Transactions on Materials, Biotechnology and Life Sciences
ISSN: 2960-1932, eISSN: 2960-2319 | Volume 3
BLSME 2024

The Microcapsule Based on the Maillard Reaction Product from Spray Drying to Deliver Probiotics

Miaoshu Wang

Agriculture and Life Science, Cornell University, Ithaca, NY 14853, U.S.A

Abstract. The physical fitness improving capacity of probiotics has been proved to be valid but easy to degrade when exposed to the environment of processing, storage, and human gastrointestinal tract. A series of research have shown that the microcapsule embedding technology or coating technology with certain Maillard Reaction products (MRPs) as the wall material has the potential to improve the delivery condition, protect the probiotic supplements and helping the ideal expressing of probiotics in the gastrointestinal environment. This article explores the tactics that enforce microencapsulation of probiotics with microcapsule, which uses MRPs as wall material. The action mechanism of probiotics in microcapsule and the potential embedding techniques to develop the probiotic delivery systems will also be covered in this essay. However, the action mechanism of microcapsule-probiotic system taken place in vivo tract is still hot topic considering the studies performed through vitro strategy are not forcible enough considering the exogenous factors that cannot be tested.

Keywords: Probiotics; degrade; Maillard Reaction products; microencapsulation.

1. Introduction

Probiotics belong to microorganisms and are considered to have health benefits to the body of human and livestock when consumed or applied [1]. Probiotics are widely used in dietary supplements, fermented foods, beauty products and so on. In order to consume probiotic cells through food products, probiotic microorganisms are commonly added to fermented or non-fermented food or dietary supplements as dried or deep-frozen culture concentrates [2]. Through meta-analyses of clinical trials in recent years, probiotics has been proved to have capacity to improve the fitness status of intestinal environment, produce adequate lactase to enhance lactose digestion, and control certain types of cancers and reduce blood cholesterol, and therefore reduces the risk of contracting chronic diseases [3, 4].

Nevertheless, the preservation mode, processing path, and the environment retained in the gastrointestinal tract are considered to have impact on the activity and effectiveness of probiotics, and these exogenous factors are difficult to be quantified and evaluated in vitro studies of probiotics' effectiveness [5]. Therefore, reducing the influence of exogenous factors such as temperature, oxygen content, and water activity on the efficacy of probiotics are essential in enhancing the contribution of probiotics to host health condition.

The utilization of MRPs as an encapsulation material to form microcapsules to encapsulate bioactive substances, such as probiotics, is currently feasible for pharmaceutical companies and food companies and is of beneficial to the human intestinal health. The combination of antioxidant properties, excellent emulsification capacity of MRPs combined and the spray drying process, which turns liquid material into solid particle, making them ideal for use as an encapsulation matrix. Meanwhile, the combined structure of MRPs can protect the target core material and improve the stability of microcapsules in adverse environmental conditions, such as processing, transportation, and stomach acid, so as to extend the efficacy and action time of probiotic functional foods or supplements.

The selection of microcapsule wall material, the control of emulsification factors, and the temperature and feed rate during spray are significant in the protective effect and mechanism of the final microcapsule on probiotics. These key factors will be discussed in following sections.

2. Microencapsulation of probiotics

2.1. Microcapsules: ways to protect probiotics

Microcapsules are defined as spherical capsules with tiny sizes that can package and protect key core materials that plays important roles and releases them when applied in certain conditions. Microencapsulation utilizes embedding materials to wrap the core material, which can be solid, liquid or gas, to form a semi-permeable or sealed capsule with a diameter of generally 5 to 400μm [6]. As people know that probiotics that are good for the human body are mostly microaerophilic or anaerobic, and not heat resistant. This makes the survival rate of probiotics during factory storage, conventional transportation, and especially in the digestive tract presents a low state, and thus unable to achieve the desired beneficial effect on the human body. With antioxidant and emulsifying properties, and eminent consistency, microcapsules function as a physical barrier to protect the probiotics from non-ideal acid, base, or high oxygen content environment.

Microcapsules have a wide range of applications, including feed, supplement or medicine improvement in agriculture, food fortification, and bio-chemical fields. David F. Willer et al. gave the review on the potential of microencapsulated diets of being nutrients, disease controller, and quality enhancer, and summarized its role in bivalve feeding and cost reduction [7]. The Sacha Inchi seeds oil microcapsules of A Rodriguez-Cortina et al. produced by spray drying, which belongs to the field of functional food, showed excellent thermal stability, while helping to enrich the oil volatilization of functional compounds and enhance the absorption of Sacha Inchi seed oil by human intestine [8]. Ghiman et al. reported the bio-medical application of microcapsules in delivering plant-derived bioactive molecules to achieve better efficiency than normal intake and injection [9].

Many researchers have verified that microencapsulated probiotics can effectively inhibit the effects of the adverse situation of gastrointestinal on probiotics through in vitro and in vivo experiments. D. Banerjee et al. established the mathematical model to predict the concentration distribution of microencapsulated and released probiotics in the gastrointestinal system, and compared and verified the simulated data with the results of in-vitro experiments, drew the conclusion that the microencapsulated process can protect probiotic cells, thereby increasing the release of probiotic cells in the gastrointestinal system [10]. Table 1 summarizes microcapsules for embedding probiotics and their advantages over traditional delivery systems.

Table 1. The advantages of microcapsule produced to deliver probiotics [11-18]

Bacteria	Wall material	Advantages
Bifidobacterium breve NCIMB 8807	Alginate-Chitosan	Improved survival and effective at measuring coat thickness
Bifidobacterium BB-12	Sodium alginate	Confer probiotic viability under frozen storage
Lactobacillus rhamnosus 6134	Whey proteins-Isomalto-oligosaccharide	More effective viability of bacteria and higher encapsulation yield
Lactobacillus acidophilus La-14	Resistant starch-chitosan with sodium alginate	Improved survival
Lactobacillus rhamnosus GG	Alginate-chitosan	Improved survival and tolerance to heat treatment
Bacillus megaterium	*Megaterium*-alginate	Inhibit the growth of mold mycelia, improved survival
Bacillus amyloliquefaciens ES-2	Maltodextrin-porous starch	Improved efficiency of microcapsule production and denser shells
Bacillus thurigiensis	Light-resistant colloidosome	Extended bioactivity

The stable physical and chemical properties of microcapsules significantly improve the survival rate of microorganisms. Therefore, microcapsules can still show the characteristics of slow release of probiotics even under the unfavourable environment for microbial survival, such as the temperature

above or below the optimal growth temperature, the environment with high acid or alkali, and the environment with high oxygen content.

2.2. Microcapsules with Maillard Reaction Products as Wall Materials

The wall material of microcapsules plays a decisive role in the physiochemical properties of microcapsules, and affects the stability, permeability, solubility, and slow-release effect of the prepared microcapsules to a certain extent [19]. Most of the current encapsulation materials are extracted from natural and synthetic polymers [20]. However, compared with the synthetic polymer, the natural polymer material is unstable in gastric juice, which will lead to the instability of its encapsulated microcapsules and poor slow-release effect.

At present, a commonly used encapsulation mechanism uses MRPs as the wall material of microcapsules, which have many structural and chemical advantages. Given that the Maillard reaction occurs between carbonyl compound and reducing sugars, the exposure of portions of the polypeptide and polysaccharide chains and the hydrophobic groups of the reaction products is generally considered to have good emulsifying properties. And the hydrophilic carbohydrate moieties can prevent droplet aggregation through electrostatic repulsion and/or steric hindrance [21]. And the carbohydrate moieties are hydrophilic, which extend into the continuous phase, can keep off droplet aggregation by steric hindrance and electrostatic repulsion.

It has been researched that utilizing MRPs as the wall material can provide good thermal, oxidation, and chemical stability for microcapsules. G. Huang et al. reported that the microcapsule prepared by soybean protein isolate-chitosan under Maillard reaction shew greater resistance to dissolution in water and better storage stability than controlled microcapsules [22]. Y. Yang et al. compared in vivo tests of intestinal chyme of chickens fed encapsulated and unencapsulated citric aldehyde, concluded that microcapsules with soybean protein-soybean polysaccharide MRPs as wall materials have relatively strong chemical stability and can effectively deliver bioactive substances [23]. S. Drusch et al. shew that the oxidation stability of their microcapsule, which was generated from fish oil, could be improved by the increase of redox-active compounds produced by Maillard reaction [24].

Many experiments have also proved that the microcapsules with MRPs as the wall material have ideal structural characterization and good encapsulation efficiency.

3. The Maillard reaction under spray drying

The Maillard reaction is a common type of thermal degradation in spray drying and occurs between amino acids and reducing sugars, which goes through three stages and characterized by non-enzymatic Browning and the production of significant flavor products. MRPs are often used as encapsulation agents, which is wall material as mentioned. Studies have shown that compared with natural materials, MRPs have better emulsification capacity, thermal stability, foaming, solubility, and hypoallergenic properties, which act better and more efficiently in the encapsulation of probiotics [25]. However, it also has drawbacks.

Reports shew that the Maillard Reactions may have negative effect on the retaining of nutritional value of the encased substance, especially the bioactive substance, in addition to the formation of nitrogen-containing brown pigments and potentially carcinogenic mutagenic products [26]. Therefore, the study and precise control of reaction conditions and the production of by-products of Maillard reaction is still a hot topic that needs more detailed research in the future.

The microencapsulation techniques commonly used by researchers include emulsification, ionotropic gelation, extrusion, starch bonding, spray drying and freeze drying. Spray drying technology can transform the pretreated mixed microcapsule material in liquid form into solid small particles, so as to achieve the effect of embedding probiotics. If the oil encapsulation process is used for spray drying to embed probiotics to generate microcapsules, then the two-step process, emulsification and spray drying, requires careful allocation of parameters to improve the encapsulation property of the oil

emulsion, so as to obtain microcapsules with good delivery effect [27]. Table 2 showed the probiotics microencapsulation experiment performed by Maillard reaction through spray drying.

The reaction mechanism of the Maillard reaction is complex, relatively. And the process of spray drying is to convert the liquid mixed material into powder at a high temperature and pressure. Any changes in the different parameter Settings during this process will have an impact on physical or sensory properties, the final form, and the encapsulation efficiency of the final microcapsule.

Table 2. Microencapsulation of probiotics with MRPs by spray drying [17, 28-30]

		Spray Drying		
Bacteria	Wall material	Drying air flow rate ($m^3 \cdot h^{-1}$)	Inlet to Outlet Temp (℃)	Pressure (MPa)
Bacillus amyloliquefaciens ES-2	Maltodextrin, porous starch	50, 60, 70	180, 200, 220	–
Bacillus thuringiensis	Prebiotics inulin, oligofructose, and oligofructose-enriched inulin	35	150±2 to 55±3	0.7
Lactobacillus acidophilus	Protein (soy protein isolate, sodium caseinate, or pea protein), maltodextrin, glucose, and vegetable oil	35	150 to 65	4
Bifidobacterium longum	Soy protein isolate, I-carrageenan	70	140 to 85~90	0.6

4. The influencing factors of microencapsulation

The embedding efficiency of microcapsules has a significant relationship with the precise orientation preparation of raw material solution, the optimization of spray drying parameters, and the storage mode. In preparation process, it is critical to research on choosing best suitable formula in terms of the solid content of the mixed solution, viscosity, and selecting the most appropriate wall material. When determining the parameters for spray drying, considering dry gas flow rate and humidity, feed flow and speed, inlet and outlet temperature and pressure is critical to process optimization, microcapsule yield maximization and microcapsule embedding efficiency maximization [31].

4.1. Wall material

For the microcapsule, the composition, structure, and properties of the wall material determine its physical and chemical properties and stability. Wall materials suitable for spray drying to produce microcapsules need to have suitable emulsification properties, heat resistance, low viscosity and drying properties [27].

Experiments conducted by Y. Xie et al. explored the influence of rheological properties of wall materials on the particle size distribution and the morphology characteristics of microcapsules [32]. On the one hand, by using the Mastersizer 2000 particle size analyser to analyze the particle size distribution and then, the average particle size, for four times, they deduced that the volume average diameter of the microcapsule (D4, 3) is directly related to the wall material viscosity. On the other hand, the conclusions they reached by using wall materials with different elastic moduli are shown as following. If the wall material of the microcapsule has high elastic modulus, such as Gel-Suc, its external elastic deformation force exceeds the stress bearing capacity, which will lead to brittle fracture and prone to cracks, pores and fractures. Microcapsule wall materials with low elastic modulus, such as HI-CAP 100, will cause the microcapsule to have a characteristic indentation when hot air induced swelling, and this cannot be recovered during the rapid solidification phase of spray drying.

4.2. Emulsification

As mentioned before, emulsification and spray drying play a decisive role in the microcapsule structure formation step. The ratio of wall material determines the emulsifying properties of the reaction products, such as emulsifying activity and emulsifying stability. The physical and chemical characteristics of the initial emulsion will have a key influence on the microencapsulation effect and the properties of microcapsules [33]. One of the factors that affect the emulsification properties of emulsions is the particle size distribution of the emulsion molecules. It has been proved that small, dispersed emulsions can improve encapsulation efficiency of microcapsules because they can provide the microcapsules with lower surface oil content [27]. During the homogenization process before spray drying, increasing the homogenization pressure of the emulsion can make the droplets of the emulsion break down to a smaller size [20]. Another influencing factor is the viscosity of the emulsion particles. High viscosity leads to large and elongated droplets, which interfere with the atomization process and make it impossible to obtain a fast semi-permeable protective film during the spray drying stage. Determine the optimal total solids content to keep the viscosity of the emulsion at the right level [20].

4.3. Temperature

The influence of temperature on microcapsules is mainly reflected in the particle size, shape and water content of microcapsules. Through controlling different temperatures under drying of avocado powder, D. Dantas et al. reports that with higher drying temperature, smaller liquid and partial drops with lower moisture and water activity will be obtained with higher yields [34]. M. Aghbashlo et al. reported that the high temperature might also result in higher encapsulation efficiency and peroxide value [35]. However, excessive drying temperature may lead to thermal damage of microcapsules [36].

4.4. Injection/Flow rate

In the process of spray drying, several important parameters, like injection rate and drying air flow rate, will affect the water content and encapsulation efficiency of microcapsules, thus affecting the environment where the encapsulated probiotics are located. Specifically, increasing feed flow will reduces the moisture content of the microcapsules [20].

5. Conclusion

The use of microcapsules to encapsulate nutrients and bioactive substances has made great contributions in food ingredients, medicine and health products. As the key to improve human intestinal health, probiotics are of great significance in the field of dietary supplements in the future to realize their targeted fixed speed release and shelf-life extension.

Considering the excellent structural properties, emulsification properties, stability and oxidation resistance of Maillard reaction products, and the low cost and high efficiency of spray drying technology, the utilization of microcapsule with Maillard Reaction Products produced under spray drying condition as the wall material has great potential in delivering probiotics to GI tracts. While different microencapsulation conditions, including appropriate wall material, emulsifying technology, spray drying parameters, and storage conditions, should be selected for different application orientation to achieve the specific release of microencapsulated probiotics.

At present, the application field of microencapsulation technology is still limited. Further exploration of probiotic microencapsulation in the field of food and medicine is still the goal of researchers. Moreover, only a few in vivo studies and tests have achieved effective GI digestive characteristics of probiotic microcapsules for now. The mechanism of action of probiotics in vivo and the environment it is subjected to still need further experimental research to further strengthen the efficacy of probiotics. And the protective and targeted release effects of probiotics embedded in microcapsules still need further data supporting to perform further exploration.

References

[1] C. Hill, F. Guarner, G. Reid, G. R. Gibson, D. J. Merenstein, B. Pot, L. Morelli, R. B. Canani, H. J. Flint, S. Salminen, Nat Rev Gastro Hepat, 11, 506 - 514 (2014).

[2] M. K. Tripathi, S. K. Giri, J Funct Foods, 9, 225 - 241 (2014).

[3] T. K. Das, S. Pradhan, S. Chakrabarti, K. C. Mondal, K. Ghosh, Appl Food Res, 2, 100 - 185 (2022).

[4] M. Yao, J. Xie, H. Du, D. J. Mcclements, H. Xiao, L. Li, Compr Rev Food Sci F, 19 (2), 857 - 874 (2020).

[5] M. L. Marco, S. Tachon, Curr Opin Biotech, 24 (2), 207 - 213 (2013).

[6] F. Nazzaro, P. Orlando, F. Fratianni, R. Coppola, Curr Opin Biotech, 23 (2), 182 - 186 (2012).

[7] D. F. Willer, D. C. Aldridge, Glob Food Secur, 23, 64 - 73 (2019).

[8] A. Rodríguez-Cortina, M. Hernández-Carrión, Food Res Int, 170, 113014 (2023).

[9] R. Ghiman, R. Pop, D. Rugina, M. Focsan, J Mol Struct, 1248, 131366 (2022).

[10] D. Banerjee, R. Chowdhury, P. Bhattacharya, Lwt-Food Sci Technol, 83, 243 - 253 (2017).

[11] M. T. Cook, G. Tzortzis, D. Charalampopoulos, V. V. Khutoryanskiy, Biomacromolecules, 12 (7), 2834 - 2840 (2011).

[12] A. T. Holkem, G. C. Raddatz, J. S. Barin, É. M. M. Flores, E. I. Muller, C. F. Codevilla, E. Jacob-Lopes, C. R. F. Grosso, C. R. de Menezes, LWT-Food Sci Tech, 76, 216 - 221 (2017).

[13] L. Liu, X. Li, Y. Zhu, A. F. M. Bora, Y. Zhao, L. Du, D. Li, W. Bi, LWT, 73, 37 - 43 (2016).

[14] M. de Araújo Etchepare, G. C. Raddatz, É. M. de Moraes Flores, L. Q. Zepka, E. Jacob-Lopes, J. S. Barin, C. R. F. Grosso, C. R. de Menezes, LWT-Food Sci Tech, 65, 511 - 517 (2016).

[15] S. Abbaszadeh, H. Gandomi, A. Misaghi, S. Bokaei, N. Noori, J Sci Foodd Agr, 94 (11), 2210 - 2216 (2014).

[16] R. Wiwattanapatapee, A. Chumthong, A. Pengnoo, M. Kanjanamaneesathian, World J Microbiol Biot, 29, 1487 - 1497 (2013).

[17] Y. Wang, X. Zhu, X. Bie, F. Lu, C. Zhang, S. Yao, Z. Lu, LWT-Food Sci Tech, 56 (2), 502 - 507 (2014).

[18] O. Bashir, J. P. Claverie, P. Lemoyne, C. Vincent, Peerj, 4, e2524 (2016).

[19] Z. Zhang, S. Zhong, F. Peng, Y. Zeng, M. Zong, W. Lou, J Food Sci, 41 (09), 246 - 253 (2020).

[20] T. T. T. Nguyen, T. V. A. Le, N. N. Dang, D. C. Nguyen, P. T. N. Nguyen, T. T. Tran, Q. V. Nguyen, L. G. Bach, T. D. Thuy Nguyen Pham, J Food Quality, 2021, 1 - 15 (2021).

[21] J. Feng, C. C. Berton-Carabin, V. Fogliano, K. Schroën, Trends Food Sci Tech, 121, 129 - 141 (2022).

[22] G.-Q. Huang, H.-O. Wang, F.-W. Wang, Y.-L. Du, J.-X. Xiao, Int J Biol Macromol, 155, 1194 - 1201 (2020).

[23] Y. Yang, F. Niu, S. W. Cui, J. Gong, Q. Wang, Food Hydrocolloid, 132, 107842 (2022).

[24] S. Drusch, S. Berg, M. Scampicchio, Y. Serfert, V. Somoza, S. Mannino, K. Schwarz, Food Hydrocolloid, 23 (3), 942 - 948 (2009).

[25] Y. Y. Lee, T. K. Tang, E. T. Phuah, N. B. M. Alitheen, C. P. Tan, O. M. Lai, J Sci Food Agr, 97 (5), 1379 - 1385 (2017).

[26] Z. Zhou, T. Langrish, J Food Eng, 305, 110615 (2021).

[27] S. Ramakrishnan, M. Ferrando, L. Aceña-Muñoz, M. Mestres, S. De Lamo-Castellví, C. Güell, Food Bioprocess Tech, 7, 1959 - 1972 (2014).

[28] C. B. Fritzen-Freire, E. S. Prudêncio, R. D. Amboni, S. S. Pinto, A. N. Negrão-Murakami, F. S. Murakami, Food Research International, 45 (1), 306 - 312 (2012).

[29] D. Dianawati, S. F. Lim, Y. B. H. Ooi, N. P. Shah, J Food Sci, 82(9), 2134 - 2141 (2017).

[30] X. Sun, R. G. Cameron, J. Bai, Food Hydrocolloids, 100, 105420 (2020).

[31] E. Assadpour, S. M. Jafari, Annu Rev Food Sci T, 10, 103 - 131 (2019).

[32] Y. Xie, A. WANg, Q. Lu, M. Hui, Czech J Food Sci, 28 (5), 433 - 439 (2010).

[33] S. Ferreira, C. Malacrida, V. Nicoletti, Emir J Food Agr, 31, 491 - 500 (2019).

[34] D. Dantas, M. A. Pasquali, M. Cavalcanti-Mata, M. E. Duarte, H. M. Lisboa, Food Chem, 266, 284 - 291 (2018).

[35] M. Aghbashlo, H. Mobli, A. Madadlou, S. Rafiee, Food Bioprocess Tech, 6, 1561 - 1569 (2013).

[36] W. Ren, G. Tian, S. Zhao, Y. Yang, W. Gao, C. Zhao, H. Zhang, Y. Lian, F. Wang, H. Du, Lwt-Food Sci Technol, 133, 109954 (2020).