Selcuk J Agr Food Sci, (2018) 32 (3), 624-631

e-ISSN: 2458-8377 DOI: 10.15316/SJAFS.2018.145

Selcuk Journal of Agriculture and Food Sciences

Encapsulation Methods and Use in Animal Nutrition

Uğur TEMİZ*[1], Ergin ÖZTÜRK[2]

[1]Amasya University, Laboratory and Veterinary Assistance Services Department, Amasya, Turkey
[2]Ondokuz Mayis University, Agricultural Faculty, Animal Science Department, Samsun, Turkey

ARTICLE INFO

Article history:

Received date: 30.09.2018
Accepted date: 28.11.2018

Keywords:

Encapsulation
Coating materials
Feed additives
Preservation

ABSTRACT

Encapsulation is a technology based on coating an active compound with one or more coating material and keeping it in the capsule. Encapsulation is a system can be used for increased stability and bioavailability, protecting the form and controlled secretion to target tissues of bioactive compounds. Coating materials are can be ranged as starch, analogs of starch, proteins, gums, lipids or their mixtures. Encapsulation is a technology based on coating an active compound with one or more coating material and keeping it in the capsule. Encapsulation is a system can be used for increased stability and bioavailability, protecting the form and controlled secretion to target tissues of bioactive compounds. Coating materials are can be ranged as starch, analogs of starch, proteins, gums, lipids or their mixtures.

1. Introduction

Encapsulation is defined as an encapsulation of a substance or mixture into capsules by coating with another substance or system (Madene et al. 2006). Encapsulation can also be expressed as the packaging of solid, liquid or gaseous components, enzymes, cells, other substances, microorganisms with protein or carbohydrate based coating material (Gökmen et al. 2012). Encapsulation technology is currently used in many different areas such as pharmacology, chemistry, cosmetics, medicine, biotechnology and food, and it offers a wide range of possibilities for improving the functional properties of the applied product (Gouin 2004; Poshadri & Aparna 2010). In the encapsulation processes used to provide many beneficial properties to capsules, mostly solid and liquid oils, aroma components, vitamins, minerals, color components (β-carotene, lycopene), fatty acids (ω-3, conjugated linoleic acid), antioxidants (tocopherol, flavonoids, polyphenols) and enzymes are encapsulated with a protective material, thus providing many benefits. (Gökmen et al. 2012, Güngör et al. 2013).

Encapsulation is used in order to carry out processes such as making it solid for easy transport of liquids in use areas, preventing evaporation loss of volatile substances, hiding the undesirable taste and smell, protecting from atmospheric conditions, increasing stability, prolonging the duration of action and enabling controlled release (Kaş & Eldem 2002). In the nutrition and food field, encapsulation is used to protect the bioactive component of the microcapsule from adverse effects (moisture, temperature, light, air, etc.) of the current environment, to prevent evaporation loss, to improve stability during handling, transport and storage of nutrients. It is also used to facilitate the processing of food, to protect living cells such as probiotics, to prevent the effects of bad aroma, to prevent oxidation, to react with other substances, and to increase the bioavailability of active ingredients (Desai & Jin Park 2005).

Types of encapsulation; can be expressed as nanoencapsulation (200 nm = less than 0.2 µm), microencapsulation (0.2 to 5 µm), macroencapsulation (greater than 5 µm). Microencapsulation is the most common application in this classification made by capsule size (Cosco 2006). Nano-encapsulation, which has film and layers, coatings or only encapsulation application at the nanometer scale with micro-dispersion, creates a nano-sized protector, allowing the active substance to remain in the nanoscale (Khare & Vasisth 2014). Microencapsulation is a process, obtaining microcapsules having sizes in the order of µm or mm by coating the surrenders of solids, liquids and gass, enzymes or other active substances with one or gases film layers (Gharsallaoui et al. 2007). The microcapsules are simply spherical, as shown in Figure 1, with a homogeneous wall around them. While the core,which is a substance contained in microcapsule or combination thereof, expressed as an internal phase or

* Corresponding author email: *ugur.temiz@amasya.edu.tr*

filler the outer wall is called the shell, the covering, the wall material or the membrane (Gharsallaoui et al. 2007). Macroencapsulation is the encapsulation of a large mass of materials in a diffusion chamber (Qi et al. 2004).

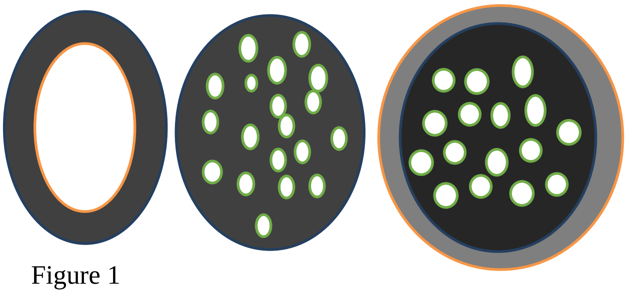

Figure 1
Schematic representation of the microcapsule; wall material, coating material, microcapsule

Depending on the nature of the active ingredient and encapsulating material used in the encapsulation process and the method of microencapsulation applied, microcapsules can be obtained in different structures (Vasisht 2014). As shown in Figure 2, the microcapsules can be of a very different structure, such as single, multi-wall, multi-core, irregular and matrix.

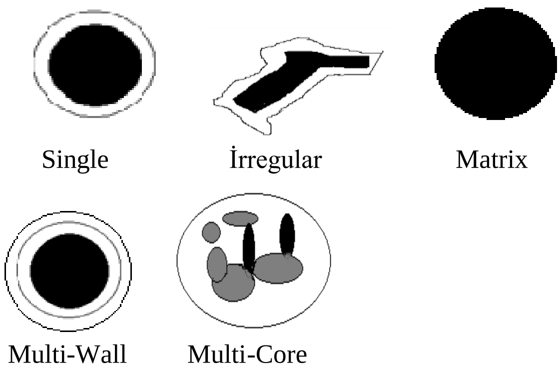

Figure 2
Different structures of microcapsules

2. Coating materials

One of the first and most important steps in encapsulation practices is to determine the appropriate coating material for the material to be encapsulated (the film). Selection of this material is made according to the active ingredient and the desired features of the last product. Need to be careful to some features of the material to be encapsulated to have the desired properties. These features can be aligned as the physicochemical structure of biocompatible components, standby time of the material will be capsuled, storage conditions of the encapsulated product, the size and density of the materials to be coated in the process and economic production cost. According to the above-mentioned subject, encapsulation process can be achieved by determining the coating method with the coating material and considering compliance with the legal regulations (Zuidam & Shimoni 2010; Gökmen et al. 2012).

The structure of the coating material is the basic element determines the functional properties of the capsules. Properties of the ideal coating material must have are;

Machinability during encapsulation should be easy. Must be a stable emulsifying property by active ingredient. In order to be encapsulated, it must not react with the material during both the process and the long-term storage. It must be able to coat active material and have the capability of impermeability under processing and long-term storage conditions. At high concentrations, the strength (rheological properties) of time-dependent deformation under any stress must be good. It should be able to maintain a high level of active material against environmental conditions (oxygen, heat, light, humidity etc.) and be in food purity. It must be soluble in the desired solvents for the food and food industry. Must not enter chemical reactions with active (core) material. Its supply must be easy and economical.

It must have the ability to dissolve the active material in the capsule dissolution properties under the desired release conditions (Desai & Jin Park 2005, Tarhan et al. 2010).

It is very difficult for a single coating material to have the properties described above. So, to use combinations of different coating materials is recommended. It ıs also better in terms of physical and mechanical properties of the coating materials modified (modified cellulose) available (Desai & Jin Park 2005).

In recent years, materials such as sugars, gums, proteins, natural and modified polysaccharides, oils or synthetic polymer, gelatin, pectin, starch, kappa-carrageenan, agar, whey (Table1), which have the ability of creating film have used as most preferred coating materials (Dubey et al. 2009).

2.1 Carbohydrates

Carbohydrates are often preferred, especially in applications where food additives are encapsulated by spray drying. Starch, maltodextrin and corn syrup varieties are used for coating flavorings because of their economic shape and wide use areas in food (Nedoviç et al. 2011). Note that they have a low viscosity even at high concentrations are properties attractive. Resolution of these materials also well serves the ideal coating materials. However, because of the lack of emulsifying properties or below the desired level, it is preferred to use them in combination with proteins, rather than alone in the microencapsulation (Dziezak 1988). The content of polysaccharide membranes constitutes such substances as starch derivatives, starch hydrolysates, cellulose derivatives, alginate, pectin, agar, carrageenan, dextrin, chitosan (Xie et al. 2002). Polysaccharides classified as homopolysaccharide or heteropolysaccharide according to their monomer structure are chemically assessed separately from each other in terms of type, sequence, type of repeating unit in the polymer chain. These chemical differences cause variations in molecular properties such as molecular weight, branching grade, structure, flexibility, electrical charge. As a matter of fact, these variants also cause differences in functional properties such as solubility, water retention capacity, gelation, surface activity, emulsification, digestion (Matalanis et al. 2011).

Table 1
Coating materials used in microencapsulation technology

Sample	Material Type
Sugar, starch, maltodextrin, dextrin, cyclodextrin, glucose syrup, cellulose, gum arabic, alginate, carrageenan, pectin	Polysaccharides
Soy, wheat, corn, gelatin, casein caseinate, whey protein, whey isolate	Proteins
Chitosan, polyethylene, glycol, polyvinyl, acetate, cellulose and it's derivatives	Other Polymers

2.2 Proteins

The proteins are very good coating materials for microencapsulation processes due to their functional properties. Especially they have a high positive effect on the binding of flavor components (Landy et al.1995). The diversity within the chemical groups is an important advantage of having water-soluble and insoluble groups together, having the properties such as interacting with each other and with a wide variety of substances, large molecular weights, a flexibility of molecular chains, as well as technological properties such as solubility, viscosity, emulsification, film formation. During emulsion formation, protein molecules absorb rapidly between the newly formed oil and water phase (Madene 2006). Protein-based coating materials which possess physicochemical and functional properties were in the Amfifik to encapsulate hydrophobic material. Generally, gelatin, whey proteins, casein, caseinates are preferred as a coating material in microencapsulation process (Gharsallaoui et al. 2007).

2.3 Gums

Gums and thickeners that have just a little or no taste show a significant direct effect on the taste and aroma of food. The hydrocolloids found in the structure cause a decrease in sweetness because they form an obstacle against viscosities and diffusion (Godshall 1997). The most well-known and commonly used gum among gums is used as encapsulation material in microencapsulation applications due to the high resolution of the acacia gum, also called arabic, low viscosity, emulsifying properties and the desired retention of volatile components (Madene 2006). The Arabic Gum, having the properties mentioned, allows the use as a suitable carrier for the encapsulation of many components. Examples include essential oils, flavorings, natural coloring matter (oleoresins and carotenoids), vitamins, natural extracts, fruit juices, bacteria and probiotics (Thevenet 2012).

2.4 Alginates

Alginate, one of the most common coating materials used in the microencapsulation of bioactive components, is obtained from brown algae such as *Laminaria hyperborea, Laminaria digitata, Laminaria japonica, Ascophyllum nodosum and Macrocystispyrifera* (Smidsrod & Skja 1990). Advantages such as widespread use and preference of alginates as encapsulating materials in encapsulation applications, not harmful to health, accessibility, high mechanical stability, creating very fine jellies, the acidity is readily apparent when the buffer is low in the buffer solution and forming low weight matrices for covering sensitive components such as calcium chloride and probiotic bacteria has also been proven through researches (Chandramouli et al. 2004).

Alginate beads are sensitive to acidic austenitization and are not suitable for microparticle resistance in stomach conditions. Furthermore, pores are disadvantageous when aimed at protecting the obtained highly porous microparticles from their environment (Gouin 2004). Alginates have a wide range of applications in biomedical, biotechnology and food industry due to the presence of sodium cations in the presence of high thermal stability and biocompatible hydrogels. It is often preferred in the encapsulation of microbial cells, enzymes, hormones, drugs, oils and flavors (Chan et al. 2009).

2.5 Other Coating Materials

Cellulose (carboxymethyl cellulose, methyl cellulose, ethyl cellulose, nitrocellulose, acetyl cellulose, cellulose acetatephthalate, cellulose acetate-butylate-phthalate), lipids (waxes, paraffin, tristearin, stearic acid, monoglycerides, diglycerides, beeswax, fats and oils, hardened fats), inorganic materials (calcium sulfate, silicates, clay) and liposomes are preferred as encapsulating materials in microencapsulation technology (Koç et al. 2010).

3. Encapsulation methods

The choice of the bioactive material to be encapsulated with the appropriate coating material selected will vary depending on the physical and chemical properties of these materials and on the area of use of the obtained microcapsules. At the selecting of appropriate microencapsulation method, the physical and chemical properties of the core and coating material and the location of the food component to be coated have significant importance (Koç et al.2010). In order for the nucleus release to be properly examined, it is necessary to consider the interactions between the encapsulation material and the core material being studied. (Druaux 1997). In addition, many factors such as variability in pH, mechanical effect, temperature, enzymatic activity, time, osmotic force can be used for the controlled release of the encapsulated component and can change the controlled release feature (Poshadri & Aparna 2010). Some techniques and applications for encapsulation are summarized below.

3.1 Spray Drying

Spray drying is the oldest and most frequently used method used in encapsulation technology. This method is often used in the food industry due to its low cost, high yield, good quality, small size, fast dissolving, high stability capsules, and its continuity in production. Starch, maltodextrin, gums are used as carrier materials (Fang & Bhandar 2010). This method is used to encapsulate food ingredients such as oils, flavors and antioxidants in encapsulation applications and to convert liquid products to powder form (Peker & Arslan 2011). It can be used in spray drying technology, the disadvantage is that the number of coating materials is limited. Since almost all spray drying processes are carried out from aqueous feed formulations in the food industry, it is desirable that the coating material is dissolved in water at the optimum level. For this reason, maltodextrin, gum arabic, modified starch and mixtures thereof are the most preferred coating materials. Polysaccharides such as alginate, guar gum, and proteins such as sodium caseinate, soy protein, and whey protein are also used in encapsulation applications. However, it is less preferred due to its high cost and low water solubility (Gouin, 2004).

3.2 Freeze Drying

Freeze drying is a preferred method of microencapsulation of heat-sensitive components, such as aroma substances. For attachment of the aroma to the encapsulating material, the microcapsules are obtained by freezing the sugar in the flavor solution after dissolving the sugar (Gökmen et al. 2012). This method consists of 3 steps as freezing, basic drying, second drying. During the ice cream phase; shocking, or freezing, the ice crystals of the water in the structure of the water, in the basic drying phase; sublimation of ice crystals away from the product, during the second drying phase, the bound water in the food left has proven (Lee & Teledo 1979). The feature that the loss of flavor and lower level of loss that can occur due to the movement of dissolved substances in the food can be counted as advantages of it. The disadvantages of the freeze-drying method are that it is 30-50 times costlier than spray drying due to high energy usage and long processing time (Özcan & Altun 2013).

3.3 Fluidized Bed Coating

In the fluidized bed coating process, the process is carried out by spraying encapsulation material on the material which is in the form of powder or mass and having kept in air at a certain temperature. The encapsulating material solution may consist of cellulose or starch derivatives, proteins, gums (Dewettinck & Huyghebaert 1999). This method is based on the formation of capsules in the form of a resultant layer in which the coating liquid is sprayed onto the particles in the bed by means of the spray head (Desai & Jin Park 2005).

3.4 Extrusion

Extrusion is the oldest and often preferred method for making capsules with hydrocolloids. Capsules are produced by injecting droplets of the colloid solution prepared in the hardening solution (Krasaekoopt et al. 2003). Used in volatile, low-stability, flavor ingredients encapsulated with vitreous carbohydrate matrices with high set-forming properties (Desai & Jin Park 2005). It is usually used as sucrose, maltodextrin, glucose syrup, glycerin and glucose encapsulating material (Arshady 1993).

3.6 Liposomal Dispensing

Liposomes are colloidal particle structures formed by bilayer lipid layers encapsulating liquid fields, and containing membrane systems (Fang & Bhandar 2010). Liposomes are biocompatible materials, have many important advantages such as being able to hold the water-soluble active ingredients in the hydrophilic center, to hold the water-insoluble hydrophobic ingredients on the membrane, to be resistant to environmental effects without side effects, to have the action of bioactive compounds in the cell and even in the cellular compartments at a high level. They also have desirable biological activities such that their size can be made desirable by various processes (Torchilin 2005).

In addition to the above methods, nowadays air suspension coating, rotary suspension separation, water removal by centrifugation, phase separation and molecular complex formation methods are also used.

3.5 Co-Crystallization

The method of merging the core material with the saccharose matrix used as a coating material. The non-sucrose bioactive material forms microcapsules that vary in diameter from 3 to 30 µm as they pass into the saccharose crystals. The present core material is added to the concentrated syrup which is mixed adequately and firmly. Through the mixing process, the saccharose and the core material are intertwined to form the encapsulation process (Rizzuto et al. 1984; Gökmen et al. 2012).

4. Use of encapsulated products in animal nutrition

Antibiotics are often preferred for the prevention and treatment of illnesses for many years as well as benefitting from feed and increasing growth rate in animal nutrition. The use of products such as antibiotics in farm animals has been prohibited as an additive ingredient since 2006 due to increased concern about the formation of resistant bacteria (resistance) that could create carcinogenic and mutagenic risks to human health and the release of residues in animal products. After the growth factor antibiotics have been banned, researchers have intensified their work on natural products such as; waste and extracts of medicinal and aromatic plants, organic acids, prebiotics and probiotics which could be an alternative to this antibiotic (Anonim 2005a; Anonim 2005b; Şergezer & Güngör 2008; Karasu & Özturk 2014). Interest in the products such as most plants like mint, thyme, rosemary, sage, which are natural additives and antioxidant and antimicrobial active phenolic compounds obtained from natural bioactive compounds evaluated in this context has increased (Çabuk et at. 2003; Erener et al. 2005; Adıyaman & Ayhan 2010; Kaya & Turgut 2012). The high antioxidant capacity of these plants is due to phenolic compounds containing volatile compounds, also known as essential oils (Velasco & Williams 2011).

Due to the ability of polyphenols to be easily oxidized in the presence of heat, light, metal ions, pH, sugar and ascorbic acid in the medium, the levels of active substances in the production process are reduced. Furthermore, evaluation of the phenolic components in the body reduces their bioavailability due to the low level of absorption. Therefore, polyphenols are encapsulated with various products to protect both the external environment and the negative effects of the environment in the digestive tract. Phenolic compounds are metabolized mostly after they are taken into the body, while the part of it reached the small intestine is disintegrating at high pH. Many new techniques have been developed for the colonic controlled release of active substances, such as pH sensitive, microflora resistant, time and pressure controlled systems. While the pH of the stomach is acidic, the pH of the small intestines and colon is higher. These pH differences in the digestive tract are used in the development of the colony-specific drug delivery systems. For this purpose, it is desirable to encapsulate the active material with pH-sensitive polymers and not dissolve in the acidic medium and dissolve at pH values of 6 and above. This encapsulation allows the passage of the bioactive components in the gastrointestinal tract without deterioration (Turk et al. 2006).

It has been reported that efficient and satisfactory results are obtained in encapsulation technology in increasing the stability and bioavailability of various phenolic compounds (Coruhli, 2013). It is desired to obtain products with high bioavailability from active ingredient from reaching the small intestine without affected by environmental conditions and acidic conditions of the stomach environment. For this reason, encapsulation technology has been applied in recent years to provide a low-pH stabilized, partially resistant to stomach conditions, inflated at high pH, such as the small intestine, without being affected by environmental conditions (Anbinder et al. 2011; Coruhli, 2013; Mohammedi et al. 2016). In addition, with microencapsulation applications, the relation between the encapsulated active ingredient and system is limited. If it is necessary to limit the active substance to its environment, it is easier to separate it from the medium by means of the microcapsules obtained by encapsulating this substance. The capsules used in this method have the feature of protecting the structure and being able to become functional in the environments where the necessary conditions are provided (Kınık et al. 2003). Encapsulation is used for various purposes such as protecting the food and feed additives from oxidation, increasing storage stability and preserving the aroma. It could be used in the fields of food, pharmacy, industry and also it is possible to apply encapsulation in feed additives. For example, core materials of lycopene, linoleic acid, fish oil, conjugated linoleic acid, etc., which can be used as a feed additive, can be coated with various coating materials (Shu 2006).

A research conducted to increase the stability of color matter and stability of an extract of black carrot anthocyanin which is used as a feed additive substance by using a spray drier coated with maltodextrin, it has been reported that black carrot anthocyanins can be used for coloring various products, products of different colors can be obtained in different concentrations at different pH ratios, and the encapsulation process increases the storage stability (Ersus & Yurdagel 2007). Recently, it has been uncovered that to obtain a capsulation formulation which would protect the chemical structure of sage oil in the most optimal degree, sage oil was used in 8%, water 52%, maltodextrin 38% and gamma 2% in sage oil spray drying method. Accordingly, it was observed that the wall materials that best preserve the natural structure of sage oil are the maltodextrin and acacia scale in the conditions determined in the encapsulation process (Yeşilcubuk 2017). It was reported that capsular forms of garlic and *Phyllanthusniruri L.* mixture encapsulated between powder and capsule form which are coated by arabic gum and whey have more powerful effects on live weight gain and feed evaluation than powder form, but they have not affected on intestinal microflora of broiler (Natsir et al. 2013).

In a study where the turmeric extract was used as chitosan, sodium tripolyphosphate as encapsulation material and applied in the rations of broiler chickens, it was concluded that it could be used as an alternative feed additive in place of antibiotics and reduce meat cholesterol to improve food digestibility (Sundari et al. 2014). Hafeez et al. 2015, found that the incipient phytogenic feed additives added to broiler rations affected the rate of feed utilization favorably compared to the powder form. Another assay suggests that waste and encapsulated forms of various essential oils and organic acids were included in the rations of broiler chickens, live weighted increase was reported to positively affect the encapsulated form compared to the powder form (Lippens et al. 2006). The performance of microcapsulated organic acid mixture and medium chain fatty acid in egg chickens by rationing, on intestinal microflora and digestibility (Lee et al. 2015) egg production, Haugh unit, calcium concentration and fecal Lactobacillus and E. coli contents, and that they could be used as an alternative to antibiotics. Zhang et al. 2005, reports that microencapsulation of probiotics can significantly improve the growth performance of broiler chickens, immune function, the number of microbial populations, and the general health of chickens. Grilli et al. 2013 reported that microcapsulated sodium selenitine is a suitable technique for conserving nutrients in dairy cattle by ruminal reduction of bioavailability and that tissues (plasma and milk) are absorbed more efficiently from free form. It has also been reported that the addition of encapsulated cinnamaldehyde and eugenol essential oil mixture increases the concentration of ruminal ammonia in dairy cattle (Tekippe et al. 2013). The microencapsulated zinc oxide has shown positive effects on growth performance and intestinal structure in piglets and that microencapsulation may be beneficial to the environment by using lower levels of zinc oxide and less waste has been reported (Grilli et al. 2015).

5. Results and suggestions

Encapsulation technology has been used for many years in many areas. It has been used in recent years to encapsulate bioactive components such as lipids, vitamins, peptides, fatty acids, antioxidants, minerals, probiotics, which are important for the metabolic requirements of farm animals. It is preferred for many purposes such as the prevention of oxidation, protection of aroma, increase of stability, lengthening effect period, controlled release to target tissues and increasing bioavailability. Most of the products produced by encapsulation technology are in the laboratory stage and there is a possibility that in the coming years, most of the studies carried out at the laboratory scale could be converted into commercial products. As a result, encapsulation is becoming an increasingly important issue in the fields of food, pharmacy, medicine, veterinary medicine, biotechnology, textile, industry, agriculture and animal nutrition. In this context, it is possible to apply many researches on laboratory scale to industrial scale by creating application areas for bioactive components and feed additives aimed at purposes and demands.

6. References

Adıyaman E. & Ayhan V, (2010) Use of aromatic plants in broiler nutrition. *Journal of Animal Production **51***, 57-63.

Anbinder PS, Deladino L, Navarro AS, Amalvy JI. & Martino MN. (2011) Yerba mate extract encapsulation with alginate and chitosan systems: interactions between active compound encapsulation polymers. *Journal of Encapsulation and Adsorption Sciencesm* 1, 80-87.

Anonim. (2005a) Europe bans antibiotics in farm animal feed-call for same in US. Access: http:www.rense.com/health/europebans.(htm Access date: 22/12/2005).

Anonim. (2005b) Bayer ends antibiotic battle with FDA. *World Poultry* 21(11): 7.

Arshady R. (1993) Microcapsules for food. *Journal of Microencapsulation* **10**, 413-435.

Chan ES, Lee BB, Ravindra P. & Poncelet D. (2009) Prediction models for shape and size of ca-alginate macrobeads produced through extrusion–dripping method. *Journal of colloid and interface science* **338**, 63-72.

Chandramouli V, Kailasapathy K, Peiris P. & Jones M. (2004) An improved method of microencapsulation and its evaluation to protect Lactobacillus spp. in simulated gastric conditions. *Journal of microbiological methods* **56**, 27-35.

Coruhli T. (2013) Encapsulation of Black Mulberry Anthocyanins by Ionic Gelation Method and Optimization of Encapsulation Parameters with Response Surface Method. Master Thesis. Istanbul Technical University, Graduate School of Natural and Applied Sciences.

Cosco S, Ambrogi V, Musto P. & Carfagna C. (2006) Urea-Formaldehyde Microcapsules Containing an Epoxy Resin: Influence of Reaction Parameters on the Encapsulation Yield. In Macromolecular symposia. Wıley-Vch Verlag, p. 184-192.

Çabuk M, Alçiçek A, Bozkurt M. & İmre N. (2003) Possibility of using antimicrobial properties of essential oils obtained from aromatic plants as an alternative feed additive. *II. National Animal Feed Congress,* 184-187.

Desai KGH. & Jin Park H. (2005) Recent developments in microencapsulation of food ingredients. *Drying technology* **23**, 1361-1394.

Dewettinck K. & Huyghebaert A. (1999) Fluidized bed coating in food technology. *Trends in Food Science Technology* **10**, 163-168.

Druaux C. & Voilley A. (1997) Effect of food composition and microstructure on volatile flavour release. Trends in Food Science Technology **8**, 364-368.

Dubey R. (2009) Microencapsulation technology and applications. *Defence Science Journal* **59**,82.

Dziezak JD. (1988) Microencapsulation and encapsulated ingredients. *Food Technology* **42**, 136.

Erener G, Ocak N, Ak FB. & Altop A. (2005) Performance of broiler fed peppermint (Menthol) or origan (Carvacrol) essential oil supplemented diet. In Proceedings of 3rd National Congress of Animal Nutrition p. 58-62.

Ersus S. & Yurdagel U. (2007) Microencapsulation of anthocyanin pigments of black carrot (Daucus carota L.) by spray drier. *Journal of Food Engineering* **80**, 805-812.

Fang Z. & Bhandari B. (2010) Encapsulation of polyphenols (review). *Trends in Food Science Technology* **21**, 510-523.

Godshall MA. (1997) How carbohydrates influence food flavor. *Food Technology* **51**, 63–67.

Gouin S. (2004) Microencapsulation: industrial appraisal of existing technologies and trends. *Trends in food science technology* **15**, 330-347.

Gökmen S, Palamutoğlu R. & Sarıçoban C. (2012) Encapsulation applications in food industry. *Electronic Journal of Food Technologies* **7**, 36-50.

Gharsallaoui A, Roudaut G, Chambin O, Voilley A. & Saurel R. (2007) Applications of spray-drying in microencapsulation of food ingredients: An overview. *Food Research International* **40**, 1107-1121.

Grilli E, Gallo A, Fustini M, Fantinati P. & Piva A. (2013) Microencapsulated sodium selenite supplementation in dairy cows: effects on selenium status. *Animal* **7**, 1944-1949.

Grilli E, Tugnoli B, Vitari F, Domeneghini C, Morlacchini MAURO, Piva A. & Prandini A. (2015) Low doses of microencapsulated zinc oxide improve performance and modulate the ileum architecture, inflammatory cytokines and tight junctions expression of weaned pigs. *Animal* **9**, 1760-1768.

Güngör Ö, Zungur A, Koç M. & Kaymak-Ertekin F. (2013) Emulsions Properties and Effect of Emulsification Conditions on Microencapsulation of Aroma and Oil. *Academic Food Journal* **11**.

Hafeez A, Männer K, Schieder C. & Zentek J. (2015) Effect of supplementation of phytogenic feed additives (powdered vs. encapsulated) on performance and nutrient digestibility in broiler

Karasu K. & Öztürk E. (2014) Antioxidant and Antimicrobial Effects of Medicinal and Aromatic Plants in Wingeds. *Turkish Agriculture and Natural Sciences* **7**, 1766-1772.

Kaş HS. & Eldem T. (2002) Targeting Controlled Release Systems. Gürsoy, A.(Editör), Controlled Release Systems, İstanbul, *Publications of Controlled Releasing Systems Association*, **308**.

Kaya A. & Turgut L. (2012) Sage (Salvia officinalis), Thyme (Thymbraspicata), Mint (Menthaepiperitae) Extracts added in Chicken Rations at Different Rates, effects of vitamin E on performance, egg quality and egg Hatch TBARS values. *Ataturk University Journal of Agricultural Faculty* **43**, 49-58.

Khare AR. & Vasisht N. (2014) Nanoencapsulation in the food Industry: technology of the future. In Microencapsulation in the food industry pp. 151-155.

Kınık Ö, Kavas G. & Yılmaz E. (2003) Microencapsulation technique and use possibilities in milk technology. *The Journal Of Food* **28**, 401-407.

Koç M., Sakin M. & Kaymak-Ertekin F. (2010) Microencapsulation and its use in food technology. *Pamukkale University Journal of Engineering Sciences* **16**,77-86.

Krasaekoopt W, Bhandari B. & Deeth H. (2003) Evaluation of encapsulation techniques of probiotics for yoghurt. *International Dairy Journal* **13**, 3-13.

Landy P, Druaux C. & Voilley A. (1995) Retention of aroma compounds by proteins in aqueous solution. *Food Chemistry* **54**, 387-392.

Lee SI, Kim HS. & Kim I. (2015) Microencapsulated organic acid blend with MCFAs can be used as analternative to antibiotics for laying hens. *Turkish Journal of Veterinary and Animal* Sciences **39**, 520-527.

Lee CM. & Toledo RT. (1979) Processing and ingredient influences on texture of cooked comminuted fish muscle. *Journal of Food Science* **44**, 1615-1618.

Lippens M, Huyghebaert G. & Scicutella S. (2006) The efficacy of microencapsulated, gastro-resistent blends of essential oils and/or organic acids in broiler diets. In European Poultry Conference, Vol. 12, pp. 359.

Madene A, Jacquot M, Scher J. & Desobry S. (2006) Flavour encapsulation and controlled release (review). *International journal of food science & technology* **41**, 1-21.

Matalanis A, Jones OG. & McClements DJ. (2011) Structured biopolymer-based delivery systems for encapsulation, protection, and release of lipophilic compounds. *Food Hydrocolloids* **25**, 1865-1880.

Mohammadi A, Jafari SM, Assadpour E. & Esfanjani AF. (2016) Nano-encapsulation of olive leaf phenolic compounds through WPC–pectin complexes and evaluating their release rate. *International journal of biological macromolecules* **82**, 816-822.

Natsir MH, Hartutik OS. & Widodo E. (2013) Effect of either powder or encapsulated form of garlic and Phyllanthus niruri L. mixture on broiler performances, intestinal characteristics and intestinal microflora. *International Journal of Poultry Science* **12**, 676.

Nedovic V, Kalusevic A, Manojlovic V, Levic S. & Bugarski B. (2011) An overview of encapsulation technologies for food applications. *Procedia Food Science* **1**, 1806-1815.

Özcan T. & Altun B. (2013) Microencapsulation of probiotic bacteria in dairy products I: encapsulation techniques. *Journal of Uludag University Agricultural Faculty* **27**, 93-104.

Peker H. & Arslan S, (2011) Microencapsulation and usage areas in milk technology. *Academic Food Journal* **9**, 70-80.

Poshadri A. & Aparna K. (2010) Microenkapsulation Technology (review). *J.Res. Angrau* **38**,86-102.

Qi M, Gu Y, Sakata N, Kim D, Shirouzu Y, Yamamoto C. & Inoue K. (2004) PVA hydrogel sheet macroencapsulation for the bioartificial pancreas. *Biomaterials* **25**, 5885-5892.

Rizzuto AB, Chen AC. & Veiga MF. (1984) Modification of the sucrose crystal structure to enhance pharmaceutical properties of excipient and drug substances. *Pharm Technol* **8**, 32-35.

Shu B, Yu W, Zhao Y. & Liu X. (2006) Study on microencapsulation of lycopene by spray-drying. *Journal of Food Engineering* **76**, 664-669.

Smidsrød O. & Skja G. (1990) Alginate as immobilization matrix for cells. *Trends in biotechnologym* **8**, 71-78.

Sundari Z, Yuwanta T. & Martien R. (2014) Effect of nanocapsule level on broiler performance and fat deposition. *International Journal of Poultry Science* **13**, 31-35.

Şergezer E. & Güngör T, (2008) Effects of Essential Oils on Animals. *Journal of Lalahan Animal Research Institute* **48**, 101 – 110.

Tarhan Ö, Gökmen V. & Harsa Ş. (2010) Applications of nanotechnology in the field of food science and technology. *Nutrient Journal* **35**, 219-225.

Tekippe JA, Tacoma R, Hristov AN, Lee C, Oh J1, Heyler KS. & Bravo D. (2013) Effect of essential oils on ruminal fermentation and lactation performance of dairy cows. *Journal of Dairy science* **96**, 7892-7903.

Thevenet F. (2012) Acacia Gum. Polymer science a comprehensive reference, (Eds: Moeller, M., Matyjaszewski, K.), Elsevier, Amsterdam, Holland. p. 205-211.

Torchilin VP. (2005) Recent advances with liposomes as pharmaceutical carriers. *Nature reviews Drug discovery* **4**, 145.

Turk ŞTC, Hasçicek C. & Gönül N. (2006) Drug delivery systems targeted to colon. *Journal of Ankara Faculty of Pharmacy* **35**, 125-148.

Vasisht N. (2014) Factors and mechanisms in microencapsulation. In Microencapsulation in the food industry pp. 15-24.

Velasco V. & Williams P. (2011) Improving meat quality through natural antioxidants. *Chilean journal of agricultural research* **71**,313.

Xie L, Hettiarachchy NS, Ju ZY, Meullenet J, Wang H, Slavik MF. & Janes ME. (2002) Edible Film Coating to Minimize Eggshell Breakage and Reduce Post-Wash Bacterial Contamination Measured by Dye Penetration in Eggs. *Journal of Food Science* **67**, 280-284.

Yeşilçubuk N. (2017) The Impact of Carrier Materials on Encapsulation of Sage Oil with Spray Dryer. Master Thesis. Istanbul Technical University, Graduate School of Natural and Applied Sciences.

Zhang KY, Yan F, Keen CA. & Waldroup PW. (2005) Evaluation of microencapsulated essential oils and organic acids in diets for broiler chickens. *International Journal of Poultry Science* **4**, 612-619.

Zuidam NJ. & 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.