Indian Journal of Traditional Knowledge
Vol 25(07), July 2026, pp 707-718
DOI: 10.56042/ijtk.v25i7.26753

Effect of spray drying on functional attributes and rehydration characteristics of probiotic-enriched traditional fermented sour rice (*Poitabhat*) powder

Pinki Malick* & Manab Deka

Department of Bio Engineering & Technology, Gauhati University, Gopinath Bordoloi Nagar, Guwahati 781 014, Assam, India

*E-mail: pinki@gauhati.ac.in

Received 19 January 2026; revised 25 June 2026; accepted 07 July 2026

Poitabhat, traditional fermented sour rice is a probiotic-rich breakfast item integral to Indian culture and common food of Assam. Despite its deep cultural roots and therapeutic value, its consumption is declining due to modern lifestyle shifts and a very limited shelf life of 24-48 h. The aim of this study was to modernize this ethnic food by incorporating a shelf-stable probiotic instant powder through spray drying. The three local rice varieties, namely Joha, Brown and Aijung rice were fermented with a standardized 10% probiotic consortium of *Lactobacillus acidophilus* and *Lacticaseibacillus paracasei*. A solution of maltodextrin (12%) was used to encapsulate the slurry that was then spray dried at an inlet temperature of 80℃. The physical stability of the developed powders was excellent (aw = 0.30–0.33), and hence ascribed microbiological safety. Functional characterization suggested strong rehydrating properties coupled with high solubility (80.11–81.48%) and low insolubility index (0.41–0.48 mL). The morphology observed *via.*, Scanning Electron Microscopy (SEM) was predominantly spherical with particle diameters of 7.79 to 9.53 µm, and the particle size distribution appeared narrow and was characterized as a monomodal size distribution. In addition, the probiotic fortified formulations were found to increase consumer acceptability on a 9-point hedonic scale over control, while retaining and not altering the characteristic flavor profile. The present work successfully converts a traditional ethnic food into a new functional product and serves as a potential approach for the preservation and commercialization of indigenous Indian food heritage.

Keywords: Fermentation, Hygroscopicity, *Poitabhat*, Particle density, Probiotics, Spay drying

IPC Code: Int Cl.[26]: A23L 7/00

Food has always been the heart of human life not just as a source of survival but more as a transmitter of culture, health and some invaluable wisdom passed down through generations. Especially fermented foods are an indivisible component of cultural heritage for many ethnic communities in India. Traditional fermented foods associated with gut health, along with indigenous microorganisms that have been linked to the therapeutic potential are treasured across various ethnic landscapes in India[1]. Fermented sour rice is one such food preparation, among the several traditional preparations that are commonly consumed in Eastern and Northeastern India. In Assam it is popularly known as *Poitabhat*, *Pantabhat* in West Bengal, *Pokhalo* in Odisha and numerous other regional names often associated to the racy local language such as *pazhankanji* in Kerala and *paani wala chawal* in Hindi-speaking regions. Over the border, in neighboring Bangladesh it is also commonly consumed as *pakhal*[2]. Traditionally, it is made by soaking leftover cooked rice in water overnight and allowing it to ferment spontaneously; creating a mildly sour, soft-textured dish that works very well in humid tropical climates. For some time, rural communities have considered it a healthy breakfast full of probiotics good for the gut and as something that can alleviate summer fatigue. For centuries, the Poitabhat has been an intriguing dish as well as a symbol of culture and is believed to offer various health advantages; yet its popularity has slowly decreased over recent decades. This traditional home-based preparation has been sidelined by the pressure of rapid urbanization and move away from convenience-based lifestyles. In addition to these, the product has a very high perish ability rate (24–48 h), and at times if fermentation process is uncontrolled, can induce food-borne diseases; thus, the case for its broader acceptance and transfer into modern commercial environment has remained limited.

Rice (*Oryza sativa* L.) remains the staple food for more than half the population of Assam, with numerous indigenous varieties cherished for their

*Corresponding author

Table1 — Formulations of the probiotic consortium (v/w)

Formulation (F1)	*Lactobacillus acidophilus* (5%):
Formulation (F2)	*Lacticaseibacillus paracasei* (5%) **(v/w)**
Formulation (F2)	*Lactobacillus acidophilus* (4%): *Lacticaseibacillus paracasei* (6%) **(v/w)**
	Lactobacillus acidophilus (6%): *Lacticaseibacillus paracasei* (4%) **(v/w)**

unique aroma, texture, and nutritional qualities. Probiotic fermentation of cereal-based foods renders them more easily digestible while imparting distinctive flavors and aromas. Moreover, various compounds generated during fermentation, such as short-chain fatty acids, increase the nutritional content which provides significant health benefits in the body[3]. Scientific studies have increasingly highlighted the nutritional potential of such traditionally fermented rice preparations[4]; yet systematic efforts to standardize and modernize them while preserving their ethnic identity remain limited.

Spray drying has emerged as an efficient and scalable method to transform perishable fermented sour rice into a stable, functional powder with minimal loss of nutritional and functional attributes[5]. The incorporation of encapsulating agents such as maltodextrinin spray drying process helps to overcome common problems like stickiness and low yield associated with high sugar content in fermented cereal products[6]. However, limited research has been conducted on the spray drying of probiotic-enriched traditional fermented rice slurries, particularly using indigenous rice varieties. The present study was therefore undertaken with the objective of transforming this age-old traditional knowledge into a shelf-stable, ready-to-use probiotic-enriched fermented sour rice powder. The work aims to evaluate the functional, physical, rehydration, and sensory attributes of the resulting powder, thereby offering a viable strategy for the scientific validation, preservation, and commercial revival of this valuable traditional fermented food of Northeast India.

Materials and Methods

The raw materials for the present study, specifically three distinct rice cultivars: Joha, Brown, and Aijung were sourced from local markets in Guwahati, Assam, India. The experiments and analysis were performed at Department of Bioengineering and Technology, Gauhati University, Assam, India.

Optimization and standardization of the probiotic consortium

The LAB cultures were grown overnight in falcon tubes and centrifuged at 7000 rpm at 4°C for 10 min and the supernatant was discarded without disturbing the pellet, washed thrice using sterile 0.85% saline solution, and the cells were dissolved in distilled water. The cell suspension containing the LAB culture was further formulated in combination of *Lactobacillus acidophilus* and *Lacticaseibacillus paracasei* according to (Table 1) and kept at 4°C for further analysis.

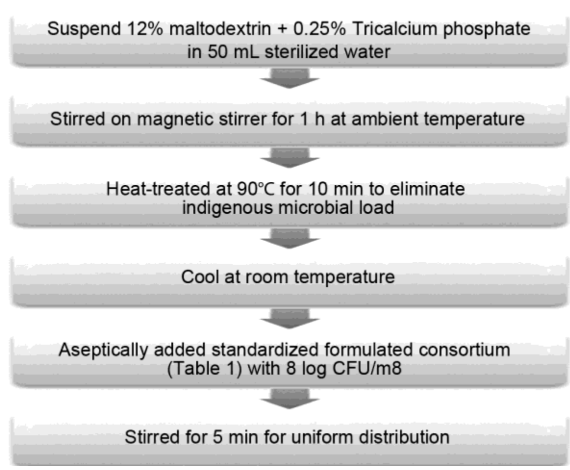
To determine the optimal inoculation level for rice fermentation prior to spray drying, probiotic consortium concentrations of 5% and 10% (v/w) were evaluated. While the 5% probiotic consortium was inadequate for maintaining bacterial density during spray drying. Increasing concentration to 10% consortium yielded maximum probiotic viability in the spray dried product. Therefore, a 10% inoculation rate was standardized for the fermentation process to ensure high-potency functional attributes in the final powder.

The probiotic consortium was standardized to a cell density of 6×10^8 CFU/mL by adjusting the culture suspension to a 2 McFarland standard, yielding an absorbance of 0.32 at 600 nm. Two different culture combinations were formulated, with varied ratio of the respective LAB species (Table 1).

Pre-processing before spay drying

Processing of encapsulation medium

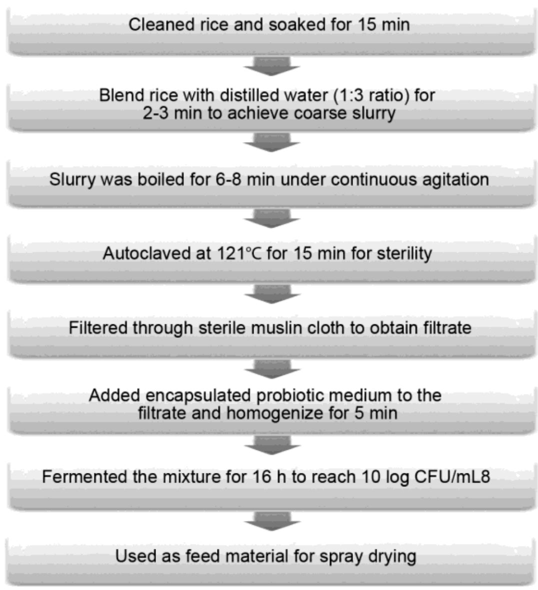
The encapsulation medium was prepared according to the method[7].



Processing rice mixture

Process of spray drying method

To produce the instant fermented sour rice powder, a laboratory-scale mini spray dryer (Model: LSD 48, JISL) was utilized. To ensure reproducibility of powder quality, a standardized protocol was



implemented at uniform operational parameters (Inlet temperature: 80°C; Outlet temperature: 70°C) and drying process conditions (Air pressure: 1.5 kg/cm²; Aspiration rate: 50%; Feed rate: 10 mL/min). The powder was recovered through an additional cyclone separator once the process finished. The samples were stored at 4°C into sterilized glass vials and preserved for further experiments.

Analysis of functional attributes

Water activity (Aw)

The water activity was measured at 30°C using an electronic water activity meter (Aqualab series 4TE, Decagon Devices Inc., Washington, USA).

Bulk density, tapped density and particle density

For bulk density (ρB) (w/v), a known mass of fermented sour rice powder was added to a 10 mL graduated cylinder, and the occupied space was measured. Tapped density (ρT) (w/v), the volume of identical sample tapped over 5 minutes (approximately 32 taps/minute). Particle density was measured using the method[9], where 1 gm of fermented sour rice powder was put into a 10 mL graduated cylinder and then 5 mL of petroleum ether was added to the sample and shaken for some minutes to achieve particle suspension. Finally, 1 mL of petroleum ether was applied to wash the wall of the cylinder and disperse together with the connected lumps of powder. The final volume reading was observed, and calculated using:

$$\rho_P = \frac{weight\ of\ the\ powder\ (g)}{Total\ volume\ of\ petroleum\ ether\ and\ suspended\ particles - 6}$$

Flowability and cohesiveness

The CI and HR were estimated from the tapped and bulk densities using themethod[9].

$$CI = \frac{\rho_T - \rho_B}{\rho_T} \times 100$$

$$HR = \frac{\rho_T}{\rho_B}$$

Particle size distribution

A particle analyzer (Litesizer, 500) was used to identify the distribution of particle size. A small quantity of powder was suspended in water as a solvent and analyzed at 25°C. The results, obtained from equipment software version 2.22.2, were expressed in D10, D50 (median size), and D90 concerning their intensity, representing the diameters for the accumulated size distribution at the 10th, 50th, and 90th percentiles of particles[10]. The polydispersity index (span) was also determined using the following equation

$$\text{Span} = \frac{D90 - D10}{D50}$$

D10, D50 and D90 represent diameters corresponding to the 10, 50 and 90 percentiles of the cumulative size distribution.

Analysis of rehydration characteristics

Solubility

The solubility was determined by the method[11].

Insolubility index

The insolubility index was performed following IDF Standard 129A[12], with slight modifications.

Dispersibility

The dispersibility method was followed and estimated using the formula given by[9].

$$Dispersibility\ (\%) = \frac{(10 + a) \times \%TS}{a \times (100 - b)/100}$$

where a is the amount of fermented sour rice powder (g) used, b is the moisture content of the powder, and % TS is the dry matter in the reconstituted powder after passing through the sieve.

Wett ability

Wett ability was determined by the method[9].

Hygroscopicity

Hygroscopicity was analysed with minor modification method[13].

Degree of caking

The caking degree was determined by the method[14].

$$CD = \frac{100.b}{a}$$

Where CD is the caking degree in (%), the weight of powder used for sieving is denoted as (a) and the mass of powder remaining on the sieve after sieving as (b).

***Scanning electron microscopy* (*SEM*)**

The surface morphology of the spray-dried powders was characterized using SEM. Micro-structural observations were conducted using a Carl ZEISS SIGMA 360VP SEM operating at an accelerating voltage of 5.0 kV and were captured at a magnification of 10,000x[15].

Sensory analysis of the fermented sour rice powder

Acceptability trial was evaluated by sensory evaluation using 9-point hedonic scale rating (scores designated as 9 “extremely like” to 1 “extremely dislike”)[16]. The acceptability trial was done in the Department of Bioengineering & Technology, Gauhati University, Assam, India by 20 semi-trained panel members.

Statistical analysis

All experiments were performed in triplicate, and the data are reported as mean ± SD (standard deviation); p<0.05 was considered significant. Statistical differences were determined by comparing across groups utilizing one way (ANOVA) and findings performed with GraphPad prism version 10.0.

Results

Bulk and tapped density, particle density

In the present study bulk and tapped density, particle densities are represented in (Table 2) for the variety 1 (Joha rice), (Table 3) for the variety 2 (Brown rice) and (Table 4) for the rice variety 3 (Aijung rice). As detailed in our earlier work, the water activity for Variety 1 (Joha rice) has already been reported as 0.31[8].

Flowability and cohesiveness

In the present study (Supplementary Fig. S1-2) represents the Flowability and cohesion in terms of CI and HR was found to be 10-18% and 0.81-0.90 respectively (supplementary materials).

Table 2 — Functional properties of Variety1 (Joha Rice)

Samples	Bulk density (kgm^{-3})	Tapped density ($kg\ m^{-3}$)	Particle density (kgm^{-3})
Control	285.71±0.04	357.15±0.04	1428±2.44
F1	285.71±0.05$^{\#}$	365.17±0.04***	1430±1.69$^{\#}$
F2	277.70±0.06***	377.16±0.04***	1433±2.05$^{\#}$
F3	285.76±0.05$^{\#}$	373.15±0.04***	1431±2.86$^{\#}$

Data are expressed as means ± standard deviation (n=3); Statistical significance is indicated as ***p<0.001,# is indicated as non-significant compared to the control (One-way ANOVA followed by post-hoc test). F1 (5% *L. acidophilus*: 5% *L. paracasei*), F2 (4% *L. acidophilus*: 6% *L. paracasei*), F3 (6% *L. acidophilus*: 4% *L. paracasei*) and Control (without probiotic culture)

Table 3 — Functional properties of variety 2 (Brown Rice)

Samples	Bulk density (kgm^{-3})	Tapped density (kgm^{-3})	Particle density (kgm^{-3})	Water activity(a_w)
Control	277.70±0.04	370.37±0.03	1428±2.05	0.31±0.02
F1	277.70±0.06$^{\#}$	384.65±0.03*	1436±2.49*	0.32±0.01$^{\#}$
F2	275.82±0.04*	370.66±0.04$^{\#}$	1431±2.86$^{\#}$	0.31±0.01$^{\#}$
F3	275.82±0.04*	384.76±0.04*	1434±2.44*	0.32±0.02$^{\#}$

Data are expressed as means ± standard deviation (n=3); Statistical significance is indicated as *p<0.05, # is indicated as non-significant compared to the control (One-way ANOVA followed by post-hoc test). F1(5% *L. acidophilus*: 5% *L. paracasei*), F2 (4% *L. acidophilus*: 6% *L. paracasei*), F3 (6% *L. acidophilus*: 4% *L. paracasei*) and Control (without probiotic culture)

Table 4 — Functional properties of variety 3 (Aijung rice)

Samples	Bulk density (kgm^{-3})	Tapped Density (kgm^{-3})	Particle Density(kgm^{-3})	Water activity(a_w)
Control	285.70±0.06	357.15±0.04	1428±2.86	0.33±0.02
F1	285.71±0.06$^{\#}$	364.32±0.05***	1429±2.16$^{\#}$	0.30 ±0.01$^{\#}$
F2	275.74±0.04***	357.65±0.04$^{\#}$	1431±2.86$^{\#}$	0.30 ±0.02$^{\#}$
F3	275.85±0.03***	369.17±0.05***	1430±1.69$^{\#}$	0.31 ±0.01$^{\#}$

Data are expressed as means ± standard deviation (n=3); Statistical significance is indicated as ***p<0.001, # is indicated as non-significant compared to the control control (One-way ANOVA followed by post-hoc test). F1 (5% *L. acidophilus*: 5% *L. paracasei*), F2 (4% *L. acidophilus*: 6% *L. paracasei*), F3 (6% *L. acidophilus*:4% *L. paracasei*) and control (without probiotic culture)

Particle size analysis

Based on the sensory analysis, the best formulation among the three rice varieties was selected for particle size analysis. The span values of these formulations are detailed in (Table 5), while the particle size distribution illustrated in (Fig. 1), and exhibits a monomodal distribution, indicated by a single, well-defined peak with narrow range, suggesting a high degree of structural uniformity and the absence of large-scale agglomeration.

Table 5 — Particle morphology of probiotic enriched fermented sour rice powder

Formulations	D_{10} (nm)	D_{50} (nm)	D_{90} (nm)	Span value
Variety 1 (F1)	600.22	7998.46	15443.77	1.85
Variety 2 (F2)	495.60	712.31	1045.23	0.77
Variety 3 (F1)	697.28	842.27	1023.79	0.38

Rehydration characteristics of probiotic enriched fermented sour rice powder

In the present study rehydration properties of probiotic enriched fermented sour rice powder was assessed by solubility, insolubility index, dispersibility and wettability and are represented in (Table 6) for variety 1 (Joha rice), (Table 7) for variety 2 (Brown rice) and (Table 8) for variety 3 (Aijung rice) respectively.

Hygroscopicity and degree of caking

In the present study (Supplementary Fig. S3-4) represent the hygroscopicity and degree of caking. The hygroscopicity values of the probiotic enriched fermented sour rice powder ranged from 10.8 to 11.10 whereas caking degree ranged from 31.5 to 32.2% respectively.

Table 6 — Rehydration characteristics of variety 1 (Joha Rice)

Samples	Solubility (%)	Insolubility Index(ml)	Dispersibility (%)	Wettability (s)
Variety1 (Joha Rice)				
Control	80.25±0.12	0.46±0.04	67.81±0.50	396±12.47
F1	80.86±0.33#	0.43±0.04#	67.83±0.13#	403±12.47#
F2	80.68±0.20#	0.48±0.02#	67.68±0.30#	406±12.47#
F3	80.50±0.58#	0.45±0.04#	68.58±0.26*	403±12.47#

Data are expressed as means ± standard deviation (n=3); Statistical significance is indicated as *$p<0.05$, # is indicated as non-significant compared to the control (One-way ANOVA followed by post-hoc test). F1 (5% *L. acidophilus*: 5% *L. paracasei*), F2 (4% *L. acidophilus*: 6% *L. paracasei*), F3 (6% *L. acidophilus*: 4% *L. paracasei*) and Control (without probiotic culture)

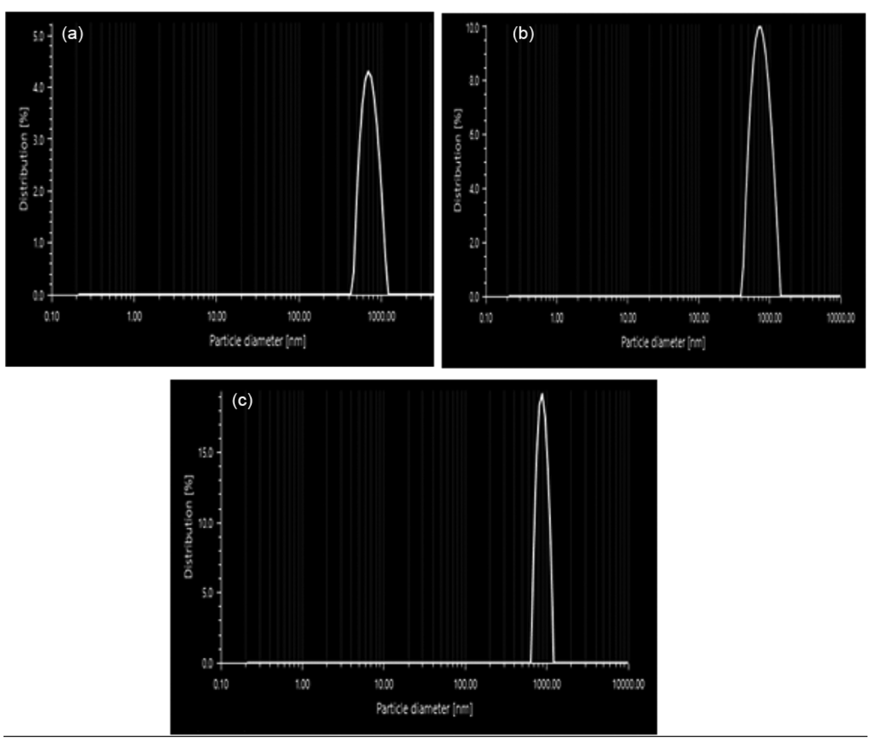


Fig. 1 — Particle size distribution of probiotic enriched fermented sour rice powder (a) Variety1 (F1), (b) Variety 2 (F2), (c) Variety 3 (F1)

Table 7 — Rehydration characteristics of variety2 (Brown Rice)

Samples	Solubility (%)	Insolubility Index (mL)	Dispersibility (%)	Wettability (s)
Variety 2 (Brown Rice)				
Control	80.31±0.11	0.46±0.04	67.71±0.20	400±16.32
F1	80.24±0.27$^{\#}$	0.41±0.02$^{\#}$	67.66±0.27$^{\#}$	403±12.47$^{\#}$
F2	80.86±0.25*	0.48±0.02$^{\#}$	68.30±0.23*	400±16.32$^{\#}$
F3	80.11±0.50$^{\#}$	0.43±0.04$^{\#}$	67.70±0.17$^{\#}$	406±12.47$^{\#}$

Data are expressed as means ± standard deviation (n=3); Statistical significance is indicated as *p<0.05, # is indicated as non-significant compared to the control **(**One-way ANOVA followed by post-hoc test). F1 (5% *L. acidophilus*: 5% *L. paracasei*), F2 (4% *L. acidophilus*: 6% *L. paracasei*), F3 (6% *L. acidophilus*: 4% *L. paracasei*) and Control (without probiotic culture)

Table 8 — Rehydration characteristics of Variety 3 (Aijung Rice)

Samples	Solubility (%)	Insolubility Index (mL)	Dispersibility (%)	Wettability (s)
Variety3 (Aijung Rice)				
Control	80.40±0.27	0.48±0.02	67.60±0.17	396±12.47
F1	80.76±0.30$^{\#}$	0.41±0.02*	68.43±0.26*	400±16.32$^{\#}$
F2	81.14±0.64$^{\#}$	0.46±0.02*	67.78±0.22$^{\#}$	406±12.45$^{\#}$
F3	81.48±0.39$^{\#}$	0.41±0.02*	67.95±0.47*	398±14.33$^{\#}$

Data are expressed as means ± standard deviation (n=3);Statistical significance is indicated as *p<0.05, # is indicated as non-significant compared to the control **(**One-way ANOVA followed by post-hoc test). F1 (5% *L. acidophilus*: 5% *L. paracasei*), F2 (4% *L. acidophilus*: 6% *L. paracasei*), F3 (6% *L. acidophilus*: 4% *L. paracasei*) and Control (without probiotic culture)

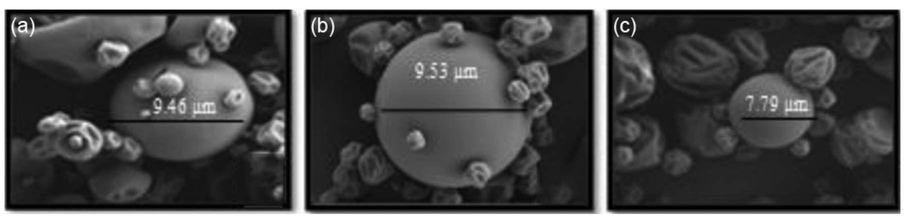


Fig. 2 — Scanning electron micrograph of probiotic enriched fermented sour rice powder of three rice varieties at 12% maltodextrin (MD) concentration (a) Variety 1 (F1) (b) Variety 2 (F2) (c) Variety 3 (F3)

Scanning electron microscope (SEM)

The morphology of the developed fermented sour rice powder from the three selected formulations (one from each rice variety), chosen based on their sensory score, was examined using SEM at a magnification of 10,000x with an accelerating voltage of 5.0 kV. In the present study (Fig. 2) presents representative SEM micrographs of the fermented sour rice powders prepared with 12% maltodextrin concentration. The particles exhibited a predominantly spherical to sub spherical shape, with some aggregation observed. Individual starch granules appeared polyhedral to irregular, consistent with typical rice starch granule morphology.

The micrograph (Fig. 2a) shows a smooth spherical particle with a diameter of 9.46 µm, although smaller satellite particles are visible adhering particularly well to the sphere surface. The 12% maltodextrin concentration appears to have created an effective barrier in minimizing surface cracks or collapses due to its integrity as a particle. Figure 2b shows spots of observed micro-particles, for which the median diameter is 9.53 µm, where an important aspect that can be seen in this image is the high level of surface "dusting" (where several smaller particles are fixed on the surface of a larger sphere). Figure 2c showed smaller, more compact particles relative to the particle diameter (7.79 µm as indicative value), although a spherical structure is still preserved and dense, largely irregular starch fragments are present in the surrounding matrix.

Sensory evaluation of fermented sour rice powder

Supplementary Figure S5 represents the sensory evaluation of Variety 1 (Joha rice), variety 2 (Brown rice) and Variety 3 (Aijung rice) across four different formulations namely Control, F1, F2 and F3. The parameters evaluated are color, flavor, taste, consistency and overall acceptability, measured on a scale of 9-point hedonic score.

For Variety1, there was no statistically significant difference between the control and the formulations

(F1-F3) regarding color and flavor. This suggests that the treatments did not negatively alter the inherent aromatic characteristics and visual appearance of Variety 1. In terms of taste, consistency and overall acceptability revealed a significant difference as compared to the control, suggesting that the experimental formulations enhanced the consumer acceptability.

For Variety 2, there was no statistically significant difference between the control and the formulations (F1-F3) regarding color, flavor and consistency. This suggests that the treatments did not negatively alter the inherent aromatic characteristics and visual appearance of Variety 2. In terms of taste attributes data revealed highly significant and overall acceptability revealed a significant difference as compared to the control, suggesting that the experimental formulations effectively balancing taste and consistency to achieve a product that panelists found superior to the control.

For Variety 3, there was no statistically significant difference among the control and formulations (F1-F3) in terms of taste. This suggests that the treatments did not negatively alter the taste of Variety 3. In terms of color attributes data revealed highly significant and in contrast flavor, consistency and overall acceptability revealed a significant difference as compared to the control, indicates that the additions in the experimental formulations effectively combining high visual appearance and flavor with improved consistency to achieve a superior product.

Discussion

Bulk and tapped density, particle density

Bulk density is influenced by the extent of interparticle spacing or porosity within the bulk volume. It is influenced by shape, particle density, size distribution and moisture content[17]. The bulk density values in the present study ranged from B_d 270.26-285.76 kg/m^3 without significant differences between the different formulations. After tapping the samples, new values of densities were recorded, which ranged from T_d 357.14-384.62 kg/m^3. An increase in tapped density compared to bulk density is a common occurrence, usually increases the outcomes. This occurs due to a more ordered arrangement of particles during the tapping process and hence reduces the space between them. However, several variables, including material characteristics, water content, and particle size, can affect the difference between tapped and bulk densities. Mostly, the particle density is about 1400 kg/m^3 in most of the dried food powder[17]. In the present study the particle densities ranged from 1429-1430 kg/m^3.

Water activity

Generally, spray-dried powders are categorized as microbiologically stable when their water activity (aw) falls within the 0.15 to 0.60 range[18]. This is critical for food safety, as most pathogenic bacteria necessitate aw above 0.90, while mold growth typically requires levels exceeding 0.70. Therefore, maintaining water activity between 0.20 and 0.40 further safeguards the product against biochemical degradation, including enzymatic activity, hydrolytic reactions, and non-enzymatic browning. In the present study, the developed powder samples exhibited aw values ranging from 0.30 to 0.33, placing them well within the zone of biological and chemical stability. Results of the current study are consistent with observations made by Kumar *et al*.[19], observed that in the same range of concentration maltodextrin was effective in reducing water activity from 0.62±0.11 to 0.32±0.02 accordingly. This decrease can probably be explained due to the good water-binding capacity of maltodextrin. Specifically, the highly branched structural configuration of this carbohydrate matrix may physically entrap moisture within its 3-D network, preventing the release of free water and thereby lowering the overall water activity of the functional rice powder[20].

Flowability and cohesiveness

Flow characteristics of powder were observed by the free flowing, semi-free flowing and cohesive flow. Particle size, distribution, morphology, hygroscopicity, and moisture content of the material are some of the parameters that affect the flow behavior of powder and are thought to be more severe in cohesive flow. Based on the Flowability classification, powder with CI greater than 38 and HR greater than 1.6 is considered as poor Flowability[21]. Hence, the present study observed within the range and thus reveals better Flowability.

Particle size distribution

The particle size distribution of the fermented sour rice powders across the three studied rice varieties is illustrated in (Fig. 1). Visually, the developed powders exhibit a refined, narrow particle range following a normal distribution pattern, which points toward a highly homogenous physical system. The small variation in the structure is quantitatively supported by span values obtained from data. The size distributions of the particles were polydispersed for all the three rice varieties (Table 5). The obtained span values show that variety 1 has the best distribution among all with a span value of 1.85 indicates heterogeneous factor in the population of particles. On the contrary, Variety 2 and Variety 3 showed rather narrow distributions with spans of 0.77 and 0.38, respectively indicating higher structural homogeneity. In rice-based products, the simultaneous reduction in mean particle size and span value are often related to improved starch gelatinization and a more sophisticated sensory profile[22]. This morphological improvement is essential for consumer preference since the particles below 10 µm either do not fall into the detection range of the human palate, preventing any "grittiness" sensation to be perceived, which lead to a more desirable mouth-feel in the final functional product. The D_{50} (median diameter) serves as the benchmark for predicting sensory texture[23]. While research by Engelen *et al.*[24] indicates that the threshold for perceiving grittiness sits around 20–30 µm, all varieties in this study fell significantly below this limit. Consequently, each formulation is likely to provide a smooth, non-gritty experience[25].

Reconstitution properties of probiotic enriched fermented sour rice powder

The solubility of dried powder in this present study varies from 80.11 to 81.48%. Seth *et al.*[11] observed 72 to 88% solubility in sweetened yoghurt powder. According to Caparino *et al.*[26], Cano-Chauca *et al.*[27] observed that the inclusion of hydrophilic components like maltodextrin may be the cause of the higher solubility value.

Powder with increased solubility takes less time to wet their surface, consequently lower wetting time or wettability. In the present study the wetting time varies from 400 to 580 s. In general, dispersibility and wettability depends on particle size, density, porosity, surface charge, surface area and the presence of amphipathic substances and the surface activity of the particles[26]. The poorer wettability as reflected by lower dissolution rates may be related to the decreased solubility of denatured protein[28-30]. Dispersibility refers to how readily and evenly distributes into a liquid without forming any lump. The result of dispersibility varies from 67.60 to 68.58 %. Seth *et al.*[11] observed dispersibility of sweetened yoghurt powder ranged from 70.62-88.74%. However, noted that dispersibility decreased with the decreasing particle size. Small particles possibly formed visible lumps and hence lowered dispersibility and can be ascribed to less porous nature at high atomization pressure[31].

Insolubility indexis animportant indicator for spray dried powders, reflecting their ability to dissolve and rehydrate properly. Lower insolubility index generally signifies better quality, indicating a more soluble and easily rehydrated powder. In the present study the values ranged from 0.41 to 0.48 mL. The insolubility index of spray dried camel’s milk and cow’s milk powder ranged from 0.4 to 0.8whereas commercial milk powder found to be 0.1 which may be due to addition of certain additives to facilitate the solubility[32].

The hygroscopicity of the probiotic enriched fermented sour rice powder was not significantly affected and the results ranged from 10.6 to 11.03. This property may influenced by several factors such as moisture, particle size and drying conditions. Similar study observed in acai pulp powder with maltodextrin ranged between (12.5-15.8 g/100 g) which is higher as compared to the present study[33]. Lower hygroscopicity value means greater physical stability[34].

The caking degree of the present study (Supplementary Fig. S4) ranged from 31.5 to 32.2% and not significant among the formulations ($p<0.05$). Also, the caking degree of yoghurt powder was reported as 30.32%[35].

***Scanning electron microscope* (*SEM*)**

The micro structural analysis presented in (Fig. 2) reveals that the microspheres maintained excellent structural integrity, with no visible surface fissures or ruptures. This lack of cracking is a strong indicator of low gas permeability, which is essential for shielding the core components from oxygen and water vapor[36]. While the particles are predominantly spherical and homogeneous, a configuration known for improving core retention and decreasing oxygen and water leakage[37,38], some surface indentations were observed which are likely the result of rapid liquid evaporation and fluctuating surface tension during the droplet-to-particle transition in the spray dryer[39-41]. Moreover, the lack of any visible "free" or non-encapsulated bacteria on the particle surfaces further certifies the high efficiency of the maltodextrin matrix. The details of morphology from spray dry products are predominately directed by parameters like drying temperature, viscosity of the carrier solution and atomization pressure[42]. The present findings are consistent with Rodriguez-Huezo *et al*.[43], demonstrated that intermediate drying rates can cause a partial wall collapse or shriveling of the particle walls, giving rise to such concave features as observed here. Additionally, these findings are consistent with the study reported a similar polyhedral and smooth morphology for *L. plantarum* encapsulated in 15% maltodextrin-litchi juice base[40]. Haque and Roos[44] also reported similar characteristics of hemispherical and smooth surfaces in their study based on a lactose-whey protein carrier system, confirming that the structural results from this study are representative for quality probiotic encapsulation. These morphological differences between varieties could be linked to intrinsic variations in polysaccharide composition as are starch granule size, amylose / amylopectin ratio and residual bran content (high in brown rice) and the extent of fermentation-induced changes. The addition of 12% maltodextrin seemed to support the formation of more spherical, encapsulated-like structures that must have helped develop good low water activity and stability in the powders.

Sensory evaluation of the fermented sour rice powder

The sensory profiles of the developed fermented sour rice powders evaluated using a 9-point hedonic scale (Supplementary Fig. S5) provide essential data regarding the consumer appeal and reveal the organoleptic shifts that occur when traditional fermented sour rice is converted into a "Ready-to-Use" (RTU) shelf-stable functional food powder.

The sensory evaluation of the fermented sour rice powder (Variety 1) reveals a highly favorable consumer response, with all attributes scoring consistently above 7.5 on the 9-point hedonic scale. These results indicate that the integration of probiotic consortium and the subsequent drying process did not adversely affect the delicate organoleptic profile of the aromatic Joha rice variety[45]. The findings suggest that the formulation enhanced the "sour" profile typical of traditional fermented rice (such as *Poitabhat*), making it more palatable for modern consumption.

As illustrated in (Supplementary Fig. S5b), all three formulations received high scores across the evaluated attributes, with mean values ranging between approximately 7.5 and 8.8. Notably, the scores for F1, F2, and F3 were comparatively higher than the control in most sensory attributes. Color and flavor scores remained consistently high (8.0-8.5) across the samples, indicating that the incorporation of carrier agents did not adversely affect the visual appeal or aromatic profile of the brown rice-based product. Taste and consistency also showed minimal variation, suggesting that the formulations maintained desirable mouth feel and palatability. These results corroborate earlier reports on spray-dried rice-based products, where the application of high molecular weight carriers (maltodextrin) improved powder rehydration properties and sensory quality without compromising consumer preference.

The mean hedonic scores for color, flavor, taste, consistency and overall acceptability ranged from 7.6 to 8.7 as shown in (Supplementary Fig. S5c), indicating that the developed formulations were accepted well by the sensory panel. The control sample and the three formulations exhibited very good color scores (higher than 8.0), indicating that Aijung rice maintained its lighter, uniform appearance after spray drying. This is especially beneficial because color is usually one of the very first things that consumers notice and assess. Across all formulations, taste and flavor scores remained high relative to the control with little decline in value.

Hence, the sensory data revealed that three varieties of rice are highly suitable for spray drying with good sensory attributes and may be considered as alternative raw materials for commercial-scale production of instant rice-based products with wider consumer acceptance.

Conclusion

This study presents a successful development of a shelf-stable probiotic fortified instant fermented sour rice powder, transitioning from its original perishable fermented sour rice (*Poitabhat*) in Assam. To modernize this ethnic staple food, indigenous rice varieties (Joha, Brown, and Aijung rice) were used along with standardized 10% microbial consortium of *Lactobacillus acidophilus* and *Lacticaseibacillus paracasei* through spray-drying method. The powders developed also exhibited excellent physical stability, with low water activity (0.30-0.33) and suitable rehydration kinetics having solubility rates between 80.11% and 81.48%. In addition, the product successfully retained narrow particle size distribution and good flowability while effectively preserving the unique sour profile, aroma, and cultural authenticity of the traditional preparation. This study justifies the indigenous knowledge of Northeast India as a scientific one by mitigating the inherent limitations of short shelf life and changing consumption habits in contemporary lifestyles. These results provide a solid basis for the formulation of rice bran-derived probiotic functional foods to enhance gut health, while also maintaining ethnic identity. This not only paves the way for commercial restoration of traditional fermented sour rice but also connects ancient dietary practices to modern food technology. Future investigations focusing on large-scale production and clinical assessment of probiotic survivability during gastrointestinal transit will be essential to confirm the long-term therapeutic potential of this functional food.

Supplementary Data

Supplementary data associated with this article is available in the electronic form at https://nopr.niscpr.res.in/jinfo/ijtk/IJTK_25(7)(2026)707-718_SupplData.pdf

Acknowledgements

The authors acknowledge the Department of Bioengineering and Technology, Gauhati University, Assam, India for providing the necessary support to carry out this research work. We also gratefully acknowledge Dr. Kandarpa Kumar Saikia, Professor, Department of Bioengineering and Technology, Gauhati University, Assam for guiding and supervising the study. We would like to acknowledge Dr. Sumi Das, Project Research Scientist, Assam Medical College & Hospital, Dibrugarh, Assam and Mrs. Meghali Nag, Research scholar, Department of Bioengineering and Technology, Gauhati University, Assam for their assistance in processing the research work.

Author Contributions

PM: Data collection, processing, methodology, writing-original draft, reviewing & editing, MD: Conceptualization, supervision, reviewing

Funding Sources

The authors received no financial support for the publication of this article.

Conflict of Interest

The author declares no conflict of interest.

Use of Artificial Intelligence

AI tools were used only to improve the writing quality and readability. All scientific data analysis and interpretations remain entirely the original work of the authors.

Data Availability

All the authors declare that if more data required then the data will be provided on request basis, even though adequate data has been provided in the form of tables and figures.

References

1 Sharma N, Handa S & Gupta A, Comprehensivestudy of different traditional fermented foods/beverages of Himachal Pradesh to evaluate their nutrition impact on health and rich biodiversity of fermenting microorganisms, *Int J Res Appl Nat Social Sci*, 1 (3) (2013) 19-28.

2 Goswami G, Baruah H, Boro R C & Barooah M, Fermentation reducesanti-nutritional content and increases mineral availability in *Poitabhat, Asian J Chem*, 28 (9) (2016) 1929-1932.

3 Poutanen K, Flander L & Katina K, Sourdough and cereal fermentation in a nutritional perspective, *Food Microbiol*, 26 (7) (2009) 693-699. doi: 10.1016/j.fm.2009.07.011

4 Rajendran E G M G & Ramesh V G, Estimation of nutrient content of unfermented and fermented rice drink, *Asian J Biol Life Sci*, 13 (1) (2024) 40-47. DOI: 10.5530/ajbls.2024.13.6

5 Gharsallaoui A, Roudaut G, Chambin O, Volley A & Saurel R, Applications of spray-drying in microencapsulation of food ingredients: An overview, *Food Res Int*, 40 (9) (2007) 1107-1121. doi:10.1016/j.foodres.2007.07.004

6 Reddy K B P K, Awasthi S P, Madhu A N & Prapulla S G, Role of cryoprotectants on the viability and functional properties of probiotic lactic acid bacteria during freeze drying, *Food Biotechnol*, 23 (3) (2009) 243-265. https://doi.org/10.1080/08905430903106811

7 Behboudi-Jobbehdar S, Soukoulis C, Yonekura L & Fisk I, Optimization for spray-drying process conditions for maximally viable microencapsulated *Lactobacillus acidophilus* NCIMB 701748, *Drying Technol*, 31 (2013) 1274-1283.

8 Malick P & Deka M, Effect of spray drying on bacterial viability and physicochemical properties of probiotic-enriched ready-to-use (RTU) fermented sour rice powder, *Int J Chem Stud*, 13 (6) (2025) 46-51.

9 Jinapong N, Suphantharika M & Jamnong P, Production of instant soymilk powders by ultrafiltration, spray drying and fluidized bed agglomeration, *J Food Eng*, 84 (2) (2008) 194-205. doi:10.1016/j.jfoodeng.2007.04.032

10 Fadini A L, Alvim I D, de Freitas Paganotti K B, da Silva L B, Queiroz M B, *et al.*, Optimization of the production of double shellmicroparticles containing fish oil, *Food Sci Technol Int*, 25 (5) (2019) 359-369. doi: 10.1177/1082013219825890

11 Seth D, Mishra H N & Deka S C, Functional and reconstitution properties of spray dried sweetened yogurt powder as influenced by processing conditions, *Int J Food Prop*, 20 (7) (2017) 1603-1611. https://doi.org/10.1080/10942912.2016.1214965

12 International Dairy Federation (IDF), Determination of Insolubility Index of Caseins and Caseinates (Reference

Method), Standard 129A. Brussels, (International Dairy Federation, Belgium), 1988.

13 Cai Y Z & Corke H, Production and properties of spray dried *Amaranthus* betacyanin pigments, *J Food Sci*, 65 (7) (2000) 1248-1252. https://doi.org/10.1111/j.1365-2621.2000.tb10273.xDigital Object Identifier (DOI)

14 Jaya S & Das H, Effect of maltodextrin, glycerol monostearate and tricalcium phosphate on vacuum dried mango powder properties, *J Food Eng*, 63 (2004) 125-134. doi:10.1016/S0260-8774(03)00135-3

15 Kumar S, Nema P K, Kumar S & Chandra A, Kinetics of change in quality parameters of khaja during deep-fat frying, *J Food Process Preserv*, 46 (2022) 16265. https://doi.org/10.1111/jfpp.16265

16 Ranganna S, *Handbook of Analysis and Quality Control Fruit and Vegetable Products*, (McGraw Hill Education Publishers, New Delhi), 2004.

17 Shamaei S, Seiiedlou S S, Aghbashlo M, Tsotsas E & Kharaghani A, Microencapsulation of walnut oil by spray drying: effects of wall material and drying conditions on physicochemical properties of microcapsules, *Innov Food Sci Emerg Technol*, 39 (2017) 101-112. https://doi.org/10.1016/j.ifset.2016.11.011

18 Corcoran B M, Ross R P, Fitzgerald G F & Stanton C, Comparative survival of probiotic lactobacilli spray-dried in the presence of prebiotic substances, *J Appl Microbiol*, 96 (5) (2004) 1024-1039. doi: 10.1111/j.1365-2672.2004.02219.x

19 Kumar S, Kumar S, Mitharwal S, Chandra A & Nema P K, Effect of different concentrations of thermoprotectant on microencapsulation of *Lactobacillus rhamnosus* GG by spray drying, and its effect on physiochemical properties and viability, 30(4) (2023) 1066-1073. https://doi.org/10.47836/ifrj.30.4.22

20 Arepally D & Goswami T K, Effect of inlet air temperature and gum Arabic concentration on encapsulation of probiotics by spray drying, *LWT*, 99 (2019) 583-593. https://doi.org/10.1016/j.lwt.2018.10.022

21 Barbosa-Canovas G V, Ortega-Rivas E, Juliano P & Yan H, Food Powders: Physical properties, processing, and functionality,(Kluwer Academic/Plenum Publishers, New York, NY), 2005.

22 Qin W, Lin Z, Wang A, Chen Z, He Y, *et al*., Influence of particle size on the properties of rice flour and quality of gluten-free rice bread, *LWT*, 151 (2021) 112236. https://doi.org/10.1016/j.lwt.2021.112236

23 Asmeda R, Noorlaila A & Norziah M H, Relationships of damaged starch granules and particle size distribution with pasting and thermal profiles of milled MR263 rice flour, *Food Chem*, 191 (2016) 45-51. doi: 10.1016/j.foodchem.2015.05.095

24 Engelen L, de Wijk R A, van der Bilt A, Prinz J F, Janssen A M, *et al*., Relating particles and texture perception, *Physiol Behav*, 86 (1-2) (2005) 111-117. doi: 10.1016/j.physbeh.2005.06.022

25 Lebrun P, Krier F, Mantanus J, Grohganz H, Yang M, *et al*., Design space approach in the optimization of the spray-drying process, *Eur J Pharm Biopharm*, 80 (2012) 226-234. doi: 10.1016/j.ejpb.2011.09.014

26 Caparino O A, Tang J, Nindo C I, Sablani S S, Powers J R, *et al*., Effect of drying methods on the physical properties and microstructures of mango (*Philippine"Carabao" var.*) powder, *J Food Eng*, 111 (2012) 135-148. doi: 10.1016/j.jfoodeng.2012.01.010

27 Cano-Chauca M, Stringheta P C, Ramos A M & Cal-Vidal J, Effect of the carriers on the microstructure of mango powder obtained by spray drying and its functional characterization, *Innov Food Sci Emerg Technol*, 6 (4) (2005) 420-428. https://doi.org/10.1016/j.ifset.2005.05.003

28 Kim E H J, Chen X D & Pearce D, Surface characterization of four industrial spray-dried powders in relation to chemical composition, structure and wetting property, *Colloids Surf B Biointerfaces*, 26 (3) (2002) 197-212. Doi: 10.1016/S0927-7765(01)00334-4

29 Fang Y, Selomulya C & Chen X D, On measurement of food powder reconstitution properties, *Dry Technol*, 26 (2008) 3-14.

30 Marabi A, Mayor G, Raemy A, Bauwens I, Claude J, *et al*., Solution calorimetry: a novel perspective into the dissolution process of food powders, *Food Res Int*, 40 (10) (2007) 1286-1298. Doi: 10.1016/j.foodres.2007.08.007

31 Millqvist-Fureby A, Elofsson U & Bergenstahl B, Surface composition of spray-dried milk protein-stabilized emulsions in relation to pre-heat treatment of proteins, *Colloids Surf B Biointerfaces*, 21 (2001) 47-58. doi: 10.1016/s0927-7765(01)00183-7

32 Sulieman A M E, Elamin O M, Elkhalifa E A & Laleye L, Comparison of physicochemical properties of spray-dried camel's milk and cow's milk powder, *Int J Food Sci Nutr Eng*, 4 (2014) 15-19. DOI: 10.5923/j.food.20140401.03

33 Tonon R V, Brabet C & Hubinger M D, Influence of process conditions on the physicochemical properties of acai (*Euterpe oleraceae* Mart.) powder produced by spray drying, *J Food Eng*, 88 (2008) 411-418. https://doi.org/10.1016/J.JFOODENG.2008.02.029

34 Lipan L, Rusu B, Sendra E, Hernandez F, Vazquez-Araujo L, *et al*., Spray drying and storage of probiotic enriched almond milk: probiotic survival and physicochemical properties, *J Sci Food Agric*, 100 (9) (2020) 3697-3708. doi: 10.1002/jsfa.10409

35 Koc B, Sakin-Yilmazer M, Kaymak-Ertekin F & Balkir P, Physical properties of yoghurt powder produced by spray drying, *J Food Sci Technol*, 51 (7) (2014) 1377-1383. DOI: 10.1007/s13197-012-0653-8

36 Fritzen-Freire C B, Prudencio E S, Amboni R D M C, Pinto S S, Negrao-Murakami A N, *et al*., Microencapsulation of bifidobacteria by spray drying in the presence of prebiotics, *Food Res Int*, 45 (2012) 306-312. Doi: 10.1016/j.foodres.2011.09.020

37 Saénz C, Tapia S, Chávez J & Robert P, Microencapsulation by spray drying of bioactive compounds from cactus pear (*Opuntiaficus-indica*), *Food Chem*, 114 (2) (2009) 616-622. Doi: 10.1016/j.foodchem.2008.09.095

38 Slavutsky A M, Chávez M C, Favaro-Trindade C S & Bertuzzi M A, Encapsulation of *Lactobacillus acidophilus* in a pilot-plant spray-dryer: Effect of process parameters on cell viability, *J Food Process Eng*, 40 (2) (2017) e12394. https://doi.org/10.1111/jfpe.12394

39 Hijo AA C T, da Costa J M G, Silva E K, Azevedo V M, Yoshida M I, *et al*., Physical and thermal properties of oregano (*Origanum vulgare* L.) essential oil microparticles, *J Food Process Eng*, 38 (1) (2015) 1-10. https://doi.org/10.1111/jfpe.12120

40 Kalita D, Saikia S, Gautam G, Mukhopadhyay R & Mahanta C L, Characteristics of synbiotic spray dried powder of litchi juice with *Lactobacillus plantarum* and different carrier materials, *LWT - Food Sci Technol*, 87 (2018) 351-360. Doi: 10.1016/j.lwt.2017.08.092

41 Moayyedi M, Eskandari M H, Rad A H E, Ziaee E, Khodaparast M H H, *et al*., Effect of drying methods (electro spraying, freeze drying and spray drying) on survival and viability of microencapsulated *Lactobacillus rhamnosus* ATCC 7469, *J Funct Foods*, 40 (2018) 391-399. https://doi.org/10.1016/j.jff.2017.11.016

42 Kim E H J, Chen X D & Pearce D, Surface composition of industrial spray-dried milk powders: 2, Effects of spray drying conditions on the surface composition, *J Food Eng*, 94 (2) (2009) 169-181. Doi:10.1016/j.jfoodeng.2008.10.020

43 Rodríguez-Huezo M E, Pedroza-Islas R, Prado-Barragán L A, Beristain C I & Vernon-Carter E J, Microencapsulation by spray drying of multiple emulsions containing carotenoids, *J Food Sci*, 69 (7) (2004) E351-E359. DOI:10.1111/j.1365-2621.2004.tb13641.x

44 Haque M K & Roos Y H, Differences in the physical state and thermal behavior of spray-dried and freeze-dried lactose and lactose/protein mixtures, *Innov Food Sci Emerg Technol*, 7 (2006) 62-73. https://doi.org/10.1016/j.ifset.2004.12.004

45 Das A Tushar, Kesari V & Rangan L, Aromatic joha rice of Assam-A review, *Agric Rev*, 31 (1) (2010) 1-10.