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Sugarcane Powder Biofortified with Kefir Grains: Effect of Spray Drying Process

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Abstract

The Spray Drying process of sugarcane concentrate fermented with Kefir Grains was evaluated using Response Surface Methodology based on the following independent variables: Air Inlet Temperature (AIT) (120-140ºC), Air Outlet Temperature (AOT) (65-75°C), and Atomizing Disk Speed (ADS) (20000-25000 rpm). Results were analyzed using the Design Expert 8.0.5.2 software, and the following conditions were found to be optimal: AIT 125ºC, AOT 65ºC, and ADS 25000 rpm. Likewise, optimal values for dependent variables were: moisture = 3.4±0.6%, a_w = 0.210±0.030, solubility = 97.54±0.01%, fractal dimension = 2.64±0.04, particle sizes ($D_{(3,2)}$ = 14.78 µm and $D_{(4,3)}$ = 35.9 µm), yield = 81.5±8.3%, and lactobacilli, lactococci and yeast survival = 85.4, 67.1 and 74.9%, respectively. Results showed that, at optimal conditions for spray drying, the process has a good yield and produces a stable powder food with good levels of microorganisms from KG. It is also very soluble in aqueous phases, which facilitates its use as a reconstituted beverage or as an ingredient in several industries.

Keywords: *Saccharum officinarum* L.; probiotics; lactobacilli, lactococci

1 Introduction

Sugarcane (*Saccharum officinarum* L.) is a crop of global importance, with 1,877,105,111.9 tons produced in 2013 [11]. Furthermore, jaggery production, one of the most traditional rural agroindustries in Latin America and the Caribbean, is derived from this crop. This agroindustry has a low technological level, mainly due to the technology transfer low rate. As a result, activities are required to transform and add value to raw materials derived from it in order to maintain or increase the participation of agroindustry in markets and to render it more dynamic, sustainable and profitable.
Some research has increased the sugarcane production chain value with contributions such as the use of bagasse as heavy metal adsorbent [24], and the production of xylose, arabinose, and glucose from acid hydrolysis. Furthermore, phenols, flavonoids, triterpenes, and phytosterols with antioxidative activity obtained from various parts of the sugarcane stem have been detected. Kefir grains (KG) and foods obtained from them are considered probiotics because the microorganisms isolated from these grains have shown probiotic activity [9]. KG have been used in some studies to develop dairy foods such as fermented beverages based on whey and milk [31], hard and matured cheeses [21], and other non-dairy foods such as fermented nut milk beverages [8], fermented bread dough [22], and vegetable juices [7].

Spray drying (SD) is a technology used to dehydrate food, since it causes rapid evaporation of water, keeps droplets at a low temperature, and requires a very short drying time. This in turn reduces thermal damage and nutrient loss, and results in good quality and stable products with low storage and transportation costs. Thus, it has been used for passion fruit dehydration [4], orange juice concentrates [15], as well as other vegetable products [25]. SD is a technically more critical process for dehydrating sugar-rich foods given their low melting and glass transition temperatures (Tg). This makes possible to use additives for increasing those temperatures and minimizing molecular mobility. Hence, maltodextrin (MD) and gum arabic, among others, have been used to increase these temperatures and minimize molecular mobility, obtaining more stable products [19]. SD has also been used to encapsulate probiotic microorganisms. In this process, the variable AOT plays a vital role in microorganism survival; the aim is to find the lowest AOT possible that enables appropriate product drying and minimal thermal damage to microorganisms. In addition, some studies on SD have been conducted with microorganisms isolated from KG such as *Lactobacillus plantarum, Lb. kefir, Saccharomyces lipolytica* [14].
Similarly, other studies have used microorganisms from other sources, namely: *Lb. acidophilus, Lb. casei, Lb. paracasei, Lb. rhamnosus, Bifidobacterium bifidum, B. animalis,* subsp. *lactis, Propionibacterium jensenii* [27]. Only one study was found in our literature review; and it used whole KG [3]. In spite of this,

no research has been conducted on the effect of SD on a food matrix different from milk previously fermented with KG.
This research aimed to optimize spray drying operating conditions of sugarcane concentrate previously fermented with KG.

2 Materials and Methods

*2.1. Materials***.** KG for this study was obtained from home consumers; the sugarcane concentrate (69.9 °Brix) was supplied by a producer from the municipality of Girardota, Antioquia, Colombia; the drying additive was MD with dextrose equivalent 18-20 (Shandong Boalingbao Biotechnology Co Ltd).

2.2. Spray Drying. KG were added at 6% w/w to sugarcane concentrate at 30° Brix, the mixture was fermented for 30 hours at 33.5°C, this liquid [30] was mixed with MD at 20% w/w, a composition that had been determined during SD optimization phase of the base sugarcane powder [20]. The final composition of dry solids was adjusted to approximately 50% w/w using sugar cane concentrate at 69.9 °Brix. This was the final dispersion to be supplied to the SD. Moreover, it was homogenized using a UTL 50 Ultraturrax IKA, for 4 minutes at 10000 rpm and filtered through a 500 µm mesh. SD process was carried out in a pilot machine with atomizer disk (Vibrasec S.A., PSALAB 1.5) with air flow in co-current mode (160 m^3/h). SD process was optimized using the response surface methodology, based on the "*Optimal*" experiment design (20 experiments, 3 samples/experiment) and considering three independent variables: AIT (120–140°C) (factor A), AOT (65–75°C) (factor B), and ADS (20000-25000 rpm) (factor C). The dependent variables in the sugarcane powder+KG (SCP+KG) were: moisture (X_w), water activity (a_w), solubility (S), fractal dimension (FD), mean diameter of the equivalent surface $D_{(3,2)}$, mean diameter of the equivalent volume $D_{(4,3)}$, yield (Y), and survival for lactobacilli, lactococci and yeasts in SCP+KG. Results were analyzed with Design Expert software, version 8.0.5.2 (Stat-Ease, Inc. EEUU) (ANOVA with 5% of significance).

2.3. Physical and physicochemical properties. X_w was determined gravimetrically by heating the sample in an oven at 105°C until reaching a constant weight, water activity (a_w) was measured with a dewpoint hygrometer at 25ºC [2], solubility (S) was determined according to Cano-Chauca et al. (2005) [6], and $D_{(3,2)}$ and $D_{(4,3)}$ were obtained with a Mastersizer 2000 meter (Malvern Instruments).

2.4. Microstructure analysis. FD for texture was obtained by sliding box method and was determined from the changes in the surface microstructure of the samples, particularly in roughness. The analysis was conducted on images at 2000X obtained with a scanning electron microscope (JEOL JSM 5800 LV), and five crops were selected, duplicated and converted to grayscale (8 bits) in order analyze them with the ImageJ 1.34s software. Furthermore, in order to observe the microstructure in the samples, a Carl Zeiss confocal laser scanning microscope was used to obtain images. The samples were excited at 450 nm and their autofluorescence was observed at 40X. Similarly, z-stacks were obtained from the samples, performing a cut every 1.7 µm.

2.5. Microbiological counts and survival rate. The counts of viable microorganisms were done through the serial dilutions and surface depletion method in selective MRS media for lactobacilli, M17 for lactococci—both incubated under anaerobiosis at 37°C/3 days — and YGC for yeasts. The latter were incubated at 32°C/24 for 48 hours. Results were recorded as Log CFU/g and survival % = log (N/No)*100, where No and N are the number of microorganisms before and after drying, respectively.

2.6. Yield. The Y was determined as the ratio between kg total solids obtained in the cyclone and kg solids fed to the SD.

3 Results and Discussion

Table 1 presents mean values plus standard deviation for physicochemical and physical parameters of sugarcane concentrate and fluid fed to SD. It is noteworthy that the feed to the spray dryer used in this study showed a viscosity within the design criteria (<1000 cP) and total solids content by approximately 50%. There are few reports of the use of sugarcane concentrate in SD processes: Largo et al, (2015) [18] used a pilot SD (Vibrasec, PASLAB 1.5) with sugarcane concentrate at 48 °Brix, viscosity = 6,290±0.010 cP, a_w = 0.962±0.002, Xw = 41% and pH = 5.71±0.01, obtaining a powder whose variables Xw, Y, deposit formation, S and hygroscopicity were affected by the process. On the other hand, Guzmán and Castaño (2002) [16], used an SD Buchi B-191 with a feeding of sugarcane concentrate between 40-50 °Brix, obtaining yields between 38 and 60%. The cane concentrate had a high content of total solids (70.6%), which corresponds mainly to sucrose with a degree of caramelization due to the high temperatures and long processing times to obtain it. This high content of solids confers a better conservation due to the decrease of a_w.

Table 1. Physicochemical and physical features of sugarcane concentrate and fluid fed to SD

Parameter	Sugarcane concentrate	Fluid fed to SD
X_w (%)	29.4±0.4	49.2±1.0
a_w	0.846±0.001	----------
°Brix	69.9±3.0	50.5±1.5
pH	5.3±0.1	----------
Acidity (meq acid/g)	0.062±0.004	0.117±0.010
Viscosity (cP)	370.7±16.9	879.0±4.0
Log Lactobacillus (CFU g^{-1})	----------	7.7±0.2
Log Yeast (CFU g^{-1})	----------	6.8±0.62
Log Lactococcus (CFU g^{-1})	----------	7.8±0.0

Table 2 shows the results of the experiment design for SD process; table 3 shows ANOVA results for the same process. Figure 1 shows response surface plots (3D) for Xw, a_w, S, $D_{(4,3)}$, lactobacilli and yeasts survival, Y and FD as a function of the studied factors.

3.1. Moisture and water activity. ANOVA showed statistically significant differences ($p<0.05$) for X_w and a_w in factor B. It can be observed that both variables had a similar behavior, as they reached their lowest values with the maximum AOT at high ADS. This could be attributed to a bigger surface area of the particles and a more efficient drying process. In general, the values obtained for these variables were low, a_w: 0.156- 0.307 and X_w: 0.52-3.62 %; this could favor product stability during storage. For instance, it could result in less interparticle bridges and thus low cohesion [18]. Conversely, higher values for these variables could affect powder flowability and result in caking problems.
Such situations are attributable to X_w and a_w in the powder and could be associated with MD addition to the mixture fed to the SD, which increases total solids and decreases the amount of free water in dispersion, thus improving SD energy consumption and efficiency. Similarly, a high ADS results in smaller particle diameters and a > surface area in droplets, thus favoring heat and mass transfer, and achieving a higher dehydration degree. Kingwatee et al. 2014 [12] obtained values of 0.3 and 3.44% for a_w and $X_{w,}$ respectively, when spray drying lychee juice with *Lactobacillus casei*, and MD at 20% (w/w) at an AOT of 60°C.

3.2. Solubility. ANOVA showed significant differences ($p < 0.05$) for S with respect to the quadratic interaction of factor B. The response surface plots show that S reaches its highest values with an AOT of 71°C and ADS of 22500 rpm across the entire AIT range.

Table 2. Results of the experiment design for SD

Test	Factor A AIT (°C)	Factor B AOT (°C)	Factor C ADS (rpm)	a_w	X_w (%)	Y (%)	FD	$D_{(3,2)}$ µm	$D_{(4,3)}$ µm	S %	Lactob SV (%)	Lactc SV (%)	Yeast SV (%)
1	120.0	65.0	25000	0.186	1.9	80.9	2.579	13.5	32.4	97.2	90.0	73.5	74.9
2	130.0	65.0	22500	0.271	3.6	82.5	2.477	15.1	33.0	97.6	84.2	79.5	83.8
3	130.0	75.0	20000	0.200	1.9	82.8	2.479	18.1	47.6	95.2	77.2	76.4	74.9
4	120.0	71.7	20000	0.204	2.2	88.6	2.466	15.4	41.2	97.3	76.1	81.1	72.0
5	130.0	65.0	22500	0.200	2.2	78.8	2.562	15.1	54.2	96.6	81.6	66.1	74.9
6	120.0	75.0	25000	0.197	1.7	82.4	2.465	14.8	45.3	95.0	73.9	67.4	76.4
7	130.0	70.0	25000	0.184	3.2	80.2	2.510	14.4	30.7	97.0	90.5	70.3	82.3
8	135.0	70.0	21250	0.237	2.9	76.5	2.498	15.7	52.3	98.2	81.6	81.7	88.2
9	135.0	70.0	21250	0.243	3.1	81.4	2.542	15.1	32.5	97.4	82.2	71.7	73.5
10	120.0	70.0	22500	0.230	2.5	85.9	2.501	18.3	34.9	97.3	79.7	68.3	73.5
11	130.0	65.0	22500	0.182	2.2	76.7	2.523	18.3	57.0	95.5	88.7	77.6	85.2
12	140.0	65.0	25000	0.250	3.2	73.6	2.570	20.3	80.5	96.2	85.3	85.3	85.2
13	140.0	75.0	22500	0.158	0.7	81.3	2.579	14.3	36.8	96.0	83.6	68.3	77.9

Table 2. (Continued): Results of the experiment design for SD

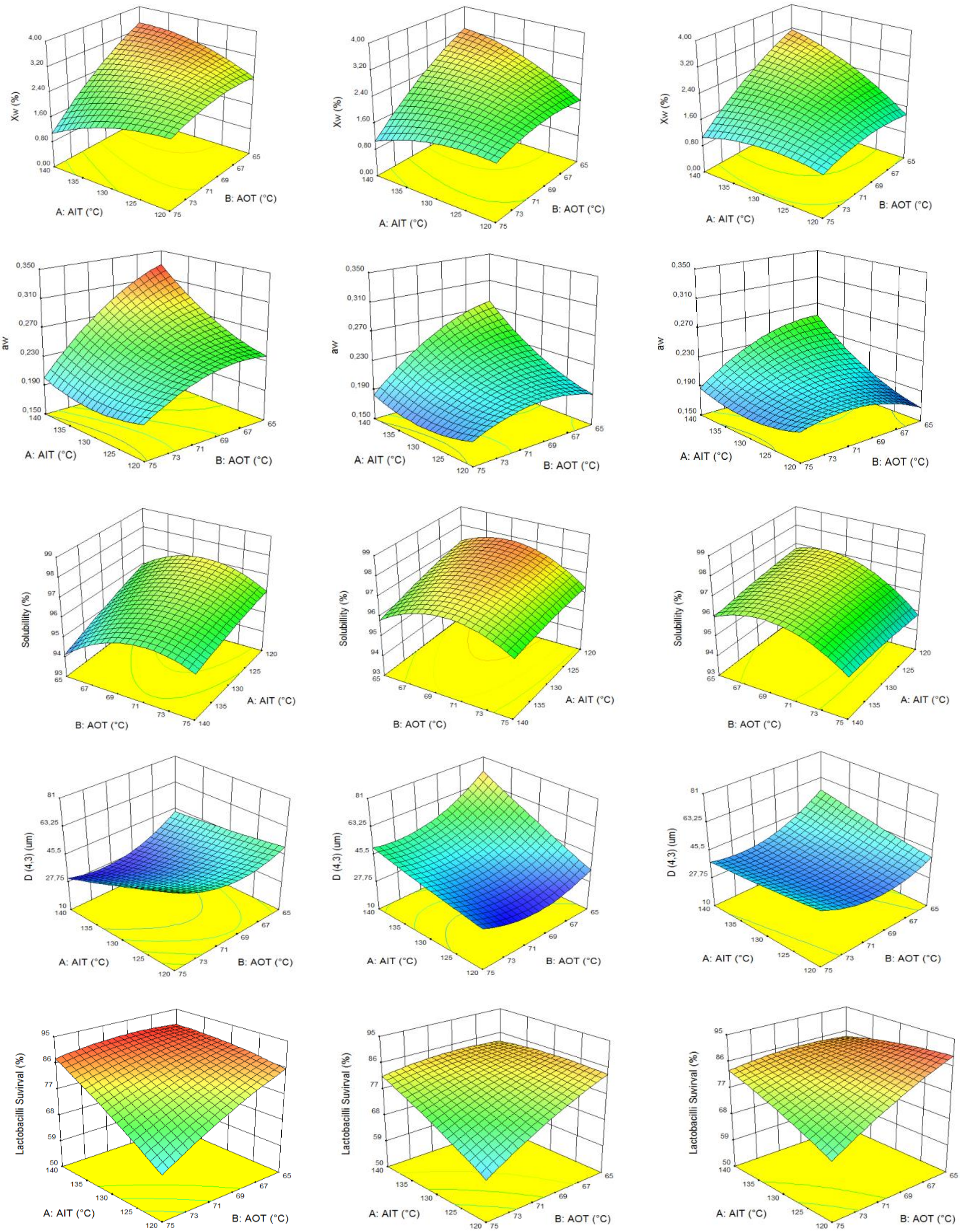
14	120.0	65.0	20000	0.242	2.7	85.0	2.528	18.5	58.2	96.3	84.4	72.7	77.9
15	120.0	70.0	25000	0.164	0.5	85.9	2.486	14.5	33.6	96.9	76.8	78.1	74.9
16	140.0	65.0	20000	0.307	3.4	17.1	2.558	19.7	35.4	93.8	89.2	79.9	89.6
17	130.0	70.0	25000	0.156	1.3	86.3	2.548	13.9	34.5	96.6	78.4	66.5	67.6
18	135.0	70.0	21250	0.265	2.5	58.4	2.565	19.5	36.8	96.9	87.9	66.3	80.8
19	140.0	71.7	25000	0.249	2.1	87.9	2.539	15.2	47.1	96.3	83.1	76.9	76.4
20	120.0	75.0	22500	0.187	1.7	86.5	2.544	18.1	37.8	96.9	58.1	42.5	48.5

SV: Survival

Table 3. ANOVA with significance test for this model, independent variables with dependent variables and their linear and quadratic interactions. Lack-of-fit test and correlation coefficient**.**

Factor	a_w	X_w (%)	Solubility (%)	$D_{(3,2)}$	D(4,3)	Lactobacil SV (%)	Lactococ SV (%)	Yeast SV (%)	Y (%)	FD
Model	0.1387	0.2419	0.1746	0.2748	0.2587	0.0227*	0.3533	0.2588	0.0012**	0.3004
A	0.0712	0.4618	0.1449	0.5462	0.5777	0.0156*	0.1727	0.0404*	0.0006**	0.0161*
B	0.0439*	0.0294*	0.4959	0.2678	0.3500	0.0057*	0.0809	0.0636	0.0082**	0.6924
C	0.0948	0.2483	0.6067	0.0766	0.7297	0.8920	0.3639	0.5500	0.0035**	0.6445
AB	0.1530	0.1212	0.4699	0.0582	0.2725	0.0293*	0.8043	0.6553	0.0289*	0.9966
AC	0.9266	0.4532	0.3950	0.4254	0.0312*	0.2534	0.8962	0.3823	0.0011**	0.4879
BC	0.3350	0.8527	0.1807	0.6814	0.7096	0.9392	0.4039	0.6576	0.3329	0.5368
A^2	0.5245	0.5614	0.8626	0.3489	0.9207	0.7317	0.7696	0.8165	0.1199	0.4441
B^2	0.3438	0.5907	0.0361*	0.6987	0.1394	0.5481	0.4805	0.8115	0.9738	0.8360
C^2	0.5607	0.9693	0.1101	0.7658	0.7647	0.1773	0.0935	0.3254	0.1478	0.2334
lack-of-fit	0.7755	0.6680	0.5567	0.4490	0.4280	0.5709	0.2083	0.4093	0.6781	0.6142
R^2	0.6490	0.5876	0.6255	0.5710	0.5790	0.7779	0.5344	0.5790	0.8860	0.5587

SV: Survival, *p< 0.05, ** p<0.01, Factor A: AIT, Factor B: AOT, Factor C: ADS.


Xw (%)
A: AIT (°C)
B: AOT (°C)
Xw (%)
A: AIT (°C)
B: AOT (°C)
Xw (%)
A: AIT (°C)
B: AOT (°C)
aw
A: AIT (°C)
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A: AIT (°C)
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Solubility (%)
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Solubility (%)
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Solubility (%)
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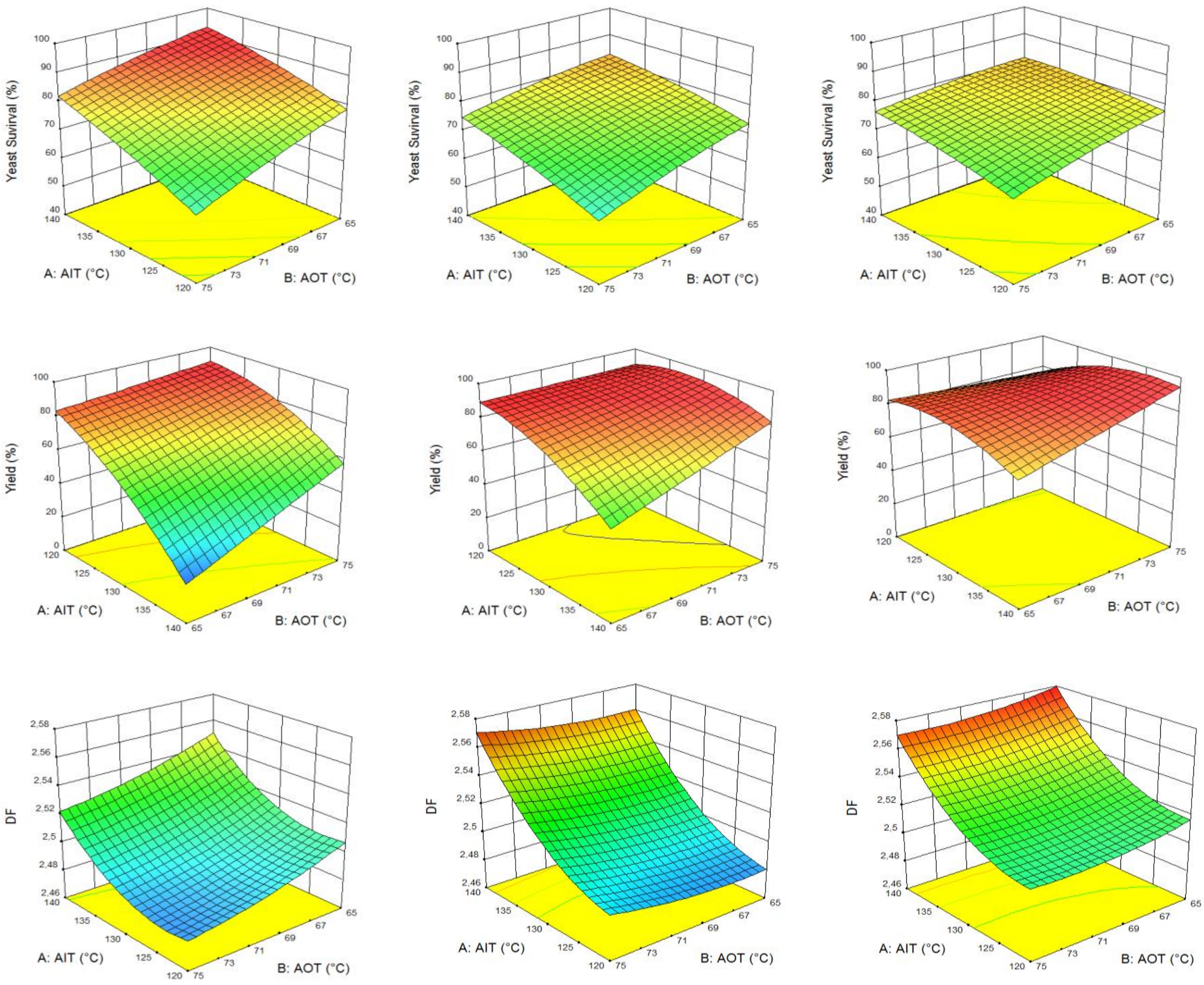
A: AIT (°C)
D (4,3) (um)
A: AIT (°C)
B: AOT (°C)
D (4,3) (um)
A: AIT (°C)
B: AOT (°C)
D (4,3) (um)
A: AIT (°C)
B: AOT (°C)
Lactobacilli Suvirval (%)
A: AIT (°C)
B: AOT (°C)
Lactobacilli Suvirval (%)
A: AIT (°C)
B: AOT (°C)
Lactobacilli Suvirval (%)
A: AIT (°C)
B: AOT (°C)



(a) 20000 rpm **(b) 22500 rpm** **(c) 25000 rpm**

Figure 1. Response surface plots (3D) for Xw, a_w, S, $D_{(4,3)}$, lactobacilli and yeasts survival, Y and FD as function of the studied factors.

S was in a range from 94.97 to 98.25% indicating that SCP+KG has good reconstitution capabilities due to its high sucrose content, which has multiple hydroxyl groups that form hydrogen bonds with water, favoring its high solubility. Moreover, the MD used as drying additive was obtained from corn starch hydrolysis and has high solubility.

3.3. Particles Size. ANOVA showed significant differences ($p<0.05$) for $D_{(4,3)}$ with AC interaction and $D_{(3,2)}$ with respect to ADS and AB interaction. $D_{(3,2)}$ decreased when AIT, AOT and ADS values were high. The response surface plots show that $D_{(4,3)}$ tends to have low values across nearly the entire AOT range when

ADS is high and AIT is low. The ranges of diameters obtained were: $D_{(3,2)}$ = 0.31–0.33µm and $D_{(4,3)}$ = 0.48-0.54 µm. Some researchers have reported < particle size when encapsulating Chia seed oil with sodium caseinate and lactose in a homogenized emulsion at a pressure of 400 bar using a laboratory-scale SD with an AIT of 135°C, an AOT of 70°C, and a nozzle with a 0.5 mm diameter [17].

3.4. Lactobacilli, lactococci and yeasts survival. The counts obtained from the fluid fed to SD, measured in Log units were 7.67±0.18, 7.76±0.02 and 6.8±0.62 CFU/g for lactobacilli, lactococci and yeasts, respectively. ANOVA showed significant differences ($p<0.05$) in lactobacilli survival with AB interaction. Yeasts survival showed significant differences ($p<0.05$) with respect to factor A, whereas lactococci survival showed no statistically significant differences. The response surface plots show that Lactobacilli survival increases as AIT increases and AOT decreases. This situation produces a negative interaction between these two factors (AB) and is strengthened mainly by the following conditions; AIT: 130ºC, AOT: 70ºC, and ADS: 25000 rpm. This produces a survival of 90.5%. The maximum survival percentage for yeasts was reached with high AIT and low AOT and ADS. According to the results, SD appears as an effective process that makes possible to have moderate AIT and AOT, which in turn favors survival. During SD process, the droplets reach a wet-bulb temperature in drying chamber and evaporation progresses as, temperature increases, having a more direct influence on the damage taken by microorganism membranes, causing porosity and allowing intracellular substances to escape, which ultimately results in microorganism death.

An important effect of AOT and AIT on microorganism survival was observed in this study. Thermal damage to microorganisms during SD occurs mainly in surface proteins, cell membranes, and cell walls [23]. Some researchers have reported that AOT has a > impact than AIT, operating these variables between (50-90°C) and (150-170°C) respectively. An optimal AOT should be kept as low as possible while making sure that the levels of moisture in the product are also minimal. Lactobacilli survival in SD varies widely. There are survival rate reports of less than 10% for *Lb. bulgaricus* in yoghurt, *Lb. paracasei* in skimmed milk reconstituted at 20% w/v, *Lb. acidophillus* in fermented soy milk and *Lb. kefir* in reconstituted skimmed milk powder [34, 14]. There are also survival rate reports above 80% for *Lb. plantaru*m in skimmed milk at 10% (w/v), *Lb. salivarius* in MD (10% w/w), *Lb. paracasei* in reconstituted skimmed milk (20% w/v), and *Lb. salivarius* in skimmed milk (11% w/v) [28] at different AIT and AOT.

Lactococci and yeasts had a more favorable survival at the same AIT and AOT (140 and 65°C respectively), although ADS was always different. For lactococci, the survival was 85.3% at 25000 rpm, which is much higher than the one obtained by To and Etzel (1997) [33] with *Lactococcus cremoris* (2.95%) in MD at 30% w/w with lactose and an AOT of 65ºC. It is also higher than the value obtained by Ghandi et al. (2013) [12] with *Lactococcus lactis* (29.2%) in Ba mixture of lactose and milk protein isolate (3:1) in laboratory SD with an ADS of 18.2 x 10^3 s^{-1}. Likewise, in this study yeasts reached 89.6% at ADS of 20000 rpm, which is higher

than the value obtained by Golowczyc et al. (2010) [13] with *Sacharomyces lypolitica* (0.52%) in skimmed milk reconstituted at 11% w/w.
Survival rates studied in this research are among the highest of those reported so far for SD processes. These results are due to a good selection of operating conditions and the role of added MD. It is also likely that kefirano along with proteins in the KG helped to increase the three groups of microorganism protection under optimal SD conditions.

3.5. Yield. ANOVA showed statistically significant differences ($p<0.05$) for Y for interactions AB and AC. The response surface plots show that Y decreases at low ADS (< 22500 rpm) and high AIT. Similarly, this decrease is > when the process is performed at low AOT. In contrast, Y is positively affected when SD operates under the following conditions: ADS beyond 25000 rpm, AIT between 130 and 140°C, and AOT between 70-75°C. This could be due to the high ADS allowing smaller particles formation with a larger total surface area, thus rendering water evaporation more effective and causing the product to become drier; however, a higher AIT may cause phase changes (melting) in sugars of the matrix. This, in turn, might lead to > cohesion between particles as well as the adherence of particles to the drying chamber walls, which might decrease Y and efficiency in drying process [18].
When working with sugar-rich materials, Y can be increased by maintaining low AOT, however, these conditions favor the appearance of high X_w and a_w, which have negative effects on product storage [18]. Adhikari et al. (2009) [1] replaced 0.5% of sucrose with sodium caseinate and hydrolyzed whey protein, as an alternative for enhancing Y of sucrose powder and reducing its stickiness, as consequence, they obtained Y values of 81% (AIT=160ºC and AOT=70ºC). In this study, the protein provided by KG might have had an effect on the good results obtained for Y: it could have modified droplets/particles surface properties by entering the interface and preventing cohesion between them and rendering them unable to adhere to the dryer walls.
MD increases Tg and improves Y in SD process, allowing > stability of powder foods [29], helping prevent melting and reducing the formation of deposits inside the chamber. When obtaining powder sumac spice extract [5], it was found that adding MD up to a solids content of 25% increased Y to 98.5%. However, < Y values (35%) were obtained when spray drying lulo pulp at AIT of 125°C and AOT of 78.6°C, to which a smaller mixture of MD and gum arabic was added at 16.4% in order to retain the nutritional and functional properties.

3.6. Fractal dimension. ANOVA showed statistically significant differences ($p<0.05$) for FD in factor A. The response surface plots show that FD tends to increase with ADS>22500 rpm and high AIT. In general, the FD in samples showed small variations in roughness (2,465-2,579), that is, no significant changes in surface microstructure were observed; based on FD studies, Pérez et al., (2010) [26] assessed changes in the structure of bread dough during the baking process. Low FD values are associated with images showing a soft fractal texture, whereas high values are associated with rough fractal textures.

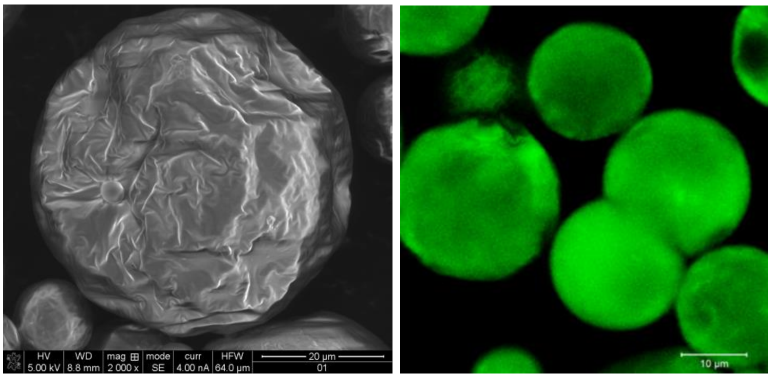
3.7. Experimental optimization. The operating conditions for SD process were optimized to maximize Y and lactobacilli survival. Results show that the models developed for response variables were significant for Y and for lactobacilli survival, as they had correlation coefficients of 0.886 and 0.778 respectively (Lack-of-fit was not significant, $p>0.05$). The results obtained were the following: AIT = 125°C, AOT = 65°C and ADS = 25000 rpm. Three experiments were performed using the optimal conditions for validation of the model. Table 4 shows the experimental values and those predicted by the model for each variable.

Table 4. Optimization model verification.

Variable	Experimental value	Theoretical Value
X_w (%)	3.4±0.6	2.0
a_w	0.210±0.030	0.180
S (%)	97.5±0.0	97.3
Y (%)	81.5±8.3	85.3
FD	2.6±0.0	2.5
$D_{(3,2)}$	14.8	14.7
D(4,3)	35.9	42.0
Lactobacilli Survival (%)	85.4	80.7
Lactococci Survival (%)	67.1	68.7
Yeast Survival (%)	74.9	75.4

The ability to survive SD conditions was different for the three groups of microorganisms: lactobacilli had the highest capacity, whereas lactococci showed > sensitivity to heat treatment. The mean particle size was 25.7 µm. These particles are soft, rounded, and not sandy, as is the case with particles which sizes are beyond 80 µm [10]. Yatsu et al. (2011) [35] obtained < values (19.6 µm) when drying the aqueous extract of mate leaves with colloidal silicon dioxide at an ADS of 10900, an AIT of 177ºC and AOT of 99ºC. The experimental values of X_w= 3.4% and a_w=0.210 in the SCP+KG make possible to identify a microbiologically stable product during storage. The values for X_w and a_w in SCP+KG were similar to those obtained in the base sugarcane powder: 1.1% and 0.183, respectively [18]. In contrast, X_w was < the one obtained by Sunny and Knorr (2009) [32] (4.0-4.5%) during SD process of two strains of *Lactobacillus rhamnosus* in trehalose 20% w/w with AOT similar to those used in this study. Furthermore, SD Lychee juice with 20% of MD at an AOT of 70°C obtained the following values: S = 93.56%, X_w = 2.6%, and a_w = 0.260, with survival of 46.0% for *L. casei* [12].

Figure 2 shows SCP+KG micrographs as observed by SEM and confocal microscopy. It can be observed spherical particles which have some degree of surface roughness or microstructural collapse in the form of cracks. This may favor heat transfer from the interior of the particle after SD, thus reducing thermal damage to encapsulated microorganisms and influencing the survival rates achieved in this research for the three groups of microorganisms studied [14]. On the other hand, micrographs suggest high encapsulation efficiency, as microorganisms were not observed.



(a) SEM 2000X (b) Confocal microscopy

Figure 2. Micrographs of the SCP+KG obtained by SD at optimal conditions.

4 Conclusions

The optimal SD process conditions allowed to obtain a SCP+KG with high lactobacilli, lactococci, and yeasts survival percentage, high yield showed that is also technologically feasible. SCP+KG is a product that can be easily reconstituted in water due to its high solubility. It can also be consumed as a functional beverage with lactobacilli and lactococci or as an effective functional ingredient for the development of new foods with sweetening features

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