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ORIGINAL PAPER

Instant cereal-based fermented beverage (Boza) powder: characterization physical, rheological and structural properties

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Abstract

Boza is a traditional lactic acid and yeast-fermented beverage. Boza has a short shelf life of up to 15 days, due to the presence of viable microbiota. Spray drying was performed to extend the shelf life. Spray-dried powders have poor reconstitution and instant properties that may restrict consumption. To overcome this problem, the fluidized bed agglomeration process was used for the first time to improve the quality of boza powders. Spray-dried boza powders were agglomerated in a fluidized bed agglomerator using sucrose binder. The optimum process conditions for obtaining samples with minimum moisture content, wettability time, angle of repose and maximum LAB number, particle size, solubility, porosity values were determined as 73.92 °C air inlet temperature, 0.7 bar atomization pressure and 22.67 mL binder amount (desirability: 0.87). Under these conditions, the number of LAB decreased by about 2 log units. At the optimum point, boza powder showed instant wetting behavior with 28.3 s wetting time while it was 99.33 in spray-dried form. Instant boza powder was categorized as having low cohesiveness and good flowability with an 11.62° angle of repose value, while it was 36.44° in spray-dried form. The loss modulus (G″) was lower than the storage modulus (G′) at all applied angular frequencies (ω), indicating the elastic properties of the reconstituted instant boza. Agglomeration technology has a strong potential to solve the dilution problems of boza powder and enable the production of boza products that can be consumed at all times of the year.

Keywords Boza powder · Fluidized bed agglomeration · Wettability · Reconstitution · Surface Modification

Introduction

Today consumer seeks useful, healthful, and varied food products that meet dietary needs such as those related to allergies, malabsorption, and food intolerances, as well as dietary preferences such as low-fat or low-salt, vegetarianism, and veganism. Cereal-based drinks contain health-promoting ingredients and have been studied as functional foods. Fermentation can improve the low organoleptic properties of raw cereals and provide functionality. Boza, a cereal-based beverage popular in Anatolia, Eastern European countries, Southern Russia, and the Middle East, is produced by fermentation of yeasts and lactic acid bacteria, mainly from the genera *Lactobacillus*, *Lactococcus*, *Pediococcus*, and *Leuconostoc* [1, 2]. It is a viscous, sour, and low-alcohol drink.

The results of clinical studies have proven the positive effects of probiotics and prebiotics on the human gastrointestinal system and various diseases such as allergic diseases, obesity, insulin resistance syndrome, type 2 diabetes, hypertension, coronary heart disease, non-alcoholic fatty liver disease and cancer [3]. Therefore, global interest in fermented functional beverages such as prebiotic and probiotic-rich boza is constantly growing [4]. Companies are looking for new insights into consumers'needs for these products. Boza has a short shelf life of up to 15 days due to the presence of viable microbiota Therefore, it is primarily consumed during the winter months and is difficult

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to procure in other seasons. One of the sector's goals is to ensure the sustainability of the food and food supply chain and reduce food loss. Especially during the COVID-19 pandemic, consumers who could not access fresh foods due to quarantine tasted dried foods they had not purchased before [5]. Demand for such products is expected to grow in the coming years [6, 7]. According to Boukid et al. [8], the market for plant-based dairy substitutes was worth US$ 22.6 billion in 2020 and is expected to reach US$ 40.6 billion by 2026.

Moreover, maintaining high-quality standards is a challenge for producers and sellers, especially during the summer months. Food dehydration has been used as a traditional food preservation technique since ancient times due to its simplicity and effectiveness in extending the shelf life of foods. Food dehydration is based on the theory of reducing the water activity value of the product below a certain value, resulting in longer shelf life and a reduction in the volume and weight of the final product, which reduces the costs associated with storage and transportation. Among drying techniques, spray drying is the most widely used method on an industrial scale for the preservation of liquid foods in powder form [9]. In our recent study, spray-drying technology was applied to boza beverages for the first time, and spray-drying conditions were optimized [10]. However, spray-dried powders generally have poor reconstitution and instant properties due to particle sizes smaller than 50 µm [11]. The small particles have the potential to negatively affect the powder's qualities because of their propensity to caking and to cause issues like product loss during processing and transportation. Typical problems connected with powders containing particles are dusting, lumping, difficulty in dissolving in water, and inhibition of flow during dosage. Both food manufacturers and consumers want the powder to dissolve or disperse quickly in water without clumping. Additionally, manufacturers need dust-free powders that flow freely [12]. The agglomeration process can be used for powders obtained using the spray drying method to improve these properties. In the literature, there are many agglomeration studies for different spray-dried powders to improve these properties [11–14]. The fluidized bed agglomeration process, the most widely used technology in the industry, was used to improve the physical properties of fine particles such as wettability, solubility, flowability and stability against particle segregation without losing their properties. The fluidized bed agglomeration process includes particle fluidization in a stream of hot air, atomization of a binder to moisten the particles during collision, and a drying step to consolidate the mixture. Liquid bridges form when the sticky particles collide. Evaporation of water during the drying phase converts the liquid bridges into solid bridges. Important adhesive forces associated with particle surface charge and particle separation include electrostatic and van der Waals forces. The strength of these adhesive forces, as well as the properties of powder, are significantly affected by process conditions. Control of the agglomeration process conditions is critical to obtain high-quality instant powders. Therefore, Response Surface Methodology was used to investigate and optimize process conditions such as inlet air temperature, atomization pressure and amount of binder concerning viable lactic acid bacteria count, moisture content, average particle size (D_{50}, µm), solubility, wettability, porosity, flowability parameters. At the optimum point, detailed powder characteristic analysis and rheological and sensory properties of reconstituted boza beverages were performed. To the best of our knowledge, there is no study focusing on the physical, rheological and structural properties of agglomerated cereal-based boza powders produced by fluidized bed agglomeration. The findings presented in this study will provide additional information for the development of agglomerated cereal-based powders.

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Material and methods

Materials

Maize, wheat, rice flour, and castor sugar were provided from a local market in Kastamonu, Turkey. Traditional boza was kindly supplied from Bursa, Turkey (the brand name of the company was kept anonymous). All the chemicals used in this study were of analytical or technical grade.

Boza and boza powder production

The process described by Hancioğlu & Karapinar [2] was used for production with some modifications. A mixture of 50% maize flour, 25% wheat flour, and 25% rice flour was combined with water (1:5 w:v) and cooked under continuous stirring for 30 min. The gelatinized mixture was then diluted by half with water, left overnight at room temperature and filtered using a sieve to remove non-gelatinized fractions. After filtration, 15% of sugar and 2% of traditional boza were added. Fermentation was performed at 28 °C for 24 h. Following the fermentation, boza samples were homogenized for 1 min using an Ultra Turrax homogenizer (IKA T25 Digital in Staufen, Germany). A

laboratory-scale spray drier (B15, Unopex, Izmir, Turkey) was used for the drying under optimized conditions (148 °C air inlet temperature, 9 °C feed temperature, and 10 mL/min feed flow rate) as described in our recent article [10]. The characteristics of boza beverage and spray-dried boza powder were given in Table 1.

Agglomeration of spray-dried boza powders

A lab-scale top-spray fluidized bed device (Mini Glatt, Beizen, Germany) was used for the agglomeration process. The top and bottom diameters of the chamber were 14 cm and 6 cm, respectively. The granulator system includes three metallic filters, a timing filter blower, a product temperature probe and a 0.5 mm diameter nozzle. The same amounts of boza powder (100 g), binder feed rate (sucrose: 2.11 mL/min) and fluidizing air flow rate (8–9 m^3/h) were kept constant in each experiment. Based on the information obtained from literature research [14–16] and preliminary experiments, independent factors including binder amount (15–25 mL), atomization pressure (0.5–1.5 bar) and air inlet temperature (50–80 °C) were used for optimization experiments (Table 2). The agglomerates were consolidated and their moisture content was reduced by final drying under process conditions for 5 min after spraying. After completion of the process, 106 and 300 µm sieves were used to obtain a uniform particle distribution of the powders.

Characterization of agglomerated boza powder

In the optimization of agglomeration process conditions, powder yield, the number of viable lactic acid bacteria (LAB), moisture content, particle size (D_{50}, µm), solubility, wettability, porosity, flowability, and general acceptability scores of boza powder were used as dependent variables. Water activity, color characteristics, microstructure, microstructure, rheological and sensory properties were also determined to characterize the agglomerated boza powder obtained under optimum conditions.

Table 1 General properties of boza beverage and spray-dried boza powder

Properties	Boza beverage	Spray-dried boza powder
LAB (log cfu/g)	8.76 ± 0.13	7.2 ± 0.18
Dry Matter Content (%)	22.87 ± 0.23	96.99 ± 0.53
pH	3.12 ± 0.02	3.2 ± 0.02
Titratable Acidity (%)	0.28 ± 0.07	0.28 ± 0.03
*L**	56.85 ± 1.32	95.42 ± 0.93
*a**	−5.13 ± 0.42	1.39 ± 0.05
*b**	9.6 ± 0.42	6.95 ± 0.03
Wettability (s)	-	99.33 ± 11.81 s
Solubility (%)	-	78.83 ± 2.14
D50 (µm)	-	24.54 ± 1.52
Porosity (%)	-	41.89 ± 0.49
θ (°)	-	36.44 ± 1.47°

Microbial characterization

The lactic acid bacteria counts of the boza samples were determined by plating on MRS Agar containing 0.01% cycloheximide using the spread plate method. After 48 h of anaerobic incubation at 37 °C, colonies were counted and the results were given as log cfu/g [17].

Physical characterization

The powder yield was calculated by weighing the obtained agglomerated boza powder and proportioning it to the initial amount (100 g) and given as % [18]. Moisture content was analyzed using the gravimetric method by drying the powder samples in an oven at 105 °C for 24 h [19]. Water activity was measured using a water activity meter (Aqualab 4TE, Decagon, Pullman, Wash., USA) at 20 °C with an accuracy of ± 0.001 [20].

The powder size analysis of aglomerated boza powders samples was performed with a laser diffraction particle size analyzer (Mastersizer 3000; Malver Instruments Ltd., Worcestshire, UK) equipped with a dry powder feeder device with a 50 kPa feed pressure [18].

For the solubility analysis, 0.1 g of boza powder was mixed with 24.9 g of distilled water at 25 °C, and the mixture was centrifuged at a speed of 4500 rpm for 20 min. The supernatant (10 g) was then dried at 105 °C to bring the weight of the dried material to a constant value. The following formula was used to calculate solubility Eq. (1) [21]

$$Solubility(\%) = \frac{mx2.5}{w} \times 100 \quad (1)$$

where m refers to the dry matter amount at the end of the drying process (g), and w refers to the initial sample amount (g). The wettability time of powders was measured as the time required for 5 g boza powder to completely sink in 100 mL water. Mass per volume is referred to as loose bulk density. Tapped bulk density (ρT), is based on the principle of measuring the volume occupied by a certain amount of powder after 125 manual shaking motions [18, 22]. Measuring cylinders were used for the measurements Following the relationship between tapped bulk density (ρT) and apparent density (ρP), porosity (ε) was calculated using Eq. (2) [23]

$$\varepsilon = \frac{(\rho P - \rho T)}{\rho P}.100 \quad (2)$$

Table 2 The central composite design of the agglomeration of boza powder and obtained experimental data for the response variables

Run	X_1	X_2	X_3	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8	Y_9	Y_{10}
1	65	1	25	22.28 ± 1.42	5.42 ± 0.12	6.52 ± 0.11	0.416 ± 0.011	274 ± 11.93	58.29 ± 2.06	82.6 ± 2.63	28.67 ± 1.15	14.62 ± 0.69	5.8 ± 0.42
2	65	1	20	24.55 ± 2.09	5.43 ± 0.19	5.55 ± 0.08	0.371 ± 0.008	225 ± 13.80	53.30 ± 1.95	80.76 ± 3.72	29.67 ± 1.15	16.22 ± 0.46	6.54 ± 0.29
3	75	1.3	22.5	26.29 ± 1.55	4.52 ± 0.09	4.92 ± 0.1	0.324 ± 0.009	240 ± 11.06	54.06 ± 2.67	83.66 ± 2.77	27.67 ± 2.08	13.71 ± 0.75	6.89 ± 0.55
4	55	1.3	17.5	20.68 ± 1.67	5.82 ± 0.21	7.7 ± 0.21	0.414 ± 0.012	222 ± 14.73	55.86 ± 3.01	74.78 ± 2.64	28.67 ± 0.58	9.56 ± 0.86	6.4 ± 0.44
5	65	1	15	24.66 ± 2.19	5.26 ± 0.23	5.89 ± 0.12	0.362 ± 0.011	253 ± 11.14	52.23 ± 2.19	77.8 ± 1.85	29.67 ± 2.89	14.94 ± 0.72	5.12 ± 0.29
6	55	1.3	22.5	18.65 ± 0.98	5.68 ± 0.28	8.09 ± 0.22	0.436 ± 0.06	243 ± 15.31	55.28 ± 2.65	77.48 ± 1.67	33.00 ± 2.00	13.17 ± 0.49	4.14 ± 0.64
7	65	1	20	30.7 ± 2.46	5.53 ± 0.31	5.52 ± 0.07	0.358 ± 0.008	203 ± 17.35	51.89 ± 2.77	81.7 ± 2.93	31.67 ± 2.08	13.59 ± 0.85	5.82 ± 0.44
8	75	0.7	22.5	32.07 ± 1.53	5.04 ± 0.08	5.01 ± 0.09	0.344 ± 0.007	306 ± 12.66	65.15 ± 3.06	83.46 ± 3.01	25.67 ± 2.08	8.31 ± 0.96	3.2 ± 0.26
9	65	0.5	20	28.2 ± 1.44	5.59 ± 0.16	6.77 ± 0.12	0.402 ± 0.009	304 ± 12.06	61.35 ± 1.85	82.55 ± 2.41	27.67 ± 2.08	14.53 ± 0.67	7.34 ± 0.45
10	50	1	20	20.35 ± 1.72	6.04 ± 0.34	9.5 ± 0.28	0.486 ± 0.012	232 ± 10.02	57.82 ± 2.75	72.93 ± 2.18	39.33 ± 1.53	14.67 ± 0.64	7.36 ± 0.47
11	75	0.7	17.5	28.19 ± 1.09	5.51 ± 0.26	4.66 ± 0.2	0.316 ± 0.008	222 ± 6.66	63.01 ± 2.09	81.5 ± 2.96	27.67 ± 1.53	11.86 ± 0.91	5.04 ± 0.37
12	80	1	20	32.4 ± 1.16	4.09 ± 0.22	4.43 ± 0.14	0.304 ± 0.006	268 ± 8.74	61.35 ± 3.02	78.2 ± 1.36	35.00 ± 1.73	12.4 ± 0.42	6.48 ± 0.41
13	55	0.7	17.5	24.49 ± 2.41	5.66 ± 0.16	7.14 ± 0.23	0.387 ± 0.012	242 ± 8.89	51.89 ± 1.99	75.95 ± 1.46	34.33 ± 1.53	15.32 ± 0.83	5.92 ± 0.46
14	55	0.7	22.5	21.82 ± 1.27	5.63 ± 0.06	8.81 ± 0.33	0.436 ± 0.011	273 ± 6.81	51.26 ± 1.06	76.49 ± 3.74	40.67 ± 3.21	17.95 ± 0.79	6.4 ± 0.39
15	65	1	20	28.44 ± 1.46	5.52 ± 0.09	5.64 ± 0.24	0.326 ± 0.08	203 ± 11.15	54.83 ± 2.74	79.35 ± 2.69	28.67 ± 0.58	16.59 ± 0.7	5.04 ± 0.27
16	65	1	20	28.88 ± 1.09	5.66 ± 0.13	5.25 ± 0.12	0.354 ± 0.007	184 ± 10.26	55.34 ± 2.64	80.44 ± 1.76	27.67 ± 0.58	14.09 ± 0.59	5.52 ± 0.46
17	65	1	20	26.75 ± 1.61	5.71 ± 0.36	5.44 ± 0.14	0.329 ± 0.01	225 ± 14.57	53.30 ± 2.38	80.16 ± 1.99	26.33 ± 1.53	15.36 ± 0.95	6.75 ± 0.51
±18	65	1	20	28.31 ± 2.13	5.47 ± 0.31	4.92 ± 0.09	0.326 ± 0.006	203 ± 16.52	54.82 ± 1.76	80.55 ± 2.68	29.33 ± 1.15	15.21 ± 0.88	6.55 ± 0.55
19	75	1.3	17.5	29.23 ± 1.57	4.55 ± 0.11	4.64 ± 0.13	0.287 ± 0.007	190 ± 12.77	50.36 ± 1.16	80.82 ± 1.09	36.33 ± 1.53	13.55 ± 0.74	5.68 ± 0.29
20	65	1.5	20	25.63 ± 1.28	5.33 ± 0.27	5.19 ± 0.17	0.341 ± 0.011	212 ± 11.85	51.07 ± 1.77	80.14 ± 2.8	29.67 ± 1.15	14.26 ± 0.42	6.6 ± 0.49

X_1, Air inlet temperature (^oC); X_2, Atomization pressure (bar); X_3, Binder amount (mL); Y_1, Powder yield (%), Y_2, LAB count (log cfu/g); Y_3, Moisture content (%); Y_4, Water activity, Y_5, Particle size (D50, µm); Y_6, Porosity (%); Y_7, Solubility (%); Y_8, Wettability (s), Y_9, Flowability (θ^o); Y_{10}, General acceptability

The angle of repose (AOR) technique was used to predict the particle's flow behavior. The output of the calibrated funnel, where the powders fall on the ground, was maintained constant at 10 mm in all measurements in the heap formation system (Torontech, Ontario, Canada). The following formula was used to get the stacking angle (θ) Eq. (3)

$$\theta = \arctan \frac{h}{r} \tag{3}$$

where h is the height of powder after dropping (cm); r is the average radius of powder after dropping (cm). When the angle of repose is below 30 indicates good flowability; between 30 and 45, there is some cohesiveness; between 45 and 55, there is real cohesiveness; and above 55, there is"extremely sticky"and limited flowability [24].

The color properties (L^*, a^*, b^* values) of powders were determined using a colorimeter (Minolta Chroma Meter, CR-400, Osaka, Japan) calibrated with black and white reference plates. The total color change (ΔE) of the samples depending on the applied treatment was calculated using Eq. (4) [25].

$$\Delta E = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{0.5} \tag{4}$$

Structural characterization

To determine the surface characteristics of instant boza powders, SEM images were obtained by using the JSM-7001F Jeol (Japan) device. Before measurement, the surface of the samples was coated with palladium-gold using Quorum SC7620 (UK) [26]. The SEM microscope was operated at 10 kV and the magnifications range from 500× to 5000x.

Rheological characterization

To perform rheological analysis, instant boza powder produced under optimum conditions was reconstituted with distilled water and the dry matter content was fixed to 22.5% (initial concentration). The boza powder-water mixture was stirred in a magnetic stirrer at 400 rpm for 5 min to obtain a homogeneous mixture. The flow properties of instant boza powder were determined by measuring shear stresses against shear rates between 1–100 s^{-1}. For the interpretation of the relationship between shear rate and shear stress, the Power-Law model was selected from the firmware (Anton Paar, MCR 302, Austria).

$$\eta_{app} = K \times \gamma^{n-1} \tag{5}$$

where η_{app} is the apparent viscosity (Pa.s); K is the consistency index (Pa. s^n); $\dot{\gamma}$ is the shear rate (s^{-1}) and n is the flow behavior index (dimensionless) [27]. The viscoelastic region was determined between 0.001 and 10 Pa at a frequency of 0.1 Hz. Frequency sweep tests were then performed within the viscoelastic region in the frequency ranges of 0.1 and 100 Hz [28].

Sensorial characterization

The sensory properties were determined by modifying the sensory evaluation chart reported by Rankin [29]. Ten trained panelists (aged 20–40 years, 5 men, 5 women) comprised of students, staff, and faculty of the food science department were used to perform the sensory analysis. Samples were presented to the panelists in the form of instant powder and reconstituted drinks. Panelists were trained for each product separately, and evaluation of the product was performed on the same day as training. Fresh boza was used as a control sample. Before starting the analysis, panelists were asked to sensory evaluate the samples on an 8-point hedonic scale. On this scale, 8 was considered as "I liked it very much" and 1 as "I did not like it at all".

Optimization and validation

The experimental design was planned using a central response surface approach to find the ideal processing conditions for the agglomeration of boza powder. This design included 20 experiments, six of which were center points. Based on the results obtained, the effect of the process variables on each response was determined by analysis of variance (ANOVA) at 95% confidence level and shown in Table 3.

Mathematical models expressing the relationship between independent variables and each response were created through multiple linear regression analyses. For this purpose, linear, squared and interaction effect terms of each variable were added to the models Eq. (6), and the model fit test (lack of fit) values were analyzed.

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}X_1X_1 + b_{22}X_2X_2 + b_{33}X_3X_3 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 \tag{6}$$

Table 3 Results of analysis of variance in terms of the *p*-value for the models correlating the responses measured of agglomerated boza powder to the variables

Source	Powder yield (%)	LAB number (log cfu/g)	Moisture content (%)	Water activity	Particle size (μm)	Porosity (%)	Solubility (%)	Wettability (s)	Flowability (θo)	General acceptability
Model	< 0.0008	< 0.001	< 0.001	< 0.0001	0.009	0.001	0.002	0.003	0.004	0.2066
X_1	0.0001	< 0.001	< 0.001	< 0.0001	0.619	0.001	< 0.001	0.002	0.019	0.5143
X_2	0.0332	0.022	0.049		0.002	0.001	0.295	0.683	0.398	0.2237
X_3	0.2597	0.539	0.017	0,0085	0.014	0.006	0.003	0.643	0.612	0.5266
X_1X_2	0.6620	0.005	0.961		0.423	< 0.001	0.928	0.001	0.001	0.1412
X_1X_3	0.2832	0.509	0.185		0.184	0.176	0.645	0.001	0.017	0.1728
X_2X_3	0.2423	0.509	0.208		0.462	0.213	0.371	0.135	0.196	0.7841
X_1^2	0.2179	0.004	0.002	0,0274	0.06	0.005	0.002	< 0.001	0.023	0.7828
X_2^2	0.3879	0.563	0.064	0,0571	0.024	0.294	0.25	0.739	0.117	0.7047
X_3^2	0.0054	0.154	0.015		0.013	0.683	0.906	0.923	0.228	0.0217
Lack of fit	0.8198	0.081	0.156	0,4438	0.181	0.12	0.104	0.731	0.456	0.0408

X_1, Air inlet temperature (°C); X_2, Atomization pressure (bar); X_3, Binder amount (mL)

The regression constant numbers are given in Table 4. Optimization of instant boza production conditions according to multiple criteria was carried out by considering the desirability function. According to each response, targets were preferred as minimum and maximum. LAB number, particle size, solubility, and porosity were chosen as maximum, moisture content, while wettability time and angle of repose values were chosen as minimum. The estimated values obtained under optimum conditions and the experimental results are given in Table 5. To conclude the adequacy of the response surface model used to predict responses as a function of independent variables, the deviation was calculated using Eq. (7) given below [30].

$$D = \frac{X_1 - X_2}{X_1} \tag{7}$$

where D represents the deviation from the mean, X_1 and X_2 indicate estimated and experimental values, respectively.

Results and discussion

Effect of process conditions on powder yield

The experimental design planned using the central response surface method and the average results obtained are given in Table 2. The obtained powders (sized with 106 and 300 μm standard sieves) were weighed and divided by the initial amount and the yield of the process was calculated. The main effects of air inlet temperature and atomization pressure from the process conditions were found to be significant (Table 3). Figure 1a shows the 3D surface graph showing the effect of air inlet temperature and atomization pressure on efficiency. Increasing the inlet temperature significantly increased the yield at both low and high atomization conditions. On the other hand, an increase in atomization pressure led to a decrease in yield. An increase in atomization pressure led to a decrease in yield. As the atomization pressure increases, the area of the wetting zone increases. The sprayed binder droplet is very small and dries out quickly. However, at low atomization pressure values, the binder droplet size is large and might not be uniformly distributed, resulting in a wide size distribution [31]. To achieve good fluidization, the drying and wetting processes must be in balance. If the drying temperature is not reached sufficiently, depending on the amount of binder and atomization pressure, wetting may become dominant and fluidization may stop during the process [14, 32]. Atalar et al. [18] sieved agglomerated gum tragacanth powders with a 125 μm sieve, and the authors achieved 45%, 54%, and 72% yield for distilled water, maltodextrin, and lactose binders, respectively. Jinapong et al. [23] found that increasing the

Table 4 Equations and regression coefficients of the best models obtained for the responses measured for agglomerated boza powder

Response	Equation[a]	R^2	R^2 adjusted	R^2 predicted	Adequate precision	CV (%)
Powder yield	$Y = 27.95k_0 + 3.69X_1 - 1.17X_2 - 0.57X_3 + 0.28X_1X_2 + 0.71X_1X_3 - 0.77X_2X_3 - 0.61X_1^2 - 0.42X_2^2 - 1.64X_3^2$	0.8941	0.7987	0.6178	11.535	6.73
LAB number	$Y = 5.55 - 0.44X_1 - 0.14X_2 - 0.03X_3 - 0.18X_1X_2 - 0.04X_1X_3 + 0.04X_2X_3 - 0.11X_1^2 - 0.03X_2^2 - 0.07X_3^2$	0.9337	0.874	0.5665	13.3837	3.17
Moisture content	$Y = 5.39 - 1.54X_1 - 0.21X_2 + 0.27X_3 + 0.01X_1X_2 - 0.18X_1X_3 - 0.17X_2X_3 + 0.54X_1^2 + 0.19X_2^2 + 0.27X_3^2$	0.9692	0.9415	0.8113	20.6284	5.84
Water activity	$Y = 0{,}3496 - 0{,}0518X1 + 0{,}0169\ X3 + 0{,}0132X_1^2 + 16.13X_3^2$	0,8745	0,841	0,8043	16,88	5,63
Particle size	$Y = 207.75 + 2.82X_1 - 22.17X_2 + 16.21X_3 + -6X_1X_2 + 10.25X_1X_3 - 5.5X_2X_3 + 11.36X_1^2 + 14.18X_2^2 + 16.13X_3^2$	0.8203	0.6586	0.0405	7.59	8.6
Porosity	$Y = 53.96 + 1.77X_1 - 2.42X_2 + 1.09X_3 - 3.97X_1X_2 + 0.88X_1X_3 + 0.2X_2X_3 + 1.72X_1^2 + 0.53X_2^2 + 0.19X_3^2$	0.9301	0.8673	0.5746	15.421	3.36
Solubility	$Y = 80.48 + 2.46X_1 - 0.35X_2 + 1.18X_3 - 0.04X_1X_2 + 0.19X_1X_3 + 0.38X_2X_3 - 1.68X_1^2 + 0.36X_2^2 - 0.04X_3^2$	0.9193	0.8467	0.497	14.04	1.44
Wettability	$Y = 29.18 - 1.74X_1 + 0.17X_2 - 0.19X_3 + 2.63X_1X_2 - 2.37X_1X_3 - 0.87X_2X_3 + 2.69X_1^2 - 0.14X_2^2 + 0.04X_3^2$	0.9171	0.8426	0.6805	13.1835	4.91
Flowability	$Y = 15.22 - 0.91X_1 - 0.29X_2 + 0.17X_3 + 2.2X_1X_2 + -1.2X_1X_3 + 0.59X_2X_3 - 0.84X_1^2 + -0.54X_2^2 + -0.41X_3^2$	0.8487	0.7126	0.2799	10.19	8.55

[a] Equation terms; X_1, Air inlet temperature (°C); X_2, Atomization pressure (bar); X_3, Binder amount (mL); CV, Co-efficient of variation

Table 5 Experimental results with estimated values obtained under optimum conditions for agglomerated boza powder

Number	Expected values										
	X_1	X_2	X_3	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Desirability
1	73.92	0.7	22.67	5.07	5.25	306	82.88	25.71	69.52	9.22	0.87
Experimental values											
1	74	0.7	22.5	5.23	4.94	292.14	87.78	28	72.74	11.18	
2	74	0.7	22.5	5.16	4.97	285.7	84.05	31	70.17	10.97	
3	74	0.7	22.5	4.92	4.96	309.91	86.99	26	69.75	12.72	
Average				5.1 ± 0.16	4.95 ± 0.02	295.91 ± 12.54	86.28 ± 1.97	28.33 ± 2.52	70.91 ± 1.29	11.62 ± 0.78	
D value				−0.0059	0.056	0.033	−0.041	−0.102	−0.02	−0.26	

X_1, Air inlet temperature (°C); X_2, Atomization pressure (bar); X_3, Binder amount (mL); Y_1, LAB count (log cfu/g); Y_2, Moisture content (%); Y_3, Particle size (D_{50}, µm); Y_4, Solubility (%);Y_5, Wettability (s), Y_6, Porosity (%); Y_7, Flowability (θ°)

maltodextrin concentration (as a binder) from 0 to 10% resulted in larger soy agglomerates. Machado et al. [33] stated that fluidizing air velocity had the greatest effect on process yield, followed by binder flow rate. Higher fluidizing air velocity increased the elutriation of fine particles, which reduced the process yield. This impact was not observed in our study as the velocity of the air was kept constant. The authors also found that the binder flow rate had the opposite effect on process yield: a higher binder flow rate increased the wetting active zone, allowing more particles to enter this area and have their surface wetted by liquid droplets.

Scale-up of the agglomeration process is often complicated because process parameters may affect more than one transformation. The numerous product changes that can take place concurrently in agglomeration processes make scale-up challenging. Using equipment characteristics to scale up agglomeration processes is known as the macro-scale technique. The macro-scale method often uses dimensionless groups like Froude number, Reynolds number, and Spray flux to calculate the ideal operating conditions over a size range of unit operations [34]. The geometric similarity between the unit operations may or may not exist. Furthermore, several other dimensioned parameters or parameter groups, such as specific energy input, tip speed, and excess fluidization velocity, are frequently employed [34]. Maintaining important product characteristics while scaling up equipment in a cost-effective and industrially efficient way is difficult. The suggested approach identifies the critical transformations based on product attributes and selects appropriate scale-up criteria.

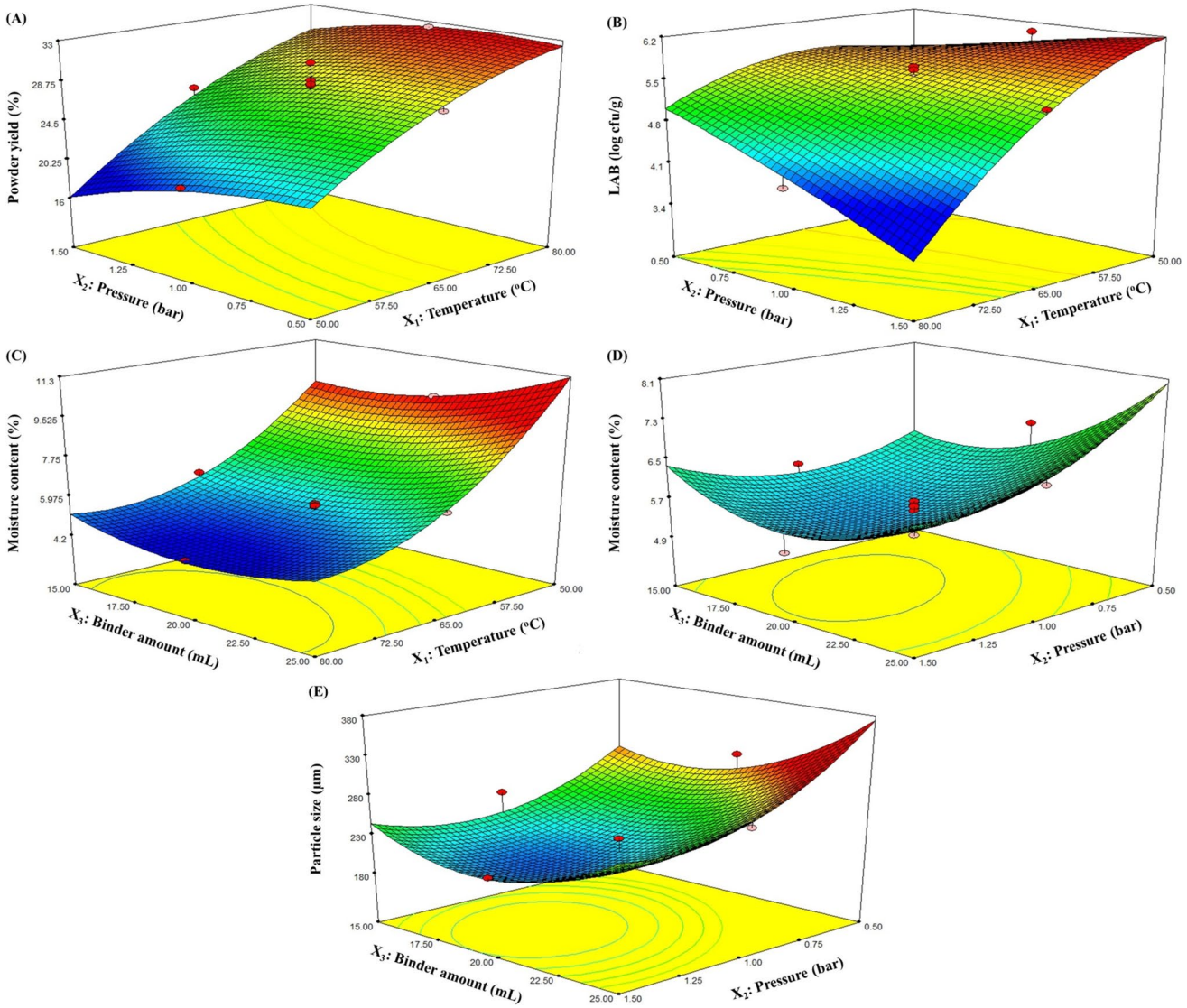

Fig. 1 **a** Effect of atomization pressure and air inlet temperature (°C) on powder yield (%) **b** Effect of atomization pressure and air inlet temperature (°C) on LAB counts (log cfu/g) **c** Effect of binder amount (mL/min) and air inlet temperature (°C) on moisture content (%) **d** Effect of binder amount (mL/min) and atomization pressure (bar) on moisture content (%) **e** Effect of binder amount (mL/min) and atomization pressure (bar) on particle size (µm)

Effect of process conditions on LAB counts

LAB counts of agglomerated boza powders were between 4.09 and 6.04 log cfu/g. Among the process conditions, air inlet temperature and atomization pressure and their interactions were found to be effective on LAB count (Table 3). Figure 1b shows the effect of temperature and atomization pressure on LAB count. As expected, an increase in air inlet temperature negatively affected viability. The maximum LAB count was determined under minimum temperature and maximum atomization pressure process conditions. The increase in the atomization pressure results in a decrease in the chamber temperature. At the lowest pressures, the binder sprays like a drip while it pulverizes at the increased atomization pressures. This caused the differences in the heating zone of the chamber. Higher atomization led to a decrease in the temperature of the chamber's heating zone, so the effect of heating on microorganisms may diminish. Schell and Beerman [35] found that the drying process was stable, and massive thermal damage to bacteria was minimized at a drying temperature of 50 °C. Lim et al. [36] found that the amount of viable *Lactobacillus rhamnosus* GG cells in fermented reconstituted skim milk decreased slightly, from 4.1×10^8 to 1.6×10^8 CFU g^{-1} at an inlet temperature of 50 °C with an airflow rate of 0.15 m^3 min^{-1} conditions. Authors attributed this loss to the stress due to

fluidized bed processing and particle entrainment. Semyonov et al. [37] dissolved *L. paracasei* in 30 g maltodextrin solution and sprayed at a low rate of 0.25 mL/min to coat the micro-crystalline cellulose and dried at two inlet temperatures: 62°and 47 °C. The authors stated that an increase in the air inlet temperature from 47 to 62 °C decreased cell survival rate over 250-fold.

Effect of process conditions on moisture content

Spraying binder during the agglomeration process can make powders sticky [12]. High moisture content may cause problems such as cake formation and stickiness during storage. Final drying without spraying is important to reduce the moisture content of the final product. In similar studies, some researchers considered 15 min to be sufficient for the final drying [23, 38], while others did not perform the drying process to prevent frictional ruptures in agglomerates [39]. For all trials in the study, a 5-min drying process was applied for the final drying process after the amount of liquid to be sprayed was spent. The moisture content of the powders obtained from the fluidized bed agglomeration process was between 4.43% and 8.81%. Among the process conditions, all independent factors were found to be effective on moisture content (Table 3). The moisture content of powders below 10% ensures stability against physical, chemical and biological deterioration during storage [40]. In all trials, the moisture content of boza powders was found to be below 10%. It was determined that a final drying process of 5 min after the treatment was sufficient to obtain the sufficient moisture content. Yuksel & Dirim [13] found that the moisture content of spinach powders agglomerated with water was between 8.97 and 9.51% and the authors stated that the moisture content increased during the agglomeration process. The effects of air inlet temperature and atomization pressure on the moisture content are shown in Fig. 1c. While high temperatures decreased the moisture content, higher binder amounts led to an increase. The highest moisture content was determined under the conditions of the lowest atomization pressure and the highest binder content level (Fig. 1d). Reducing the atomization pressure led to excessive wetting of the powders.

Effect of process conditions on particle size and porosity

The average particle size values of the powders obtained from the fluidized bed agglomeration process were determined as 184–306 µm. Among the process conditions, atomization pressure and binder amount were significant. (Table 3). The interaction of air inlet temperature and atomization pressure on the average particle size is shown in Fig. 1e. A decrease in atomization pressure caused the binder to be sprayed intensively at drip level, excessive wetting may occur and irregular agglomerates may form. A similar effect on moisture content is also supporting this finding. Chen et al. [41] determined that the particle size of cornstarch decreased with increasing atomization pressure. The formed droplets promoted the formation of liquid bridges between the particles, increasing particle size. The inlet air temperature did not affect the particle size due to the low flow rate of the air entering the equipment. As the amount of binder sprayed increased, the collision of wetted particles increased and agglomeration growth progressed. Similar findings were found in milk protein isolates, in which particle size of control samples increased from 33 to 111 µm using a sieve size fraction of 106–180 µm [42]. The spinach powder average particle size increased from 13.92 to 333 µm without sieving [13]. The airflow rate is an important parameter affecting the chamber temperature and the outlet temperature of the powder product. An increase in the airflow rate can significantly increase the chamber temperature and cause the fine particles to move away from the agglomeration zone and reach the filters. High airflow rates also caused ruptures in the agglomerates and reduced particle size. The airflow rate applied to the powders was kept constant in the range of 8–9 m^3/h, which is the minimum flow rate required for the heating function of the device to be activated, and it was determined that controlled agglomeration was achieved in preliminary trials. The porosity values of the powders were determined as 50.39–65.15%. The porosity value of spray-dried was 41.89 ± 0.49% (Table 1). All of the independent parameters were found to be significant (Table 3). As seen in Fig. 2a, the increase in atomization pressure caused the porosity value to decrease. The formation of a porous structure by the agglomeration process caused the powders to have high particle sizes. The porous structure also positively affected the improvement of instant properties, especially wettability and dispersibility. The porous structure facilitates the penetration of liquids into the particles and powders can be easily wetted and dispersed. The maximum porosity value was determined under the conditions with the lowest air inlet temperature and the highest amount of binder. Pashminehazar et al. [43] determined the average porosity of the control maltodextrin particles to be 67.6%, and this value increased to 78.9% with the agglomeration process. The authors also noted that open pores are formed during the agglomeration process according to the X-ray images.

Effect of process conditions on solubility, wettability and flowability

The solubility values of the powders were determined as 72.93–83.66%. The air inlet temperature and binder amount were found to be effective on the solubility values. While the increase in air inlet temperature up to

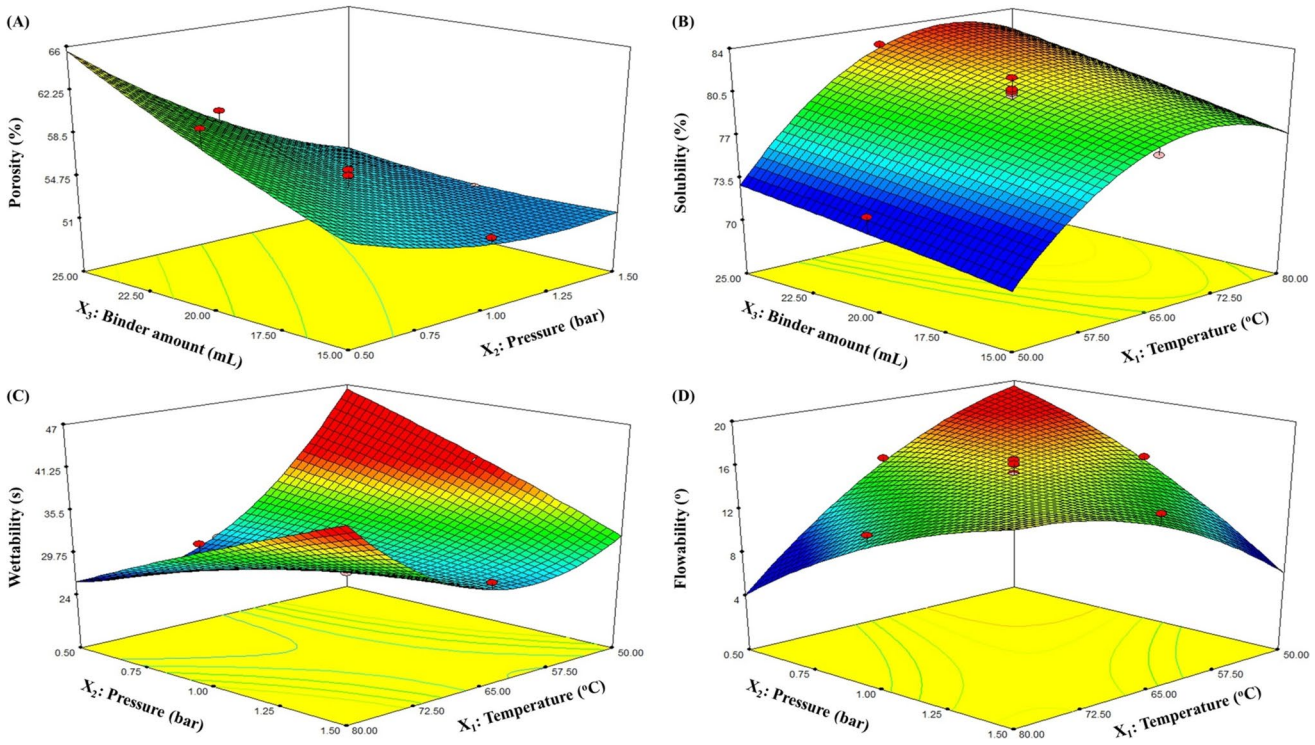

Fig. 2 **a** Effect of binder amount (mL/min) and atomization pressure (bar) on porosity (%) **b** Effect of binder amount (mL/min) and air inlet temperature (°C) on solubility (%) **c** Effect of atomization pressure and air inlet temperature (°C) on wettability time (s) **d** Effect of atomization pressure and air inlet temperature (°C) on flowability (angle of repose) (°)

70 °C positively affected the solubility values, a decrease occurred at higher temperatures. In Fig. 2b, the solubility value was found to increase with the increase in the amount of binder. At temperatures exceeding 65 °C, the solubility decreased at low and high binder amounts. Air inlet temperature and interactions with atomization pressure and binder amount were effective on wettability (Table 3). While increasing inlet air temperature at low atomization pressure increased the wettability time, the opposite situation occurred at high atomization pressure. At higher inlet air temperatures, increasing atomization pressure increased the wettability time. At low inlet air temperature, increasing atomization pressure led to a decrease in wettability time. While the wetting time of spray-dried boza powders was 335 s, the wetting time of agglomerated boza powders was determined as 26–39 s. This improvement could be attributed to the increase in particle size and porosity. The highest wettability was observed at the conditions of highest porosity and particle size observed in Fig. 2c. Similar findings were observed for spray-dried honey powder, in which the wettability time of 180 s was reduced to 15 s with the agglomeration process[12].

The small particle size creates a high contact area per unit powder mass, thus increasing the effect of Van der Waals forces. Moisture content is another important parameter affecting the fluidity of powders. Above a certain level, liquid bridges form between the particles, resulting in capillary forces at the contact points of the particles. The resulting capillary forces bind the particles and restrict their movement. The angle of repose values of Boza powders were determined between 8.31 and 17.95°. Air inlet temperature and its interactions with atomization pressure and binder amount were found to be significant (Table 3). As seen in Fig. 2d, the decrease in temperature at low atomization pressure increased the flowability and the maximum value was observed under these conditions.

Different studies in the literature have emphasized improvements in flowability. In the studies, the flowability value decreased from 49.11° to 26.02° for yoghurt powder [14], from 54° to 30° for milk-based multi-component [38] and from 68.17° to 53.89° for green banana flour [44].

Determination of optimum process conditions and validation

According to the ANOVA results, responses for which the model was not insignificant or the model's lack of fit was significant were not included in the optimization. The model significance value of the general acceptability parameter

was insignificant, and the lack of fit value was significant. Therefore, general acceptability was not included in the optimization stage. As a result of the optimization study, the regression coefficient (R^2), corrected regression coefficient (R^2_{adj}), and coefficient of variation (CV) values were used to determine the extent to which the model meets the experimental data. The value of R^2 is close to the R^2_{adj} value in the applied model, which shows that the model does not contain statistically insignificant terms. It can be said that the models formed for each response did not contain insignificant data. While the CV expressed the deviation from the mean value, high values indicate that the data deviate too much from the mean. The CV was low in the parameters included in the optimization. In the subsequent observations of the regression model, adequate precision values were used for the prediction model. The adequate precision should be greater than 4. All the adequate precision values were found to be greater than 4. The regression constants in terms of coded variables of the second-order polynomial model determined as a result of the regression analysis performed for the optimization trials are shown in Table 4. The optimum processing conditions were determined as 73.92 °C inlet temperature, 0.7 bar atomization pressure and 22.67 mL binder amount with 0.87 desirability level (Table 5).

Characterization boza powder

Microbial characterization

Freshly prepared boza sample's LAB counts are found 8.76 ± 0.13 log cfu/g which is similar to different studies 8.79 log cfu/ml [45] and 9.09 log cfu/ml [46]**.** While the count of LABs in spray-dried boza powder was determined as approximately 7.2 log cfu/g, the LAB counts decreased by approximately 2 log and it was determined as 5.1 ± 0.16 log cfu/g in agglomerated boza powder at the optimum processing conditions. Similarly, Schell & Beermann [35] reported that the viability rate of *Lactobacillus reuteri* after the granulation process (without the use of preservatives) was lower than 20% while this rate was between 16.95% and 42.85% in the case of the use of different preservatives.

Physical characterization

Under optimum processing conditions, the moisture content of boza powder was determined as 4.95 ± 0.02%. The moisture content was around 3.4% in non-agglomerated (spray-dried) powders, indicating that an increase in moisture content was observed with the agglomeration process. Similar to moisture content, the water activity of the non-agglomerated boza powder was 0.25 ± 0.001, while it was measured as 0.314 ± 0.001 after the agglomeration process. Considering that the maximum water activity required for food to be oxidative and microbiologically stable in general is 0.4, the water activity of the aglomerated boza powder is sufficient for product quality during storage.

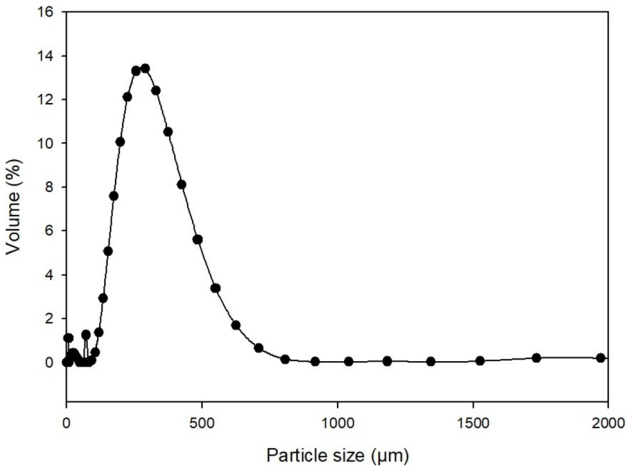

Fig. 3 Particle size distribution of instant boza powder at the optimum agglomeration conditions

The average particle size of the boza powders agglomerated using optimum processing conditions increased from 29.09 [47] ± 0.93 µm to 295.91 ± 12.54 µm and showed an unimodal distribution (Fig. 3). Non-agglomerated guar gums'average particle size was increased from 56.7 µm to 152.2 µm when 20% sucrose concentration was used as a binder in the fluid bed agglomeration process [48].

Color is one of the most important parameters that can affect the sensory acceptability of powders. The L*, a* and b* values of spray-dried boza powder were 96.99 ± 0.16, −0.68 ± 0.01 and 5.24 ± 0.19, respectively, while the color values of agglomerated boza powder obtained by agglomeration process under optimum conditions were 84.35 ± 1.11, 5.56 ± 0.38 and 21.32 ± 0.8, respectively. L* values of boza powder decreased with the agglomeration process, while a* and b* values increased (Supplementary File 2). The difference between the color values of boza powder obtained by spray drying and agglomerated boza powder was evaluated by total color difference (ΔE) and ΔE value was calculated as 21.38 ± 1.35. In the literature, it was observed that the color values of the agglomerated powders obtained in the study in which spinach powder was agglomerated changed significantly, L* value decreased and b* value increased with the agglomeration process and the total color difference was determined between 9.65 and 24.16 depending on the binders used [13].

Particle density is the measurement of the mass of particles corresponding to 1 cm^3 volume. As a result of the measurements made with gas multipycnometry, the particle density values of instant boza powders agglomerated at the optimum point were increased from 1.44 ± 0.02 g/cm^3

[10] to 1.66 ± 0.02 g/cm^3. In the study on the agglomeration of the baby food powder mixture, the particle density of the control sample was found to be 1.33 g/cm^3, which increased to 1.44 g/cm^3 with the agglomeration process [38]. The porosity value increased from 41.89 ± 0.49% [10] to 70.91 ± 1.29% by the agglomeration process. In the literature, the porosity value of yogurt powder samples increased from 51% to 80.75% with the agglomeration process [15]. In another study, where the agglomeration process was applied to baby food mix powder, porosity increased from 57.6% to 69.2% [38].

The solubility value of the instant boza powders produced at the optimum point increased from 78.83 ± 2.14% [10] to 86.28 ± 1.97%, and it was observed that the agglomeration process provided a slight improvement in the solubility value of the boza powder compared to control powder. Similarly, Yuksel & Dirim [13] reported a partial increase in solubility value with agglomeration of spray-dried spinach powders. The control boza powders had very poor wettability time and had a long wettability of 335.67 ± 11.81 s. The wettability value of agglomerated boza powder by fluidized bed agglomeration process was determined as 28.33 ± 2.52 s. Similar to our results, in a study in which fluidized bed agglomeration of milk protein isolate was performed, a period of 5 min was required for the dissolution of the protein isolate, while this time was determined as 40 s with the agglomeration process [33].

The AOR value (θ) of the agglomerated boza powder produced at the optimum point was determined as 11.62 ± 0.78°, which was 36.44 ± 1.47° for the control powder. [10]. Very good flowability classification of instant boza powders produced at the optimum point was supported by AOR values. In the study investigating the agglomeration of multicomponent food powders, the angle of repose values of three different powder formulations before agglomeration were 51.5°, 52°, and 52.1°, while they decreased to 26.9°, 48.3°, and 32.7° with agglomeration depending on the powder formulations [49]. The bulk density value for agglomerated boza powders produced at the optimum point was determined as 0.28 ± 0.02 g/cm^3, while the tapped bulk density value was determined as 0.54 ± 0.02 g/cm^3. The agglomeration process caused a decrease in the density values of instant boza powder compared to the control sample. Similar results were also observed in the agglomeration of guar and locust bean gums with maltodextrin binder. The authors determined that the decrease in bulk and tapped density values became sharper compared to the control gums as the concentration of binder solution increased [50].

Sensorial characterization

Sensory evaluation of the boza powder agglomerated under optimum processing conditions was carried out both as powder and reconstituted. In terms of powder characteristics, the powder showed a homogeneous distribution, no clumping or caking observed, and it had highly acceptable scores (> 7) (Supplementary File 1). In the reconstituted product, the level of appreciation in terms of physical appearance was slightly lower (> 6) compared to the powdered product, which was found to be due to the presence of partially separated particles in the product. In terms of aroma, it was found that the reconstituted ready-to-drink boza had

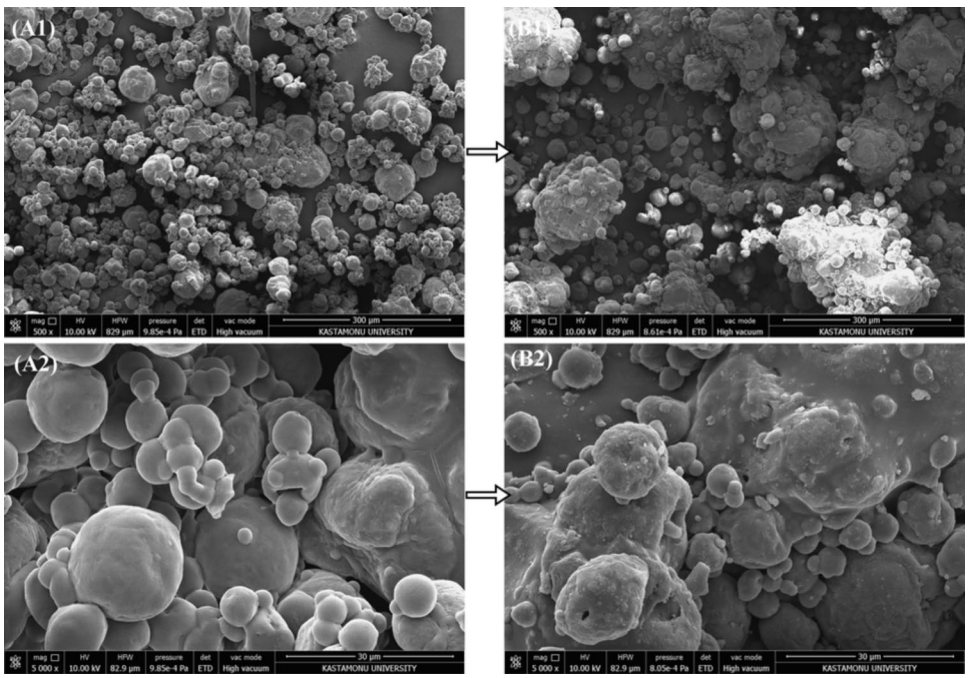

Fig. 4 SEM microphotographs of spray dried (control) and instant boza powders at optimum agglomeration conditions. (A1) and (A2): spray-dried boza powder with the magnifications of 500 and 5000x, respectively; (B1) and (B2): Instant boza powder with the magnifications of 500 and 5000x

a pleasant fruity aroma, but the acidic characteristic was reduced compared to fresh boza. Considering the general appreciation score (> 6.5), it can be said that instant boza powder is an acceptable product and could be consumed with pleasure by consumers.

Structural characterization

SEM images of non-agglomerated and agglomerated boza powders at 500 and 5000 × magnification are given in Fig. 4. Non-agglomerated boza powders (Fig. 4a) consist of small particles, and there are no bridging forces between particles, whereas in agglomerated boza powders (Fig. 4b), bridges were formed between the particles, resulting in significant increases in the particle size. On the other hand, pores and voids were formed in larger particles. The smooth surface of the spray-dried particles is disrupted by the agglomeration process. Various studies have shown that this porous structure formed by the agglomeration process is essential for a good reconstitution of powder products [15, 33].

Rheological characterization

Rheological properties of the agglomerated boza powder were measured after reconstitution (dry matter content was set to 22.5%), and the results are given in Fig. 5. The viscosity value of the reconstituted boza showed a decreasing trend with increasing shear rate and exhibited shear thinning behavior. Similar flow behavior was also observed for boza beverages fermented with *Lactobacillus casei Shiorata* [46]. Shear thinning behavior is commonly observed in starch pastes and starch-rich food matrices [51]. The Power law model was applied to the shear stress-shear rate graph and the R^2 value was found to be 0.999. The flow index value was determined as 0.65, which was below 1, indicating that the sample exhibited pseudoplastic flow characteristics. This result is similar to findings of boza produced with *Lactobacillus casei Shiorata* [52].

The consistency index value of the agglomerated boza powder was determined as 0.64 Pa.s^n. The reconstituted boza beverages showed lower consistency index value than boza samples produced with maize, whole wheat and rice flours in ratio of 2:1:1 [46] and commercial boza samples purchased from local markets in different regions of Turkey [53]. Since starting cultures can alter the composition of boza, the variations in consistency coefficient and apparent viscosity seen in various studies may have been due to these variations.

The frequency-dependent graph of the values of the storage (G′) and loss (G″) modulus is shown in Fig. 5. The increase in the modulus values depending on the increase in frequency showed that the viscoelastic properties were frequency-dependent. The loss modulus (G″) was lower than the storage modulus (G′) at all applied angular frequencies

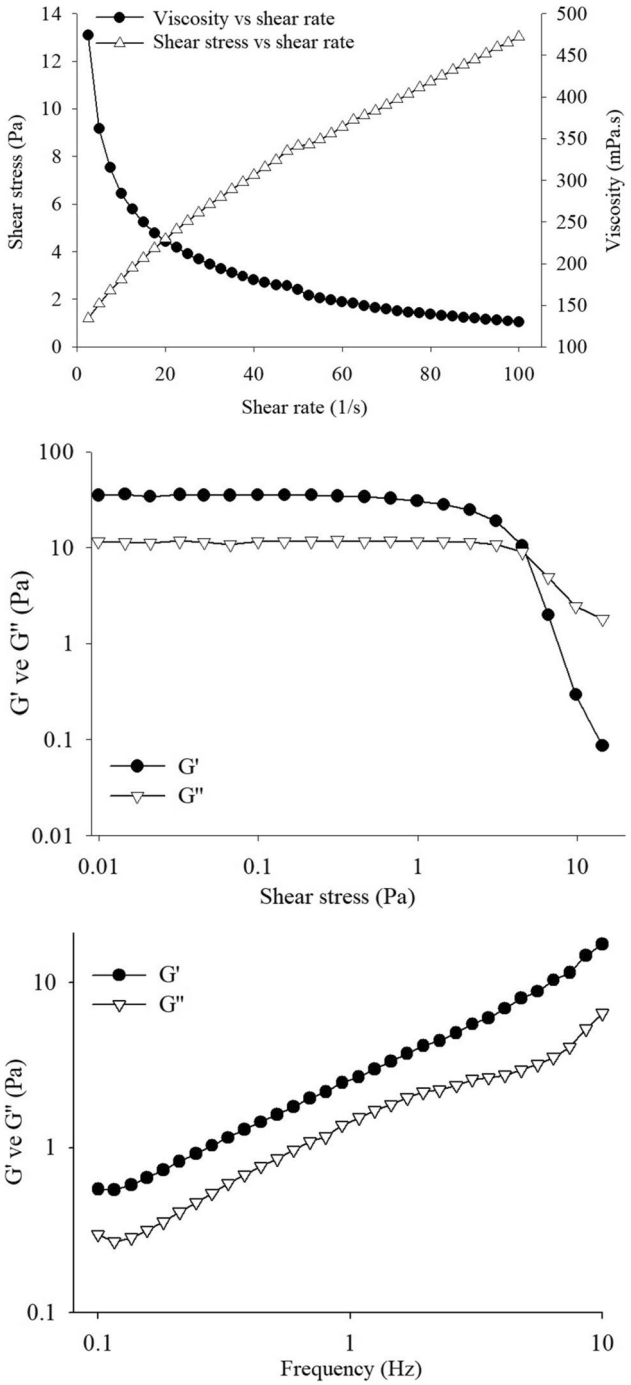

Fig. 5 Rheological parameters of reconstituted boza powders **a** Shear stress vs. shear rate **b** Plots of storage (G′, filled symbols) and loss (G″, open symbols) modulus as a function of shear stress **c** Plots of storage (G′, filled symbols) and loss (G″, open symbols) modulus as a function of frequency

(ω). This is attributed to the elastic properties of the reconstituted boza beverage. The elastic properties of boza result from the starch content. Boza samples were able to maintain their fluidity at increasing shear rates. Maintaining

consistency is an important parameter in dissolution processes. Therefore, the high stability of boza samples against mixing is an important feature. The dynamic rheological properties of Guar gum particles were found to have been greatly affected by the agglomeration process and sucrose binder concentration [48]. In another study, the G' and G"values of the guar gum powders prepared with maltodextrin binder were relatively higher than those of the control. The authors stated that better intermolecular interaction between the gum particles was observed in the presence of maltodextrin binder [50].

Conclusion

There are many parameters affecting the kinetics of agglomeration development in spray agglomeration systems. Optimizing these conditions according to the powder characteristics is important for the success of the process. Unless these conditions are properly adjusted, fine particles can reach the filters with excessive drying, and if they remain too humid, they stick in the heat transfer area and cannot show fluidity. The use of response surface methodology was effective for the experimental optimization of multiple responses for boza powder with the desirability of 0.87 and the optimum process variables were determined. With the increase in particle size, the density values of boza powder decreased and the instant properties of boza powder were modified as a reduction in wetting time nearly 10 times. The reconstituted boza samples showed shear thinning behavior and the loss modulus (G″) was lower than the storage modulus (G′), which means that the elastic character was dominant at the original dry matter content (22.5%). The agglomerated boza powder beverage was found acceptable, indicating that consumers can consume it with pleasure. Food manufacturers and consumers desire the powder to dissolve or disperse quickly in water without clumping. Additionally, manufacturers need dust-free powders that flow freely.In conclusion, agglomeration technology has a strong potential to solve the dilution problems of boza powder and enable the production of boza products that can be consumed at all times of the year. Studies with the effect of different binder solutions on the boza powder characteristics and LAB survivability should also be conducted in the future.

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Authors contribution Osman Gül: Conceptualization, Methodology, Validation, Formal analysis, Writing – original draft, Visualization. İlyas Atalar: Methodology, Validation, Writing – original draft. Aysegül Besir Özgeçen: Formal analysis. Latife Betül Gül: Formal analysis. Fatih Törnük: Conceptualization, Formal analysis, Writing – original draft. Durmuş Sert: Formal analysis. Fehmi Yazıcı Supervision.

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Data availability Data will be made available on request.

Declarations

Competing interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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