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USE OF MICROENCAPSULATION AND NANOENCAPSULATION TECHNIQUES IN DAIRY TECHNOLOGY

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Abstract

Encapsulation is a new technology known as packing of food components, enzymes, microorganisms, cells or different substances, which are found in solid, liquid and gas form, with coating materials such as proteins, hydrocolloids, polymers, polysaccharides and lipids. Encapsulation techniques have the high potential to protect the food systems. They are divided into three categories according to sizes of produced capsule: these are nanoencapsulation, microencapsulation and macroencapsulation. Microencapsulation is commonly used in pharmacy, agriculture, cosmetic industries for encapsulation of solid and liquid oils, vitamins, minerals, flavour components, enzymes, and colouring components used in dairy technology. Nanoencapsulation is especially used in packing systems to ensure food safety and to detect pathogen microorganisms. This review is focused on microencapsulation and nanoencapsulation, which maintain the controlled preservation of dairy products.

Key words: *coating materials, dairy products, encapsulation techniques, microencapsulation, nanoencapsulation*.

INTRODUCTION

In recent years, people have been turning to healthier eating habits. As known, foods are not only important sources for human nutrition but also, they play a crucial role for preventing diseases, which are related to nutrition (Varhan and Koç, 2018; Aspri et al., 2020). Healthy nutrition has been important from both quality and reliability points of view (Onwluata, 2013). Depending on the technological developments, there have been many positive changes related to health and nutrition, such as the search for various functional foods and new food matrices rich in beneficial components. These changes in human history and culture present a promising situation for progress (Şengün and Yahşi., 2021).

The developments in the food industry supply have many advantages especially in microbial systems, food safety, composition of raw materials, sensorial, textural and organoleptic properties of final product. Moreover, these quality parameters are important not only for the consumer but also for the food producers (Iravani et al., 2015).

Encapsulation technology, which includes all these advantages, is used in food technology in addition to many industrial applications such as consumer products, cosmetics, pharmaceutical/medical products and agricultural products. Encapsulation involves the coating or entrapment of a pure material or a mixture into another material. The coated or entrapped material is usually a liquid but can be a solid or gas. The coating material can be of protein, carbohydrate and lipid source (Gökmen et al., 2012). By using this technique, produced encapsulated materials can be protected from moisture, heat or other extreme conditions, thus their stability is enhanced and viability is maintained (Varhan and Koç, 2018). Although the sizes of the produced capsules vary, they are divided into 3 groups: nanocapsule, microcapsule and macrocapsule (Geniş and Tuncer, 2019). In addition, the covering materials should maintain the stability, increase the bioavailability, be nontoxic and inexpensive (Atak and Koç, 2017; Çınkır et al., 2019).

For an effective encapsulation, the suitable encapsulation materials should be selected. The most widely known coating materials among carbohydrate sources are starch, polyols, chitosan, pectin, agar, carrageenan and alginate (Zimet and Livney, 2009; Spada et al., 2012; Çınkır et al., 2019). Various techniques are used to form the capsules, including spray drying, spray chilling or spray cooling, extrusion coating, fluidized bed coating, liposome entrapment, coacervation, inclusion complexation, centrifugal extrusion and rotational suspension separation (Sobel et al., 2014). The most important techniques are further presented.

Spray Drying

Spray drying is a method based on reducing water activity and thus microbial growth of the product is minimized and the quality of the product is enhanced. Moreover, during storage and transport, the cost is also reduced (Boza et al., 2004). Due to this method, the specific properties of the final product are protected. It is mostly used in milk powder production in dairy industry (Gökmen et al., 2012). Besides these advantages, some disadvantages of this technique are reported. One of them is controlling of particle size which is difficult and another one is degradation of materials due to the differences in heat stability of compounds (Suganya and Anuradha, 2017).

Freeze Drying

Freeze drying is also called lyophilization. This technique is based on the sublimation of water in foods. The applied temperature ranges between -40ºC and -80ºC. Although it is a simple technique, the cost is high. Whey protein, gelatin and pullulan can be given as examples of the most commonly used coating materials in the encapsulation process applied with this technique (Çınkır et al., 2019).

Extrusion Method

Due to its low cost and simple formulation, extrusion provides highly ease of use. It is based on solidification of the solution containing hydrocolloid. The applied temperature is quite low (<100°C). This technique provides an extremely protective feature of products against oxidation. By means of extrusion method it is possible to prevent the loss of compounds in foods and in this way the shelf-life of foods is prolonged. Its disadvantage is that capsule formation rate is low (Geniş and Tuncer, 2019). For example; Harz et al. (2000) determined the following method for the encapsulation of enzymes: all the essential ingredients are mixed in the method and the resulting mixture is fed into the extruder at 40°C. It is rolled under a temperature of 100°C and cooled to 45°C in a few seconds (Harz et al., 2000; Açu et al., 2014). The advantage of extrusion is that the material is totally isolated by the wall material and that any core is washed from the outside. It is mainly used for encapsulation of components such as visible flavor fragments, vitamin C, colors.

Emulsification Method

In the emulsion technique, a discontinuous phase is added into the continuous phase. This mixture is used to form a water-in-oil emulsion, homogenized and the prepared emulsion is kept for a while, so that the non-continuous phase passes into a small gel form without dissolving in the continuous phase. And then the obtained capsules are separated from the liquid solution by filtration (Gökmen et al., 2012). Hydrocolloids such as carrageenan are used as coating material (Gökbulut and Öztürk, 2018).

Spray Cooling

The most important difference between spray cooling and spray drying is the particle formation area. In the particle formation zone, the particles are formed not by evaporation of a solvent, but by cooling and hardening of the droplets (Poshadri and Aparna, 2010; Kanat and Gülel, 2021). Spray cooling is an inexpensive encapsulation technique. However, no matter how small the microparticles are, there is a medium used for possession and storage (Kanat and Gülel, 2020).

Coavercation Method

In this technique, phase separation takes place first to separate the polyelectrolyte and/or polyelectrolyte mixture from a solution, then a coacervate phase is formed and the core is completely coated (Çınkır et al., 2019).

APPLICATION OF ENCAPSULATION TECHNIQUES IN MILK AND DAIRY PRODUCTS

In recent years, most studies have focused on the encapsulation techniques due to their protective properties against the environmental conditions such as O_2, temperature, light, humidity, and providing of controlled release of the active ingredients, not only in food but also in pharmacy, cosmetics and agricultural industry (Balci-Torun and Özdemir, 2021). In general, the components used for encapsulation applications can be listed as follows: food active ingredients, colorants, enzymes, minerals and vitamins, flavoring agents, additives, probiotic microorganisms etc. Therefore, it is possible to use such encapsulated products in dairy technology especially in yoghurt, ice cream, milk powder, cheese production and in this way the desired quality is maintained and the product stability is ensured for a certain period of time (Peker and Arslan, 2011).

One of the applications areas of encapsulation techniques is the production of fermented dairy products such as cheese, yogurt, kefir and cream in terms of lactic acid bacteria. The encapsulation applications in cheese generally provide benefits in terms of the desired level of taste, flavor and aroma formation, shortening the ripening time of ripened cheeses, by reducing and/or eliminating the problems that may arise from the direct addition of the enzymes, and by preventing rapid and excessive proteolysis. The use of encapsulation techniques in different products is shown in Table 1.

Table 1. Some selected studies carried out using encapsulation techniques

*Encapsulation method	Study	Key findings	References
NE	An extract from *Plinia peruviana* plant was prepared by nanoemulsion and added it into cow's milk and investigated the antioxidant activity and phenolic content of cow's milk.	The antioxidant properties of cow's milk and phenolic substance content in milk increased	Di Maio et al., 2019
ME	*Lactobacillus plantarum* was microencapsulated using serum protein. The spray drying method was used.	There was no decrease in the viability of the bacteria after 56 days of storage. Bacterial cells still maintained their viability.	Eckert et al., 2017
NE	In this study, turmeric was encapsulated with nanoencapsulation technology and prepared by the freeze-drying technique. Turmeric, was added to the ice cream mixture	There were no changes in the sensorial properties of the nanoemulsion added ice cream compared to the control sample, and the encapsulation efficiency was 93.7%.	Kumar et al., 2016
ME	*Lactobacillus acidophilus* was encapsulated with polymerized serum protein, which was used in yoghurt production.	It has been stated that encapsulates, in which polymerized serum proteins are used as coating material during the storage of yoghurt, are more efficient, more effective and more protective.	Jiang et al., 2016
NE	Isolated lactoferrin from camel milk nanoencapsulated with 0.2-0.5% calcium alginate.	Calcium alginates are a very natural tool for the digestion of lactoferrin. Using 0.5% calcium alginate lactoferrin release was actually high.	Raei et al., 2015
ME	In order to accelerate the ripening of Cheddar cheese, microencapsulated aminopeptidase enzyme was added and showed that some properties of the samples with encapsulated enzyme were better	The taste, aroma and textural values of cheeses containing encapsulated enzymes were higher than the control. The total amount of free amino acids during storage was in the cheese sample containing the encapsulated enzyme increased the proteolysis.	Açu et al., 2014
ME	In this study the probiotic *Lactobacillus acidophilus* (La-5) cells either in free & encapsulated form was incorporated into yoghurt-ice cream and their survivability were studied.	Encapsulation of bacteria with fructooligosaccharide protected the live probiotic cells both during the freezing stage and during frozen storage.	Ahmadi et al., 2014

*ME:microencapsulation; NE:nanoencapsulation

In a study performed by Mudgil et al. (2022), the effects of microencapsulation of probiotics (*Pediococcus pentosaceus*) on the stability and viability in Chami cheese were investigated. It was stated that probiotics that were encapsulated by camel milk proteins and wheat starch had higher cell viability in Chami matrix, especially those using camel milk proteins (Mudgil et al., 2022).

In another study performed by Siyar et al., (2022) the physicochemical and textural properties of cheese were investigated by adding encapsulated saffron extract at varied concentrations in ricotta cheese. It is stated that the saffron extract encapsulated in nanoliposomes provided stability, as well as protecting the bioactive substances of saffron during storage and did not significantly affect most compositional parameters. The study revealed that saffron extract encapsulated in nanoliposomes can be incorporated into a ricotta cheese production.

Jeong et al. (2017) investigated the influence of the addition of powdered tomato extracts on the physicochemical, microbial and sensory properties of Queso Blanco cheese in their studies. It has been reported that the lactic acid bacteria count and lycopene concentrations found in cheeses containing encapsulation were higher when compared to the control cheese group without encapsulation. It was determined that increasing the encapsulated tomato extract concentration in cheese causes the accession of gumminess, chewing and hardness parameters. It was also determined that the addition of these encapsulated additives improve the texture properties of the cheese.

The encapsulation technique was investigated to increase the viability of *L. plantarum* 564 in soft goat cheese. It was stated that spray drying of *L. plantarum* 564 strain can be used successfully to increase the number of viable probiotic cells after cold storage (Radulović et al., 2017).

Rashidinejad et al. (2016) conducted a study in which catechin or green tea extract was encapsulated in soy lecithin nanoliposomes and used in the production of a full-fat cheese. Some analyzes such as the determination of antioxidant capacity after 90 days of storage at 8°C were made and it was stated that the encapsulated green tea extract could be used in the cheese product. During cheese ripening total phenolic content (TPC) and antioxidant activity were measured. It has been stated that an addition of encapsulated bioactive compounds increases the relevant parameters (total phenolic content and antioxidant activity).

The viability of *Bifidobacterium bifidum* BB-12 and *Lactobacillus acidophilus* LA-5 microencapsulated by extrusion-emulsion technique was investigated in white brine cheese production and ripening. Although there was no sensory difference between the control cheese and encapsulated microorganisms added cheese, it was reported that the cell viability was slightly limited. It was observed that both microorganisms encapsulated during the production and maturation of white brine cheese preserved cell viability better than cheeses without capsules (Özer et al., 2009).

In addition, encapsulation techniques often provide benefits in fermented products such as yogurt in the dairy industry. The food industry aims to overcome the problems, which are related with the production of live starter microorganisms, because the yogurt should contain bacteria in live form so that the yogurt bacteria can metabolize lactose to lactic acid and in this way it increases the shelf life of yogurt (Değirmenci, 2017). In order to eliminate these problems and improve the physicochemical properties, it may be preferred to apply encapsulation techniques to yogurt production. By means of the encapsulation technique, the bacteria used as a culture can be protected against the external environmental conditions and increase the vitality rate at 80-95%. It is also possible to add probiotic live cells to increase the functional properties of yogurt. Encapsulation techniques reveal that the encapsulation of microorganisms and probiotics used at this point is a beneficial practice for the continuation of their viability (Altun and Özcan, 2013). According to recent studies, it has been revealed that encapsulating probiotic bacteria with prebiotic foods as well as encapsulating them alone increases the resistance of probiotics to external factors (Peker and Arslan, 2011).

In a study performed by Wang et al. (2018) the effects of microencapsulation on the viability of *Lactobacillus acidophilus* LA-5 on the physicochemical properties of yogurt was investigated. It was found that *Lactobacillus acidophilus* LA-5 remained highly viable in the gastrointestinal tract without damaging as a result of microencapsulation. They also found that the structure of yogurt was improved significantly and the water release (syneresis) reduced, contributing to the development of the physicochemical properties of the yogurt (Wang et al., 2018).

In a study, which was carried out in probiotic yogurt production trial with encapsulated *Lactobacillus acidophilus* by using whey protein powder, changes in storage of yogurt containing encapsulated *Lactobacillus acidophilus* and yogurt without encapsulated bacteria were observed. It was stated that yeast and mold formation were still not observed in yoghurt samples containing encapsulated probiotics, even after 28 days of storage (Değirmenci, 2017).

Probiotics were encapsulated with sodium alginate as coating material and used in the production of stirred (broken) type fruit yoghurt. Further, the viability of encapsulated probiotic bacteria during transition in gastrointestinal tract was investigated and the study concluded that the number of encapsulated probiotic bacteria were higher than the free cells, which showed more therapeutic activity (Palamutoğlu and Sariçoban, 2013). In another study, *Bifidobacterium breve* R070 was added to yogurt after encapsulation with whey proteins and the microbiological changes during 28 days of storage were investigated. It was reported that *Bifidobacterium breve* maintained its viability 2.6 log more than other microorganisms that were not encapsulated (Kanat and Terzi Gülel, 2021).

Encapsulated *Lactobacillus acidophilus* and *Bifidobacterium bifidum* cultures coated with a mixture of calcium alginate and corn starch were added to yogurt, and then their viability levels were investigated in artificial gastrointestinal conditions. It was stated that the encapsulation did not have a significant effect in terms of resistance within the gastrointestinal tract. However, the encapsulated bacteria lost 0.5 log unit of their viability at the end of the storage period, while the loss of nonencapsulated free cells was 1 log unit (Sultana et al., 2000; Açu et al., 2014).

Altın (2016) encapsulated cocoa shell phenolic compounds with nanoliposomal systems and used them in the production of buttermilk, and compared different encapsulation techniques regarding encapsulation efficiency. The aim of this study was enrichment of ayran with bioactive components and determine the efficiency of encapsulation. The results of the study showed that liposomes in powder form provided high encapsulation efficiency, and the bioavailability of cocoa phenolic components in spray-dried liposomes increased at least 7 times during the shelf life. Encapsulated phenolic components were preserved better *in vitro* conditions before and after digestion than phenolic compounds that did not undergo encapsulation.

Kalkan, (2019) investigated the probiotic kefir microorganism called *Saccharomyces cerevisiae* var. *boulardii* encapsulated by the extrusion technique. The aim is to investigate the fermentation of milk by taking advantage of the benefits provided by probiotic microorganisms. The probiotic kefirs were stored at 4°C for 28 days and the microbiological and chemical properties of kefir samples were compared with each other. According to the results of the research, it was stated that the microbiological and chemical properties of kefir samples containing encapsulated *S. boulardii* were similar to those of kefir without encapsulated *S. boulardii*. It has also been demonstrated that this microorganism can be used as a probiotic in fermented milk products.

Homayouni et al. (2008) carried out the encapsulation of lactic acid bacteria with different encapsulation techniques in ice cream production. The encapsulation of lactobacilli was performed with calcium alginate gel as coating matrix. It was stated that the application of encapsulation techniques ensures that the bacteria in the products are more durable and longer lasting compared to the unencapsulated free bacterial cells in freezing and/or cryopreservation processes (Kınık et al., 2003; Peker and Arslan, 2011).

Similar to this study *Bifidobacterium longum* CFR815j was encapsulated and added into the ice cream formulation to find out whether it had an effect on the viability of the bacteria and on the physiological properties of the ice cream. It was stated that all the properties analyzed were comparable to normal ice cream, and they also revealed that the encapsulation application can maintain the viability of the probiotic *Bifidobacterium*, which has the minimum biological value required for the final product, without affecting the sensory properties of the ice cream (Kataria et al., 2018).

In a study in which barberry, known as an anthocyanin-rich plant fruit, was encapsulated by the ionic gelation method by applying extraction, the obtained capsules were included in the ice cream formulation. As a result of the research, the usability of these capsules for ice cream production and pH, antioxidant activity, etc. were investigated. As a result of the storage analyzes of the capsules added to the ice cream, it was stated that the anthocyanin content of the ice cream with the capsule addition preserved the stability of the product quite well and its usability in ice cream production was positive (Okurkan, 2018).

Milk fat is a valuable component that significantly affects the organoleptic properties of milk and dairy products. Since it is a very sensitive substance compared to other milk components, it has a short shelf life and is susceptible to oxidation (Himmetağaoğlu et al., 2019). However, with the application of microencapsulation by spray drying, it is possible to protect fast perishable foods and to obtain more stable products that are more resistant against to external factors (Himmetağaoğlu et al., 2019). Peker and Arslan (2011) investigated the encapsulation of milk fat by using the spray drying method. As a result of their study, the encapsulation technique was successfully applied and more than 90% encapsulation efficiency was obtained.

CONCLUSIONS

Recently, the encapsulation techniques presented great success in the dairy industry especially in cheese technology. Therefore, it has been possible to offer consumers more nutritious, reliable products with a relatively longer shelf life. It is known that despite the economic feasibility of applying the techniques, it is not very burdensome, limited and still does not require large investments. It is thought that there is a great potential in the future especially in the food industry and that these developments should be increased and more comprehensive researches should be carried out in our country.

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