicin, essential oils and so on. These components are highly stable to gravitational separation and droplet aggregation and the nanoemulsions are equally thermally stable in comparison to the conventional emulsions (Jamuna and Vittal, 2019). The various nanoemulsion evapsulations are subsequently discussed.

Table 1: Functional compounds encapsulated into Nanoemulsions for food applications (Adopted from Jamuna and Vittal, 2019).

S/N	Bioactive compounds	Methods	Particle size	Functions	Constituents
1	Citral	i. High pressure homogenization (HPH, 6cycles) for 150Mpa	109-129nm	Flavouring agent	O/W: palmkernel fat/citral/undecane/lecithin
2	β-carotene	i. Sequential HPH (3 cycles to-140MPa) ii. Ultrasonication (US), and Microfluid-ization (MF) HPA	60-140nm 70-160nm		
3	Resveratrol	i. Spontaneous emulsification (SE)	100nm		
4	Vitamin D	i. HPH	<200nm		
5	Vitamin E and phytosterol	i. HPH (4cyles/28000psi)	100nm		
6	Astaxanthin	i. Spontaneous emulsification (SE)	150-160nm		
7	Curcumin	i. HPH (20cycles/103 MPa)	80nm		
8	Lecithin	i. Microfluidization (MF) (5 cyles/150MPa)	<400nm		
9	Oregano Essential Oil (EO)	i. Ultra sonication (750W) ii. Ultrasonication (20KHz/400W/10 mn)	148nm 180-250nm		
10	Oragano EO	Ultrasonication (20KH$_2$/750W/10mm)	20-30nm		

11	Cinnamaldehyde	i. Spontaneous emulsification (SE)	20-500nm	Preservative	O/W: cinnamaldehyde Tween 80/distilled water (Otoni *et al.*, 2014a).
12	Ginga EO	i. MF (10cyles/1000psi) ii. Ultrasonication (20KHZ/200W/5min).	133nm 57nm	Preservative	O/W: Ginger Eo/Tween 20/Span 80/Canola oil (Acevedo-Fani *et al.*, 2015). O/W: Ginger EO/Tween 80 (Noori *et al.*, 2018).
13	Capsaicin (capsicum oleoresin)	i. HPH (5cyles/140MPa) Ultrasonication (75% amplitude/5min).	65nm	Preservative	O/W:Capsaicin oleoresin/Tween 80/water (Akbas *et al.*, 2018).
14	Curcumin	Spontaneous Emulsification	40-130nm	Preservative	O/W: Curcumin/ Tween 80/Glycerol water (Abdou *et al.*, 2018).

Encapsulation of flavouring and colouring agents within nanoemulsions

Normally the flavouring and colouring compounds used in food have aldehyde, ketone and esters as functional groups which make them susceptible to oxidative and photolytic degradation (Jamuna and Vittal, 2019). Encapsulation of bioactives within the nanoemulsions can prevent this undesirable character and enhance the shelf life of the processed food (Goindi *et al.*, 2016). The various functional compounds encapsulated within nano-emulsions for flavouring and colouring of foods are as follows:

Citral

This is a □, β-unsaturated aldehyde with one additional double bond. It is an aromatic compound and utilized as flavours in food and cosmetics and also used to increase the stability of nanoemulsions (Jamuna and Vittal, 2019). It is claimed that o/w nanoemulsions of citral combined with natural oxidants such as β-carotene, tanshinone and black tea extract had a high chemical stability during storage (Alfadull and Elneshwy, 2010). The nanoemulsions in this aspect are prepared with lecithin stabilized palm kernel lipid on pH_3 buffer 1:1 ratio of citral and anti-oxidants and the encapsulation with antioxidants leads to decreased formation of off-flavour compounds like □, p-dimethylstyrene and p-methylacetophenone (Yang *et al.*, 2011).

β-Carotene

It is an organic, strongly coloured red-orange pigment, which is a precursor of

Vitamin A. The pigment is used as a natural colorant and antioxidant in the food industry (Jamuna and Vittal, 2019). Nanoemulsions are usually prepared by emulsifying organic solution of β-carotene in aqueous phase containing emulsifier and stable β-carotene nanodispersions produced with weighted mean diameter ranging from 60 to 140nm (Tan and Nakajima, 2005). Generally, β-carotene nanoemulsions are prepared by high pressure homogenization (HPH). The physicochemical properties of β-carotene nanoemulsions are improved by coating emulsions with starch caseinate and chitosan-epigallocatechin-3-gallate conjugates (Wei and Gao, 2016).

Encapsulation of Nitraceuticals within Nanoemulsions

Nutraceuticals is a generic term used to designate any product derivate from food sources with extra health benefits. They are used in food industry to enhance the quality of processed foods. The nutraceuticals often encapsulated into nanoemulsions include resveratrol, vitamin D, vitamin E, phytosterol, astaxanthin, curcumin, lecithin and so on.

Resveratrol

Resveratrol is a type of stilbenoid, which is a form of natural phenol and a phytoalexin produced by several plants in response to injury or when the plant is attacked by pathogens (Jasinski *et al.,* 2013). This compound is found in grape skins, blue barriers, raspberries, knot weeds, pine trees, peanut plant, cocoabushes and Vaccinium shrubs that produce berries such as mulberries, cranberries and bilberries (Jasinski *et al.,* 2013; Sales and Resurreccio, 2014). Resveratrol has many functional properties such as antioxidant, anticancer, anti-obesity, reduction of blood pressure and used in the treatment of Alzheimers diseases (Liu *et al.,* 2014; Carter *et al.,* 2014). Nanoemulsions based delivery systems have been employed to encapsulate resveratrol and encapsulation of this compound is by spontaneous emulsification using 10% oil phase (grape seed oil and orange oil), 10% surfactant (Tween 80) and 80% aqueous phase with 100nm droplet size and 120+10ug/ml of resveratrol (Davidov-Pardo and McClements, 2015). The encapsulated resveratrol improves the chemical stability against UV-light degradation (Davidov-Pardo and McClements, 2015).

Vitamin D

Vitamin D is a group of fat-soluble secosteroids responsible for increasing intestinal absorption of calcium, magnesium and phosphate and multiple other biological effects in humans (Holick 2004). The most important of the vitamin D compounds are vitamin D3 (cholecalciferol) and vitamin D2 (egocalciferol) (Holick, 2006). The o/w edible nanoemulsions of vitamin D have been used for the fortification of dairy emulsions. The preparation involves emulsifiers polysorbate 20, soybean lecithin and their mixtures and dispersed oil phase of soybean oil or mixtures of the oil with cocoa butter for nanoemulsions of mean diameters of <200nm with the method of high pressure homogenization (Golformitsou *et al.*, 2018). Vitamin D3 (0.1-0.5ug/ml) can be encapsulated in the oil cores of the stable nanoemulsions while whole fat milk can be fortified with vitamin D3 nanoemulsions and can be stable for 10 days against particle growth and gravitational separation (Golformitsou *et al.*, 2018).

Vitamin E and Phytosterol

Vitamin E is a group of eight fat-soluble compounds that include for example tocopherols and four tocotrienols. Vitamin E has many biological functions including a role as a fat-soluble antioxidant in which it acts as a radical scavenger by delivering a hydrogen (H) atom to free radicals (Galli *et al.*, 2017). Phytosterol, composed of plant sterols and stanols, are phytosteroids occurring in plants and vary only in carbon side chains and/or presence or absence of double bonds. Phytosterols are claimed to reduce blood cholesterol and coronary heart diseases (EFSA, 2008). It is reported that O/W nanoemulsions of kenaf seed oil stabilized with emulsifiers of sodium caseinate, beta-cylodextrin and Tween 20 (Table 1) improved *in vitro* bioavailability and physicochemical stability of bioactive copounds and antioxidants (Galli *et al.*, 2017). It was also observed by Cheong *et al.* (2018) that after 8 weeks of storage at 4^0C, the nanoemulsions were stable and maintained antioxidant activities with high percentage retention of vitamin E and phytosterol.

Astaxanthin

Astaxanthin is a carotenoid pigment used as a dietary supplement which is a light sensitive molecule (Jamuna and Vittal, 2019). It has some biological activities including antioxidant and anti-inflammatory properties, immune-enhancing effects, DNA and skin repair effects (Davinelli *et al.,* 2018). Nanoemulsions have been formulated to photostabilize the pigment for its use in foods and chitosan-coated and carrageenan-coated nanoemulsions of astaxanthin provide nanoemulsions protection against UV light and photodegradation (Alarcon Alarcon *et al.,* 2018).

Curcumin

Curcumin is a bright yellow chemical produced by *Curcuma longa* plants, sold as herbal supplement, cosmetic ingredient, food flavouring and food colouring (Majecd, 2015). Curcumin has wide functional features such as anti-diabetic anti-cancer anti-inflammatory and anti-oxidant activities (Zahra *et al.*, 2019). Curcumin nanoemulsions prepared with chitosan and alginate had improved antioxidant capacity during *in vitro* digestion and a better control over high lipophilic bioactive compounds and these nanoemulsions can be used to fortify functional foods for targeting obesity (Silva *et al.,* 2018).

The pharmacokinetic properties of curcumin including biological half-life and bio-availability (or bio-accessibility) can be improved by nanoencapsulation into nanoemulsions for better clinical and functional efficacy *in vivo* (Zahra *et al.,* 2019). Nanoemulsions of curcumin have been formulated with improved antioxidant capacity.

Lecithin

Lecithin is a generic term to denote any group of yellow brownish fatty substances occurring in animal and plant tissues which is amphiphilic, and attracts water and fatty substances. It is used for smoothing food textures, emulsifying, homogenizing liquid mixtures and repelling sticky materials (Smith and Hong-Shum, 2011). Lecithin is used in the preparation of nanoemulsions for use in food industry. Lecithin-stabilized nanoemulsions of curcumin have been reported by Bhosale *et.al.* (2014) to have an encapsulation efficiency of 75% and were stable for 86 days in comparison to other surfactants such as Tween 20 stabilized curcumin nanoemulsions.

Encapsulation of Natural Preservatives within Nanoemulsions

Natural preservatives are ingredients that are found in nature and can without artificial processing or synthesis with other substances prevent products from premature spoilage. These substances can be safe and effective alternatives to controversial synthetic preservatives such as parabens (Bhosale *et al.,* 2014). Natural preservatives are used to extend the shelf life of products, reduce spoilage, and retain smell or taste (Jamuma and Vittal, 2019). Natural preservatives have strong anti-microbial activities by inhibiting food borne pathogens including bacteria and fungi. They are equally antioxidant by delaying or stopping the process of oxidation in food and also some natural preservatives act on enzymes to stop aging of food products (Rauch, 2019). Natural preservatives used in food processing are mainly essential oils (EOs) including oregano EO, Orange EO, and ginger EO as well as such compounds like cinnamaldehyde, curcumin, capsaicin and so on.

Oregano Oil

Oregano oil, also called carvacrol, is an essential oil extracted from the oregano plant (*Origanum vulgare*), a flowering plant in the mint family, Lamiaceae. Oregano oil is widely recognized for its antimicrobial, antiviral, anti-fungal, anti-oxidant, anti-inflammatory, anti-diabetic, and cancer suppressor properties which are of potential interest in food, cosmetics and pharmaceutical industries (Leyva-Lopez *et al.,* 2017). Nanoemulsion formulations of oregano oil is composed of O/W oregano oil, Tween 80 and prepared by ultrasonication with 148um droplet size. It has been reported that oregano oil nanoemulsion inhibited the growth of food borne bacteria namely *Listeria monocystogenes*, *Salmondla typhimurium and Escherichia coli* on fresh lettuce (Jamuna and Vittal, 2019). Also, it was observed that oregano oil nanoemulsions disrupted bacterial membranes (Bhargava *et al.,* 2015).

Orange Oil

Orange oil is an essential oil produced by cells within the rind of an orange fruit (*Citrus sinensis*) of the family Rutaceae. The orange oil is described as providing various benefits including possibility of reducing stress, controlling anxiety, enabling relaxation and lighting mood (Verzera *et al.,* 2004). Sugumar *et al.* (2015) reported that orange oil nanoemulsion is prepared by ultrasonication techniques using O/W of orange oil, Tween 80 and distilled water and it inhibited spoilage of apple juice by *Saccharomyces cerevisiae.*

Cinnamaldehyde

Cinnamaldehyde is an aldehyde that occurs naturally in the bark of cinnomon tree (*Cinnamomum zeylanicum*) of the family

Lauraceae which gives the plant its flavor and odour. It is used as flavouring in chewing gum, ice cream, candy, liquid and beverages as well as in some perfumes of natural, sweet or fruity scents and as a food adulterant (Friedman *et al.,* 2000). Cinnamaldehyde nanoemulsions incorporated in pectin edible films, reportedly inhibited the growth of *E.coli*, *Salmonella enterica, Listeria monocytogenes* and *Staphylococcus aureus* (Otoni *et al.,* 2014). The nanoemulsion is prepared by spontaneous emulsification technique with 20-500nm droplets size composed of cinnamaldehyde, Tween 80 and distilled water

Oregano Oil Clove Budoil

The formulation of clove bud oil and oregano oil into nanoemulsion with 180-250um droplet size incorporated into edible methyl cellulose films had been reported by Otoni *et al.* (2014b) to have improved antimicrobial activity and also prevented the growth of yeast and molds and equally improved shelf life. The clove bud oil (eugenol) is the essential oil extracted from the buds of the flowering plant clove (*Syzygium aromaticum* belonging to the family of Myrtacae. The oil of clove is used to relieve pain, toothache, and as local anesthetic (Chung and Oh, 2013).

Ginger Oil

Ginger essential oil is extracted from the rhizomes (roots) of the ginger plant (*Zingiber officinale*) of the family Zingiberaceae which is usually used to add flavour to foods. It has antibacterial, antifungal, analgesic, anti-ulcer, imnmuno-modulatory, relaxant, warming and anti-inflammatory properties (Mahboudi, 2019). Nanoemulsions of ginger essential oil incorporated into gelatin-based films have been shown to improve the physical poperties of food packing films (Alexandre *et al.,* 2016).

Curciumin

Curcumin nanoemulsions prepared by spontaneous emulsification with mean droplet size of 40nm and pectin edible coatings were reported by Abdou *et al.* (2018) to increase the shelf life of chilled chicken at 4^0C for 12 days and also reduced microbial spoilage by inhibiting growth of psychrophiles (extremo philic organism capable of growth and reproduction in low temperatures), yeasts and molds in food products. Also the curcumin nanoemulsions showed reduced values of total volatile nitrogen and thiobarbituric acid, water holding capacity and texture, and higher sensory scores in comparison to the control (Abdou *et al.*, 2018).

Capsaicin

Capsaicin belongs to a class of compounds called capsaicinoids produced as secondary metabolites by chili peppers which are of the genus *Capsicuin* in the family Solanaceae. Capsaicin (oleoresin capsicum) is used as an analgesic in topical ointments and dermal patches and used for the treatment of arthritis, back ache, strains and sprains (Padhan *et al.*, 2015). Capsaicin nanoemulsions are prepared by high pressure homogenization and ultrasonication with Tween 80 as the aqueous phase and droplet size of 65nm. According to Akbas *et al.* (2018), ultrasonication improved physical properties as nanoemulsions with particle size below 65nm were obtained while high pressure homogeuization resulted in the preparation of nanoemulsions with good inhibitory activity against *Staphylococcus aurous* and *E.coli.*

Industrial Applications

Some food industries have practically utilized nanoemulsions in their food systems. For instance Nestle and Unilever and a few start-ups have used nanoemulsions in their food products (Silva *et al.*, 2012, Salvia-Trujillo *et al.*, 2017). Nestle has developed O/W (water and oil) nanoemulsions and patented polysorbates and micelle-forming emulsions for rapid and uniform thawing of frozen foods in the microwave (Moller *et al.*, 2009). Unilever has used nanoemulsions in ice creams for reducing fat content from 16to1% (Martins *et al.*, 2007;Unilever, 2011). Novel nanoencapsulation method known as nano-sized self-assembled structured liquids (NSSL) has been developed by Nutralease, a technology start-up company. Small compressed micelles, called nanochops are developed and these micelles serve as carriers for fat soluble bioactives. The micelles are incorporated in food products usually pass through the digestive system effectively and to the absorption sites without undergoing degradation. These nanoemulsions have been used for developing beverages with functional compounds. Nutraleave with NSSL technology has fortified beverages with nanoemulsions of lipophilic compounds such as β-carotene, omega-3, vitamins, phytosterols, and is flavones (Nutra Leave, 2011). In the same vein AquaNova Industry has developed NovaSol beverages fortified with nanoemulsions of functional compounds and natural colorants eg β-carotene, apocarotenal, chlorophyll, curcumin, lutein, and sweet pepper extract). It is claimed that these encapsulated compounds in nanoemulsions had enhanced stability and standardized additive concentrations (AquaNova, 2011).

Conclusion

There has been tremendous development in the application of nanotechnology in food industry particularly in food processing. Nanotechnology plays critical roles in the detection of pesticides, toxins and pathogens, prevention and destruction of pathogens in food products which help in the maintenance food quality and safety. Different types of nanomaterials are utilized in food industries such as nanocomposites, encapsulated nanomaterials, nanosensors, nanoparticles and nanoemulsions. Nanoemulsions are particularly used in food processing as colouring and flavouring agents, as antimicrobials and antioxidants and for the fortification of the functional properties of food products. The nanoemulsions-based delivery systems and nanoemulsion edible coatings can improve the functionalities of foods and equally enhance food quality and shelf life. In actual fact, nanoemulsions of bioactive compounds and functional food ingredients have a great potential for applications in the food industry particularly in food processing sector especially in developing countries like Nigeria. It is recommended here that further studies be carried out on the biological events and the health and environmental risks associated with the use of nanoemulsions in food products in order to ensure safety of nanoprocessed foods to humans.

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