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Comparative effects of prebiotic addition on the physicochemical and microstructural properties of spray-dried yogurt powder

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Abstract

This experimental study examined the effects of inulin and fructooligosaccharides (FOS) additions as partial maltodextrin (MD) replacement on the physicochemical and microstructural properties of spray-dried yogurt powder. Pasteurized whole milk, maltitol, yogurt cultures, and carrier materials were used to make yogurt. The carrier materials were 15% MD (Control), a combination of 5% MD and 10% inulin (Inulin), and a combination of 5% MD and 10% FOS (FOS). Spray-drying conditions were inlet and outlet temperature of 150ºC and 90ºC, with a feed rate of 9 mL/min. Physicochemical properties, solubility, hygroscopicity, particle size, and microstructure of the spray-dried yogurt powder were analyzed. Results showed that replacement of MD with inulin and FOS did not affect product yield (13.16–15.07%), moisture content (2.47–2.70%), and water activity (0.21–0.25) of the powder. Inulin and FOS additions significantly increased powder tapped density compared to the Control ($p<0.05$), indicating smooth and uniform particle surfaces. Replacement of MD with inulin and FOS improved the solubility of the powder, while addition of inulin decreased powder hygroscopicity and flowability compared to the Control ($p<0.05$). Mean particle diameters of the powder ranged from 26.43 to 29.99 µm, with morphological structure as spherically shaped with smooth surfaces and varying particle size with uniform distribution. Results suggested that inulin effectively enhanced the quality of spray-dried yogurt powder by reducing hygroscopicity and improving the solubility and tapped density.

Keywords: Spray-dried yogurt powder, Prebiotics, Physicochemical properties, Microstructure

1. Introduction

Yogurt is a semi-solid fermented milk product manufactured by fermentation with bacterial cultures such as *Lactobacillus bulgaricus* and *Streptococcus thermophilus* [1]. Yogurt has high nutritional value and various human health benefits [2, 3]. However, yogurt must be refrigerated and has a short shelf life. The dehydration of yogurt is an effective process to produce yogurt powder, thereby extending shelf life and reducing both storage and transportation costs [4, 5]. Yogurt powder can be used as an ingredient in various foods to make instant yogurt, dry dessert mixes, frozen desserts, yogurt smoothies, and healthy drinks [6]. Yogurt powder is normally prepared by freeze-drying and spray-drying techniques. Freeze-drying provides better nutrition, flavor, and yogurt cultures compared with spray-drying but is a more expensive process [6].

Spray-drying is widely used to change liquid foods into solid form. This extends the shelf life of food products and also encapsulates various nutrients and heat-sensitive compounds [7, 8]. Moisture content and water activity of spray-dried powders are generally less than 5% and 0.3, respectively contributing to microbiological and chemical safe products [9, 10]. The most common encapsulating agents are carrier materials as polysaccharides and proteins. Maltodextrin (MD) is a carrier material often used in microencapsulation to increase product yield and improve the physical and chemical properties of the powder [7, 10, 11]. Fructans are oligosaccharides and polysaccharides composed of fructose units linked with glycosidic bonds. Fructans consisting of 2–9 fructose units are referred to as fructooligosaccharides (FOS), while fructans with 10–60 fructose units are categorized as inulin [12, 13]. FOS and inulin are soluble dietary fibers which are used as carrier materials for microencapsulation of spray-dried powder due to their nutritive properties [12]. They are also widely used as functional foods and recognized as effective prebiotics, supporting the growth of some microorganisms in the colon [13].

Spray-dried powder quality is assessed based on its chemical, physical, and morphological properties that contribute to product stability, storage, handling, and final application. These properties are influenced by the spray-drying conditions and carrier agents [4, 11, 14]. Tontul and Topuz [10] documented that higher inlet temperature and atomization pressure increased product yield, with higher atomization pressure yielding smaller particle sizes, while lower inlet air temperatures resulted in smaller particles. Smaller particle size increases bulk density because of fewer void spaces [4]. Particle size is also influenced by feed viscosity and carrier material concentration, with higher viscosity and concentration yielding larger particles [10]. The type of carrier material also affects powder particle size and bulk density, with MD generally resulting in larger particles and higher bulk density compared to whey protein [14] and gum Arabic [10].

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Previous research investigated different spray-drying conditions for the production of yogurt powder and measured physical properties as bulk and tapped densities, particle size distribution, and morphology [4]. Kumar and Mishra [6] found that the quality of spray-dried yogurt powder was affected by carrier material characteristics and spray-drying conditions such as total solid content, inlet and outlet temperatures, and atomizer speed. The addition of hydrocolloids such as carrageenan and xanthan enhanced the flavor and solubility of spray-dried yogurt powder [6]. However, the impact of adding inulin and FOS as replacements for MD on the physical and microstructural properties of spray-dried yogurt remains inadequately examined. Therefore, this study investigated the effects of carrier materials (MD, inulin, and FOS) on the yield, physicochemical, and microstructural characteristics of spray-dried yogurt powder.

2. Materials and methods

2.1 Yogurt preparation and spray-drying process

Based on previous studies, the yogurt was made from a mixture of 80% pasteurized milk, 5% maltitol as a sweetener, and 15% carrier materials as follows: 15% MD (Control), a combination of 5% MD and 10% inulin (Inulin), and a combination of 5% MD and 10% FOS (FOS). The 1,000 mL mixtures were poured into a double boiler and pasteurized at 85ºC for 15 min. The pasteurized mixtures were then cooled to 45ºC, inoculated with an active bacteria culture (FD-DVS ABY-3 Probio-Tec®, Chr. Hansen, Hoersholm, Denmark), and incubated at 45ºC until a pH of 4.0–4.3 was reached [6]. The yogurt was then stored at 4ºC for further experiments. All experimental yogurts were prepared in triplicates. Before spray-drying, the yogurt was mixed with water at a yogurt-to-water ratio of 3:1 (w/w), and directly homogenized using a homogenizer (Ultra-Turrax T25 digital, IKA, IKA-Werke GmbH&Co.KG, Staufen, Germany) at 8,000 rpm for 5 min. Total solid content, total soluble solids (TSS), and the pH of the homogenized yogurt were analyzed using a moisture analyzer (MB-25, OHAUS Instruments Co., Ltd., Shanghai, China), a refractometer (81150-25, Cole-Parmer, IL, USA), and a multimeter (Multimeter, PC2700, Oakton, IL, USA), respectively.

The homogenized yogurt was spray-dried using a spray dryer (Mini Spray Dryer B-290, Buchi, BÜCHI Labortechnik AG, Flawil, Switzerland). Based on a preliminary experiment, the spray-drying conditions were as follows: inlet temperature 150ºC, outlet temperature 90ºC, feed rate 9 mL/min, airflow 35 m^3/h, and nozzle size of atomizer 1.4 mm diameter. The spray-dried yogurt powder was collected, stored in sealed plastic bags, and retained in a desiccator at room temperature for further analysis.

2.2 Yield and physicochemical properties

The yield of the spray-dried yogurt powder was calculated using equation (1) below:

$$Yield\ (\%) = \frac{Weight\ of\ the\ solids\ in\ dried\ powder(g)}{Solid\ content\ in\ the\ feed\ material(g)} \times 100 \quad (1)$$

Moisture content and water activity were analyzed using a moisture analyzer (MB-25, OHAUS Instruments Co., Ltd., Shanghai, China) and a water activity meter (AquaLab Pre, METER Group, Inc., WA, USA), respectively. All experiments were performed in triplicate.

Bulk and tapped density were measured following Saikia et al. [15] with some modifications. Briefly, two grams of powder were weighed and poured into a 15 mL graduated cylinder to measure the bulk density. The cylinder was then tapped 50 times, and the volume was measured to calculate the tapped density. Bulk density and tapped density were calculated using equations (2) and (3), respectively. All experiments were performed in triplicate, with results expressed in g/mL. To assess the cohesiveness and flowability of the powder, Hausner's ratio (HR) and Carr index (CI) were calculated following Saikia et al. [15] using equations (4) and (5) below:

$$Bulk\ density\ (g/mL) = \frac{Weight\ of\ the\ spray\text{-}dried\ yogurt\ powder\ (g)}{Volume\ of\ the\ spray\text{-}dried\ yogurt\ powder\ (mL)} \quad (2)$$

$$Tapped\ density\ (g/mL) = \frac{Weight\ of\ the\ spray\text{-}dried\ yogurt\ powder\ (g)}{Tapped\ volume\ of\ the\ spray\text{-}dried\ yogurt\ powder\ (mL)} \quad (3)$$

$$Hausner's\ ratio\ (HR) = \frac{Tapped\ density}{Bulk\ density} \quad (4)$$

$$Carr\ index\ (CI) = \frac{Tapped\ density - Bulk\ density}{Tapped\ density} \times 100 \quad (5)$$

The solubility of the powder was assessed following Yousefi et al. [16] with minor modifications. Two grams of powder were mixed with 10 mL of distilled water and stirred for 30 min at 30ºC. The mixture was then centrifuged at 10,000 rpm for 10 min (Centrifuge, Thermo Scientific, Sorvall Legend XTR, Germany). The supernatant was transferred to an aluminum can and then dried at 105ºC for 5 h. All experiments were performed in triplicate. The solubility was calculated using equation (6):

$$Solubility\ (\%) = \frac{Weight\ of\ dried\ supernatant\ (g)}{Weight\ of\ initial\ powder\ (g)} \times 100 \quad (6)$$

The hygroscopicity of the powder was determined following Saikia et al. [15] with some modifications. Briefly, 1 g of the powder was placed in an aluminum can in an environmental test chamber (CTC256, Memmert GmbH + Co. KG, Schwabach, Germany) at 30ºC and 75±3% relative humidity. The aluminum cans were weighed at 0, 3, 5, and 7 days after storage. All experiments were performed in triplicate. The hygroscopicity was calculated using equation (7):

$$Hygroscopicity\ (\%) = \frac{Weight\ of\ absorbed\ moisture(g)}{Weight\ of\ initial\ powder(g)} \times 100 \quad (7)$$

Color values of the spray-dried yogurt powder were measured using a colorimeter (ColorQuest® XE, Hunter Associates Laboratory, Inc., VA, USA) based on the CIE L*a*b* system (lightness, redness, and yellowness). All experiments were performed in triplicate.

2.3 Particle size distribution, microstructure and statistical analysis

A particle size distribution analyzer (Horiba, LA 920, Kyoto, Japan) was used to characterize the particle size distribution of the spray-dried yogurt powder, using a dispersant refractive index of 1.460 for the spray-dried yogurt powder and 1.378 for isopropanol. All samples were determined in triplicate. The particle size distribution was characterized by the span value and evaluated using equation (8):

$$Span\ value = \frac{D_{90}-D_{10}}{D_{50}} \tag{8}$$

where D_{10} represents the diameter at which 10% of the particles are smaller, D_{50} represents the diameter at which 50% of particles are smaller and 50% are larger, and D_{90} represents the diameter at which 90% of particles are smaller.

A field emission scanning electron microscope (FE-SEM, AURIGA, Carl Zeiss, Germany) was used to determine the surface morphology of the spray-dried yogurt powder at 500x, 1500x, and 3000x magnifications.

Results were expressed as means ± standard deviations. One-way analysis of variance (ANOVA) was used to evaluate the effects of prebiotic additions on the physicochemical characteristics of the spray-dried yogurt powder. The Tukey-HSD multiple comparison test was used to compare means at the 5% significance level ($p<0.05$), with statistical analyses performed using Minitab® 17 (Minitab Inc., State College, PA, USA).

3. Results and discussion

3.1 Physicochemical properties of homogenized yogurt

Table 1 illustrates the total solid content, pH, and total soluble solids (TSS) of the homogenized yogurt. Total solid contents varied between 25.87 and 28.00%, consistent with Kumar and Mishra [6] (23–25%). Replacement of MD with FOS significantly reduced the total solid content of the homogenized yogurt ($p<0.05$) because FOS has high water solubility and retention capacity [12], leading to reduced water evaporation during pasteurization, thereby retaining the moisture content and reducing the solid content in the homogenized yogurt.

In this study, pH and TSS ranged between 3.74 and 3.84 and 23.00 and 23.30°Brix, respectively. Results suggested that replacement of MD with inulin and FOS did not impact levels of pH and TSS in the homogenized yogurt ($p>0.05$), while addition of FOS significantly decreased the solid content of the feed material compared to the Control.

Table 1 Total solid content, pH and total soluble solids (TSS) of homogenized yogurt before spray-drying.

Treatment	Total solid (%)	pH	TSS (°Brix)
Control	28.00 ± 0.26^{a}	3.74 ± 0.01^{a}	23.30 ± 1.50^{a}
Inulin	26.93 ± 0.32^{ab}	3.81 ± 0.02^{a}	23.00 ± 1.70^{a}
FOS	25.87 ± 0.70^{b}	3.84 ± 0.01^{a}	23.30 ± 0.60^{a}

Note: Values are the mean of three replications ± standard deviation. Different superscripts in each column indicate statistical differences between treatments ($p<0.05$).

3.2 Yield and chemical properties of spray-dried yogurt powder

The yield and chemical properties of the spray-dried yogurt powder are compared in Table 2. Product yields ranged 13.16–15.07%, and lower than reported by Leylak et al. [17] (48.36%). The discrepancies were attributed to variations in spray-drying parameters and the disparate physical properties of different feed materials. Leylak et al. [17] stated that low product yield was impacted by the stickiness of the drying chamber during spray-drying, while Tontul and Topuz [10] reported that low product yield was due to the stickiness of the feed material. Our results suggested that replacement of MD with inulin and FOS did not improve product yield. Similar results were also recorded for spray-dried bioactive compounds of cactus pear extract by Saénz et al. [18].

In Table 2, the moisture content (MC) and water activity (a_w) of the spray-dried yogurt powders ranged from 2.47 to 2.70% and 0.21 to 0.25, respectively. Our results concurred with Lira de Medeiros et al. [1], Tontul and Topuz [10], and Sornsomboonsuk et al. [19] who reported moisture contents and a_w values of the spray-dried powder at less than 5% and 0.3, respectively and microbiologically and chemically safe, resulting in effective long-term storage. The replacement of MD with inulin and FOS did not impact product yield, moisture content, and a_w of the spray-dried yogurt powder.

Table 2 Yield, moisture content (MC) and water activity (a_w) of spray-dried yogurt powder.

Treatment	Yield (%)^{ns}	MC (%)^{ns}	a_w^{ns}
Control	13.16±3.02	2.50±0.17	0.24±0.02
Inulin	14.27±0.31	2.70±0.71	0.25±0.09
FOS	15.07±1.43	2.47±0.23	0.21±0.02

Note: Values are the mean of three replications ± standard deviation. “ns” indicates not significant ($p>0.05$).

3.3 Physical properties of spray-dried yogurt powder

The physical parameters of spray-dried yogurt powder are listed in Table 3. The bulk density and tapped density of the Control, Inulin, and FOS were between 0.41 and 0.43 g/mL and 0.56 and 0.66 g/mL, respectively and slightly lower than reported by Koç et al. [4] (0.54 g/mL) and Kumar and Mishra [6] (0.60 g/mL) for bulk density. Tontul and Topuz [10] reported that bulk density varied depending on the size, shape, and surface characteristics of the particles, while smaller particle size resulted in increased bulk density because of fewer void spaces.

Results showed that prebiotic addition as carrier material replacement significantly increased the tapped density ($p<0.05$). The higher tapped density observed in Inulin and FOS was attributed to the smooth and uniform particle surface resulting from the characteristics of the carrier material [10, 15]. Koç et al. [4] documented that higher bulk and tapped density of spray-dried powder are preferred to reduce packaging volume and minimize the risk of product degradation due to oxidation, thus enhancing storage stability.

Flowability is commonly used to evaluate spray-dried powder quality [14]. Hausner's ratio (HR) and Carr index (CI) describe the cohesiveness and flowability properties of the powder [15]. Results showed that HR and CI ranged between 1.34 and 1.59 and 24.94 and 37.01, respectively consistent with Saikia et al. [15]. Replacement of MD with inulin significantly increased the HR and CI values ($p<0.05$), suggesting that inulin addition increased cohesiveness while reducing the flowability of the spray-dried yogurt powder compared with the Control. Yousefi et al. [16] reported that HR values between 1.46 and 1.59 and CI values of 32 to 37% indicated very poor powder flowability, while Arepally and Goswami [20] found that HR and CI specifications for excellent flowability of spray-dried products were 1.0–1.1 and 0–15%, respectively. Very poor flowability was indicated by HR exceeding 1.6 and CI above 38%.

High solubility of spray-dried powder is a desirable property for fast reconstitution [14]. In this study, powder solubility varied between 59.21 and 67.98%, consistent with Šavikin et al. [21] (63.34–69.63%). However, Lira de Medeiros et al. [1] reported that the solubility of yogurt powder ranged from 68.2 to 81.1%. These variations were probably due to differences in feed materials and conditions of the spray-drying operation. Our results showed that addition of FOS significantly enhanced powder solubility compared with the Control ($p<0.05$). MD, inulin, and FOS are all water-soluble compounds [12, 18, 22], and this was attributed to an increase in mean particle size (refer to Table 3), resulting in increased powder solubility. The shapes and sizes of spray-dried powders are influenced by the surface tension and viscosity of the carrier materials [10]. Koç et al. [4] also reported that an increase in particle size enhanced powder solubility and flowability, while Tontul and Topuz [10] documented that increasing MD content enhanced spray-dried powder solubility, with excessive carrier material decreasing the solubility.

Lightness (L*), redness (a*), and yellowness (b*) of the spray-dried yogurt powder are compared in Table 3. The L*, a*, and b* values ranged from 93.39 to 95.52, -0.41 to -0.69, and 6.82 to 7.94, respectively. Our results suggested that replacement of MD with inulin and FOS had no significant effect on the color values of spray-dried yogurt powder, with the L* and a* values comparable to Arepally and Goswami [20] who reported that the L* and a* values of spray-dried probiotic powder encapsulated with 20% MD concentration ranged from 95.32 to 95.68 and -0.34 to -0.22, respectively. The L* and b* values in this study differed from values reported by Lira de Medeiros et al. [1] for spray-dried probiotic goat milk yogurt powder at 78.46–79.20 and 20.20–23.18, respectively.

Table 3 Physical properties of the spray-dried yogurt powder.

Parameter	Treatment		
	Control	**Inulin**	**FOS**
Bulk density (g/mL)	$0.42±0.02^a$	$0.41±0.01^a$	$0.43±0.03^a$
Tapped density (g/mL)	$0.56±0.01^b$	$0.66±0.02^a$	$0.64±0.06^a$
HR	$1.34±0.09^b$	$1.59±0.06^a$	$1.48±0.06^{ab}$
CI (%)	$24.94±4.91^b$	$37.00±2.35^a$	$32.41±2.57^{ab}$
Solubility (%)	$59.21±2.02^b$	$64.16±2.65^{ab}$	$67.98±3.37^a$
L*	$95.52±0.87^a$	$93.39±2.87^a$	$93.63±2.66^a$
a*	$-0.58±0.08^a$	$-0.69±0.14^a$	$-0.41±0.11^a$
b*	$6.89±0.36^a$	$6.82±0.51^a$	$7.94±0.24^a$
Mean particle size (µm)	$26.43±1.23^b$	$26.78±1.34^b$	$29.99±1.06^a$
Span value	$1.21±0.06^b$	$1.37±0.08^{ab}$	$1.48±0.06^a$

Note: Values are the mean of three replications ± standard deviation. Different superscripts in each row indicate statistical differences between treatments ($p<0.05$).

Figure 1 illustrates the particle size distribution of spray-dried yogurt with results ranging from 2 to 41 µm. In Table 3, mean particle diameters of the powder ranged from 26.43 to 29.99 µm and were consistent with Lira de Medeiros et al. [1] who reported that mean particle size of yogurt powder ranged between 12.7 and 23.4 µm. In this study, mean diameters of FOS were significantly higher than the Control and Inulin ($p<0.05$). An increase in particle size resulted in enhanced powder solubility and flowability [4], attributed to the influence of carrier material characteristics on the particle size of the spray-dried powder. Tontul and Topuz [10] reported that the particle size of the powder was influenced by the type and concentration of the carrier material and the feed viscosity, with higher concentrations and higher viscosity resulting in larger particles.

The span values of the powder ranged 1.21–1.48, with the span value of FOS significantly higher than the Control ($p<0.05$). According to Koç et al. [4] the span value represents the width of the particle size distribution. Results suggested that replacement of MD with FOS increased the particle size distribution of the powder, attributed to the effect of carrier type and viscosity of the feed materials.

Tontul and Topuz [10] reported that hygroscopicity represented the capacity of the powder to absorb environmental moisture. Our powder had less than 20% hygroscopicity and was considered slightly hygroscopic. Figure 2 shows the hygroscopicity of spray-dried yogurt powder after 1, 3, 5, and 7 days of storage. Replacement of MD with FOS exhibited higher hygroscopicity compared with the Control and Inulin. Results suggested that inulin effectively decreased the hygroscopicity of the spray-dried yogurt powder because FOS is highly hygroscopic and has better solubility than inulin. Lira de Medeiros et al. [1] reported that powders with higher MD content had lower hygroscopicity values.

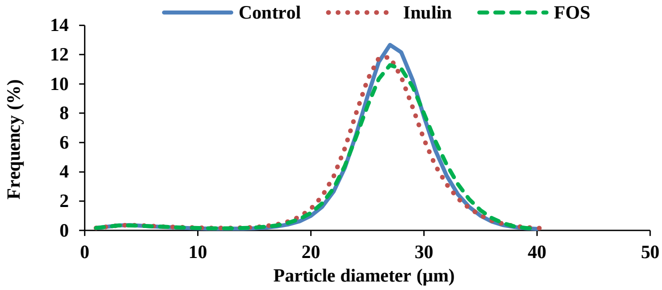

Figure 1 Particle size distribution of spray-dried yogurt powder.

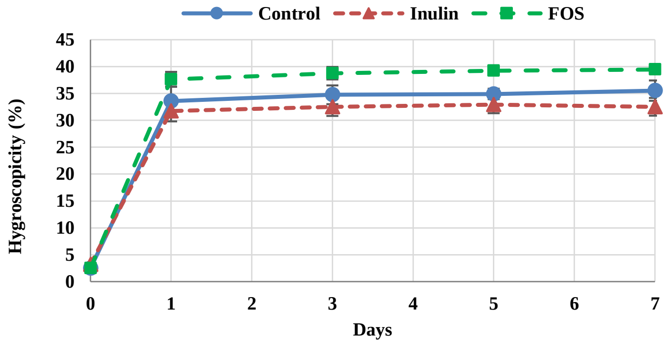

Figure 2 Hygroscopicity of the spray-dried yogurt powder.

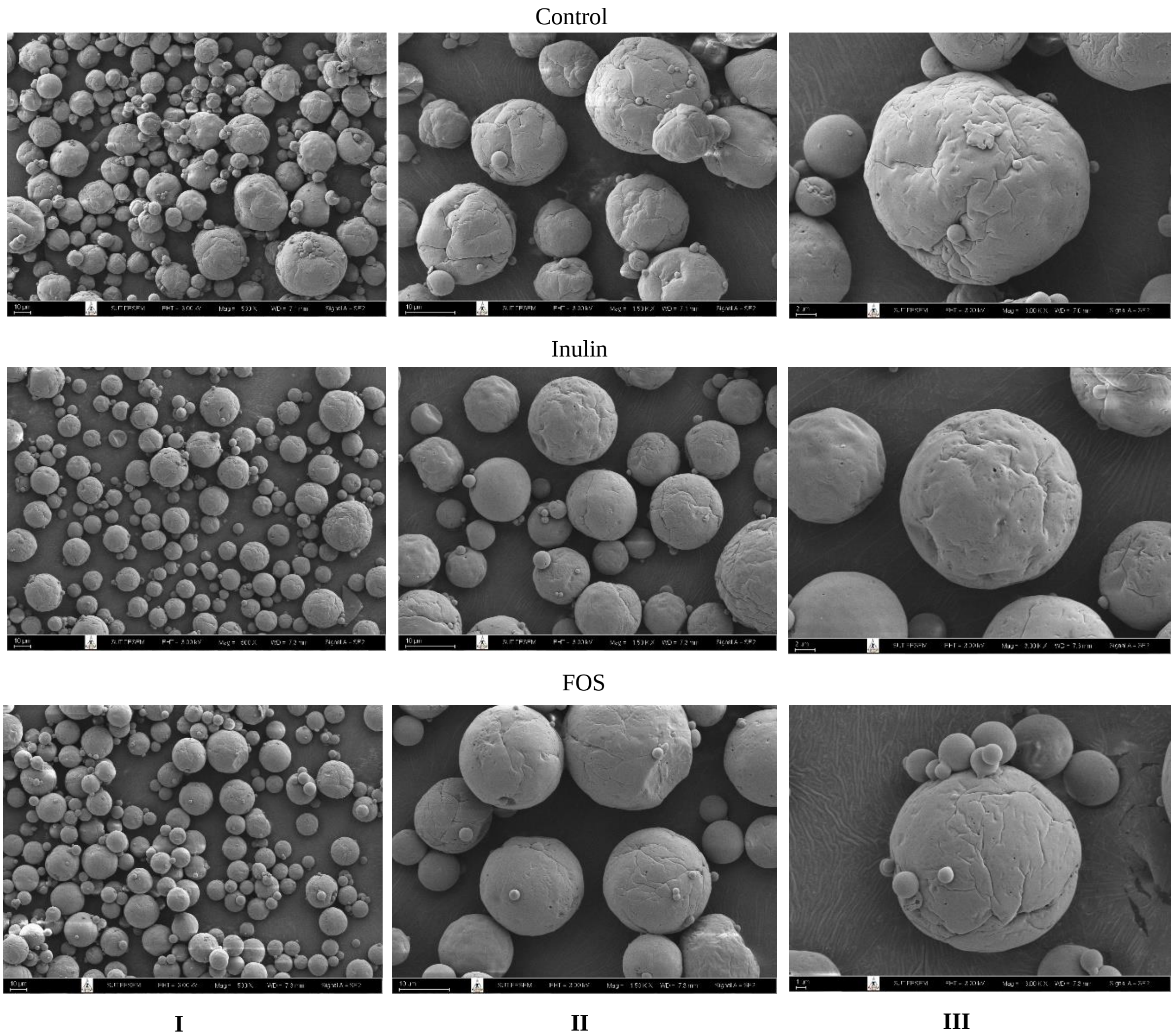

Figure 3 FE-SEM images of spray-dried yogurt powder: I, II, and III represent magnifications of 500x, 1500x, and 3000x, respectively.

3.4 Microstructure of spray-dried yogurt powder

Figure 3 shows the morphological characteristics of spray-dried yogurt powder. The powder particles exhibited a spherical shape with smooth surfaces in all samples. The spray-dried yogurt powders had varied particle size with uniform distribution (Figure 3 I, II), consistent with Lira de Medeiros et al. [1], who documented that characteristics of spray-dried dairy powder generally presented spherical shape, smooth surface, and varying size. In Figure 3 (III), the powders revealed the formation of holes on the surface, probably due to fast evaporation during drying [10]. Koç et al. [4] reported that holes or porous surfaces improved the wetting and solubility of the powder.

4. Conclusions

This study investigated the effects of carrier materials (MD, inulin, and FOS) on the quality of spray-dried yogurt powder. Results showed that replacement of MD with inulin and FOS did not influence the yield, moisture content, and water activity of spray-dried yogurt powder, while addition of inulin and FOS as MD replacement significantly increased tapped powder density. Inulin effectively decreased the hygroscopicity of the spray-dried yogurt powder, whereas FOS increased its hygroscopicity. Inulin and FOS addition increased powder solubility, while replacement of MD with inulin effectively improved the quality of spray-dried yogurt powder by reducing the hygroscopicity and enhancing solubility and tapped density. However, further studies should focus on the survival of yogurt bacteria and storage stability to scale up the spray-drying process and assess the commercial benefits.

5. Acknowledgement

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6. References

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