International Journal of Social Science and Education Research

ISSN Print: 2664-9845
ISSN Online: 2664-9853
Impact Factor: RJIF 8.00
IJSSER 2024; 6(1): 25-28
www.socialsciencejournals.net
Received: 19-11-2023
Accepted: 30-12-2023

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Preserving the power of probiotics using spray drying approaches for widespread public benefits

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DOI: https://doi.org/10.33545/26649845.2024.v6.i1a.74

Abstract
Probiotics, live microorganisms touted for their health-promoting properties, face limitations in stability and delivery, hindering their widespread public outreach. This review examines the potential of spray drying, a microencapsulation technique, as a key solution to unlock the power of probiotics for public benefit. Spray drying techniques is being employed for probiotics after analysing their advantages and challenges in preserving viable cultures, enhancing shelf life, and enabling diverse delivery formats. Spray drying empowers the incorporation of probiotics into various food products, facilitates the development of convenient supplements, and paves the way for targeted delivery for specific health needs and for the betterment of human being. Furthermore, the potential drawbacks of spray drying, such as viability loss and allergenicity concerns, emphasizing the need for further research to refine methods and optimize formulations are need to be analysed while using for drying applications. By critically evaluating the current landscape and future directions, this review highlights the transformative potential of spray drying in ensuring the accessibility and potency of probiotics for a healthier public.

Keywords: Probiotics, spray drying, microencapsulation, public health, food fortification

Introduction
The increasing global demand for functional probiotic foods can be attributed to consumers' growing understanding of the health benefits of probiotics and their well-being. As a result, food producers are now placing more of an emphasis on creating probiotic and functional meals. Probiotics are "live microorganisms which when administered in adequate amounts confer a health benefit on the host," according to FAO/WHO (2001). To attain the desired health advantages, the Food Safety Standards Authority of India (FSSAI) states that the products live probiotic bacteria concentration should be greater than 10^8 CFU/100 g at the time of intake. Prebiotics, on the other hand, are food ingredients that stimulate intestinal bacterial growth and are beneficial to harmful bacteria. In food, the FSSAI has approved 16 substances as prebiotics and about 30 live microorganisms as probiotics.

Functional Properties of Probiotic Culture
According to Sanders *et al*. (2013) and Hao *et al*. (2015) [11, 25], consuming certain probiotics may reduce the risk of diarrhea using antibiotics. To maintain optimal fitness and health, the epithelial cell lining must continue to function while remaining intact. The intestinal barrier's primary job is to protect the body against infection and inflammation by preserving the integrity of the epithelium. According to Gaudier *et al*. (2005) [10], *L. rhamnosus* inhibited inflammation and intestinal epithelial lining cell death. According to Zhang *et al*. (2011) [3, 28], pathogenic activity is reduced by *L. rhamnosus*. According to Siitonen *et al*. (1990) [27], consuming yogurt containing *L. rhamnosus* reduced the risk of diarrhea, upset stomach, gas, and stomach pain. The immuno-modulation property of probiotics on the host was also reported by Flach *et al*. (2018) [8]. Probiotic consumption may reduce the risk of gestational diabetes mellitus, according to Luoto *et al*. (2010) [17], who reported that *L. rhamnosus* GG and *B. animalis* subspecies *lactis* BB-12 positively impacted insulin sensitivity, blood glucose levels, cytokines, and precursors of breast milk fatty acids in pregnant women.

Consumption of *L. rhamnosus* helps to boost the immunological response, reduce blood cholesterol, improve lactose metabolism, improve intestinal health, and prevent cancer, according to Corcoran *et al*. (2004) [4]. Pathogenic strains of *Salmonella enterica*, *Yersinia enterocolitica*, and Staphylococcus aureus were all suppressed in growth by *L. rhamnosus* (Hill *et al*., 2014) [12]. Similarly, lipopolysaccharide-induced human damage and inflammation can be avoided by using *L. rhamnosus*. Zang *et al*. (2021) found that *L. rhamnosus* inhibited the pathogenicity of E. coli in chicken. Probiotics are defined as living organisms that exhibit health benefits; however, during processing and storage, probiotic viability may be lost (Hill *et al*., 2014) [12]. The viability of probiotic microbes in food matrices has been reported to be negatively impacted by salt, sugar, pH, and food microenvironment. Probiotics need to be protected by changing into a more stable and resistant form because of their sensitivity to the environment, including the stomach, food, and ambient conditions.

Spray Drying

Corcoran *et al*., (2004) [4] studied the Probiotic cultures that are also encapsulated by spray drying in the dairy and pharmaceutical industries. In this procedure, water is rapidly evaporated when the suspension solution containing microbial cells with wall material is atomized inside the drying chamber. Inside the drying chamber, the atomized spray droplets come in contact with the hot, dry air. The heat in the drying air causes the water to evaporate, resulting in the probiotic cells being dried into a powder. The bottom of the drying chamber is where the dried solid particles are gathered after being extracted from the drying air. It is an effective and quick process that yields spherical powder particles with the right amount of moisture left in them, as well as consistent size and shape. As a result, when drying, the heat-sensitive probiotic may become inactive. The process of spray drying includes dispersing the core material into the wall material, homogenizing the dispersion to emulsify it, atomizing the mixture in the drying chamber, and drying the droplets in hot air. A biopolymer that dissolves in the infinite phase serves as the wall material in this encapsulation technique. Due to its low cost and high production rate, it is the ideal method for microencapsulating probiotic cultures in the food industry (Schuck *et al*., 2013) [26]. The process is also continuous. The impact of higher temperature spray drying on cell viability without the use of protective agents was investigated by Ananta *et al*. (2005) [1]. According to Desmond *et al*. (2002) [5], Chen *et al*. (2011) [3], Liu *et al*. (2015) [15], and others, the presence of encapsulating matrices improved the resilience of cells and increased the viability of dried probiotic culture. During spray drying, the survival of probiotic bacteria depended more on the outlet temperature than on the inlet temperature and atomized air pressure (Martin *et al*., 2015) [19]. On the other hand, the input rate affects the drying air's exit temperature. Probiotics' equivalent survival rate improved inlet temperature settings when feed rates higher and output temperatures lower.

Dianawati *et al*. (2016) [6] found a significant correlation between the water activity of microcapsules and the survival rate of probiotic bacteria. The probiotics' viability was compromised by raising the input and outlet temperatures in order to attain low aw and moisture content in microcapsules. These results also supported the findings of Gardiner *et al*. (2000) [9], who reported that moisture content decreased by approximately 1-2% and *L. paracasei* survival drastically decreased as outlet temperatures increased from 70 to 120°C. Probiotics that were spray-dried at 55°C showed a viability of 70.1 to 75.1%, according to Chen *et al*. (2011) [3]. Temperature at the exit and flow rate have an impact on the viability of dried probiotics. Reyes *et al*. (2014) [2] found that the temperature of the inlet air had an impact on the survivability of probiotics, which resulted in a significant decrease in the population from 0.72 to 0.11 log CFU/g because the microorganisms are heat-sensitive.

Thermal-protectants used for Encapsulation of Probiotic by Spray Drying

Rajam *et al*. (2012) [23] used spray drying to encapsulate *L. rhamnosus* using denatured whey protein isolate (WPI)/sodium alginate (SA) and WPI/SA. When comparing the spray-dried culture with denatured WPI/SA to that of WPI/SA (80%), the greatest viability of 87% was found. The outcomes demonstrated that the encapsulating characteristics of denatured whey proteins were superior to those of undenatured proteins. Probiotics were sprayed-dried using wall materials made of denatured WPI and FOS (Rajam *et al*., 2012) [23]. The scientists found that using a combination of denatured WPI and FOS was an efficient way to preserve the viability of probiotics following spray drying. *L. plantarum* that had been spray-dried had an encapsulation effectiveness of 98.63%. Similar results were obtained by Avila-Reyes *et al*. (2014) [2] at an intake air temperature of 145 °C for *L. rhamnosus* microencapsulation effectiveness of 74 and 54% in native starch and inulin, respectively.

After spray drying, Rajam *et al*. (2012) [23] found an 84% encapsulation efficiency for *L. acidophilus*. Spray drying was performed with wall materials consisting of D-glucose, whey protein concentrate (WPC), and maltodextrin in a 60:20:20 (w/w) ratio at inlet air temperatures of 120, 140, and 160 °C respectively. Probiotic bacteria vary in survivability from 70 to 85% under spray drying by Huq *et al*. (2013) [14]. Gaudeir *et al*. (2005) [10] reported that *L. casei shirota* encapsulated with gum Arabic, skim milk, and maltodextrin exhibited a vitality ranging from 82.93 to 95.44%. The findings demonstrated that gum Arabic, maltodextrin, and skim milk were effective wall components for enhancing probiotic viability.

Maciel *et al*. (2014) [18] reported microencapsulated probiotics by spray-drying using 30% sweet whey or skim milk inoculated with the suspension of *L. acidophilus* La-5 (1% v/v) at 180 °C inlet temperature and 85 to 95 °C outlet temperature. Encapsulation yield, moisture content and resistance to *in vitro* GI conditions (pH 2.0 and 7.0) were evaluated between the samples, which were vacuum-sealed and stored at 4 °C and 25 °C. The encapsulation yield, mean diameter, and moisture content of the microcapsules were observed to be 76.58±4.72%, 12.9±0.78 µm, and 4.53±0.32%, respectively, after 0, 7, 15, 30, 45, 60, and 90 days of storage, as shown in figure 1.

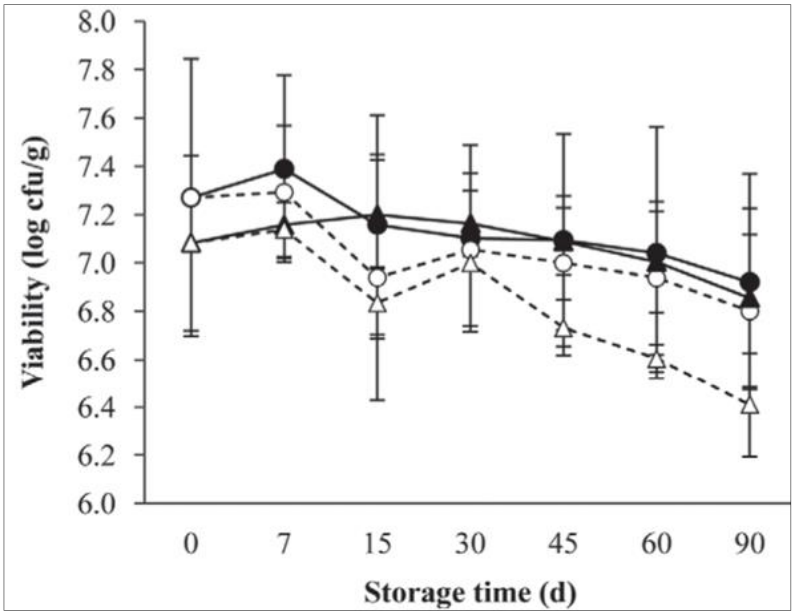

Fig 1: Lactobacillus acidophilus La-5's changes in the viability (log CFU/g) in sweet whey microparticles kept at 20 °C (empty Δ) or 4 °C (filled Δ) and in skim milk microparticles preserved at 20 °C (○) or 4 °C (●). Error bars represent the standard deviation (n = 3)

The viability of microencapsulated *L. acidophilus* La-5 was greater than 10^6 CFU/g after 90 days of storage at 25 °C, but it declined by 0.43 log CFU/g on average. Rajam and Anandharamakrishnan (2015) [22] reported the spray-dried of *L. plantarum* by utilizing a variety of prebiotics, including inulin, fructo-oligosaccharides (FOS), and oligosaccharides with maltodextrin and isolate from milk protein. Prebiotics enhanced the viability and encapsulation efficiency of the probiotic following spray drying. According to Pinto *et al.* (2015) [21], 95.43% of the spray-dried culture of Bifidobacterium BB-12 was successfully encapsulated in sweet whey and prebiotics such polydextrose and inulin. The viability of Bifidobacterium BB-12 was better preserved by sweet whey both during and after spray drying and exposure to GI conditions. A maximum viability of 9.54 log CFU/g was observed. Similarly, spray-dried *L. lactis subsp. lactis* R7 was shown to have an encapsulation effectiveness of 94.61% in whey and inulin.

Hugo *et al.* (2016) [13] evaluated the viability of whey protein and whey protein supplemented with galacto-oligosaccharides (WP-GOS) as a carrier to generate viable spray-dried probiotic after drying *L. plantarum* CIDCA 83114. The dried probiotic was observed for a period of 10 weeks while it was kept at 20 °C. The strain exhibited satisfactory growth in unsupplemented whey protein and exhibited a comparable pattern in both whey protein and WP-GOS, according to the data. Compared to the probiotic produced and dehydrated in whey protein alone, *L. plantarum* cultivated and dehydrated in WP-GOS exhibited a much greater survival rate following storage. *L. plantarum's* acid tolerance was enhanced by whey proteins, and its survival in low pH, dehydrated environments was significantly increased by the addition of GOS.

Gum Arabic or gum ghatti matrices containing sodium caseinate were used by Liu *et al.* (2016) [16] to encapsulate *L. zeae* LB1. This process involved spray drying. It was found that increased cell viability during GI digestion and storage was a consequence of increasing the sodium caseinate level in the encapsulating materials. According to El-Salam *et al.* (2015) [7], this could be explained by the fact that probiotic bacteria had several macromolecules adsorbed on their Surface, which enabled them to interact hydrophobically and electrostatically with proteins and carbohydrates. Nunes *et al.* (2018) [20] investigated the encapsulation efficiency of *Lactobacillus acidophilus*, they found that inulin and Hi-Maize, respectively, achieved the highest efficiency of 93.12 and 94.26%. After 120 days of storage at room temperature, the vitality of the microparticles using trehalose as the wall material decreased. The viability was observed greater than 6 log10 CFU/g.

Conclusion

The landscape of spray drying as a versatile and impactful technique for preserving and potentiating probiotic cultures has been traversed in this review paper. By encapsulating these microscopic powerhouses within a protective shell, spray drying unlocks numerous opportunities for widespread public benefits, enhancing accessibility, stability, and functionality. From addressing the challenges of shelf-life and sensitivity to expanding the range of probiotic delivery formats, spray drying opens doors to enriching consumer options and optimizing probiotic delivery. Whether it's fortifying food staples, formulating convenient supplements, or targeting specific health concerns, this technology allows us to harness the full potential of probiotics for a healthier populace.

Moving forward, research focused on further refining spray drying methods, optimizing formulations, and addressing potential drawbacks like potential loss of viability or allergen city remains crucial. By continuously advancing this technology, the gap between the promise of probiotics and their widespread reach can be fulfilled, paving the way for a future where everyone can reap the benefits of these microbial allies.

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