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Design and optimization of a strawberry-based dispersion to produce a spray drying functional powdered product, fortified with folic acid and zinc

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ABSTRACT

The optimization of a strawberry-based dispersion to produce a powdered product fortified with Folic Acid (FA) and Zinc (Zn) was realized. The methodology involved production and characterization of strawberry pulp and strawberry-based dispersion, optimization of the dispersion process, and the manufacture and description of a powdered product. The optimal conditions for obtaining the strawberry-based dispersion were determined to be 11.7 % arabic gum (AG) and 23.3 % maltodextrin (MD). The recovery percentage of the powder was 71.38 %. The folic acid (FA) and zinc (Zn) contents in the strawberry powder were 272.3 mg/100 g and 0.21 %, respectively. The powder contains 20 % and 58 % of the daily reference values for pregnant mothers for FA and Zn, respectively. It is concluded that it was possible to optimize dispersion and obtain a strawberry powder fortified with AF and Zn suitable for consumption by pregnant women.

1. Introduction

For the year 2020, global strawberry production reached 8,885,028 tons, with China, USA, and Mexico being the leading producers, with productions of 3,221,557, 1,021,490, and 881,337 tons, respectively (FAOSTAT, 2020). In the case of Colombia, strawberry production in 2020 amounted to 86,534 tons (Dirección de Cadenas Agrícolas y Forestales (2021)).

The strawberry is a non-climatic fruit (Vergauwen and De Smet, 2019), widely consumed for their aroma (Vergauwen and De Smet, 2019) and health benefits, as they contain bioactive compounds (phenols, carotenoids, organic acids), vitamins, and minerals (Ruiz-Rodríguez et al., 2011; Wang et al., 2019; Hossain et al., 2016).

However, strawberries have a short shelf life of approximately 5 days (Robledo et al., 2018), due to factors such as a high respiration rate, post-harvest damage, and attack by microorganisms such as *Botrytis cinerea* (Barkaoui et al., 2021; Lafarga et al., 2019; Asch et al., 2019), resulting in losses of up to 89 % (Li et al., 2019) corresponding to economic losses of approximately US$10 million per year for producers worldwide (Oliveira et al., 2019).

Freezing, radiation, modified atmospheres, and different drying methods, have been applied to preserve strawberries (Galetto et al., 2010; Rossi et al., 2009; Loyola López et al., 2008, De Bruijn and Bórquez, 2014). However, methods such as radiation have the disadvantage that they can affect the color, flavor and texture of the food (Rossi et al., 2009), while freezing can cause texture degradation, structural collapse and drip loss (Galetto et al., 2010), and modified atmospheres can affect color and flavor (Loyola López et al., 2008). Therefore, drying can be an excellent alternative for the processing of strawberries (Shishir and Chen, 2017).

Drying is crucial for the processing of foods and fruits, since it decreases the moisture content, which reduces its water activity, providing high stability during storage, by limiting the metabolism of microorganisms that cause spoilage; Additionally, after drying, a decrease in the

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volume of the food is obtained by eliminating part of the water that composes it, generating foods with added value by generating a decrease in transportation costs (Ibarz and Barbosa-Cánovas, 2011).

Various drying methods have been applied to transform fruits, including convective drying (Zielinska et al., 2017), microwave drying (Weiqiao et al., 2019), infrared drying (Adak et al., 2007), freeze-drying (Marques et al., 2009), and spray drying (Henao-Ardila et al., 2019). Specifically, spray drying is defined as a process where liquid or pasty foods are directly converted into powder through the application of heat and pressure, preserving the quality attributes of the foods due to the short processing time (5–100 seconds) (Shishir and Chen, 2017). Spray drying has been used to produce powders from fruits like avocado (Dantas et al., 2018), feijoa (Henao-Ardila et al., 2019) and strawberry (Gong et al., 2018; Leyva-Porras et al., 2021; Sadowska et al., 2020)

Spray drying can also be used to encapsulate different compounds or raw materials such flavors (Balci-Torun and Ozdemir, 2021), antioxidants (Lu et al., 2021), *Lactobacillus acidophilus* (Hân et al., 2016), probiotic cells (Rodrigues et al., 2020), essential oils, enzymes, and vitamins (López Alex et al., 2012). Additives include wall materials or drying agents such as maltodextrin, gum arabic, whey protein, and cyclodextrin are utilized in the encapsulation process (Balci-Torun and Ozdemir, 2021). Yeast cell walls has been reported as wall material in a study by Coradello and Tirelli (2021).

On the other hand, to develop a powdered product, it is necessary to formulate a dispersed system. A dispersed system for spray drying typically consists of fruit pulp, drying agents (surfactants and wall materials), and compounds to be encapsulated. The functions of wall materials in dispersion are to prevent product stickiness, increase process yield and reduce the moisture content of the final product (Shishir and Chen, 2017). Surfactants are used to facilitate the incorporation of insoluble additive, as well as to reduce the surface tension of the dispersion (Badui Dergal (2006)). These dispersions often have viscosities ranging from 600 to 4500 mPa·s (Gong et al., 2018). Viscosity is an important parameter in dispersed systems since it defines the size of the droplets to be dried and, consequently, the size of the particles in the final powder product. In that sense, the higher the viscosity, the larger the droplet size and the size of the larger powder (Jinapong et al., 2008).

One of the major food safety concerns is nutritional deficiencies in pregnant women, particularly the lack of micronutrients such as Zinc (Zn) and Folic Acid (FA), which play a crucial role in health. Zinc contributes to the development of biochemical processes and supports cellular respiration mechanisms (Rubio et al., 2007). The low amount of zinc in pregnant women can lead to growth retardation in the child, mental disturbances, and other genetic diseases (Ahmad and Ahmed, 2019). Whereas FA aids in the formation of new tissues, red blood cells and protein synthesis (Sobczyńska-Malefora, 2018). FA deficiency in pregnant women can cause megaloblastic anemia and growth retardation in children (Sobczyńska-Malefora, 2018). Thus, fortifying foods with zinc and FA can be a good alternative to help to avoid these issues. Currently, there are no reports on fortifying strawberry pulp with FA and Zn.

As mentioned earlier, the main goal of this study was to develop a formulation of a strawberry-based dispersion system using response surface methodologies to optimize some physicochemical and rheological properties of the dispersed system to be dried by spray drying, producing a fortified powder product with Zn and FA.

This research presents a novel method for the development of a strawberry-based powder fortified with Zn and FA. To do that, a study on design, formulation, and optimization of a disperse system with fruit pulp to guarantee a correct spray drying process was carried out. Give the above to solving the nutritional problems of vulnerable population groups, such as pregnant and lactating women, and can contribute to the reduction of the maternal mortality rate (MMR) worldwide and the fulfillment of objective 3 of the Sustainable Development Goals (SDG) “Ensure healthy lives and promote well-being for all at all ages”.

2. Materials and methods

2.1. Materials

Strawberries of the Sabrina variety were harvested in the municipality of La Unión, Colombia in January 2022 (5°58’22"N 75°21’40"W), with an average altitude of 2,500 m above sea level and an average temperature of 17°C. Upon harvesting, the strawberries were transported to the laboratory under refrigeration conditions at 6±0.5°C for 3 hours. Subsequently, the strawberries were selected at a maturity level of 4–6 by NTC 4103 standards (ICONTEC, 1997), and cleaned and disinfected.

The wall material for preparing the dispersed system included maltodextrin DE: 18–20 (LLC Interstarch Ukraine Lot 61) and Arabic Gum (Madretierra Food Lot F&M-12596–001). Folic acid (Smart Chemical lot 201905018), and zinc citrate (Quiminaturales lot MC 21112019 with 99.5 % purity) were also used. Additionally, tween 80 (Bell Chem Internacional S.A. lot 161029J3152) was used as a surfactant.

For antioxidant and anthocyanin determinations, the following reagents were used: ethanol (Merck Lot. K46211583 503), methanol (J.T. Baker Lot. Y04C03), acetone (Merck Lot. K49726314 747), trolox (MP Biomedicals Lot 9987 K), gallic acid (Merck Lot S7433849 745), ABTS radical (Wako Lot. STE7075), TPTZ Reagent (2,4,6-tri(2-pyridyl)-s-triazine) (Merck Lot. L012023138 339), Sodium Acetate (Carlo Ebra Reagents Lot. 7G263137I), Hydrated Iron (III) Chloride (Merck Lot. B1516143 807), and Hydrochloric Acid (Panreac Lot. 0001565361). For the hygroscopicity determination, ammonium chloride (Panreac Lot.0000445092) was used.

2.2. Methods

2.2.1. Strawberry pulp production

For strawberry pulp production, the strawberries were first washed and sanitized by immersion in a 0.2 % (v/v) solution of the disinfectant "BioDes Ultra" in water. The strawberry pulp was obtained using a pulper (Estructuras y Montajes, Colombia) equipped with a No. 16 sieve with an opening of 1180 microns (Gong et al., 2018; Leyva-Porras et al., 2021). The obtained pulp was packed in sealed polyethylene bags and stored at freezing conditions (-18±0.5°C) in a Samsung freezer (model RS23T5B00S9) until further use and analysis. Each bag contained approximately 400±0.1 g of sieved pulp.

2.2.2. Preparation of the dispersed system

The strawberry-based dispersed system was prepared in a 500-ml beaker, i.e., on a laboratory scale. Initially, 114 mg of zinc citrate and 4 ml of folic acid solution with a concentration of 0.2 mg/ml were added to approximately 300 g of strawberry pulp. Next, 5 % Tween 80 and different concentrations of maltodextrin and Arabic gum (Table 1) were added to this mixture to obtain 500 g of dispersion. Finally, all components were homogenized at 14000 rpm in 3 cycles of 3 minutes each using an MDT-G25 ultraturrax homogenizer (Kinematica, Switzerland).

All components of the dispersed system were weighed using an analytical balance (Radwag, Poland) with an accuracy of 0.1 mg. The quantities of Zinc and Folic Acid were calculated based on providing 60 % of the daily reference value, as stipulated in Resolution 810 of 2021 by the Ministry of Health and Social Protection of Colombia.

2.2.3. Physicochemical characterization of strawberry pulp and strawberry-based dispersed system

The characterization of strawberry pulp and the strawberry-based dispersed system was carried out through the determination of density, pH, soluble solids (SS), water activity (aw) at 25°C, and rheological properties at 20ºC. Each of the methodologies employed is described below.

Table 1
Results of physicochemical analysis of strawberry dispersions.

Run	MD (%)	AG (%)	Density (g/cm^3)	°Brix	pH	aw	Consistency Index (k) (mPa.s^n)	Flux Index (n)	Viscosity (mPa.s)
1 (f)	30	15	1.135±0.003	47.3±0.2	3.65±0.02	0.896±0.001	4.45	0.78	1850.10
2 (*)	20	2.9	1.090±0.002	27.6±0.2	3.50±0.03	0.914±0.002	0.37	0.79	187.31
3 (*)	20	17.1	1.133±0.002	37.3±0.3	3.65±0.02	0.911±0.001	2.35	0.77	1064.80
4 (*)	34.1	10	1.146±0.002	44.9±0.2	3.63±0.01	0.906±0.001	2.92	0.79	1776.60
5 (c)	20	10	1.128±0.002	32.0±0.2	3.58±0.02	0.912±0.002	0.69	0.78	329.45
6 (f)	10	15	1.104±0.001	27.6±0.2	3.61±0.01	0.915±0.000	0.83	0.75	356.55
7 (f)	10	5	1.079±0.003	20.0±0.2	3.5±0.02	0.914±0.002	0.38	0.63	111.26
8 (*)	5.9	10	1.074±0.002	19.8±0.3	3.56±0.02	0.915±0.001	0.70	0.60	169.81
9 (c)	20	10	1.134±0.001	32.4±0.1	3.6±0.01	0.910±0.001	0.73	0.78	331.09
10 (c)	20	10	1.135±0.003	32.3±0.2	3.61±0.01	0.911±0.001	0.77	0.76	330.10
11 (f)	30	5	1.156±0.002	37.1±0.5	3.56±0.03	0.907±0.002	0.56	0.83	280.94
12 (c)	20	10	1.142±0.002	34.3±0.1	3.59±0.01	0.911±0.001	0.69	0.75	294.56

(f): Factorial point; (c): Central point; (*): Star point. MD: Maltodextrin, AG: Arabic Gum. (The determinations of °Brix, pH and aw density were carried out in triplicate; the parameters k, n and viscosity derived from flow curves, and are obtained through linearization using the power law model. This model yields various parameters considered in the analysis of response surfaces, aligning with the experimental design that includes multiple points and replicates to address significance and model fit).

2.2.3.1. Density. The density of strawberry pulp and the strawberry-based dispersed system was determined by pycnometry, following the methodology given by Yosefzadeh Sani et al. (2018). The density was calculated using Eq. 1, and all weights were determined using an analytical balance with an accuracy of 0.0001 g (Radwag, Poland).

$$\rho = \frac{m_{pf} - m_{pi}}{V_p} \quad (1)$$

Where: ρ: Density (g/cm^3), m_{pf}: Mass of the pycnometer filled (g), m_{pi}: Mass of the empty pycnometer (g); V_p: Volume of the pycnometer (cm^3).

2.2.3.2. Soluble solids, pH, and water activity (aw). The soluble solids (°Brix) were measured using a digital refractometer from Bellingham+Stanley and the pH was determined using a Hanna-HI8424 pH meter, according to the Association of Official Analytical Chemists (1997). Water activity (aw) was measured using an Aqualab-Pre analyzer (Lab-Ferrer, Spain) (Pui et al., 2020).

2.2.3.3. Rheological properties. Rheological essays were performed using an Anton-Paar-C-PDT-180 rheometer (Anton Paar GmbH, Austria) with a concentric cylinder with a diameter of 26.646 mm and a length of 39.99 mm, according to by Chen et al. (2020) with modifications which consisted of including maintenance and descent ramps on analyses. A linear ramp test was conducted with a shear rate range of 1–200 s^{-1} and 200 intermediate data points during ascent, maintenance for 1 minute, and descent ramps.

The power law model (Eq. 2) was fitted to the data obtained with shear thinning behavior using Microsoft Excel® (Version 2209, Redmond, USA).

$$\eta = k \quad \dot{\gamma}^n \quad (2)$$

Where η = apparent viscosity (Pa·s), k = consistency index (Pa·s^n), $\dot{\gamma}^n$ = shear rate (s^{-1}), n = flow index.

2.2.4. Spray drying

The optimized strawberry dispersion underwent a spray drying process using a Lab spray dryer TP-S15 Xl from An Toption Instrument Co., Ltd., following the methodologies described by Gong et al. (2018) and Leyva-Porras et al. (2021). The process conditions included an inlet air temperature of 170°C and an airflow rate of 5.5 m^3/min. The feed flow rate for the dispersion was 2.63 ml/min. Powder recovery was determined according to the method indicated by Muzaffar and Kumar (2016) by calculating the percentage ratio between the total mass of the recovered product after the drying process and the total solids content in the feed material.

2.2.5. Physicochemical characterization of the powdered product

2.2.5.1. Bulk density, tapped density, and flow properties. For bulk density determination, a 10-ml graduated test tube was filled with a volume between 5 and 6 ml of the powder, and then the powder mass was determined (Tonon et al., 2011). For taped density, the loaded test tube was dropped 50 times from a height of 10 cm, and the new volume of the compacted powder was read (Tonon et al., 2011). The densities were calculated using Eq. 3a and b.

$$\rho_b = \frac{w_p}{V_{ip}} \quad (3a)$$

$$\rho_t = \frac{w_p}{V_{cp}} \quad (3b)$$

Where: V = V_{ip}: initial powder volume (cm^3), for ρ = ρ_b: bulk density (g/cm^3), and V = V_{cp}: compacted powder volume (cm^3), for ρ = ρ_t: tapped density (g/cm^3). In both cases, w_p: powder weight (g).

To quantify the flowability of strawberry powder, the Carr index (CI) and Hausner ratio (HR) were calculated using Eqs. 4 and 5 respectively (Arumugham et al., 2023; Gallo et al., 2011).

$$CI = \frac{\rho_t - \rho_b}{\rho_t} x100 \quad (4)$$

$$HR = \frac{\rho_t}{\rho_b} \quad (5)$$

Where: CI = Carr index (%), HR = Hausner ratio, ρ_b = bulk density (g/cm^3), ρ_t = tapped density (g/cm^3).

2.2.5.2. Solubility and hygroscopicity. To determine the solubility of the powdered product, an amount of powder was dispersed in water under agitation and then, submitted to centrifugation (Eastman et al., 1984; Cano-Chauca et al., 2005; Serna-Cock et al., 2015). Thus, an aliquot of 25 ml was taken of the supernatant and was dried for 5 hours at 105°C in an air oven (Binder, Germany), and weighted. The solubility was calculated according to Eq. 6.

$$S = \frac{w_{ss} \; x \; 2}{w_i} x \quad 100 \quad (6)$$

Where: S: solubility in water (%), w_{ss}: Weight of soluble solids in the aliquot of supernatant (g), w_i: Initial weight of the sample (g), 2: Adjustment factor for the aliquot.

Furthermore, hygroscopicity was calculated as the increase in mass when an amount of powder was conditioned in a desiccator containing a saturated ammonium chloride solution with a relative humidity of 80 %

at 25°C (Arigo et al., 2019). After equilibrium was attained, the samples were weighed, and the hygroscopicity was determined using Eq. 7.

$$Hg = \frac{[(w_3 - w_2) \; x \; 100]}{[w_2 - w_1]} \quad (7)$$

Where: Hg: Hygroscopicity (%), w_1: Weight of the empty Petri dish (g), w_2: Initial weight of the Petri dish with the sample (g), w_3: Weight of the Petri dish with the sample after equilibrium reached (g).

2.2.5.3. Moisture content and water activity (aw). The moisture content of the blackberry powder was determined using a thermobalance MA 210.X2 (Radwag, Poland) (Melo-Guerrero et al. (2020). The Water activity (aw) was measured using an Aqualab-Pre analyzer (Lab-Ferrer, Spain) (Pui et al., 2020).

2.2.5.4. Folic acid and zinc analysis

2.2.5.4.1. Determination of folic acid. To determine folic acid, 0.2 ml of a 50 % citric acid solution was added until a pH of 4.3 was achieved. Subsequently, 70 µL of dextrozima GA enzyme was added at 60°C in a water bath for 10 minutes, since at the optimal pH of 4.3, the enzyme facilitates the extraction of FA by generating a breakdown of maltodextrin. Then, 5 ml of citrate-phosphate buffer solution at pH 7.5, adjusted to pH 10 with NaOH, was added to each sample. The mixture was agitated for 5 minutes in an ultrasonic bath, and a 2 ml aliquot was taken, filtered, and subjected to HPLC analysis (Akhtar et al., 1997, Lopera Cardona et al., 2010). The results were expressed as mg FA/100 g powder.

2.2.5.4.2. Determination of zinc. Zinc determination was conducted following the method described by (Cherfi et al., 2014) using a dual-beam atomic absorption spectrophotometer, Sensa Dual (GBC Scientific Equipment Ltd., Australia). Measurements were performed with a yellow oxidizing flame (air-acetylene gases) using a 5-mA lamp and a wavelength of 213.7 nm for zinc. The concentration range used for the calibration curve was between 0.1 and 1 ppm. The results were expressed as percentages.

2.2.5.5. Total polyphenols content, antioxidant activity and anthocyanins. Previously to these analyses, a strawberry pulp or powder extract was prepared using acidified methanol-water (50:50, v/v pH 2) and acetone-water (70:30) solutions as solvent (Contreras-Calderón et al., 2011).

2.2.5.6. FRAP assay (Ferric Reducing Antioxidant Power). The antioxidant activity of the sample was determined using a calibration curve with aqueous solutions of Trolox at concentrations ranging from 0 to 500 µM. For these assays, 1350 µl of the FRAP reagent (containing TPTZ, $FeCl_3$, and acetate buffer) was mixed with 135 µl of distilled water, 45 µl of Trolox standard for the calibration curve, and 45 µl of strawberry pulp or powder extract, diluted with distilled water in a 1:5 ratio, for the sample to be analyzed. The mixtures were incubated at 37°C for 30 minutes. The maximum absorbance values at 595 nm were measured after 30 minutes using a spectrophotometer (UV-3300 Mapada Instruments, Shanghai, China), and the results were expressed as micromoles of Trolox equivalents (TEs) per gram of the sample (µmol TEs/g) (Contreras-Calderón et al., 2016).

2.2.5.7. ABTS assay – TEAC (Trolox Equivalent Antioxidant Capacity). The antioxidant activity of the sample was determined using a calibration curve with aqueous solutions of Trolox at concentrations ranging from 0 to 200 µM. The ABTS assay was performed by taking 150 µl of Trolox standard for the calibration curve and 150 µl of strawberry pulp or powder extract, diluted with distilled water in a 1:10 ratio, for the sample to be analyzed. Both were mixed with 1500 µl of ABTS+ radical and incubated at 30°C for 30 minutes. A spectrophotometer (UV-3300 Mapada Instruments, Shanghai, China) was used to measure the maximum absorbance values at 730 nm. The results were given as micromoles of Trolox equivalents (TEs) per gram of the sample (µmol TEs/g) (Contreras-Calderón et al., 2016).

2.2.5.8. Total polyphenols content (TPC). The determination of TPC was carried out using the Folin-Ciocalteu assay (Contreras-Calderón et al., 2011). To construct the calibration curve, aqueous solutions of gallic acid were used with concentrations ranging from 0 to 1000 ppm. For the sample to be analyzed, 200 µl of strawberry pulp or powder extract and 200 µl of gallic acid standard for the calibration curve were mixed with 1580 µl of distilled water. Then, 300 µl of 20 % sodium carbonate and 100 µl of Folin reagent were added to each mixture. The mixtures were incubated at room temperature without shaking in the dark for 1 hour. The maximum absorbance values were measured at 725 nm using a spectrophotometer (UV-3300, Mapada Instruments, Shanghai, China). The results were expressed as milligrams of gallic acid equivalents (GAEs) per gram of the sample (mg GAE/g).

2.2.5.9. Total monomeric anthocyanins content (TMAC). The total monomeric anthocyanin content (TMAC) was determined using the AOAC method 2005–02, which is based on the monomeric anthocyanin pigments reversibly change color with a change in pH; the colored oxonium form exists at pH 1.0, and the colorless hemiketal form predominates at pH 4.5. Two portions of 500 µl of strawberry pulp or powder extract, diluted with distilled water in a 1:2 ratio, were taken and added to 500 µl of pH 1.0 and pH 4.5 buffer solutions, respectively. Finally, a spectrophotometer (UV-3300 Mapada Instruments, Shanghai, China) was used to compare the absorbance of these dilutions to a blank cell filled with distilled water at 520 nm and 700 nm. The results were calculated using Eq. 6 and expressed in cyanidin-3-glucoside equivalent content.

$$TMAC = \frac{(\text{A x MW x DF x}10^3)}{(\epsilon)} \quad (8)$$

Where: TMAC = total monomeric anthocyanins content expressed as anthocyanin pigment (cyanidin-3-glucoside equivalent), (mg/L); A = Absorbances (A520nm – A700nm at pH 1.0 or A520nm – A700nm at pH 4.5), MW (Molecular Weight) = 449.2 g/mol para cyanidin-3-glucoside, DF = 2 (Dilution Factor), ϵ = 26900 Extinction molar coefficient (L. $mol^{-1}.cm^{-1}$)

2.3. Experimental design

For the optimization of the strawberry-based dispersion drying process, the response surface methodology (RSM) was applied using a central composite rotatable design (CCRD) with 4 central points, resulting in a total of 12 experiments (Table 1). The independent variables were the concentrations of maltodextrin (MD) (10–30 %) and Arabic gum (AG) (5–15 %) in the strawberry-based dispersions. Meanwhile, the dependent variables included water activity (aw), pH, SS, density, viscosity, consistency index (k), and flow index (n).

The response variables were analyzed using an RSM, and a second-order equation (Eq. 9) was fitted to the experimental values.

$$Y = b_0 + \sum_{i=1}^{2} b_i X_i + \sum_{i=1}^{2} b_{ii} X_i^2 + \sum_{i<j=1}^{2} b_{ij} X_i X_j \quad (9)$$

Where Y is the response variable, b_0 is a constant, b_i are coefficients related to the linear effect, b_{ii} are coefficients associated with the quadratic effect, b_{ij} are constants for interaction effects, and X_i and X_j are the independent variables.

An analysis of variance (ANOVA) was conducted at a 95 % confidence level, which included assessing the statistical significance of each term in the adjusted model (p-value), the estimated coefficients for each term (α_i), the model's coefficient of determination (R^2), and lack of fit to establish the model's accuracy in representing the data.

Ultimately, since the objective was to optimize the dispersion formulation, a multi-response optimization methodology using the desirability function was employed. In general terms, this approach involves transforming each response y_i into a desirability function di ranging from 0 to 1 (Tápia-Blácido et al., 2011). If the response y_i is at or close to its target, then $d_i = 1$, and if the response is outside an acceptable region, $d_i = 0$. Each response is standardized into the desired function di of the form $d_i = h_i(y_i)$.

Subsequently, the design variables are selected to maximize the overall desirability of the responses as follows:

$$D = (d_1 d_2 \ldots d_m)^{1/m} \quad (10)$$

The optimal values of the factors were determined based on the values of individual desirability functions that maximize D. The quality of fit of the polynomial model equation was evaluated by adjusting the coefficients of determination by degrees of freedom or the percentage of explained variability (% R^2), the standard error of estimation, and lack of fit (Saavedra et al., 2017).

The analysis of variance (ANOVA), response surface generation, and multi-response optimization were carried out using STATGRAPHICS Centurion XIX® (Statistical Graphics Corporation, Rockville, USA).

3. Results and discussion

3.1. Characterization of strawberry pulp and dispersions

3.1.1. Strawberry pulp

Determinations for characterization of Strawberry Pulp and dispersions were carried out in triplicate. The strawberry pulp presented the following properties: aw = 0.913±0.002, density = 1.022±0.002 g/

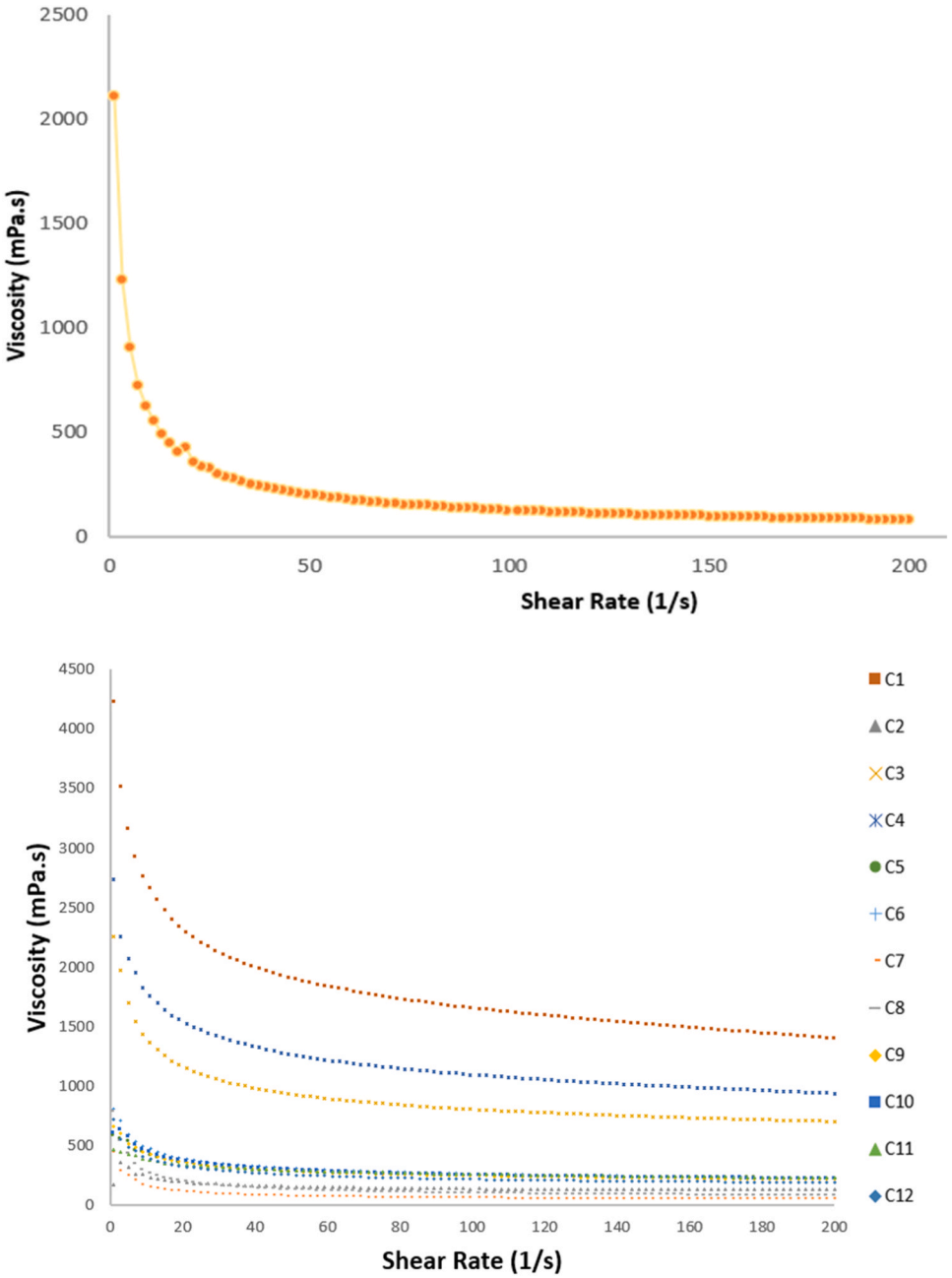

Fig. 1. Behavior of strawberry pulp (1 A) and dispersions (1B) viscosity as a function of shear rate. The flow curves in Fig. 1 are the average of 2 replicates for each sample.

cm^3, soluble solids = 6.7±0.4°Brix, and pH = 3.38±0.03. Overall, these values were like some data found in the literature. Bhat and Stamminger (2015) determined that the SS and pH of the strawberry pulp of the duch variety grown in Malaysia were 4.5°Brix and 3.18, respectively. Similarly, Bebek Markovinović et al. (2022) found pH and SS of 3.25 and 8.98°Brix, respectively, in strawberry pulps of the albión variety cultivated in Croatia. On the other hand, Kallio et al. (2000) analyzed strawberry pulps of different varieties, including senga, johnson, korona, polka, honeoye, bounty, and jonsok, and found pH values ranging from 3.20 to 3.66 and SS between 7.2 and 13.1°Brix. And, according to the U.S. Department of Agriculture (2019), the density of Strawberry Pulp is 0.82 g/cm^3, a lower value than that found in this work. These values depend on the planting location, harvest season, and cultivation conditions, among others (Kallio et al., 2000).

The strawberry pulp viscosity decreased as the shear rate increased, exhibiting a shear thinning behavior (Fig. 1), consistent with the findings of Chen et al. (2020). Eq. 2 was fitted to experimental data with good fitting quality (R^2 = 97.97 %), allowing the calculation of the consistency index (k = 2.65 $Pa.s^{-n}$) and the flow index (n = 0.34) (Steff, 1996). The k values were quite different from those determined by Chen et al. (2020) (85.8 $Pa.s^{-n}$) and Oliveira et al. (2012) (11.1 $Pa.s^{-n}$) but, the n values were almost similar (0.43 and 0.35, respectively).

The antioxidant activity of strawberry pulp was 10.4±0.8 and 13.6 ±3.2 μmol Trolox/g samples, as determined using the ABTS and FRAP methods, respectively. The total polyphenol content in strawberry pulp was 176.6±9.4 mg gallic acid equivalents/100 g sample, while the anthocyanin content was 9.5±0.6 mg cyanin-3-glucoside equivalents/100 g sample of strawberry pulp, measurements were performed in triplicate. These results were consistent with those reported by Bhat and Stamminger (2015), who found anthocyanin contents of 9.6 mg cyanidin-3-glucoside equivalent/100 g sample in strawberries grown in Malaysia. Additionally, Bebek Markovinović et al. (2022) reported total polyphenol values of 46.8 mg gallic acid equivalents per 100 g sample in strawberries cultivated in Croatia. It can be suggested that strawberries (Sabrina variety) cultivated in the municipality of La Unión, Colombia, present a range of desirable nutritional and quality attributes sought after by the industry and consumers (Kallio et al., 2000).

3.1.2. Strawberry-based dispersed system

Table 1 presents the results of the physicochemical analysis of the strawberry-based dispersed system. In general, SS varied from 19.8 ±0.3–47.3±0.2°Brix, pH values stayed around 3.50±0.03 – 3.65±0.02, and density changed between 1.074±0.02 and 1.156±0.02 g/cm3. It was found that the strawberry dispersions generally had higher °Brix and density values compared to strawberry pulp. The reason for this is that adding maltodextrin raises the amount of soluble solids, which in turn raises the final °Brix values and the system's density (Lopez M et al., 2009).

The values of aw stayed close to 0.896±0.001–0.915±0.001. This narrow variation occurred because water activity depends on the molecular weight of solutes present in a food system, and molecules with higher molecular weights do not have the ability to provoke water vapor lowering (Adhikari et al., 2002). Maltodextrin (MD) and arabic gum (AG) have high molecular weights (MD > 1800 g/mol and AG > 380 kDa) (Kingwatee et al., 2015).

Eq. 7 fits very well with the data presented in Table 1. The R^2 values for all response variables were above 70 %, and p-values were greater than 0.05, except for k and h data, indicating a good fit (Table 2) (Saavedra et al., 2017). The models obtained for each dependent variable, using only significant parameters, were presented as Eq. 9. These equations were used in the preparation of surface response graphics (Fig. 2).

$$SS = 9.2 + 0.79\ [MD] + 0.53[AG] - 4x10^{-4}[MD]^2 + 1.3x10^{2}[MD][AG] - 4.9x10^{-5}[AG]^2 \quad (9a)$$

$$pH = 3.37 + 4x10^{-3}[MD] + 2.1x10^{-2}[AG] - 1.3x10^{-5}[MD]^2 + 1x10^{-4}[MD][AG] - 4.5x10^{-4}[AG]^2 \quad (9b)$$

$$aw = 0.92 - 4.5x10^{-4}[MD] - 2.1x10^{-4}[AG] + 8.8x10^{-6}[MD]^2 - 1x10^{-5}[MD][AG] + 0.00001.5x10^{-5}[AG]^2 \quad (9c)$$

$$\rho = 0.940 + 9.1x10^{-3}[\mathrm{MD}] + 1.4x10^{-2}[AG] - 1x10^{-4}[MD]^2 - 0.2.3x10^{-4}[MD][AG] \quad (9d)$$

$$n = 0.36 + 2.8x10^{-2}[MD] + 1.1x10^{-2}[AG] - 3.4x10^{-4}[MD]^2 - 8.5x10^{-4}[MD][AG] + 3.5x10^{-4}[AG]^2 \quad (9e)$$

Where: [MD]: Maltodextrin concentration, [AG]: Arabic gum concentration, SS: soluble solids (°Brix), aw: water activity, ρ: density (g/cm^3), n: flow index.

Regarding the experimental design, both the concentrations of MD and GA significantly influenced ($p < 0.05$) the SS and pH of the dispersion (Table 2). Figs. 2b and 2c also show that when the MD and GA contents are higher, the SS and pH of the dispersions also rise, which is in line with what Lopez M et al. found in 2009. This behavior was due to maltodextrin being an oligosaccharide with high solubility in water (Lopez M et al., 2009).

Regarding rheological properties, it can be observed that the effective viscosity decreased as the shear rate increased for all treatments (Fig. 1), which means that strawberry dispersions flow curves presented shear thinning behavior, consistent with the findings of Chen et al. (2020). Other types of dispersions and fruit pulps have exhibited typical power-law behavior, as reported for soursop (M. C. Quek et al., 2013), orange juice (Ricci et al., 2021), and papaya pulp (Quintana et al., 2017). Therefore, it can be suggested that the addition of Arabic gum and maltodextrin does not alter the flow characteristics compared to strawberry pulp. The consistency index ranged from 0.38 to 4.45 $Pa.s^{-n}$, the flow index varied between 0.60 and 0.83, and the effective viscosity of the strawberry dispersion fluctuated between 111.26 and 1850.20 mPa.s (Table 1).

The effective viscosity (*n*) and the consistency index (k) were not significantly affected ($p > 0.05$) by any of the factors, while the flow index (n) was significantly influenced ($p < 0.05$) by the linear (MD) and quadratic (MD2 and GA2) components. It can be observed in Fig. 2e that

Table 2
p-values from ANOVA tables for response variables.

Source	ρ	°Brix	pH	aw	k	n	Viscosity
A: [MD]	0.0010	0.0002	0.0121	0.0059	0.0000	0.0013	0.0000
B: [GA]	0.0280	0.0018	0.0015	0.1629	0.0000	0.4000	0.0000
AA	0.0193	0.9130	0.8182	0.0734	0.0000	0.0108	0.0000
AB	0.0278	0.3027	0.4950	0.3081	0.0000	0.0109	0.0000
BB	0.0235	0.9978	0.1149	0.3271	0.0003	0.2352	0.0005
Lack of fit	0.1016	0.5242	0.9327	0.0707	0.0023	0.2462	0.0010
R^2 (%)	92.45	99.19	99.95	71.86	97.97	95.39	96.79

ρ: Densit; k: Consistency index; n: Flow index.

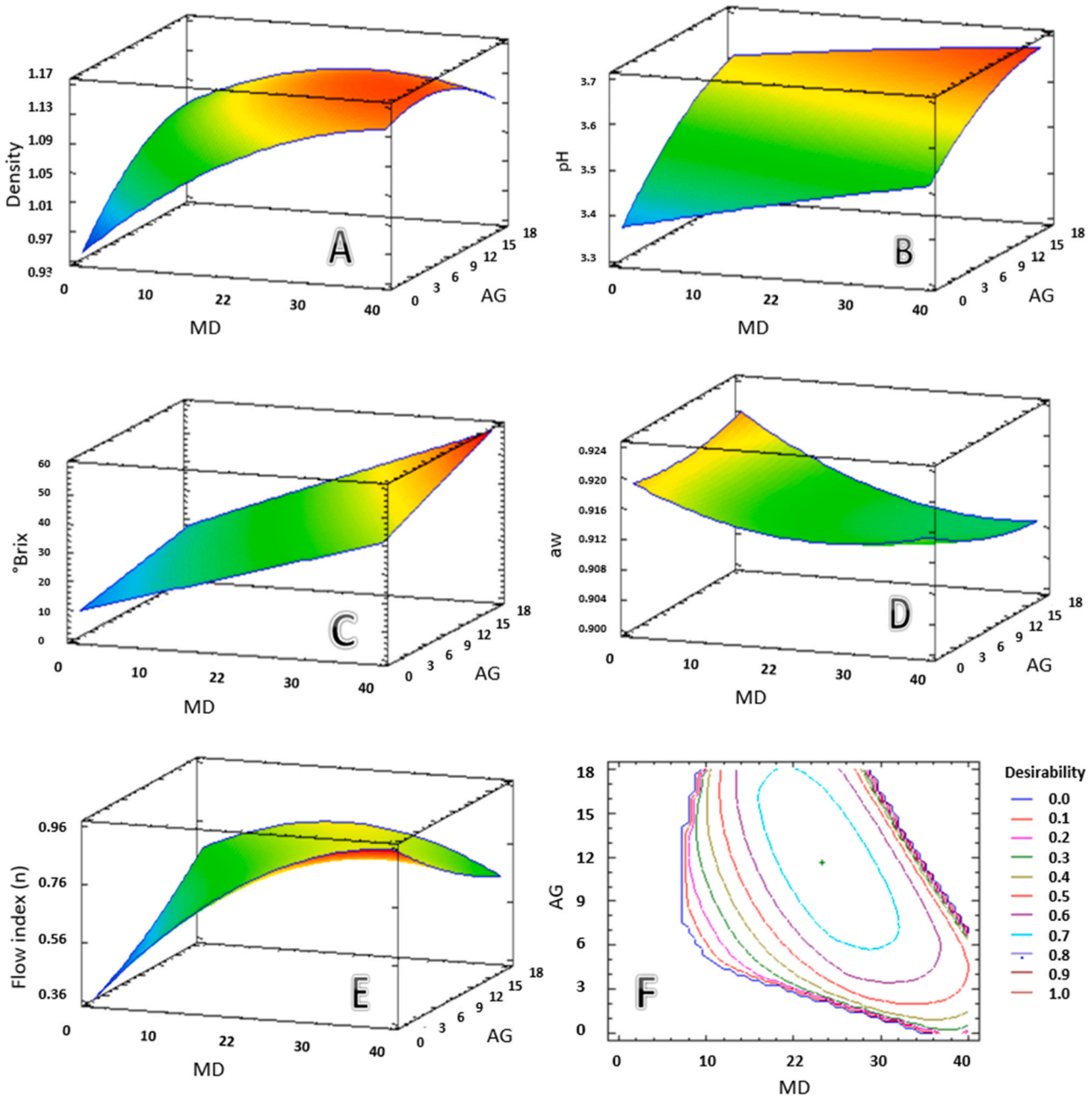

Fig. 2. Estimated response surface for dependent variables. A. Density; B. pH; C. °Brix; D. aw; E. Flow index (n); F. Optimization.

as the concentration of MD and GA increased, the flow index (n) remained below 1, consistent with the findings of Mothé and Rao (1999) and Udomrati et al. (2013). This behavior was provoked by some breakdown of material microstructure as a consequence of shear stress, resulting in decreased viscosity (Zhao et al., 2016).

The density of the dispersion ranged from 1.074 to 1.156 g/cm3 (Table 1), and it was significantly affected by the linear and quadratic components of the independent variables ($p < 0.05$) (Table 2). Higher concentrations of MD and GA lead to increased density values (Fig. 2a). This was because the addition of MD and GA increased the dissolved solids in the mixture with a negligible contribution to its volume, resulting in a higher mass per unit volume (Beltrán Mieles and Casilla Pertuz (2015)).

3.2. Optimization

To perform optimization, the response variables significantly affected by the independent variables, with $R^2 > 70$ % and p-value > 0.05 for lack of fit, were considered. In this regard, the optimization of the dispersed system was carried out with water activity (aw), pH, SS, density, and flow index (n).

The aw was minimized since lower aw values result in less water availability for biochemical reactions, leading to increased dispersion stability over time (S. Y. Quek et al., 2007). On the other hand, pH, density, and flow index (n) were maximized as they increased with maltodextrin (MD) concentration, favoring reduced water diffusivity and aiding in retaining moisture in the final product after drying (Shishir and Chen, 2017). This translates into a lower amount of available water, which, as mentioned earlier, limits biochemical reactions, and provides greater stability to the final product over time.

Finally, SS was set to 30°Brix because higher concentrations showed high viscosity, which can make it hard to pump and form drops during atomization, leading to powder products that are less soluble and flowable (Turk-Gul et al., 2023).

Once the target points for each response variable were determined, following Eq. 10, a desirability function with an optimal value of 76.64 % was obtained, with optimal conditions for the factors being 11.7 % for AG and 23.3 % for MD, along with optimal values for each response variable (Table 3). Finally, a dispersed system was prepared at the optimal concentrations of AG and MD. Subsequently, the SS, aw, pH, density, and flow index (n) values were determined, finding that these values did not differ by more than 5 % from the optimal values calculated by the desirability function (Table 3).

3.3. Spray drying and characterization of the powdered product

With the established drying conditions, a powder recovery of 71.4 % was obtained, which agreed with the results obtained by Muzaffar and Kumar (2016), who achieved powder recovery percentages of 68.4 % for tamarind pulp.

3.3.1. Proximal analysis

The dried strawberry powder presented a moisture content and aw of 1.3 % and 0.16, respectively (Table 4). These values were similar to those reported by Gong et al. (2018), who found moisture content in the order of 4.5–4.9 % and aw values around 0.21 for strawberry powders. Additionally, Quek et al. (2007) found that when obtaining watermelon powder, aw values ranged from 0.21 to 0.29 and moisture content was between 1.5 % and 2.8 %. Finally, Tonon et al. (2008) found moisture values between 0.64 % and 2.89 % in acai powder. With this, the strawberry powder can be considered microbiologically stable, allowing to have a longer shelf life because it aw is very inferior to the minimum value for microorganisms living (S. Y. Quek et al., 2007). However, according to S. Y. Quek et al. (2007) and Tonon et al. (2008), the drying process conditions, wall material concentration, inlet temperature, outlet temperature, and feed rate all affect the moisture and aw of fruit powder.

The solubility and hygroscopicity of strawberry powder were 97.0 % and 21.3 %, respectively (Table 4). Usually, fruit powder solubility is above 90 %, as seen in date powder (Arumugham et al., 2023) and citron powder (Mahdi et al., 2020). The hygroscopicity of fruit powders can range between 10 % and 25 %, as reported for acai powder (Tonon et al., 2008), sweet potato powder (Arebo et al., 2023), and pomegranate juice powder (Hadree et al., 2023). The values of hygroscopicity and solubility shown in Table 4 are similar to what has been written in the past. This means that the powder that was obtained is of a high quality and can be used in industrial processes, which will help keep costs down (Mahdi et al., 2020).

Values of 0.482 and 0.803 g/cm3 were obtained for the bulk and tapped densities of the strawberry powder, respectively (Table 4). These values were similar to those (0.45–0.55 g/cm3) reported by Gong et al. (2018) for strawberry powders (Cultivar Mei 13). Dantas et al. (2018) found bulk and tapped densities for avocado powders averaging 0.377 and 0.689 g/cm3, respectively. With the density values shown in Table 4, it can be said that the strawberry powder obtained in this research is a powder that could reduce transportation and packaging costs (Arumugham et al., 2023; Ding et al., 2020; Zhang et al., 2020).

The CI (39.95 %) and the HR (1.67 %) values can indicate that the flow of the powdered product was reduced (Gallo et al., 2011). For the HR, the obtained value indicates high cohesiveness (Arumugham et al., 2023). Similar flow and cohesiveness behaviors have been reported for citron powder (Mahdi et al., 2020) and date powder (Arumugham et al., 2023).

Table 3
Predicted and observed values of response variables after optimization.

Variable	Predicted	Observed	Deviation (%)
Density (g/cm^3)	1.143	1.136	0.4 %
Soluble solids (°Brix)	37.1	38.7	4.5 %
pH	3.62	3.46	4.4 %
Water activity (aw)	0.91	0.92	1.3 %
Flux index (n)	0.78	0.77	1.3 %

Table 4
Powder product analysis.

Parameter	Value
Humidity (%)	1.3±0.00
Aw	0.16±0.00
Solubility (%)	97.0±0.600
Hygroscopicity (%)	21.3±0.200
Bulk density (g/cm^3)	0.482±0.009
Tapped density (g/cm^3)	0.803±0.006
Carr Index (CI) (%)	39.9
Hausner Ratio (HR)	1.7
Total Zinc (%)	0.021±0.000
Folic Acid content (ug/100 g)	272.3±0.1
Antioxidants ABTS method (μmol Trolox/g sample)	34.4±1.30
Antioxidants FRAP method (μmol Trolox/g sample)	61.0±1.00
Polyphenols (mg Galic Acid/g sample)	7.3±0.90
Anthocyanins (μg Cyanidin-3-glucosid equivalent/g sample)	79.0±6.5

3.3.2. Zinc and folic acid analysis

The contents of folic acid (FA) and zinc (Zn) in the strawberry powder were quantified at 272.3 ug/100 g and 0.021 %, respectively (Table 4). Now, in order to compare these values with the daily requirements established by Colombian regulations, we defined a portion of 30 g of the powdered product; in this portion, there are 81.7 ug of FA and 6.4 mg of Zn, and these values indicate that the powder contains amounts equivalent to 20 % and 58 % of the daily reference values for pregnant mothers for FA and Zn, respectively, according to Colombian regulations (Resolución, 3803,03, 2016).

3.3.3. Antioxidants, polyphenols, and anthocyanins

The antioxidant activity of the strawberry powder was 34.4 and 61.0 μmol Trolox/g sample, as measured using the ABTS and FRAP methods, respectively. The total polyphenol content was 7.3 mg gallic acid/g sample, and finally, the anthocyanin content was 79 μg cyanidin-3-glucoside equivalents/g sample (Table 4). These findings are consistent with those of Leyva-Porras et al. (2021), who reported polyphenol values in the range of 5.9–10.8 mg gallic acid/g sample and antioxidant activity by the DPPH method in the range of 49.0–81.5 μmol trolox/g sample for strawberry powders obtained by spray drying. These parameters were obtained under drying temperature conditions ranging from 150 to 220°C, similar to those used in this research. Additionally, the results of this work were higher than those found by Sadowska et al. (2020), who reported polyphenol values of 1.3 mg/g sample and anthocyanin values of 52.2 μg Cyanidin-3,5-di-O-glucoside/g sample for strawberry powders obtained by spray drying with maltodextrin as a drying agent and drying temperatures ranging from 90 to 160°C.

The polyphenol content, antioxidant activity, and anthocyanin content of the strawberry powder obtained by spray drying were relatively similar and, in some cases, higher than those reported in the literature, suggesting that the selected drying conditions positively influenced the preservation of these compounds.

4. Conclusions

In conclusion, it was possible to produce a dried strawberry pulp with good physical characteristics and rich in bioactive compounds. Moreover, through experimental design methodologies, it was possible to optimize a dispersed system formulation made from strawberries with optimal concentrations of 11.7 % arabic gum (AG) and 23.3 %

maltodextrin (MD), which was suitable for producing spray-dried powder. The strawberry powder retained the proximate properties and antioxidant activity, polyphenols, and anthocyanin contents typical of these products.

Consequently, the low values for moisture, water activity and hygroscopicity and high values for solubility and density show that the powder that was made is of high quality, can be used in industry, and tends to reduce the economic losses that could come from factors such high transportation costs, deterioration by humidity absorption during storage and damage by microorganism. Lastly, the zinc and folic acid contents make the strawberry powder a potential product for consumption by vulnerable populations such as children and pregnant mothers, who often have deficiencies in these micronutrients.

CRediT authorship contribution statement

Dairon David: Data curation, Methodology, Software, Validation. **Paulo Jose do Amaral Sobral:** Formal analysis, Resources, Validation, Writing – original draft, Writing – review & editing. **Juan Torres-Oquendo:** Conceptualization, Data curation, Formal analysis, Methodology, Software, Writing – original draft. **Daniel Henao-González:** Conceptualization, Data curation, Formal analysis, Methodology, Validation, Writing – original draft, Writing – review & editing. **OSCAR VEGA CASTRO:** Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

All authors declare that we have no conflicts of interest and that the manuscript ""Design and Optimization of a Strawberry-Based Dispersion to Produce a Spray Drying Functional Powdered Product, Fortified with Folic Acid and Zinc" has only been submitted to this Journal.

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