Review article
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Significance of Microencapsulation Technology: A review

Muhammad Hamza Naveed Hashmi[1], Tayyab Jan[1], Huma Qureshi[2], Kausar Mumtaz.
[1]Department of Food Technology, Arid Agriculture University, Rawalpindi.
[2]Department of Horticulture, The University of Haripur, Pakistan
Corresponding author email: hamzanaveed910@gmail.com

Abstract
Microencapsulation is an emerging technology that involves the formation of microcapsules by entrapping active agents inside coating or wall material; all these ingredients must be biodegradable. Different technologies are being adopted for better microencapsulation of food ingredients and novel drug delivery. Selection of microencapsulation technology, coating/wall material & core material in relevance with each other can play a significant role in getting potentially promising results. The main reason for using microencapsulation technology is to protect sensitive components of food, prevent nutritional losses, ensure the utilization of sensitive ingredients, mask the unpleasant smell, and convert liquid into solid ingredients that can be handled easily. Drugs are released at their targeted sites in the gastrointestinal tract due to different mechanisms like Diffusion, osmosis, dissolution & erosion. This review paper aims to provide reasons, applications of microencapsulation, core & coating material, some effective technologies used for microencapsulation, and recent literature on these aspects.

Keywords: Micro-encapsulation, ingredients, technologies, bio-degradable, applications

Highlight

- Microencapsulation is an emerging technology used in entrapping active agents inside coating or wall material
- Role of Microencapsulation in various industrial uses
- In pharmaceutical industries, microencapsulation technology has the potential to outperform traditional drug delivery techniques

1. Introduction:

Microencapsulation is a technique wherein the minute droplets of liquid or solid substance are encapsulated in a polymeric capsule (Mishra et al., 2013). The encapsulated materials are usually referred to as active, internal, or payload section, core, or fill. The substance encapsulates the core or fills, generally known as the shell, capsule, external section or matrix, coating membrane, carrier material (Fang & Bhandari, 2010). Microencapsulation is a beneficial method that is particularly helpful for aggregating tiny particles into thin layers. Wall of consistent or inconsistent thickness surrounds the core in the simplest of the microcapsules.

The coat's thickness varies from a few to several hundred micrometers (0.2–500.0 mm) and protects against chemical reactions that degrade the material (Rodrigues and Grosso, 2008). Recently, the food industry has demonstrated increasingly complex formulations, such as microorganisms in soured meat; the addition of polyunsaturated fatty acids that are susceptible to auto-oxidation in milk, yogurts, or ice creams; and, as a result, the use of highly volatile flavor compounds in instant foods, which are frequently checked only by microencapsulation (Gharsallaoui et al., 2012). Microencapsulation has been used to develop new materials for the food industry and pharmaceuticals, cosmetics, and textiles, where compound stability, efficiency, and bioactivity are required (Dias et al., 2015). The dimension of microencapsulated items typically ranges from 1 to 1000 millimeters. Commercially available microparticles typically have a core content of 10-90 percent w/w. Live cells, adhesives, flavours, agrochemicals, enzymes, prescription medications, and other fundamental ingredients are frequently encapsulated (Kreitz et al., 1999).

Encapsulation technologies are frequently used in the food industry for various reasons. Encapsulation has the potential to improve the delivery of bioactive compounds (such as vitamins, minerals, and antioxidants) as well as living cells (such as probiotics) into foods (de Vos et al., 2010). Encapsulation attempts to keep bioactive substances stable during processing and storage while preventing unwanted interactions with the food matrix. Bioactive food compounds are primarily characterized by their rapid inactivation. An encapsulating approach would benefit these substances since it slows or avoids degradation (e.g., hydrolysis or oxidation) until the product is transported to the required locations (Lesmes, & McClements, 2009). Microencapsulation proves itself as an efficient means of making foods that are not solely a source of nutrients with sensory charm but additionally a source of well-being and health for people, for example, by increasing the extent of calcium to stop osteoporosis, exploitation of microorganism-produced lactic acid to decrease cholesterol and adding phenolic compounds to overcome heart issues (Sanguansri & Augstin, 2006).

Microencapsulation has been regularly improved, altered, and adapted for various reasons. As a result, it turned out as an example of a knowledge-intensive and dynamic technology, characterized by the ascension of patent applications,

shedding light on the industrial research and development, as well as by an increasing range of latest scientific articles, deriving from the fundamental research (Boh & Kardoš, 2003). This review aims to discuss relevant aspects such as applications, reasons, methods, materials, and microencapsulation techniques.

1.1 The rationale for Microencapsulation technology:

The fundamental reason for using microencapsulation technology is the achievement of prolonged and sustained unharness of the drugs. The site of absorption is often altered by using microencapsulation technology. This application is beneficial for those drugs which are toxic at lower pH. Another vital purpose of microencapsulating most drugs is to reduce GI irritation & toxicity, including with KCl and ferrous sulphate. Liquid drugs are often converted into free-flowing powder by using Microencapsulation technology. Microencapsulation technology is used to prevent incompatibility among the drugs. Toxic chemicals like pesticides could also be microencapsulated to scale back the chance of sensitization of a factorial person. Microencapsulation technology protects the drugs sensitive to moisture, light, and oxygen. The volatile drugs that could vaporize at room temperature are microencapsulated to prevent vaporization. Microencapsulation is often used to prevent drugs like aspirin and peppermint oil (Swarbrick, 1995).

1.2 Applications of Microencapsulation:

1.2.1 Poultry & Meat industry:

The result of microencapsulation of ascorbic acid on physicochemical & sensory stability of chicken frankfurters was investigated by Comunian et al. (2014). Although highly volatile, ascorbic acid is an important antioxidant found in fruits and vegetables. Many factors can dissolve it, such as heating, light, high oxygen levels, and intense water activity. Ascorbic acid is commonly used in frankfurters o replace sodium erythorbate. As a result, the primary goal of this research was to encapsulate ascorbic acid in frankfurters since this approach allows for the insertion of an effective antioxidant with vitamin activity while also improving the product's durability. The results revealed that it was possible to produce frankfurters with excellent sensory properties by employing ascorbic acid as an antioxidant. Omega-3 from fish oil was microencapsulated for enhancement of frozen chicken nuggets. The effect of frozen storage time on sensory properties and oxidative stability of this product was compared to that of bulk fish oil addition. It was discovered that the sensory properties of chicken nuggets supplemented with omega-3 fatty acids are unaffected by frozen storage duration (Jiménez-Martín et al., 2016).

1.2.2 Beverages production:

The Spray-drying technique is used to encapsulate lemon oil with maltodextrin (Kausadikar et al., 2015). Lemon oil features a sharp and fresh smell. As a result, lemon oil is mainly employed as a flavouring additive in the food and beverage industry. Due to the presence of substantial levels of oxygen functionalized chemicals and unsaturated compounds in this oil, the oxidation process is hampered during storage. As a result, the microencapsulation approach was applied to solve the problem. Curcumin and catechin microcapsules were made using W/O/W emulsions (water-in-oil-in-water) (Aditya et al., 2015). This study aimed to prevent curcumin and catechin from degrading in beverage systems. The results showed that the biological activities of catechin & curcumin increased when they were used in combination (Manikandan et al., 2012).

1.2.3 Baked products:

The primary goal of encapsulating vegetable shortening was improving oxidative stability and transforming fat into a stable powder for usage in short dough biscuits (O'Brien et al., 2003). The lycopene microcapsules were made using a spray-drying process using modified starch as the encapsulating agent. The application of microcapsules to the cake was used to determine their functioning. Lycopene is a carotenoid found in various plants and fruits, and its most commonly utilized as a red food dye (Rocha et al., 2012).

1.2.4 Dairy industry:

The implications of spray-drying microencapsulation on the persistence of probiotic bacteria in the ice cream were investigated, and different functional ice creams were created by introducing probiotic bacteria (Champagne et al., 2015). Flavorzyme microcapsules with diverse wall materials have been created for cheese making (Anjani et al., 2007).

1.3 Probiotic industry:

Probiotic bacteria are beneficial microorganisms and bioactive food constituents with serious health advantages in the host if they are present in sufficient quantities. Microencapsulation will not solely enhance their bioavailability but particularly their functionality. One of the most important reasons for encapsulating active ingredients is to enhance the stability in final products and throughout the process. For instance, probiotics are extremely sensitive to changes in pH, transport conditions, mechanical stress, and digestive enzymes within the gastrointestinal tract (de Vos et al., 2010). At present, probiotics are the main driving force in the production of functional foods, especially in dairy products, sustaining their functional properties for supporting human health. However, before these living cells can be helpful, they need to survive the food process, storage, and food intake. The selection of an encapsulation technique is always vital since it has to be efficient, economical, and easily incorporated into the food without meddling with the taste and texture. A few microbes like

bifidobacteria and *lactobacilli* seem to benefit from the encapsulation matrix during lyophilization and dehydration (Kim et al., 2000).

Industry	***Achievements***	***References/Source***
Poultry Industry	Microencapsulating ascorbic acid (antioxidant) in chicken frankfurters has improved its sensory character.	Comunian et al. (2014)
	Omega-3 from fish oil was encapsulated to enrich frozen chicken nuggets, and it was found that sensory properties are not affected by the time of frozen storage.	(Jiménez-Martín et al. 2016).
Beverage industry	Lemon oil was encapsulated with maltodextrin by spray drying technique to overcome oxidation problems.	Kausadikar et al.2015
	Degradation of catechin and curcumin was prevented in beverage products by encapsulating both using water-in-oil-in-water emulsions (W/O/W).	Aditya et al. 2015
Bakery products	Vegetable shortening was encapsulated to achieve oxidative stability in short dough biscuits production.	O'Brien et al. 2003
	Lycopene was encapsulated through a spray drying method, and functionality was determined by application on cakes.	Rocha et al. 2012
Dairy Industry	Flavourzymes have been encapsulated to be used in cheese production.	Anjani et al. 2007
	Including probiotic microorganisms in ice cream has resulted in functional ice cream.	Champagne et al. 2015
Probiotic Industry	Active ingredients are encapsulated to improve stability against change in pH digestive enzymes stress etc.	de Vos et al. 2010
	Gut-friendly bacteria are encapsulated to produce functional foods that improve human health.	Kim et al. 2000

1.4 In the Pharmaceutical industry:

In the Pharmaceutical industry, colon-specific delivery of a water-soluble peptide drug was the primary purpose behind the formulation of microcapsules. (Arimoto et al. 2004). Controlled release and sustained release dosage forms are the main rationales of such a vast of this technology (Nokhodchi et al., 2002). Microencapsulation technology is often used to encapsulate oily medicines to tableted dosage forms. It is usually done to overcome issues inherent in producing tablets from otherwise tacky granulations. Chen et al. (2014) manufactured heparin co-loaded microcapsules using chitosan for synergistic cancer therapy. The core materials are protected against atmospheric effects, e.g., vitamin A palmitate, using microencapsulation (Wu et al., 2003). The electronic tongue detects bitter taste-masking microencapsulation of active pharmaceutical ingredients (APIs), notably roxithromycin and ibuprofen, two prominent anti-inflammatory, non-steroidal, and antibacterial medications. Separations of incompatible chemicals, such as medicinal eutectics, have been achieved using microencapsulation technology. A liquid formation can occur when materials come into close contact (Jańczyk et al., 2010).

1.5 Other Applications:

Acidulants are flavor modifiers and are added for processing and preservation aids. A wide range of textures can develop due to the interaction of acidulants with proteins, gums, starches, and pectins. Reduction in hygroscopicity and dusting can also be achieved through microencapsulation of these agents. Temperature and moisture can cause the degradation of sweeteners. In chewing gum, aspartame, which is a sugar and artificial sweetener, is encapsulated with fats. The chewing action and moisture in the mouth cause the slow release of these sweeteners. Encapsulation of "Aspartame" can protect it from high temperature in baking goods. The primary purpose of adding citric acid to tea is to increase tartness. Citric acid can cause discolouring of the tea bag by reacting with tannins. Encapsulation can help to overcome this problem, and at the same time, the function of the citric acid is not disturbed as well (Kaity et al., 2010). Partially hydrogenated vegetable oil is encapsulated with sodium chloride, due to which its flowability is improved and clumping and caking are reduced. Sodium

chloride helps in controlling water absorption yeast growth, reduces the degradation of color, and prevents rancidity. This is particularly applicable for yeast dough, pretzel snacks, and pulverized meats (Rajera et al., 2011).

Examples of Encapsulated drugs (Rajera et al., 2011; Kaity et al. 2010)

Sr. No.	Drug Material	Advantages	Product form
1.	Urease	Permselectivity of reaction substrate, enzyme, and product	Available in 'dispersion' form
2.	Pancreatic islets or "Islets of Langerhans."	Stabilization of diabetic condition produces insulin hormone, which helps control blood glucose level.	Available as 'Injectables'
3.	Progesterone hormone	Prolonged-release.	Many varying forms, i.e., capsule, tablets, etc.
4.	Salicylic acid	Target specific site (Anti-inflammatory).	In "Microcrystal" form
5.	Retinyl palmitate or Vit. A palmitate	Resistance against oxidation	Available in 'Dry powder form'
6.	Isordil/Isosorbide dinitrate	Slow-release capsule/Extended-release capsule	In "Capsules" form
7.	5-fluorouracil	Decreases the irritation	Available in 'Cream form'
8.	Acetaminophen	The primary purpose is taste masking	In 'Tablet' form
9.	Aspirin	The main objectives are prolonged unleash, reduction of gastric irritation, and taste masking	Both in 'Capsule' & 'Tablet' forms
10.	Potassium chloride	Lessen the gastric irritability	In 'Capsule' form

1.6 The material used for Microencapsulation:

The fundamental qualities of microcapsules, such as understanding the nature of the core and coating/wall materials, as well as microencapsulation processes, are significant parts of understanding microencapsulation technology (Haznedar & Dortue, 2004).

1.6.1 Core Materials:

Core materials are generally used in the form of dispersions and solids or droplets of liquids purpose of which may include protection of reactive material from their environment for controlled release properties and also for some other reasons such as to prevent foul odour, taste masking, and production of free-flowing powders and to change the drug physical properties (Alireja et al. 2005). Saravanan and Rao et al. (2009) used pectin-gelatin and alginate-gelatin complex coacervation to encapsulate a variety of pharmaceuticals, including metronidazole hydrochloride (MH), diclofenac sodium (DS), and indomethacin (IM). The intended physical characteristics of the product being encapsulated and the intended application of the finished product must be taken into account (Patel et al., 2000).

1.6.2 Examples of core material:

Minerals, Bases, Pharmaceuticals, Dextrins, Biocides, and Herbicides included as solid Core Material Nutrients, Vegetable Oils, Sugars, Salts, Dyes, Bleaches, Pigments, Cosmetics, Insecticides, Acids, Pesticides, Fungicides, Perfumes, Solvents, and Catalysts included Liquid as Core Material (Singh et al. 2010).

1.6.3 Coating/Wall Materials:

The biocompatibility and lack of toxicity of coating material must be considered before using it as wall material. The properties and activity of the active substance (i.e., the activity proteins) should also be preserved by coating material (Martín, & Cocero, 2008). The selection of coating material plays a crucial role in affecting the encapsulation stability and efficiency of the microcapsule. Excellent coating material must have the following properties: 1) it must be economically feasible & should not have an unpleasant taste. 2) Coating material must be non-reactive with the core. 3) Coating material must have the ability to keep the core within the capsule and seal. 4) The coating material must have the ability to protect the core from an unfavorable environment (Nazzaro et al., 2012). Carneiro et al. (2013) investigated the encapsulation effectiveness and oxidative stability of flaxseed oil microencapsulated using a spray-drying process, with various coating materials such as gum Arabic, whey protein concentrate, maltodextrin, whey protein concentrate, and modified starches. The primary purpose of this research was to assess the potential of maltodextrin in combination with whey protein concentrate, Gum Arabic, and modified starch as alternative materials

during spray-drying microencapsulation of flaxseed oil. According to the findings of the study of Carneiro et al. (2013), the blend of modified starch and maltodextrins had the most excellent encapsulation effectiveness.

However, the combination of whey protein concentrate & maltodextrins performed satisfactorily with the protection of active ingredients during storage. So, it could be inferred from the results that a combination of whey protein concentrate, maltodextrin, and modified starch could be used as appropriate coating materials for flaxseed oil microencapsulation. The non-toxic polymethacrylate copolymers are soluble in a selected pH range, illustrating inert and swellable sort of changing porosity, and therefore, it has newly been used as coating material (Majeti & Kumar 2000). Studies have been conducted on natural latex from the peduncle of jackfruit. The results showed an excellent option for a coating polymer for mucoadhesive microspheres (Bal 2005). The coating material is amenable, which is employed in microencapsulation. For example, the coating could be plasticized and changed chemically by cross-linking; elegance, charm, and masking of unpleasant taste or odour is usually attained by adding colorants; or to execute the controlled release & permeability of drugs. Magnetic localization at particular locations has been achieved by adding magnetic components (Ahuja et al., 2004). However, most coating materials still do not have desired properties, according to Comunian et al. (2008); therefore, a combination of two or more coating materials is usually required. Some primary coating materials are the following:

1.6.4 Carbohydrates Polymers:

Carbohydrates consist of more than 90% of the dry mass of all biomass, and more than 90% of those are carbohydrate polymers – polysaccharides. Carbohydrates are used extensively in spray-drying; carbohydrates have extensively been used as a coating material for encapsulations of food ingredients. These materials have desired characteristics that are usually required and expected from an excellent encapsulating agent, such as low viscosities at high solids contents and good solubility. Encapsulate aroma compounds are encapsulated using starch and products derived from starch, i.e., b-cyclodextrin & maltodextrins. Several studies are in progress to understand interactions between core and these polysaccharides, i.e., coating material (McNamee et al., 2001).

1.6.4.1 starch:

Starch is usually a white powder, odorless and tasteless, not soluble in ethanol, cold water, and common solvents. After cellulose, starch is the most abundant polysaccharide. Starch is naturally found in various ranges of size, such as 5–900 mm, 1–100 mm (Murphy, 2000), and in different shapes, such as spherical or lentil-shape. The volatile compounds are protected and retained in the food industry by extensively using starch and starch-based ingredients, like modified starches, maltodextrins, and b-cyclodextrins. A highly porous structure can be created by treating amylase enzymes and starch granules (Varavinit et al., 2001). Natural starches do not show emulsifying properties. Partially hydrolyzed starches obtain their emulsifying power through Esterification with a cyclic dicarboxylic acid anhydride. During spray drying, modified starches are found to be greater in volatile flavours retention and emulsifying properties than gum acacia, and improved targeted functionality in starches are obtained by genetic modification of starch (Jobling, 2004; Chaplin, 2007).

1.6.4.2 Cellulose:

Cellulose is made up of a b-d-glucose polymer. b-(1→4)-glycosidic linkages connect the chain units. In starch, all -CH_2 OH groups are aligned along the same side of the molecular plane, but in cellulose, the –CH_2 OH groups alternate above and below the plane, resulting in long linear chains (Coffey et al., 2006). Cellulose is insoluble in a wide range of common solvents, as well as in water. Compared to starch, cellulose is substantially more crystalline. In water, cellulose becomes amorphous around 320°C, although starch transitions from crystalline to amorphous at 60–70°C. The hydroxyl group of cellulose can be partially or exclusively reacted with various chemicals to yield valuable derivatives. Those derivatives have desired properties required for their application in the food industry (Chaplin, 2007).

1.6.4.3 Gums:

Gums and thickeners have a tremendous impact on the flavor & taste of food because they are generally bland or tasteless. Generally, hydrocolloids decrease sweetness due to properties like viscosity and hindered Diffusion (Godshall, 1997).

1.6.4.4 Gums Arabic:

Gum Arabic is a complex combination of oligosaccharides, polysaccharides, and glycoproteins derived from arabinogalactan. The chemical content of these combinations can be affected by the timing of exudation, the source, the age of the trees, rainfall, climate, season, and other variables (Verbeken et al., 2003). Furthermore, the gum Arabic wall material is ideal for microencapsulating lipid droplets because it acts as a surface-active agent and a drying matrix, preventing the loss of volatile compounds in contact with the environment (Shiga et al., 2001). Due to its

features such as emulsification, viscosity, and solubility, Gum Arabic is commonly utilized for encapsulating matrices. Gum Arabic is used as a coating material (Reineccius, 2004) to encapsulate orange oil. Due to the frequent shortage of gum Arabic and increase in its cost, other materials are being investigated for its replacement.

1.6.4.5 Alginate:

Alginate is a kind of anionic polysaccharide that belongs to the linear anionic polysaccharide family. Their composition, structure, and molar mass influence "alginates" functional qualities. The type of counterion and rate of dissociation affects the solubility of alginate in water (Draget et al. 2006). Alginates are hydrocolloids that may be derived from kelp. When alginates react with calcium ions, a stable gel is created. They may be utilized for encapsulating flavour oils at room temperature. At lower concentrations, the solution exhibits Newtonian behavior at low shear rates, and at higher shear rates, the solution exhibits pseudoplastic features (Draget 2000).

1.6.4.6 Carrageenan:

Carrageenans belong to a family of high molar mass sulfated polysaccharides, in which each structure highly depends on the source and conditions throughout the process of extraction and purification (Falshaw et al. 2001). Carrageenans show a wide range of rheological behavior because of the variation in their chemical structure (Mangione et al., 2003). Carrageenan is non-gelling, but carrageenan's highest anionic charge density causes strong electrostatic interaction in solution, the best solubility, & extended chain conformation (Kara et al. 2006).

1.6.5 Proteins:

Dietary hydrocolloids are the most often utilized microencapsulated; nevertheless, food proteins such as sodium caseinate, whey protein, and soy protein isolates have not been frequently employed for this purpose. The protein molecules get swiftly adsorbed at the oil-water interface during the emulsion formation process. This technique produces a steric-stabilizing layer that quickly prevents the oil droplets from recoalescence and then offers physical stability to the emulsion during processing and storage (Dickinson, 2001).

1.6.6 Caseins:

Caseins are the most predominant phosphoproteins found in milk (CAS# 9000-71-9). Caseins do not coagulate by heat because they are highly heated stable. Caseins are insoluble at pH 4.6, which is their isoelectric point. Variation in the solubility of caseins could be caused by caseins fractions separated from milk. Surface films of sodium caseinate or b-casein have the best flexibility. The lowest visco-elasticity of sodium caseinate or b-casein makes it much better than the films of other materials. Caseins are good fat emulsifiers. Sodium caseinate has amphiphilic character and emulsification properties that offer those physical and functional characteristics required to encapsulate oil materials (Hogan et al., 2001). The solubility of films from caseins in water depends on the pH conditions in preparation. The water vapor permeability of the films depends on the protein type (CAS# 9000-71-9).

1.6.7 Gelatin:

In terms of charge distribution and size, gelatins come in a wide range of sizes (Ledward, 2000). Gelatin comprises a heterogeneous mix of single-stranded and multi-stranded polypeptides with extended left-handed proline helix conformations and between 300 and 4,000 amino acids (Chaplin, 2007). Collagen hydrolysis is used to make gelatin. Gelatin is often used in complicated coacervation (Ducel et al., 2004). Warm-water fish gelatin and, in particular, cold-water fish gelatin films have very low water vapour permeability. This low water vapour permeability is advantageous for microencapsulation since it reduces water loss at low temperatures, such as those seen in refrigerated or frozen food films (Avena-Bustillos et al., 2006).

1.6.8 Whey proteins:

Whey proteins are globular proteins, pH-independent. In their natural form, Whey proteins are soluble in the ionic environment of milk. Whey proteins exhibit all desirable functional properties necessary as wall material. Non-denatured solutions of whey proteins are less viscous than caseinate solutions. The structure of whey proteins shows such functional properties, which are considered desirable for efficient microencapsulation of anhydrous milk fat. The combination of whey protein, maltodextrin, and corn syrup solids is the most effective encapsulation material for the spray drying technique. To encapsulate volatile compounds, whey proteins with carbohydrate have been effectively combined as carrier material (Chen et al. 2006).

1.6.9 *Lipids:*

1.6.9.1 Waxes:

Waxes are essential fatty acid esters. In contrast to fats and oils, fatty acids are esters of higher primary monovalent alcohols rather than glycerol esters. Paraffin (about 15%), triacontylpalmitate (approximately 75%), and triacontylcerotinate (approximately 5%) make up the majority of beeswax (about 10 percent) (Parish et al. 2002).

1.6.9.2 *Candelilla wax:*

Candelilla wax is soluble in a wide range of organic solvents. It has a light brown to light yellow color with a 67–79 degrees Celsius melting point. It does not have the same hardness as carnauba wax. It may be used in particular amounts with all vegetable and animal waxes, fatty acids, a wide range of natural and manufactured resins, hydrocarbons, and glycerides (Strahl and Pitsch 2008b).

1.6.9.3 ***Carnauba wax:***

Carnauba wax is one of the hardest natural waxes. Carnauba wax melts at 78–85°C (usually 83°C). Its consistency with other materials is complementary to beeswax (Strahl and Pitsch 2008a).

1.6.9.4 Glycerides:

Glycerides are water-insoluble. Monoglyceride, diglyceride and Triglyceride are related to the family of glycerides. The main component in vegetable oils and animal fats is triglycerides. The mixture of varying triglycerides is primarily present in different natural fats. The variety of mixtures used mainly determines the span of the melting range. The commercial source of mono- and diglycerides and triglyceride is the same, but total synthesis is also possible (Walstra 1999).

1.7 Techniques and methods used for Microencapsulation:

1.7.1 Freeze-drying/Lyophilization:

Drugs, natural aromas, and water-soluble extracts are mostly encapsulated with the help of the freeze-drying method. Apart from the fact that this technique generally requires an almost 20 hours long dehydration period, freeze-drying is a simple technique that is especially appropriate for the encapsulation of aromatic materials. The chemical nature of the system mainly determines the retention of volatile compounds during freeze-drying. The microencapsulation of whey protein isolate with a combination of maltodextrin and garcinia fruit extract by freeze-drying & then its use in bread have shown desirable characteristics, such as colour, softer crumb texture, higher volume, and sensory attributes (Ezhilarasi et al. (2013).

High energy inputs, long processing time, and high cost are significant drawbacks of using this technique. Additionally, a barrier would develop between the active agent and its surroundings which consists of an open porous structure. Therefore, in those drugs where the prolonged release of an active is required, this high-porous wall provides poor safety (Zuidam & Shimoni, 2009). Another disadvantage is that the cost of the freeze-drying method is 50 times higher than spray drying, which makes freeze-drying less attractive than spray drying. The transport of produced particles and their storage requirements are also extremely costly. The commercial application of freeze-drying is also poorly bound due to its long processing time (Jacquot & Pernetti, 2004).

1.7.2 Spray drying:

Spray drying is a typical encapsulation process used in both the pharmaceutical and food sectors (Gouin, 2004). Boake Roberts, in 1937 devised a spray dying technique to manufacture microcapsules of taste when acetone was accidentally added to tomato puree during spray drying, allowing him to keep the colour and flavour of tomato powder. Spray drying is a cost-effective, versatile, and continuous method. Spray-dried particles are of high quality and typically have a diameter of less than 40 m. (Zuidam & Heinrich, 2009). Due to the core material's lower temperatures, spray drying is beneficial for encapsulating low boiling and heat-labile materials (Sharma & Tiwari, 2001). During the spray-drying process, the core material is homogenized in the solution of the wall material to produce a stable emulsion. By feeding emulsion into a spray dryer, dried particles are created with the aid of hot air (Loksuwan, 2007). To achieve appropriate spray-drying outcomes, the wall material must be water-soluble and have good film-forming, emulsification, and drying capabilities (Reineccius, 2004). The Leaflish spray dryer is a new high-velocity drier that operates at 300 to 400 degrees Celsius (Fang & Bhandari, 2010).

1.7.3 Spray cooling:

Microencapsulation with the help of spray cooling technique involves the injection of cold air, which will allow solidification of the particles (Champagne & Fustier, 2007). The mixture that contains the core and wall material in droplets produces the micro-particles. Atomizer nebulizes this mixture, and then the mixture has introduced a chamber in which air flows at reduced temperature. The advantage of having low temperature is that it enables core material to be encapsulated by causing solidification of wall material. This technique involves spray cooling the molten matrix, which contains tiny droplets of the core material. In techniques like spray chilling and spray cooling, the requirements of exceptional handling and storage conditions are usually considered as a demerit. Oil hydrogenated palm is used by Wegmüller et al. in (2006) to increase the nutritional value of salt by developing microcapsules with the help of spray cooling technique, which contained iron, iodine, and vitamin A. These microcapsules thus produced had no sensory difference, and they were highly stable.

1.7.4 Spray chilling:

The melting point of lipids is a significant variation between spray cooling and spray chilling procedures. Spray chilling temperatures vary from 34 to 42°C, whereas spray cooling temperatures are more significant than spray chilling temperatures (Zuidam & Shimoni, 2009). The coating substance is melted and atomized into a vessel using a pneumatic nozzle in this method. As in the case of the holt-melt fluidized bed, this vessel has a carbon dioxide ice bath at a temperature of 50 °C. As a result of the droplets attaching to the particles and solidifying, a coating film is created. This technology can be used to safeguard water-soluble yet thermo-sensitive compounds that are prone to damage or volatilization during thermal processing (Augustin et al., 2001).

1.7.5 Coacervation:

Coacervation is a process that usually takes place in colloidal solutions. Coacervation is usually regarded as the earliest method for encapsulation. Coacervation initiates with a step in which H_2SO_4, HCl, or organic acids are added to alter the pH value of dispersion. The solubility of the dispersed phase, i.e. (shell material), is reduced due to a change in pH value of dispersion. This results in the precipitation of shell material from the solution. In this way, a continuous coating of shell material is formed around the core droplets, and this coating of shell material is cooled down to form the final capsule. Hardening agents like formaldehyde are suitable for hardening shell material and, therefore, can be added during the process. The microcapsules are fit to be dried because they are stable in the suspension. A spray dryer or a fluidized bed dryer is used to dry the suspension in the drying phase. A spray dryer is more appropriate for heat-sensitive products (Bansode et al., 2010).

Coacervation-phase separation is done by continuous agitation and usually consists of three major steps:

(1) Three immiscible chemical phases are formed in the first step.
(2) Second step involves deposition of the coating.
(3) Finally, the coating is rigidized/hardened.

Simple coacervation and complex coacervation are two basic categories of coacervation-phase separation. The presence of a single macromolecule is called simple coacervation. At the same time, complex coacervation involves two or more molecules of opposite charges (FREITAS et al., 2005). Sweet orange oil is microencapsulated by Jun et al. in (2011) with soybean protein isolate using coacervation technique, indicating good core protection.

1.7.6 Extrusion:

In the extrusion method, droplets of an aqueous solution of polymer and active are dropped into a gelling bath. In this method, a jet cutter, a vibrating nozzle, a spraying nozzle, a syringe, or atomizing disk and pipette can be used as dripping tools (Wandrey et al., 2009). The main benefit of using the extrusion method is that it prevents flavor oxidation and increases flavor stability against oxidation. The matrices of carbohydrates have excellent barrier properties in the glassy state, which facilitates the microencapsulation of flavours in these matrices through a process of extrusion (Gouin, 2004). Limonene was microencapsulated with β-cyclodextrin by Yuliani et al. in (2006) through extrusion, which offered an efficient medium against oxidation. For laboratory-scale use, beads or capsules are created by extrusion of polymer solution through nozzles (Heinzen, 2002).

1.7.7 Centrifugal extrusion method:

Another essential technique for microencapsulation is centrifugal extrusion, which some producers have investigated and used. Flavorings, seasonings, and vitamins have been encapsulated after the formation of a food-approved coating system & cellulose derivatives, carrageenan, sodium alginate, gelatin, starches, etc., are an example of that food-approved coating material. A spinning extrusion head with concentric nozzles is utilized to encapsulate liquids in this approach. In this process, a sheath of wall solution/melt surrounds a jet of the liquid core. As the jet moves through the air, it breaks up into core droplets, which are then coated with the coating material solution. When a molten coating material is in flight, it may solidify, or a solvent may evaporate from the coating material solution. As a result, most droplets' diameter is within 10% of the mean diameter. A small ring of droplets surrounds the spray nozzle. After that, if necessary, the capsules can be hardened by capturing them in a ring-shaped hardening bath after formulation. Those particles produced through this technique have a diameter range of 150 to 2000 mm (Bansode et al. 2010).

1.7.8 Fluidized bed coating:

Fluid bed coating is a method of applying a coating to powder particles in a batch processor. Coating ingredients for this approach include aqueous protein solutions, cellulose or starch derivatives, and gums (Depypere et al., 2009). This approach is appropriate for the food sector because of its versatility, simplicity, flexibility, and relatively large batch size (Depypere et al., 2009). This method for creating microcapsules may be divided into three stages: nucleation, transition, and ball growth. Particles are suspended in the coating chamber during the first phase of the fluidized bed coating process. Then droplets of the polymer solution are sprayed to improve the possibilities of

particle-droplet collision and distribution on the particle surface, followed by microcapsules are formed by evaporation of droplets at the end of this process (Teunou and Poncelet, 2002). Fluidized bed dryers are less expensive in underdeveloped nations than spray dryers, which need state-of-the-art drying equipment (Chua & Chou, 2003). In the pharmaceutical and cosmetic industries, this approach is widely employed. The pharmaceutical and cosmetic industries both have larger budgets than the food business. Fluidized bed coating has also been studied for use in the food sector to encapsulate flavours (Lee & Krochta, 2002).

1.8 Polymerization:

In this technique, a monomeric unit reaction occurs at the interface between the core material and the continuous phase in which the core is dispersed. The continuous phase or supporting core could be a gas or a liquid in polymerization. Therefore, polymerization might occur in liquid-gas, solid-liquid, liquid-liquid, or solid-gas. For instance, the protein is incorporated in the aqueous di-amine phase to produce protein solutions comprising microcapsules (Goud and Park, 2005). In the technique of polymerization, a solid polymeric wall is created due to the polymerization of monomers all over the droplets of an emulsion. The structure and terminology of microencapsulated commodities may vary because of the expertise, advances, and improvement in its methods and applications (Boh, 1996 a, b).

1.8.1 In-situ polymerization:

The in-situ formation of a hydrogel is a beneficial and straightforward technique because it has three-dimensional (3D) cell culture, injectable tissue engineering, and controlled-release drug delivery as its biotechnological and biomedically attainable functions. In this technique, pre-condensates or monomers are mixed solely to the aqueous phase of the emulsion. The surface of the particles is directly polymerized by using a single monomer (Boh, 1996a, b). In one process, e.g., immersed in dry toluene, the encapsulation of Cellulose fibers with polyethylene is done successfully. The range of coating thickness ranges from0.2-75µm, while 0.5µm/min is the general deposition rate. The coating is consistent everywhere, including sharp projections (Shinde et al., 2013).

1.8.2 Interfacial polymerization:

Interfacial polymerization is a microencapsulation technique in which monomerization occurs at the junction (interface) of two immiscible materials. This technique works on the Schotten Baumann reaction between an acid chloride and a compound consisting of an active hydrogen atom. Polyurethane, amine or alcohol, polyuria, and polyesters are examples of those active hydrogen compounds. When circumstances go right, then at the junction/interface, a thin elastic wall is formed rapidly. The emulsification of di-acid chloride and pesticide solution is done along with the addition of aqueous solutions containing an amine and a poly-functional iso-cyanate. The base is generally used to neutralize the acid formed during the reaction. At the end of the process, the polymer wall is instantly formed at the interface/ junction of emulsified particles (Bansode et al., 2010).

1.9 Liposomal entrapment:

Liposomes comprise phospholipids, which form spherical bilayers identical to cellular membranes. Hydrophobic molecules are entrapped in the oil-like portion while hydrophilic in the water-soluble interior of liposomes (Gouin, 2004). The capsule created by liposomes have less brittleness and have high flexible properties compared to those made up of fats. These liposome capsules have been used to transfer and distribute hormones, enzymes, vaccines, and vitamins throughout the body. Liposomal entrapment protects bioactive materials against chemical and environmental stresses. This method prevents reaction in the presence of reactive chemicals or enzymes and offers protection when exposed to high pH, high ion concentrations, and temperature (Foged et al., 2007).

Liposomes have their application as anti-microbials, small molecules, and enzymes & in a variety of products of cheese industries, beverages, and in the illustration of vaccines (Oxley, 2014). Liposomes were initially used with medical objectives, and after that, liposomes were employed in the cosmetics industry. Uprising costs are the main disadvantage of this technique, and often the requirement of keeping formulations in dilute aqueous suspensions results in extra costs (Gouin, 2004). The technique of formulation of liposomes with a vesicle diameter less than 50 µm consisting of one or more entrapped Bacillus subtilis was patented by Gregoriadis et al. 2001. The liposome was freeze-dried after formulation. The cell activity remains stable after the processes of dehydration and rehydration (Gregoriadis et al. 2001).

2. Pan coating:

Large particles are microencapsulated using the pan coating technique to provide an efficient coating. Coatings are generally applied in the coating pans when the solid core is passed through coating material, and that coating might be applied in the form of a solution or atomized spray. During the application of coatings in the coating pans, warm air is generally passed through the coating material to withdraw the coating solvent. Sometimes, it is dried in the

oven to remove the final solvent. The pan coating technique is among the most ancient industrial methods and has also extensively been used in the pharmaceutical industry for making tablets and other coating particles. The particles need to be encapsulated, dropped in a pan or some other device, and then the coating material is applied gently. For microencapsulation purposes, the size of the solid particles is usually considered necessary to be greater in size than 600 µm for efficient coating (Kreitz et al. 1999).

2.1 Air suspension:

Professor Dale E. Wurster of the University of Wisconsin's Department of Pharmacy was the first to develop the air suspension coating process. Air suspension equipment includes a control panel, a nozzle for applying film coatings, a coating chamber, and an air distribution plate. The drying rate is directly proportional to the volume temperature of the supporting air stream. Applying air-suspension coating of particles in the form of solution and melt can increase flexibility and control. Particles are suspended and covered in an upward-moving air stream. Perforated plates with specific holes inside and outside cylindrical insert support this construction. The settling particles are fluidized by an adequate amount of air which is allowed to rise through the outer annular space. Most of the rising is generally heated, causing the particles to rise quickly by flowing inside the cylinder.

At the top, the air stream settles back onto the outer bed when the air stream diverges and slows and then moves down to repeat the cycle (Hideki et al. 2001). The solid core materials are encapsulated mainly by applying the air-suspension technique. Most of the time, the encapsulating materials determine the drugs unleash. There is a wide range of coating materials that qualify and can be applied for encapsulation through the air-suspension technique. The coating material can be applied in emulsions, solvent solutions, aqueous solutions, dispersions, or hot melts in this technique. The capacity of equipment range from one pound to 990 pounds. Agglomeration of the particles is usually done to some larger size for encapsulation purposes. Still, core material particles that range from micron or submicron sizes can also be microencapsulated efficiently by the air-suspension technique (Jegat & taverdet, 2000).

2.2 Emulsification:

Food active agents which are soluble in water are mostly encapsulated processes of emulsification. Oil/water emulsions, water/oil emulsions, and water/oil/water double emulsions are essential components of emulsification. Spray or freeze-drying techniques can be used to dry oil-in-water emulsion type of emulsion combination to produce a powder. These dried emulsions could be used in several food products as encapsulates or an instant formulation (Zuidam & Shimoni, 2009). The core is initially dissolved in an organic solvent, where the wall material after the emulsification of dispersion into the water or oil is done, which comprises an emulsion stabilizer. Then the evaporation of organic solvent and stirring is done, due to which compact polymer globules are formed in which the core material is encapsulated. A newly patented technique produces stable emulsions. This stable emulsion is usually added in powdered nutritional products for infants, children, and adults.

Bifidobacteria and acidophilic bacteria can be assimilated described by the method (Mazer & Kessler, 2014). The microencapsulation of probiotics in alginate chitosan through the emulsification method has shown more protection in simulated gastrointestinal conditions (Song et al., 2013). Another technique to develop stable w/o/w emulsion was formulated, particularly beneficial to probiotics. Such emulsion has many benefits; for instance, it masks the flavor of the aqueous component of the inner water phase and sustains stability for a long time (Vos & Poortinga, 2010). In cheese production, the rate of proteolysis increases when emulsification encapsulates enzymes compared with the production of free enzymes (Kailasapathy & Lam, 2005). The emulsification method is mainly used to encapsulate microorganisms, enzymes, vitamins, and minerals (Azeredo, 2005).

2.3 Melt-dispersion technique:

In the melt-dispersion technique, temperature up to 80°C is given to cause the melting of coating material. The drug is suspended in it, and after that, it is emulsified in water which consists of an emulsifying agent at 80°C with continuous agitation. As the system's temperature declines and reaches at room temperature, microcapsules are formed (Nokhodchi et al., 2002; Rao et al., 2009).

2.4 Inclusion complexation:

Beta-cyclodextrin is used in the technique of inclusion complexation because 1-4 linkage in glucose units makes its outer surface hydrophilic while its center is hydrophobic. Less polar molecules replace water molecules present in the center of Beta-cyclodextrin. Hydrophobic interaction helps entrap guest's apolar molecules into the apolar internal cavity. Inclusion of crucial oil compounds is permitted in the internal cavity, whose diameter is about 0.65nm, which can take up one or more flavor volatile molecules (Goud and Park, 2005).

2.5 Solvent evaporation technique:

This process of solvent extraction is used by various businesses to make microcapsules. This technology makes use of a liquid production vehicle. The microcapsule coating is combined with a volatile solvent incompatible with the liquid production vehicle phase. The solution in which the core material encases is either dissolved or dispersed is known as the coating polymer. The core and coating material combination is dispersed in the liquid production vehicle phase with continuous agitation to make the microcapsule size acceptable. If necessary, the mixture is heated to evaporate the solvent and extract the solvent from the polymer. When the core material is disseminated in a polymer solution, the polymer shrinks around it. The dissolving of core material into the polymer solution results in a matrix-type microcapsule. After the solvent has completely evaporated from the polymer, the temperature of the liquid vehicle is decreased to room temperature/ambient temperature, with continued stirring if necessary. Microcapsules may be coated on substrates or separated as powders at this stage, and microcapsules are employed in suspension form (Obeidat & Price, 2004).

The solvent extraction method may be used on a wide range of liquid and solid core materials. The core materials employed can be either water-soluble or water-insoluble, and a range of film-forming polymers can be used to cover the surface (Youan et al., 2003). The techniques for creating dispersions, the evaporation rate of the solvent for coating polymer, agitation rates, and temperature cycles are all elements that might impact the microencapsulation process through solvent evaporation. The rate of agitation/stirring, temperature cycles, and the rate at which solvent evaporates for coating polymer all impact the phenomena of micro-encapsulation by solvent extraction. The choice of coating polymer and vehicle phase impacts microcapsule characteristics and solvent recovery strategies. As a result, attention must be made while selecting a solvent and vehicle phase (Obeidat & Price, 2004).

3. Mechanism and Kinetics of Drug Release:

Diffusion, erosion, dissolution & osmosis are the main mechanisms involved during drug release.

3.1 Diffusion:

In this mechanism, the shell is penetrated by dissolution fluid; after this, both the core material and dissolution fluid come into contact. At last, leakage occurs through the pores or interstitial channels (Brazel and Peppas 2000). Thus, the drug release depends upon three factors (1) the rate at which the wall of microcapsules is penetrated by dissolution fluid, (2) the rate at which the dissolution fluid is dissolved into drugs, (3) drug release depend on the leakage rate at of dissolved drug and rate at which it disperses from the surface. Drug release kinetics can be explained by Higuchi's equation (Higuchi, 1963) which is written below:

$$Q = [D/J\ (2A - \varepsilon\ Cs)\ Cs\ t]\ ½$$

In this equation, 'Q' represents the quantity of drug released per unit area of the exposed surface in time 't'; 'D' represents the diffusion coefficient of the solute in the solution; 'A' represents the total amount of drug released per unit volume. Cs represents the solubility of the medication in permeating dissolution fluid; the porosity of the microcapsule wall is represented by, and the tortuosity of the capillary system in the wall is represented by J. The simplified form of the preceding equation is Q = vt, where v denotes the apparent release rate.

3.1.1 Diffusion controlled monolithic system

In this system, diffusion causes the release of an active agent either prior or co-current with the polymer matrix degradation. The degradation of polymer either by homogeneous or heterogeneous mechanism also determines the rate of drug release.

3.1.2 Diffusion controlled reservoir system

In this system, the active agent is encapsulated by a rate controlling membrane through which the agent diffuses, and after its delivery is completed, the membrane slowly erodes. The degradation of the matrix does not affect the drug release in this system.

3.2 Erosion

Microcapsules occur in a wide range of physical configurations, including size, shape, and the arrangement of core and coat materials; as a result, illustrating the release of pharmaceuticals from the microcapsule has become difficult. (Nokhodchi et al. 2002). The drug is released by erosion of coat due to pH or enzymatic hydrolysis (Haznedar and Dortue 2004).

3.3 Dissolution

When the coat is soluble in the dissolution fluid, the dissolution rate of the polymer coat determines the rate of drug release from the microcapsule. The thickness of the coat and the solubility of the dissolving fluid determine the rate of medication release (Costa and Lobo 2001).

3.3.1 Osmosis

Another mechanism for medication delivery is osmosis. A semipermeable membrane is required for the osmosis process in microcapsules, and the polymer coat fulfills this need. When technology progresses, medication release through microscopic pores occurs as osmotic pressure between the interior and outside of the microcapsule membrane is created (Swarbrick, 1995).

4. Conclusion:

In both the food and pharmaceutical industries, microencapsulation technology has the potential to outperform traditional drug delivery techniques. The efficiency of components has been improved by using different encapsulating technologies to protect health compounds. The product's quality is influenced not only by the selection and development of superior encapsulation technologies, walls, and core materials but also by the talent in the field of food processing. The advancements in this sector have been significant with nutraceuticals and food additives; nevertheless, the technology for micro-encapsulating live probiotic bacterial cells appears to be lacking. The notion of a healthy gut microflora underpins probiotic treatment (or microbial intervention). Given the increasing number of microencapsulated items that have been created, produced, and successfully sold in the pharmaceutical and cosmetic sectors, the food business has a significantly smaller market for microencapsulation. Many microencapsulation approaches have been hampered by high production costs and a scarcity of food-grade ingredients. To overcome these constraints, more research is required. For a deeper understanding of microencapsulation and its future uses, further research and development are required to find and create novel wall materials as well as to enhance and optimize existing encapsulation processes.

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References:

Aditya N, Aditya S, Yang H-J, Kim HW, Park SO, Lee J and Ko S (2015) Curcumin and catechin co-loaded water-in-oil-in-water emulsion and its beverage application. J. Funct. Foods, 15: 35-43.

Anjani K, Kailasapathy K and Phillips M (2007) Microencapsulation of enzymes for potential application in acceleration of cheese ripening. Int. Dairy J., 17: 79-86.

Anuja, A., Khar, R. K. & Ali, J. (2004) Dosage form design. IN: Controlled Drug Delivery Systems, pp. 168–232 (India: Birla Publications Pvt. Ltd.).

Arimoto M, Ichikawa H and Fukumori Y (2004) Microencapsulation of water-soluble macromolecules with acrylic terpolymers by the Wurster coating process for colon-specific drug delivery. Powder Technol., 141: 177-186.

Augustin, M.A., Sanguansri, L., Margetts, C. & Young, B. (2001). Microencapsulation of food ingredients. Food Australia, 53, 220–223.

Avena-Bustillos RJ, Olsen CW, Olson DA, Chiou B, Yee E, Bechtel PJ, McHugh TH (2006) Water vapor permeability of mammalian and fish gelatin films. J Food Sci 71:E202–E207.

Azeredo, H. D. (2008). Encapsulação: aplicação à tecnologia de alimentos. *Alimentos e Nutrição Araraquara*, *16*(1), 89-97.

Bal, T. (2005) Design and Development of the Sustained Release Mucoadhesives Microspheres of Montelucast Using Jackfruit Latex. M. Pharm. Thesis, Dibrugarh University, Dibrugarh Assam (India).

Bansode SS, Banarjee SK, Gaikwad DD, Jadhav SL. Microencapsulation: a review. Inter J Pharm Sci Review and Research. 2010; 1:38–43.

Boh, B. (1996a): Microencapsulation technology applications: with special reference to biotechnology: developing support for introducing knowledge intensive technologies. In: Kornhauser, A., Dasilva, E. (Eds.): The integrating triangle: research - education - development: a challenge for higher education. Ljubljana, International Centre for Chemical Studies: Slovenian National Commision for UNESCO, pp. 51-76.

Boh, B. (1996b): Microencapsulation for pollution prevention: developing support for introducing clean(er) technologies and products. In: Kornhauser, A. (Ed.): Developing information support for research and education in toxic waste management. Ljubljana: International Centre for Chemical Studies: Slovenian National Commission for UNESCO, pp. 205-222.

Boh, B., Kardoš, D. (2003): Microcapsule patents and products: innovation and trend analysis. In: Arshady, R., Boh, B. (Eds.): Microcapsule patents and products; The MML series, Vol. 6, Citus reference series, London, pp. 47-83.

Brazel, C. S., & Peppas, N. A. (2000). Modeling of drug release from swellable polymers. *European journal of pharmaceutics and biopharmaceutics*, *49*(1), 47-58.

Carneiro HC, Tonon RV, Grosso CR and Hubinger MD (2013) Encapsulation efficiency and oxidative stability of flaxseed oil microencapsulated by spray drying using different combinations of wall materials. J. Food Eng., 115: 443-451.

Champagne CP, Raymond Y, Guertin N and Bélanger G (2015) Effects of storage conditions, microencapsulation and inclusion in chocolate particles on the stability of probiotic bacteria in ice cream. Int. Dairy J., 47: 109-117.

Champagne, C. P., & Fustier, P. (2007). Microencapsulation for the improved delivery of bioactive compounds into foods. *Current opinion in biotechnology*, *18*(2), 184-190.

Chaplin MF (2007) Water structure and Science. http://www.lsbu.ac.uk/water/. Accessed on October 18, 2007.

Chemical Abstract Service # 9000-71-9.

Chen J-X, Liang Y, Liu W, Huang J and Chen J-H (2014) Fabrication of doxorubicin and heparin co-loaded microcapsules for synergistic cancer therapy. Int. J. Biol. Macromol., 69: 554-560.

Chen LY, Remondetto GE, Subirade M (2006) Food protein-based materials as nutraceutical delivery systems. Trends Food Sci Technol 17:272–283.

Chua, K.J. & Chou, S.K. (2003). Low-cost drying methods for developing countries. Trends in Food Science and Technology, 14, 519–528.

Coffey DG, Bell DA, Henderson A (2006) Cellulose and cellulose derivatives. In: Stephen AM, Phillips GO, Williams PA (eds) Food polysaccharides and their applications, 2nd edn. Taylor & Francis, Boca Raton, FL, pp 147–179.

Comunian A, Thomazini M, Gambagorte VF, Trindade MA and Favaro-Trindade CS (2014) Effect of Incorporating Free or Encapsulated Ascorbic Acid in Chicken Frankfurters on Physicochemical and Sensory Stability. J. Food Sci. Eng., 167-175.

Costa, P., & Lobo, J. M. S. (2001). Modeling and comparison of dissolution profiles. *European journal of pharmaceutical sciences*, *13*(2), 123-133.

de Vos, P., Faas, M. M., Spasojevic, M., & Sikkema, J. (2010). Encapsulation for preservation of functionality and targeted delivery of bioactive food components. International dairy journal, 20(4), 292-302.

Depypere F, Pieters J and Dewettinck K (2009) PEPT visualisation of particle motion in a tapered fluidised bed coater. J. Food Eng., 93: 324-336.

Dias MI, Ferreira IC and Barreiro MF (2015). Microencapsulation of bioactives for food applications. Food Funct. 6: 1035-1052.

Dickinson, E. (2001). Milk protein interfacial layers and the relationship to emulsion stability and rheology. Colloids Interfaces B, 20, 197–210.

Draget KI (2000) Alginates. In: Phillips GO, Williams PA (eds) Handbook of hydrocolloids. Woodhead Publishing Limited, Cambridge, England, pp 379–395.

Draget KI, Moe ST, Skjåk-Bræk G, Smidsrød O (2006) Alginates. In: Stephen AM, Phillips GO, Williams PA (eds) Food polysaccharides and their applications, 2nd edn. Taylor & Francis, Boca Raton, FL, pp 289–334.

Ducel, V., Richard, J., Saulnier, P., Popineau, Y & Boury, F. (2004). Evidence and characterization of complex coacervates containing plant proteins: application to the microencapsulation of oil droplets. Colloids and Surfaces A: Physicochemical Engineering Aspects, 232, 239–247.

Ezhilarasi, P.N. et al. Freeze drying technique for microencapsulation of Garcinia fruit extract and its effect on bread quality. Journal of Food Engineering, v.117, n.4, p.513-520, 2013.

Falshaw R, Bixler HJ, Johndro K (2001) Structure and performance of commercial kappa-2 carrageenan extracts I. Struct Anal, Food Hydrocolloids 15:441–452.

Fang Z. & Bhandari B... Encapsulation of polyphenols – a review. Trends Food Sci Technol 2010; 21:510-23.

Foged C, Nielsen HM and Frokjaer S (2007) Liposomes for phospholipase A 2 triggered siRNA release: Preparation and in vitro test. Int. J. Pharm., 331: 160-166.

Freitas, S., Merkle, H. P., & Gander, B. (2005). Microencapsulation by solvent extraction/evaporation: reviewing the state of the art of microsphere preparation process technology. *Journal of controlled release*, *102*(2), 313-332..

Gharsallaoui, A., Roudaut, G., Beney, L., Chambin, O., Voilley, A., & Saurel, R. (2012). Properties of spray-dried food flavours microencapsulated with two-layered membranes: Roles of interfacial interactions and water. *Food Chemistry*, *132*(4), 1713-1720.

Godshall, M.A. (1997). How carbohydrates influence food flavor. Journal of Food Technology, 51, 63–67.

Goud, K and Park, H.J., 2005. Recent Developments in Microencapsulation of Food Ingredients. Drying Technology. 23: 1361–1394.

Gouin S (2004) Micro-encapsulation: industrial appraisal of existing technologies and trends. Trends Food Sci Technol 15: 330–347.

Gregoriadis G, Antimisiaris SG, Gursel I (2001) Liposomes containing particulate materials. US 6451338 B1.

Haznedar, S., & Dortunc, B. (2004). Preparation and in vitro evaluation of Eudragit microspheres containing acetazolamide. International journal of pharmaceutics, 269(1), 131-140.

Heinzen, C. (2002). Microencapsulation solve time dependent problems for foodmakers. European Food and Drink Review, 3, 27–30.

Hideki I, Kazuhiro F, Christianah AM, Yoshinobu F. Use of Ion-exchange Resins to Prepare 100 ìm-sized Microcapsules with Prolonged Drug-release by the Wurster Process. Int J Pharm 2001; 216:67-76.

Higuchi, T. (1963) Mechanism of sustained action medication, theoretical analysis of rate of release of solid drugs dispersed in solid matrices, Journal of Pharmaceutical Sciences, 52: 1145–1149.

Hogan, S.A., McNamee, B.F., O'Riordan, E.D. & O'Sullivan, M. (2001). Microencapsulating properties of whey protein concentrate 75. Food Engineering and Physical Properties, 66, 675–680.

Jacquot, M., & Pernetti, M. (2004). Spray coating and drying processes. In Fundamentals of Cell Immobilisation Biotechnology (pp. 343-356). Springer, Dordrecht.

Jańczyk, M., Kutyła, A., Sollohub, K., Wosicka, H., Cal, K., & Ciosek, P. (2010). Electronic tongue for the detection of taste-masking microencapsulation of active pharmaceutical substances. Bioelectrochemistry, 80(1), 94-98.

Jiménez-Martín E, Pérez-Palacios T, Carrascal JR and Rojas TA (2016) Enrichment of Chicken Nuggets with Microencapsulated Omega-3 Fish Oil: Effect of Frozen Storage Time on Oxidative Stability and Sensory Quality. Food Bioprocess Technol., 9: 285-297.

Jobling, S. (2004). Improving starch for food and industrial applications. Current opinion in plant biology, 7(2), 210-218.

Jun-xia, X., Hai-yan, Y., & Jian, Y. (2011). Microencapsulation of sweet orange oil by complex coacervation with soybean protein isolate/gum Arabic. *Food chemistry*, *125*(4), 1267-1272.

Kailasapathy, K., & Lam, S. H. (2005). Application of encapsulated enzymes to accelerate cheese ripening. *International Dairy Journal*, *15*(6-9), 929-939.

Kaity, S., Maiti, S., Ghosh, A. K., Pal, D., Ghosh, A., & Banerjee, S. (2010). Microsponges: A novel strategy for drug delivery system. Journal of advanced pharmaceutical technology & research, 1(3), 283.

Kara, S., Arda, E., Kavzak, B., & Pekcan, Ö. (2006). Phase transitions of κ-carrageenan gels in various types of salts. Journal of applied polymer science, 102(3), 3008-3016.

Kausadikar, S., Gadhave, A. D., & Waghmare, J. (2015). Microencapsulation of lemon oil by spray drying and its application in flavour tea. Adv. Appl. Sci. Res, 6(4), 69-78.

Kim, K. I., Yoon, Y. H., & Baek, Y. J. (1996). Effects of rehydration media and immobilization in Ca-alginate on the survival of Lactobacillus casei and Bifidobacterium bifidum. Korean Journal of Dairy Science (Korea Republic).

Kreitz, M., Brannon-Peppas, L., & Mathiowitz, E. (1999). Microencapsulation. Encyclopedia of controlled drug delivery. John Wiley Sons publishers, pp 493-553.

Ledward, D. A. (2000). Gelatin. Handbook of hydrocolloids, Woodhead Publishing Limited, Cambridge, England, pp 67–86.

Lee, S. Y., & Krochta, J. M. (2002). Accelerated shelf life testing of whey-protein-coated peanuts analyzed by static headspace gas chromatography. Journal of agricultural and food chemistry, 50(7), 2022-2028.

Lesmes, U., & McClements, D. J. (2009). Structure–function relationships to guide rational design and fabrication of particulate food delivery systems. Trends in Food Science & Technology, 20(10), 448-457.

Loksuwan, J. (2007). Characteristics of microencapsulated β-carotene formed by spray drying with modified tapioca starch, native tapioca starch and maltodextrin. Food hydrocolloids, 21(5-6), 928-935.

Majeti, N. V., & Kumar, R. (2000). Nano and microparticles as controlled drug delivery devices. J Pharm Pharm Sci, 3(2), 234À258. Mangione MR, Giacomazza D, Bulone D, Martorana V, San Biagio PL (2003) Thermoreversible gelation of k-carrageenan: relation between conformational transition and aggregation. Biophys Chem 104:95–105.

Manikandan, R., Beulaja, M., Arulvasu, C., Sellamuthu, S., Dinesh, D., Prabhu, D., & Prabhu, N. M. (2012). Synergistic anticancer activity of curcumin and catechin: An in vitro study using human cancer cell lines. Microscopy research and technique, 75(2), 112-116.

Martín, A., & Cocero, M. J. (2008). Micronization processes with supercritical fluids: fundamentals and mechanisms. Advanced drug delivery reviews, 60(3), 339-350.

Mazer T, Kessler T (2014) Methods for extruding powered nutritional products using a high shear element. WO 2014093832 A1.

Mishra, D. K., Jain, A. K., & Jain, P. K. (2013). A review on various techniques of microencapsulation. Int J Pharm Chem Sci, 2(2), 962-968.

Mohammadifar, M. A., Musavi, S. M., Kiumarsi, A., & Williams, P. A. (2006). Solution properties of targacanthin (water-soluble part of gum tragacanth exudate from Astragalus gossypinus). International Journal of Biological Macromolecules, 38(1), 31-39.

Murphy, P. (2000) Starch. In: Phillips GO, Williams PA (eds) Handbook of hydrocolloids. Woodhead Publishing Limited, Cambridge, England, pp 41–65.

Najafabadi, A. R., Vatanara, A., Gilani, K., & Tehrani, M. R. (2005). Formation of salbutamol sulphate microparticles using solution enhanced dispersion by supercritical carbon dioxide. *DARU Journal of Pharmaceutical Sciences*, *13*(1), 1-5.

Nazzaro, F., Orlando, P., Fratianni, F., & Coppola, R. (2012). Microencapsulation in food science and biotechnology. Current opinion in biotechnology, 23(2), 182-186.

Nokhodchi, A., Zakeri-Milani, P., Valizadeh, H., & Hassan-Zadeh, D. (2000). EVALUATION OF Microcapsules of acetylsalicylic acid prepared with cellulose acetate phthalate, ethylcellulose, or their mixtures by an emulsion non-solvent addition technique. In Pharmaceutical Technology Conference (Vol. 2, pp. 272-280).

Obeidat, W. M., & Price, J. C. (2004). Evaluation of enteric matrix microspheres prepared by emulsion–solvent evaporation using scanning electron microscopy. Journal of microencapsulation, 21(1), 47-57.

O'Brien, C. M., Chapman, D., Neville, D. P., Keogh, M. K., & Arendt, E. K. (2003). Effect of varying the microencapsulation process on the functionality of hydrogenated vegetable fat in shortdough biscuits. Food research international, 36(3), 215-221.

Oxley, J. (2014). Overview of microencapsulation process technologies. In Microencapsulation in the food industry Academic Press. 35–46.

Parish, E. J., Boos, T. L., & Li, S. (2002). The chemistry of waxes and sterols. Food Science and Technology-New York-Marcel Dekker-, 103-132.

Patel, A. V., Pusch, I., Mix-Wagner, G., & Vorlop, K. D. (2000). A novel encapsulation technique for the production of artificial seeds. Plant Cell Reports, 19(9), 868-874.

Rajera, R., Nagpal, K., Singh, S. K., & Mishra, D. N. (2011). Niosomes: a controlled and novel drug delivery system. Biological and Pharmaceutical Bulletin, 34(7), 945-953.

Rao, M. R. P., Borate, S. G., Thanki, K. C., Ranpise, A. A., & Parikh, G. N. (2009). Development and in vitro evaluation of floating rosiglitazone maleate microspheres. Drug development and Industrial pharmacy, 35(7), 834-842.

Reineccius, G. A. (2004). The spray drying of food flavors. Drying technology, 22(6), 1289-1324.

Rocha, G. A., Fávaro-Trindade, C. S., & Grosso, C. R. F. (2012). Microencapsulation of lycopene by spray drying: characterization, stability and application of microcapsules. Food and bioproducts processing, 90(1), 37-42.

Rodrigues, R. A. F., & Grosso, C. R. F. (2008). Cashew gum microencapsulation protects the aroma of coffee extracts. Journal of microencapsulation, 25(1), 13-20.

Sanguansri, P., & Augustin, M. A. (2006). Nanoscale materials development–a food industry perspective. Trends in Food Science & Technology, 17(10), 547-556.

Saravanan, M., & Rao, K. P. (2010). Pectin–gelatin and alginate–gelatin complex coacervation for controlled drug delivery: Influence of anionic polysaccharides and drugs being encapsulated on physicochemical properties of microcapsules. Carbohydrate Polymers, 80(3), 808-816.

Sharma, D. K., & Tiwari, B. D. (2001). Microencapsulation using spray drying. Indian Food Industry, 20(2), 48-51.

Shiga, H., Yoshii, H., Nishiyama, T., Furuta, T., Forssele, P., Poutanen, K., & Linko, P. (2001). Flavor encapsulation and release characteristics of spray-dried powder by the blended encapsulant of cyclodextrin and gum arabic. Drying Technology, 19(7), 1385-1395.

Shinde, U. P., Yeon, B., & Jeong, B. (2013). Recent progress of in situ formed gels for biomedical applications. Progress in polymer science, 38(3-4), 672-701.

Singh, M. N., Hemant, K. S. Y., Ram, M., & Shivakumar, H. G. (2010). Microencapsulation: A promising technique for controlled drug delivery. Research in pharmaceutical sciences, 5(2), 65.

Song, H., Yu, W., Gao, M., Liu, X., & Ma, X. (2013). Microencapsulated probiotics using emulsification technique coupled with internal or external gelation process. Carbohydrate polymers, 96(1), 181-189.

Strahl & Pitsch. Quality waxes (2008a) Data tables Carnauba Wax from http://www.spwax.com/ spcarnau.htm.

Strahl & Pitsch. Quality waxes (2008b) Data tables Candelilla Wax from http://www.spwax.com/ spcandel.htm

Swarbrick, J. (1995). Encyclopedia Of Pharmaceutical Technology Third Edition Vol. 1. Informa, New York. 1325-1333.

Teunou, E., & Poncelet, D. (2002). Batch and continuous fluid bed coating–review and state of the art. Journal of food engineering, 53(4), 325-340.

Varavinit, S., Chaokasem, N., & Shobsngob, S. (2001). Studies of flavor encapsulation by agents produced from modified sago and tapioca starches. Starch-Stärke, 53(6), 281-287.

Verbeken, D., Dierckx, S., & Dewettinck, K. (2003). Exudate gums: occurrence, production, and applications. Applied microbiology and biotechnology, 63(1), 10-21.

Vos H, Poortinga AT (2010) Double emulsion and method to produce such. WO 2010039036 A1.

Walstra, P. (1999). Dairy technology: principles of milk properties and processes. CRC Press.

Wandrey, C., Bartkowiak, A., & Harding, S. E. (2010). Materials for encapsulation. In Encapsulation technologies for active food ingredients and food processing (pp. 31-100). Springer, New York, NY.

Wegmüller, R., Zimmermann, M. B., Bühr, V. G., Windhab, E. J., & Hurrell, R. F. (2006). Development, stability, and sensory testing of microcapsules containing iron, iodine, and vitamin A for use in food fortification. Journal of food science, 71(2), S181-S187.

Wu, P. C., Huang, Y. B., Chang, J. S., Tsai, M. J., & Tsai, Y. H. (2003). Design and evaluation of sustained release microspheres of potassium chloride prepared by Eudragit®. European journal of pharmaceutical sciences, 19(2-3), 115-122.

Youan, B. B. C., Hussain, A., & Nguyen, N. T. (2003). Evaluation of sucrose esters as alternative surfactants in microencapsulation of proteins by the solvent evaporation method. Aaps PharmSci, 5(2), 123-131.

Yuliani, S., Torley, P. J., D'Arcy, B., Nicholson, T., & Bhandari, B. (2006). Extrusion of mixtures of starch and d-limonene encapsulated with β-cyclodextrin: Flavour retention and physical properties. Food Research International, 39(3), 318-331.

Zuidam, N. J., & Heinrich, E. (2010). Encapsulation of aroma. In Encapsulation technologies for active food ingredients and food processing (pp. 127-160). Springer, New York, NY.

Zuidam, N. J., & Shimoni, E. (2010). Overview of microencapsulates for use in food products or processes and methods to make them. In Encapsulation technologies for active food ingredients and food processing (pp. 3-29). Springer, New York, NY.

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