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A Systematic Review of Encapsulation and Control Release Technology in food Application

Research Article

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Abstract

This study is aims to give a brief description ofencapsulation and control release technology in food application with research reports and verification of well-known common sense in elsewhere, that exist as part of the commonly known and very effective in food preservation. Besidesthe material give potential information for those who interested for futuredevelopment perspectives of the sector and also create awareness potentiallyfor readers, traders, Students, factory workers, technologist and related stakeholder. A process to entrap active agents within a carrier material called Encapsulation and it is a useful tool to improve delivery of bioactive molecules and living cells into foods. Therefore, encapsulation preserve stability of the bioactive compounds during processing and storage and to prevent undesirable interactions with food matrix. During encapsulation process, a large number of substances are used to encapsulate solid or liquid food ingredients. Micro-organisms are the main agents responsible for food spoilage and food poisoning and therefore food preservation procedures are targeted towards them. Generally,the selection of encapsulating materials depends on the types, origins, and properties of these food ingredients.It is being increasingly popular in pharmaceutical, nutraceutical and functional food industries as a highly effective method that performs various functions; the major being prolonging the shelf-life of the active, masking the undesirable flavour, colour and taste and controlling the release of bioactive.

Keywords: Food Preservation; Technology; Encapsulation; Control Release; Future Potential.

Introduction

A process to entrap active agents within a carrier material called Encapsulation and it is a useful tool to improve delivery of bioactive molecules and living cells into foods. The encapsulated substance, except active agent, named as the core, fill, active, internal or payload phase. The substance that is encapsulating is often named as the coating, membrane, shell, capsule, carrier material, external phase, or matrix [1, 2]. In the food industry, encapsulation process can be applied for a variety of reasons. Encapsulation is a useful tool to improve delivery of bioactive molecules (e.g., antioxidants, minerals, vitamins, phytosterols, lutein, fatty acids, lycopene) and living cells (e.g., probiotics) into foods [1, 3]. In most cases, encapsulation refers to a technology in which the bioactive components are completely enveloped, covered and protected by a physical barrier, without any protrusion of the bioactive components [3]. Produced particles usually have diameters of a few nm to a few mm [1]. Functional compounds are used to control flavour, colour, texture or preservation properties. Bioactive compounds with various potential health benefits are included, too.

There is a multitude of possible benefits of encapsulated ingredients in the food industry. Encapsulation aims to preserve stability of the bioactive compounds during processing and storage and to prevent undesirable interactions with food matrix. Mainly, bioactive food compounds are characterized by rapid inactivation. In addition to the above, encapsulation can be applied for modification of physical characteristics of the original material in order to (a) allow easier handling, (b) to help separate the components of the mixture that would otherwise react with one another, (c) to provide an adequate concentration and uniform dispersion of an active agent [4].

These compounds would profit from an encapsulation procedure, since it slows down the degradation processes (e.g., oxidation or hydrolysis) or prevents degradation until the product is delivered at the desired sites [5]. The European Directive (3AQ19a) defines controlled release as a “modification of the rate or place at which

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an active substance is released." Such a modification can be made using materials with specific barrier properties for manipulating the release of an active and to provide unique sensory and/or functional benefits. Addition of small amounts of nutrients to a food system, for example, may not affect its properties significantly; however, incorporating high levels of the nutrient either to meet certain requirements or to treat an ailment will most often result in unstable and often unpalatable foods. Examples of such nutrients include fortification with calcium, vitamins, polyunsaturated fatty acids, and so on, and the associated grittiness, medicinal and oxidized taste, respectively. Different types of controlled-release systems have been formulated to overcome these challenges and to provide a wide range of release requirements. The two principal modes of controlled release are delayed and sustained release.

Delayed release is a mechanism whereby the release of an active substance is delayed from a finite "lag time" up to a point when/where its release is favored and is no longer hindered. Examples of this category include encapsulating probiotic bacteria for their protection from gastric acidity and further release in the lower intestine, flavor release upon microwave heating of ready-meals or the release of encapsulated sodium bicarbonate upon baking of a dough or cake batter.

Sustained release is a mechanism designed to maintain constant concentration of an active at its target site. Examples of this release pattern include encapsulating flavors and sweeteners for chewing gum applications so that their rate of release is reduced to maintain a desired flavor effect throughout the time of chewing. A wide range of cores (encapsulants), wall-forming materials (encapsulating agents), and technologies for controlling the interactions of ingredients in a given food system and for manufacturing microcapsules and micro particles of different size, shape, and morphological properties are commercially viable. Therefore, the objective of this material is to providebrief overview to the basic understanding and common process to encapsulate food active agent and control release system in food processing.

Overview Of Encapsulation And Control Release

Principles and equipment of encapsulation and control release

Wall-Forming Materials: Wall forming materials are a shell material used for food ingredients encapsulation. Because, a large number of substances are used to encapsulate liquid or solid food ingredients; the selection of encapsulating materials depends on the origin,types, and properties of these food ingredients. Among various shell materials only some numbers have been certified for food applications as "overall recognized as safe" materials. In general, these encapsulating agents are biopolymeric substances such as lipids, proteins, gums or their derivatives. Materials used in film coating or matrix formation include several categories:

• Waxes and lipids: Candelilla, beeswax, and carnauba waxes, wax micro- and wax macroemulsions, modified fats and glycerol distearate, natural.
• Proteins: soy proteins, gelatins, whey proteins, gluten,zein, and so on. All these proteins are available both in modified forms and native.
• Carbohydrates: maltodextrins, starches, chitosan, sucrose, ethyl cellulose, cellulose acetate, glucose, alginates, chitosan, carrageenan's, and so on.
• Food grade polymers: poly vinyl acetate, polypropylene, polybutadiene, polystyreneand so on.

Carbohydrates: Starch and starch derivatives for instance maltodextrin, cellulose derivatives for instance carboxymethyl cellulose, gums for instance gum Arabic, guar gum and chia seed gum and β-cyclodextrin are the most commonly used carbohydrate-based wall materials. This is because of their abundant availability, excellent core protection ability, bland flavour, these wall materials are used to encapsulate diverse food materials such as oxygen sensitive and PUFA-rich oil, vitamins, proteins & bioactive peptides, enzymes and flavour [6-8]. Modified starches are produced by inducing side chains of lipophilic succinic acid to increase the emulsifying ability of starch. Moreover, Modified starches are found to show better protection than native and waxy starch [9] and offer exciting emulsion stability [10].

Proteins: Superior functional and physicochemical properties including gel forming ability, emulsifying capacity and film formation capability make proteinan excellent encapsulating material which find huge applications in food industries [11, 12]. Gelatin is the widely used shell matrix used to manufacture highly stable soft gels of omega-3, vitamin D and fish oil. Milk proteins such as sodium caseinate and whey protein isolate, and other plant proteins such as soy proteins, pea proteins have been used as wall materials for several years. Whey protein has also been reported as fantastic wall materials for encapsulating sensitive flavours and PUFA-rich oils. This protein possesses excellent encapsulation efficiency (up to 89.6%) over other proteins such as soy protein (up to 75.9%) [13, 14]. The authors found that resultant microcapsules recovered by spray drying remain stable over 60 days at high water activity (aw = 0.74 - 0.90) [14]. One of the major limitations of using protein as encapsulants is their allergenicity to some individuals.

wheat protein (e.g., gluten), Soy proteins, and peanut proteins are reported to be highly allergenic to a number of individuals. This not only limits their application but also warrants manufacturer declaration on the label for their presence in the designed foods. In addition, proteins are sensitive to structural changes and their effectiveness as wall materials is greatly dependent such as pH, ionic strength and temperature of the emulsions or solution [5, 14]. Even Hough, blending these proteins with other materials, particularly carbohydrate-based biopolymers, such as maltodextrin, corn syrup solids and lactose has been reported to be an effective method to minimize environmental effect on their functionality as encapsulants [15, 16].

Lipids: Since lipids are hydrophobic materials and are insoluble in water and hence, they are widely used to encapsulate hydrophilic substances.Many different types of lipids including phospholipids, glycerides, fatty acidsand waxes have been explored for their ability to encapsulate food actives [1]. Although lipid-based encapsulation technology is relatively new and emerging field, it is becoming highly popular as a means of delivering pharmaceutical, bioactive food and nutraceutical ingredients. Main types of lipid-based delivery systems are four: Nano emulsions, nanoliposomes, solid lipid nanoparticles and nanostructure lipid carriers [17].

Core Materials: Coating substances that are basically film forming materials can be selected from a wide variety of synthetic polymers or natural, depending on the characteristics desired in the final microcapsules the material to be coated. The coating composition is the main determinant of the functional properties of the microcapsule and of the method to be used to improve the performance of a particular ingredient. An effective coating material should have good rheological properties at high concentration and ease of manipulation during the process of encapsulation and also, selected so that it produces a stable emulsion or dispersion with the active ingredient, and does not react or degrade the active material during processing and storage. Beside this, it should meet specified or desired capsule solubility properties and active material release properties.

Coating materials for encapsulation of food ingredients can be subdivided into cellulose, gums, lipids, and proteins. Core materials include flavors, nutraceutical, antimicrobial agents, and therapeutic actives, vitamins, alkalis, buffers, sweeteners, minerals, antioxidants, colors, acids, nutrients, enzymes, cross-linking agents, yeasts, chemical leavening agents, and so on. For instance, encapsulation by extrusion and spray drying depends primarily on the carbohydrates used for the encapsulation matrix. Furthermore, Gums usually used as control crystallization, texturing ingredients, stabilize emulsions, and inhibit syneresis (the release of water from fabricated foods), thereby improving coating properties. Lipids are generally used for encapsulation for water soluble ingredients. Protein ingredients are also effective in encapsulating food ingredients. In particular, gelatin is used in coacervation.

Processing technology of encapsulation and control release

Release Triggers: Encapsulation and controlled-release systems can be designed to respond to one or a combination of triggers that can activate the release of the entrapped substance and to meet a desired release target or rate. Triggers can be one or a combination of the following:

• Temperature: fat/wax matrices
• Moisture: hydrophilic matrices
• pH: enteric coating, emulsion coalescence, and others.
• Enzymes: enteric coating as well as a variety of lipid, starch and protein matrices.
• Shear: chewing, physical fracture, and grinding
• lower critical solution temperature (LCST) of hydrogels.

The Payload is means to estimate the amount of active (core) entrapped in a given matrix or wall material (shell) and the percentage of payload is expressed as Equation: Payload (%) = [core) / (core + shell)] * 100

Entrapment of Actives in Food Matrices: Encapsulation of active into an amorphous matrix, generally, involves melting a crystalline polymer using heat and/or shear to transform the molecular structure into an amorphous phase. The encapsulant is then incorporated into the metastable amorphous phase followed by cooling to solidify the structure and form glass, thus restricting molecular movements. Carbohydrates are excellent candidates for encapsulation applications due to the several attributes possessed by them.

• They form an integral part of many food systems.
• They are cost-effective.
• They occur in a wide range of polymer sizes.
• They have desirable physicochemical properties such as solubility, melting, phase change and so on.

Sucrose, maltodextrins, native and modified starches, polysaccharides, and gums have been used in encapsulating flavors, minerals, vitamins, probiotic bacteria as well as pharmaceutical actives. The unique helical structure of the amylose molecule, for example, makes starch a very efficient vehicle for encapsulating molecules like lipids, flavors, and so on [18]. Some carbohydrates such as inulin and trehalose can provide additional benefits for encapsulation applications. Inulin, for example, is a prebiotic ingredient that can enhance survival of probiotic bacteria while trehalose serves as a support nutrient for yeasts.

Spray drying and Extrusion are the two main technologies have been used in large-scale encapsulation applications into amorphous matrices, though using different mechanisms.

In spray drying, for example, the active is trapped within porous membranes of hollow spheres, while in extrusion the goal is to entrap the active in a dense, impermeable glass. Encapsulating actives via spray drying requires emulsifying the substrate into the encapsulating agent. This is important for flavor applications, in particular, considering the fact that most flavors are made up of components of various chemistries (polarity, hydrophobic to hydrophilic ratios), thus limiting their stability when dispersed or suspended in different solvents. Hydrophobicity is one of the most critical attributes that can play a significant role in determining flavors' payload as well as their release in food systems. The basic principle of spray drying has been adequately covered by [19].

Briefly, the process comprises atomizing a micronized (1–10-micron droplet size) emulsion or suspension of an active and an encapsulating substance and further spraying the same into a chamber. Drying takes place at relatively high temperatures (210°C inlet and 90°C outlet), though the emulsion's exposure to these temperatures lasts only for few seconds. The process results in free flowing, low bulk density powders of 10–100-micron size. Optimal payloads of 20% can be expected for flavors encapsulated in starch matrices. Maltodextrins and sugars with lower molecular weight, due to their low viscosities and inadequate emulsifying activities, result in lower flavor payloads. Several factors can impact the efficiency of encapsulation via spray drying, mainly those related to the emulsion (solid content, molecular weight, emulsion droplet size, and viscosity) and to the process (feed flow rate, inlet/outlet temperature, gas velocity, and so on).

Release of flavors from spray-dried matrices takes place upon reconstitution of the dried emulsion in the release medium, water most often. Reasonable prediction of the release behavior should take into consideration the complex chemistry of flavors and the prevailing partition and phase transport mechanisms between aqueous and non-aqueous phases [20, 21]. Encapsulation into an amorphous matrix via extrusion has gained wide popularity with applications ranging from entrapping flavors for their controlled release to masking the grittiness of minerals and vitamins. Hot melt extrusion is a highly integrated process with many unique advantages for encapsulation applications, namely:

• Extruders are multifunctional systems (many unit operations) that can be manipulated to provide desired processing temperature and shear rate profiles by varying screw design, barrel heating, mixing speed, feed rate, moisture content, plasticizers, and so on.
• Possibility of incorporating actives and other ingredients at different points of the extrusion process. Heat-labile actives, for example, can be incorporated via temperature-controlled inlets toward the end of the barrel and their residence time in the extruder can be minimized to avoid degradation of the active and to preserve its integrity.
• Extruders are also formers: encapsulated products can be recovered in practically any a desired shape or size (pellets, rods, ropes, and so on).
• Only very limited amount of water is needed to transform carbohydrates from their native crystalline structure to amorphous glassy matrices in an extruder, thus limiting the need for expensive downstream drying.
• High payload: up to 30% can be expected when encapsulating solid actives in extruded pellets.
• Economics: attributes such as high throughput, continuous mode, and limited need for drying make extrusion a very attractive process for manufacturing encapsulated ingredients.

Carbohydrate (encapsulating matrix), a mixture of sucrose and maltodextrin, is dry fed and melted by a combination of heat and shear in the extruder barrel so that the crystalline structure is transformed into an amorphous phase. It should be cautioned that although glass transition and associated microcapsule stability are clearly related to the material properties of the matrix and rates of crystallization, there is growing evidence that in the glass transition region small molecules are more mobile than might be expected from the high viscosity of the matrix [22].

Types of Encapsulated Food Ingredients

The types of food ingredients that can be encapsulated are shown in Table [23]. Applications for encapsulation have been slow to expand since the technique was formerly thought to be too expensive and highly specific. However, since production volumes have increased and become more cost-effective, a wide variety of encapsulated foods can be found. Flavored oil encapsulated in food-grade hydrocolloid is an example of water-soluble capsules commonly found.

Flavoring agents and spices are encapsulated by a variety of processes and offer numerous advantages to the food processor. Citrus oil and other flavors, for example, provide enhanced stability to oxidation, volatilization, and light, controlled release, resistance to clumping and caking, and substantially longer shelf life [24]. Encapsulated flavors are available as natural flavors, natural and artificial flavors, essential oils (menthol, peppermint, and spearmint), oleoresins, natural flavors with other natural flavors added, chips, and artificial flavors. Although encapsulated flavors may be used in many different applications, they are currently gaining considerable attention for their stability through high-temperature/short-time processes such as those utilized in preparing extruded foods and microwavable foods.

Acidulants are added to foods as flavor modifiers, preservatives, and processing aids. Unencapsulated food acids can react with food ingredients to produce many undesirable effects. These include deceased shelf life of citrus flavored foods and starch containing foods, loss of flavor, degradation of color, and separation of ingredients. Encapsulated food acids resolve these and other problems because they preclude oxidation and provide controlled release, with their coating formulated to dissolve or melt at specific temperatures. Furthermore, encapsulated acids reduce hygroscopicity, reduce dusting, and provide a high degree of flowability without clumping. Examples of encapsulated acidulants that are commercially available are adipic acid, ascorbic acid, citric acid, fumaric acid, lactic acid, and malic acid [24]. Encapsulated acidulants can be used as dough conditioners and in meat processing (e.g., in cured meat products). For example, uncoated lactic acid and citric acid cannot be used in the production of cured meats because they react almost instantaneously with the meat, rendering it unsuitable for further processing. However, an encapsulated acid that is formulated for delayed release at smoldering temperatures can be used, reproducing the same pH as that obtained with lactic acid bacteria, eliminating the need for fermentation. Thereby, production time can be reduced.

Table. Various food ingredients that can be encapsulated [23].

Type of ingredient
· Flavoring agents such as oils, spices, seasonings and sweeteners
· Acids, alkalis, buffers
· Lipids
· Redox agents (bleaching, maturing)
· Enzymes and microorganisms
· Artificial sweeteners
· Leavening agents
· Antioxidant
· Preservatives
· Colorants
· Cross-linking and setting agents
· Agents with undesirable flavors and odors
· Essential oils, amino acids, vitamins, minerals

Microencapsulation also enables ingredients such as enzymes to maintain their viability for extended periods of time, avoiding their exposure to ions, protons, free radicals or other type of deleterious agent. Sweeteners are often subject to the effects of moisture and/or temperature. Encapsulation of sweeteners, namely sugars and other nutritive sweeteners, reduces their hygroscopicity, improves their flowability, and prolongs their sweetness perception. Sodium chloride, encapsulated with a variety of coatings, including partially hydrogenated vegetable oil, is used in formulations to control color degradation, rancidity, water absorption, and yeast growth. The encapsulated form also improves flowability and reduces clumping and caking. Typical product applications include ground meats, pretzel snacks, and yeast dough [24]. Leavening agents such as sodium bicarbonate are used in baked goods to achieve volume andlightness of texture. Encapsulated sodium bicarbonate protects the base from premature reaction with acid or water, and delays the release of its contents until optimum baking conditions are present. This ensures that maximum leavening is achieved and proves to be economically attractive.

Mechanisms Of Microbial Inactivation

Micro-organisms are the main agents responsible for food spoilage and food poisoning and therefore food preservation procedures are targeted towards them. Food preservation methods currently used by the industry rely either on the inhibition of microbial growth or on microbial inactivation. Methods which prevent or slow down microbial growth cannot completely assure food safety, as their efficacy depends on the environmental conditions. Microbial can be inactivated through the treatment by heat, chemical agents, radiations and the combination of these.

Inactivation by Heat

Heat has been widely used in the food industry as a preservation agent, since it is capable of inactivating most microorganisms and enzymes present in foods. Therefore, heat is a method that can simultaneously guarantee food safety and food stability. Heat treatments can be classified into two groups depending on their intensity and their objective: pasteurization and sterilization treatments. Pasteurization treatments aim to inactivate vegetative cells of pathogenic species present in foods; they also extend shelf life, as long as foods are maintained under refrigeration conditions. Sterilization treatments are applied in order to guarantee the stability of the food product at room temperature, an objective that requires the application of temperatures above 100°C in most cases. Such intense treatments are capable of inactivating microbial spores as well as many enzymes and toxins present in foods, but can also severely modify their organoleptic and nutritional properties. Thermal treatments are widely used because of their capacity to inactivate vegetative cells, bacterial spores, yeast and molds. The type of inactivated microorganism depends, of course, on the treatment's intensity. The degree of heat resistance of different microbial groups varies widely, due to their differing structure and composition, as well as the mechanisms of resistance they are able to develop. The application of this basic knowledge could help improve the design of current pasteurization processes, leading to milder and/or more effective treatments that could fulfill consumer requirements for fresh-like foods while maintaining the advantages of traditional heat treatments [25].

Inactivation by irradiation

Irradiation of foods and feeds for the purpose of killing indigenous microbes, and thereby extending shelf life, has been recognized as a preservation technique for several decades. Irradiation also can be successfully applied to fresh fruits and vegetables for the purpose of controlling disease and deterioration caused by molds as well as for achieving insect disinfestation.

The survival of microbial cells upon treatment with irradiation depends on several factors [26]. These include the nature and extent of direct damage produced inside the vital target, the number, nature, and longevity of irradiation-induced reactive chemical species, and the inherent. ability of the cell to withstand these assaults and undergo repair. Resistance also depends on extracellular environmental conditions such as pH, temperature, and chemical composition of the food in which cells are suspended. Ionizing irradiation damages DNA at the cellular level, thus debilitating normal biochemical processes.

Chemical inactivation

There are many chemicals that will kill or inhibit the growth of microorganisms. An antibiotic generally refers to a chemical that can be used on or inside a patient (humans, pets, livestock, etc.) to inhibit the growth of microbes or kill microbes. Commonly used chemical preservatives include sorbic acid, benzoic acid, and propionic acid, and their more soluble salts potassium sorbate, sodium benzoate, and calcium propionate, all of which are used to control the growth of molds in acidic foods.

Critical Factors Determining Microbial Inactivation

Microbial inactivation by irradiation, ultrasound under pressure, HHP and PEF has been found to depend on many factors. Effective comparison of data published in literature is hampered by the diversity of equipment's and experimental conditions employed by the different authors. Nevertheless, this section tries to give an overview on the most relevant factors affecting resistance to novel technologies. The factors are classified into three groups: process parameters, microbial characteristics and product parameters.

Process parameters

Some process parameters are intrinsic to each technology and no general conclusions can be drawn. For instance, the intensity of an irradiation treatment is given by the irradiation dose absorbed, as the radiation energy is normally fixed [25]. Critical inherent parameters for ultrasound under pressure are treatment time, amplitude of the ultrasonic waves and external pressure applied [26].

Microbial characteristic

Maximum inactivation levels attained with each technology will depend on factors such as equipment technical developments and food characteristics. The point is that comparison of data is compered by the different equipment's, treatment media, strains, etc. Microbial resistance to different physical agents depends not only on the intrinsic resistance of the micro-organisms but also on their physiological state. It is well known that bacterial heat resistance varies widely depending on the growth phase, growth temperature and exposure to previous stressing environments [27].

Product parameters

Environmental factors, such as composition of the treatment medium, pH, water activity or addition of preservative substances, strongly affect the resistance of micro-organisms to heat. The relative influence of such factors on microbial resistance to novel technologies depends on their mechanisms of action. One of the most important factors influencing irradiation sensitivity is the composition of the treatment atmosphere. The presence of oxygen during irradiation has been found to enhance lethal effect because of oxygen radical formation [25].

Current Emerging Combination Technologies For Food Processing

Microwave Combination Technology

food products heated by MW shows better retention in color, texture, and flavor compared with conventionally treated products, MW heating is associated with numerous problems, such as nonuniform heating, partial overheating, and limited penetration [28, 29]. Conventional methods such as vacuum drying (VC) and hot air (HA) heating can preserve the quality of perishable agricultural products without any damage during processing; however, it takes considerable time and consumes more energy with low energy efficiency to complete the processing [30]. MW technology combined with the aforementioned conventional methods has been investigated particularly in drying and baking processes.

Infrared Radiation Combination Technology

IR heating is considered a promising method especially for drying processes, observed problems in IR drying include scorching heat on the surface of food products and a limited IR penetration depth [31]. Case hardening is a troublesome problem occurring in conventional HA drying process because the surface of food material is dried first, and as drying process progress, the dried surface of food becomes a barrier to heat transfer [32]. To prevent undesirable phenomenon caused by either IR or conventional heating methods, a number of studies on dehydration of food products using integrated IR and conventional methods have been conducted.IR-assisted HA drying processes for fruit and vegetable has been evaluated and developed [33, 34].

High-Pressure Processing Combination Technology

High-pressure processing (HPP) has been mainly applied to pasteurize liquid food products; however, it often times could not inactivate bacterial spores (e.g., Bacillus and Salmonella) which are heat and acidic resistant [35]. Therefore, thermal treatment has been applied to HPP as a pretreatment step. The effectiveness of HPP combined with thermal treatment (TH) on the inactivation of PMEs and the inactivation kinetics in various agricultural products were evaluated by a number of researchers [36].

Radio Frequency Electric Field Combination Technology: Ukuku and Geveke [37] developed a combined UV light and RF electric field (RFEF) system to inactivate Escherichia coli K-12 in apple juice. Apple juice was preheated up to 25, 30, and 40 0C and then treated by individual UV, RF and combined UV with RF treatment. After all treatments, apple juice samples inoculated with microbial contaminant were analyzed for leakage of UV-absorbing substances as the function of cell membrane injury. The individual UV and RFEF treatment at 40^{0}C showed the minimum surviving population of E. coli K-12 in the juice. A higher bacterial inactivation was expected when the two treatments were combined; however, the determined number was only an approximately 0.6 log microbial reduction higher than UV treatment alone. Although inactivation of E. coli K-12 in apple juice was not influenced by the combination system, UV-absorbing substances determined in the juice treated by combined treatment was substantially different from individual UV treated sample. The results suggested that combination treatment would damage bacterial cells and lead to more leakage of intracellular UV-absorbing substances than individual treatment.

Combined RF with HA treatment was investigated to improve the quality and mold control of enriched white bread [38]. Prior to RF–HA treatment, the bread columns inoculated with mold spores were kept under a sterile hood in order to equilibrate moisture content in the breads. Additionally, target HA and treatment temperatures controlled by an electrical fan heater and RF power were evaluated to maximize the mold lethal condition. Visible mold growth was observed from the surface of untreated bread loaves stored for five weeks at room temperature; on the other hand, mold was found in the sample after an extra four weeks using the combined RF–HA treatment. Moisture migration from the bread crumb to crust was caused by generation of internal vapor pressure during the RF heating. The consequent moisture loss in the bread crumb and increased moisture at the crust led to a more even distribution of moisture in the treated bread samples. Combined RF and HA treatment had little effect on the water activity of breads during storage.

Pulsed Electric Field combination technology: Synergistic effect of combined thermal treatment (TH) and pulsed electric field (PEF) on inactivation of microorganisms in liquid food products has been investigated by a number of researchers [39, 40]. In these studies, liquid food products (such as salad dressing, liquid whole egg, liquid egg york, apple juice, fruit smoothie-type beverage) pretreated using a heat exchanger, heating coil, or hot water bath at different temperatures were sequentially applied to the pulsed electric field (PEF) treatment. The effect of sequential TH and PEF treatment on inactivation of microbial contaminants, i.e., Lactobacillus plantarum, Escherichia coli O157:H7, Salmonella enteritidis in respective salad dressing, liquid whole egg, and liquid egg yolk was also investigated [39, 40]. Prior to PEF treatment, the liquid food product was preheated up to a certain temperature in the hot water bath. Preheated sample flowed between two disk electrodes and then through an electric field with a range of 9–15 kV/m with different pulse numbers and high frequency. The pulse width and frequency were adjusted using external transistor–transistor logic (TTL) with a frequency trigger. Increasing the pretreatment temperature of liquid food product (apple juice and liquid egg yolk) and higher electric field strength had a significant effect on the inactivation of peroxidase (POD), polyphenol oxidase (PPO), and E. coli O157, as well as, lower D-values [39].

Ohmic Heating Combination Technology: Combined ohmic and plate heating system for cooking hamburger patties was developed for the enhancement of physical properties of the patties [41]. A domestic plate grill was modified for the combination system. The plate was preheated first and then 50 V of alternating current was applied for OH. The required cooking time was determined to be 117 and 163 s for the combined and conventional techniques, respectively. The elasticity index of the conventionally cooked meat has a slightly higher value than that of cooked meat by ohmic–plate heating. This suggested that the meat cooked by the combination system would be less chewy. Otherwise, the mechanical properties of the meats cooked by individual plate and OH methods were very similar. The application of OH for cooking of hamburger patties did not affect the taste and texture of the meat.

Future Perspective (Development Potentials)

Encapsulation technology has been used in various industries for more than seven decades, there have been several advancements in both the science as well as the practical application of this technique since its first commercial application in 1950. It is being increasingly popular in pharmaceutical, nutraceutical and functional food industries as a highly effective method that performs various functions; the major being prolonging the shelf-life of the active, masking the undesirable flavour, colour and taste and controlling the release of bioactive. Encapsulation methods for new bio-actives are being explored and research advancement is underway to improve the process and product characteristics.

Innovative food-grade encapsulants are being explored to reduce the production costs and meet other technical specifications and consumer expectations. With the escalating demand of functional foods including omega-3s, probiotics, vitamins and phytochemicals, these functional ingredients are being incorporated into wide range of products such as breads, milk, fruit juices, tortillas, chocolate, yoghurt drinks, spreads, peanut butter, eggs and meat. Accordingly, various methods of microencapsulation of different bioactives have been developed. At present, spray drying-based microencapsulation method is being widely used in various industrial applications; however, more advanced methods including complex coacervation are gaining increased attention in recent years. Complex coacervation technology has been reported to receive a high product yield and the resultant product possesses prolonged stability even at a very high payload (up to 99%). In addition, it yields products with lowest unit product cost [43]. The biggest disadvantage of this technology is limited availability of shell materials. So far, gelatin is the only protein which is successfully used in commercial scale.

A number of studied have reported that the plant proteins are capable of forming coacervates in the presence of polysaccharides [44, 45]. This corroborates that plant proteins can be used instead of animal proteins in complex coacervation process. Reference [46] used α-gliadin (cereals) and pea globulin (legume) in complex coacervation process. These authors found that both these proteins form excellent complex coacervates with the gum Arabic. However, the application of α-gliadin in the coacervation process will not achieve widespread acceptance as this protein is associated with some kind of allergenicity in some individuals [46]. So, there is a need to test other plant polysaccharides for their potential as encapsulating and delivery vehicles of active ingredients. There are certain characteristics which are looked for before using a biopolymer as an encapsulant. Among them are emulsifying and interfacial properties, film forming abilities, solubility and gel-forming properties. Emulsifying properties of flaxseed protein, chia seed protein and lentil protein have been evaluated in recent years [44, 47, 48]. It was found that emulsions stabilized by flax protein concentrate (FPC) at neutral pH and in the absence of salt had a smaller droplet size and higher surface charge which makes them good candidates to be used in coacervation process. FPC-stabilized emulsions were more stable against the effect of salt concentration.

The FPC can be effective stabilizing emulsions where droplet size and zeta-potential are major factors influencing the emulsion stability. Flaxseed gum is also found to possess good potential in stabilizing the protein-based emulsions. Encapsulating unstable and bioactive core materials with a protein-gum complex shell matrix isolated from the same plant source is a very recent idea of microencapsulation. Reference [47] successfully encapsulated flaxseed oil (core) by novel matrix of flaxseed protein-flaxseed gum complex coacervate. Similarly, [44] successfully encapsulated chia seed oil using chia seed protein-gum complex coacervate shell matrix. The authors have compared the effectiveness of protein only and gum only shell matrix with the complex coacervate shell matrix and concluded that complex coacervation based shell matrix is more effective over the other two. However, this laboratory experiments need further study for their effectiveness and reproducibility in pilot plant or commercial trials.

Conclusion

There are various reasons of encapsulation, many bioactive ingredients are encapsulated to enhance their longevity and functionality. Several bioactive ingredients are encapsulated to prevent their degradation from environmental stressors and control their release in the gastrointestinal tract. For example, baking yeast and dough conditioners are encapsulated to increase their performance or to overcome other processing challenges. It has been reported that uncoated chemical leaveners release carbon dioxide prematurely. This is even more prominent in warmer environments. In addition, ingredient degradation or flavour loss during the baking process can occur in systems where uncoated ingredients are used. For instance, PUFAs-rich oils are encapsulated to prevent or minimize their oxidation. Bioactive peptides are encapsulated to control their release in targeted site. Therefore, encapsulation method is dependent on the nature of core material and intended use of the final product. As a consequence, various methods of encapsulation are developed.

References

[1]. Zuidam NJ, Nedovic V. Encapsulation technologies for active food ingredients and food processing. 2010.
[2]. Fang Z, Bhandari B. Encapsulation of polyphenols–a review. Trends in Food Science & Technology. 2010 Oct 1; 21(10): 510-23.
[3]. de Vos P, Faas MM, Spasojevic M, Sikkema J. Encapsulation for preservation of functionality and targeted delivery of bioactive food components. International dairy journal. 2010 Apr 1; 20(4): 292-302.
[4]. Desai KG, Jin Park H. Recent developments in microencapsulation of food ingredients.Drying technology. 2005 Jul 1; 23(7): 1361-94.
[5]. Lesmes U, McClements DJ. Structure–function relationships to guide rational design and fabrication of particulate food delivery systems.Trends in Food Science & Technology. 2009 Oct 1;20(10):448-57.
[6]. King W, Perry P. Modified starch encapsulating agents offer superior emulsification, film forming, and low surface oil [Incorporation into dry food

systems].Food Product Development. 1976.
[7]. Drusch S, Serfert Y, Schwarz K. Microencapsulation of fish oil with n-octenylsuccinate-derivatised starch: Flow properties and oxidative stability. European Journal of Lipid Science and Technology. 2006 Jun;108(6):501-12.
[8]. Jeon YJ, Vasanthan T, Temelli F, Song BK. The suitability of barley and corn starches in their native and chemically modified forms for volatile meat flavor encapsulation. Food Research International. 2003 Jan 1;36(4):349-55.
[9]. Trubiano PC,Lacourse NL. Emulsion-Stabilising Starches: Use in Flavor. In: Risch SJ and Reineccius, GA., Eds., Flavor Encapsulation, American Chemical Society, Washington. 1988. 45-54.
[10]. Bylaitë E, Venskutonis PR, Maþdþierienë R. Properties of caraway (Carum-carvi L.) essential oil encapsulated into milk protein-based matrices. European Food Research and Technology. 2001 Jun;212(6):661-70.
[11]. Li JK, Wang N, Wu XS. Gelatin nanoencapsulation of protein/peptide drugs using an emulsifier-free emulsion method.J Microencapsul. 1998 Mar-Apr;15(2):163-72. PMID: 9532522.
[12]. Kim YD, Morr CV, Schenz TW. Microencapsulation properties of gum arabic and several food proteins: liquid orange oil emulsion particles. Journal of Agricultural and Food Chemistry. 1996 May 16; 44(5): 1308-13.
[13]. Jimenez M, Garcia HS, Beristain CI. Spray-drying microencapsulation and oxidative stability of conjugated linoleic acid.European Food Research and Technology. 2004 Nov;219(6):588-92.
[14]. Damodaran S. Protein stabilization of emulsions and foams. Journal of Food Science. 2005 Apr;70(3):R54-66.
[15]. Sheu TY, Rosenberg M. Microstructure of microcapsules consisting of whey proteins and carbohydrates. Journal of Food Science. 1998 May;63(3):491-4.
[16]. Keogh MK, O'kennedy BT, Kelly J, Auty MA, Kelly PM, Fureby A, et al. Stability to oxidation of spray-dried fish oil powder microencapsulated using milk ingredients. Journal of Food Science. 2001 Mar;66(2):217-24.
[17]. Fathi M, Mozafari MR, Mohebbi M. Nanoencapsulation of food ingredients using lipid based delivery systems. Trends in food science & technology. 2012 Jan 1;23(1):13-27.
[18]. Conde-Petit B, Escher F, Nuessli J. Structural features of starch-flavor complexation in food model systems. Trends in food science & technology. 2006 May 1; 17(5): 227-35.
[19]. Masters K. Spray drying handbook. Spray drying handbook. 1985.
[20]. Labrousse S, Roos Y, Karel M. Collapse and crystallization in amorphous matrices with encapsulated compounds. Sciences des aliments. 1992;12(4):757-69.
[21]. Shimada Y, Roos Y, Karel M. Oxidation of methyl linoleate encapsulated in amorphous lactose-based food model. J Agric Food Chem. 1991 Apr;39(4):637-41.
[22]. Parker R, Ring SG. Diffusion in maltose-water mixtures at temperatures close to the glass transition.CarbohydrRes. 1995 Aug 25;273(2):147-55.
[23]. F. Gibbs, SelimKermasha, InteazAlli, Catherine N. Mulligan B. Encapsulation in the food industry: a review. Int J Food SciNutr. 1999 Jan 1;50(3):213-24.
[24]. Shahidi F, Han XQ. Encapsulation of food ingredients.Crit Rev Food Sci-Human Nutr. 1993 Jan 1;33(6):501-47.
[25]. Gould GW. Heat-induced injury and inactivation.Mechanisms of action of food preservation procedures. 1989:11-42.
[26]. Farkas J. Microbiological safety of irradiated foods. Int J Food Microbiol. 1989 Aug 1;9(1):1-5.
[27]. Gentry TS, Roberts JS. Design and evaluation of a continuous flow microwave pasteurization system for apple cider. LWT-Food Science and Technology. 2005 May 1;38(3):227-38.
[28]. Nguyen LT, Choi W, Lee SH, Jun S. Exploring the heating patterns of multiphase foods in a continuous flow, simultaneous microwave and ohmic combination heater. J Food Eng. 2013 May 1;116(1):65-71.
[29]. Varith J, Noochuay C, Netsawang P, Hirunstitporn B, Janin S, Krairiksh M (2007) Design of multimode-circular microwave cavity for agri-food processing. In: Microwave conference, 2007. APMC 2007. Asia-Pacific IEEE. pp 1–4.
[30]. Sakai N, Hanzawa T. Heat Transfer Analysis in Food Heated by Far-Infrared Radiation. Developments in Food Engineering.Springer USA; 1994.pp 313–315.
[31]. Ratti C. Shrinkage during drying of foodstuffs. J Food Eng. 1994 Jan 1;23(1):91-105.
[32]. Afzal TM, Abe T, Hikida Y. Energy and quality aspects during combined FIR-convection drying of barley. J Food Eng. 1999 Dec 1;42(4):177-82.
[33]. Hebbar HU, Vishwanathan KH, Ramesh MN. Development of combined infrared and hot air dryer for vegetables.J Food Eng. 2004 Dec 1;65(4):557-63.
[34]. Krebbers B, Matser AM, Hoogerwerf SW, Moezelaar R, Tomassen MM, van den Berg RW. Combined high-pressure and thermal treatments for processing of tomato puree: evaluation of microbial inactivation and quality parameters. Innov Food SciEmerg. 2003 Dec 1;4(4):377-85.
[35]. Castro SM, Loey AV, Saraiva JA, Smout C, Hendrickx M. Inactivation of pepper (Capsicum annuum) pectin methylesterase by combined high-pressure and temperature treatments. J Food Eng. 2006;75(1):50–58.
[36]. Ukuku DO, Geveke DJ. A combined treatment of UV-light and radio frequency electric field for the inactivation of Escherichia coli K-12 in apple juice.Int J Food Microbiol. 2010 Mar 31;138(1-2):50-5.
[37]. Liu Y, Tang J, Mao Z, Mah JH, Jiao S, Wang S. Quality and mold control of enriched white bread by combined radio frequency and hot air treatment. J Food Eng. 2011 Jun 1;104(4):492-8.
[38]. Amiali M, Ngadi MO, Smith JP, Raghavan GS. Synergistic effect of temperature and pulsed electric field on inactivation of Escherichia coli O157: H7 and Salmonella enteritidis in liquid egg yolk. J Food Eng. 2007 Mar 1;79(2):689-94.
[39]. Bazhal MI, Ngadi MO, Raghavan GS, Smith JP. Inactivation of Escherichia coli O157: H7 in liquid whole egg using combined pulsed electric field and thermal treatments. LWT Food Sci Technol. 2006 May 1;39(4):420-6.
[40]. Gin B, Farid M. The use of carbon electrodes in ohmic cooking of meat patties.Asia-Pacific J Chem Eng. 2007 Sep;2(5):474-9.
[41]. Erkmen O, Bozoglu TF. Food Microbiology, 2 Volume Set: Principles into Practice. John Wiley & Sons; 2016 Jun 13.
[42]. Barrow CJ, Nolan C, Jin Y. Stabilization of highly unsaturated fatty acids and delivery into foods. Lipid Technology. 2007 May;19(5):108-11.
[43]. Timilsena YP, Wang B, Adhikari R, Adhikari B. Preparation and characterization of chia seed protein isolate–chia seed gum complex coacervates. Food hydrocolloids. 2016 Jan 1;52:554-63.
[44]. Kaushik P, Dowling K, Barrow CJ, Adhikari B. Complex coacervation between flaxseed protein isolate and flaxseed gum. Food Research International. 2015 Jun 1;72:91-7.
[45]. Ducel V, Richard J, Popineau Y, Boury F. Adsorption kinetics and rheological interfacial properties of plant proteins at the oil– water interface. Biomacromolecules. 2004 Nov 8;5(6):2088-93.
[46]. Kaushik P, Dowling K, McKnight S, Barrow CJ, Adhikari B. Microencapsulation of flaxseed oil in flaxseed protein and flaxseed gum complex coacervates. Food research international. 2016 Aug 1;86:1-8.
[47]. Wang B, Li D, Wang LJ, Adhikari B, Shi J. Ability of flaxseed and soybean protein concentrates to stabilize oil-in-water emulsions. Journal of Food Engineering. 2010 Oct 1;100(3):417-26.
[48]. Wang B, Wang LJ, Li D, Adhikari B, Shi J. Effect of gum Arabic on stability of oil-in-water emulsion stabilized by flaxseed and soybean protein. Carbohydrate polymers. 2011 Aug 1;86(1):343-51.