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Development of an instant heme iron-fortified beverage

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Abstract

Iron deficiency is the most widespread cause of anemia and it is estimated that it currently affects population in both low-income and developed countries. Blood is a by-product of meat industry with high nutritional value and important functional properties, as well as, a valuable source of heme iron. The influence of inlet air temperature in a range of 120 to 150 °C and feed flow rate between 300 and 600 mL/h were analyzed to develop an instant beverage for use as a nutritional supplement by spray-drying bovine blood using response surface design. The following response variables were evaluated: yield, moisture and heme iron retention. The best combination was achieved with an inlet air temperature of 124 °C and feed flow rate of 300 mL/h. With these conditions a product with 92.4% yield, 6.7% wb moisture content and 50.7% heme iron retention were obtained. The instant beverage obtained with the optimized parameters presented a good sensory quality.

Keywords: *bovine blood, beverage, nutritional supplement, optimization, spray drying*

1. INTRODUCTION

Malnutrition affects people of all countries and ages, since many of them do not have the necessary resources to acquire nutritious food or are unaware of the need for good nutritional habits (WHO, 2018). One of the most important and common problems that often affects vulnerable subpopulations is iron deficiency anemia (Martín et al., 2015).

Blood is a by-product of the meat industry with high nutritional value and important functional properties. This body fluid is constituted of plasma, which is a protein-rich component, and red blood cells, which contain the blood pigment called hemoglobin (Polo et al., 2004). The low demand in relation to the volume produced and the nutritional properties of blood have motivated the search for alternatives for its use in the field of food, in addition, this by-product constitutes a contaminant for the environment. However, due to its high moisture content, water activity, pH and because it is a nutrient-rich culture medium favorable to the development of microorganisms. Therefore, dehydration is an excellent alternative to prolong its useful life and give the product greater stability, lower volume and easy transportation (Salvador et al., 2009; Jamroz et al., 2012; Drvenica et al., 2019).

Spray drying is one of the most common techniques widely used in the agri-food industry thanks to the fact that it is simple, flexible, low cost and preserves the original properties of the product (Ruiz-Ruiz et al., 2017; Shishir and Chen, 2017; Geranpour et al., 2020).

Certain studies have shown an incidence of drying on functional properties of proteins, yield and moisture content, among other physical and chemical characteristics of the product (Polo et al., 2004; Toldrà et al., 2004; Salvador et al., 2009; Fontes et al., 2010; Salvador et al., 2010; Jamroz et al., 2012; Drvenica et al., 2019; Arévalo-Delgado et al., 2021); but spray-drying parameters were not optimized in any studies. In this work, the optimum inlet air temperature and feed flow rate for spray drying an instant heme iron-fortified beverage were elucidated using response surface methodology.

2. MATERIALS AND METHODS

2.1. Materials

Blood was collected through an open collection system at the pilot plant of the Food Industry Research Institute in January 2022, in compliance with all established hygienic-sanitary measures and using a 0.4% wb citric acid solution was used as anticoagulant. For the formulation of the beverage, 0.05% wb of a strawberry flavoring (code 004105, Ipra France, Nice, France) and 0.05% wb of Aspartame were added. This sweetener was selected due to enhances and extend flavors, helpful for individuals with diabetes and it is beneficial in weight control.

2.2. Spray drying

The experiments were carried out in a lab-scale spray dryer (Buchi MiniSpray Dryer B-290, Labortechnik AG, Flawil, Switzerland), coupled to a dehumidifier B-296 with inlet air relative humidity constant (60%). The drying conditions were mixture feed temperature 25 °C, 0.5 mm injector nozzle, aspirator flow rate 35 m^3/h, drying air flow rate 601 L/h and Outlet air temperature between 54 and 76 °C. Inlet air temperature between 120 and 150 °C and feed flow rate between 300 and 600 mL/h were evaluated. These parameters were chosen based on preliminary experiments, which yielded what appeared to be an acceptable spray dried powder. The experimental runs were made randomly and 100 g of liquid feed were processed each time. The dehydrated products were packed in high-density polyethylene bags and placed in a desiccator until analysis.

2.3. Instant beverage analysis

Moisture content was determined by a thermobalance Sartorious MA37 (Gottingen, Germany) at 105 °C. Yield was calculated by the ratio of the amount of powder collected to total dry matter of the feed solution according to Tontul et al. (2016).

Table 1. Experimental matrix for the drying of the beverage

Temperature (°C)	Feed flow rate (mL/h)	Yield (%)	Moisture (% wb)	Heme iron retention (%)
135	300	92.9	6.44	40.0
135	450	92.0	6.54	42.3
150	450	93.8	6.23	36.7
135	600	92.2	7.37	43.1
120	300	91.8	7.00	52.5
135	450	93.0	6.68	46.8
135	450	92.4	6.50	42.8
135	450	92.7	6.59	45.3
150	600	93.0	6.43	35.6
120	450	90.7	7.18	56.9
150	300	90.3	5.93	42.8
120	600	85.8	8.20	53.1

Heme iron content was obtained by determining hemoglobin derivatives with the originally proposed equations (Salvador et al., 2009). Absorbance readings were obtained at 540, 560 and 576 nm on a UV-Visible UV-2600 spectrophotometer (Shimadzu Corp., Japan). The results were expressed as heme iron retention based on its concentration before and after drying.

2.4. Sensory analysis

The product obtained with the optimal parameters was evaluated sensorially by dissolving 5 g of powder in a glass of water (200 mL). Based on this formulation, a sensory description was carried out with seven experienced tasters (20-32 years, 71% female and 29% male) in the evaluation of blood-based products. Tests were carried out in individual air-conditioned booths (24 °C) in the Sensory Analysis Laboratory/Food Industry Research Institute and evaluated under white light, thus ensuring comfort and privacy for the panelists. The sensory quality was evaluated using a seven-category scale (NC ISO 13299:2007)

2.5. Statistical analysis

The optimization of the inlet air temperature and feed flow rate was performed by response surface techniques (Montgomery, 2013). A three-level factorial design model was used, i.e. two factors with three levels. The response variables were yield, moisture, and heme iron retention. Heme iron yield and retention were maximized, while moisture was minimized, to calculate optimal values. The results were processed by the Design-Expert program ver. 12.1.0.1, 2019 (Stat-Ease, Inc., Minneapolis, USA).

3. RESULTS AND DISCUSSION

3.1. Experimental design

Table 1 shows the experimental matrix of response surface design. The design results for the coded models of each response variable are presented in Table 2. The F values were greater than the value of the Fisher table, therefore, the differences were significant. The lack of fit F value was not significant for any of the models. The determination coefficients (R2) were high in each variable. The predicted R^2 values were reasonable agreement with the adjusted R^2, due to the difference was less than 0.2. Adequate precisions (signal to noise ratio) were well above the accepted value of four (Stat-Ease, Inc., 2019). For all the above, the models can be considered suitable for use in the design space.

3.2. Process yield

The yields varied between 85.8 and 93.8% (Table 1), much higher than those reported between 3 and 27% (Arévalo-Delgado, 2021).

In the model, inlet air temperature and intercept were significant (Table 2). An increase in inlet air temperature improved process yield. According to Shiga et al. (2004), this may be caused by the faster evaporation due to higher heat and mass transfer, inducing water to evaporate quickly with minimal powder loss. Some authors observed this effect during blood spray drying (Arévalo-Delgado, 2021).

3.3. Moisture content

The moisture content remained between 5.93 to 8.20% m/m, similar to those informed for drying of bovine blood (Arévalo-Delgado, 2021) and porcine blood (Fontes et al., 2010).

The inlet air temperature negatively influenced the moisture content. A higher temperature difference between the drying air and the droplets leads to a higher rate of heat transfer within them, which provides the conduction force for moisture extraction. The use of a high inlet air temperature provides more energy to dry the medium and increases heat transfer (Tontul and Topuz, 2017).

The positive sign of the feed flow rate can be explained because the higher the feed flow rate, the slower the transfer of heat and mass, which difficult the proper drying of the microdroplets and, consequently, wetter particles are produced (Shishir and Chen, 2017).

3.4. Heme iron retention

Heme iron has shown a tendency to degradation during heat treatment, some fractions are

Table 2. Parameters of the coded models

Parameter	Yield (%)	Moisture (% wb)	Heme iron retention (%)
Intercept	92.85	6.60	44.83
X_T	1.47**	-0.63***	-7.92***
X_F	-0.65	0.44***	-0.59
X_T^2	-1.29*	0.06	-
X_F^2	-0.98	0.26*	-
$X_T X_F$	2.16**	-0.18*	-
Model *F* value	14.90**	43.64***	18.38***
Lack of fit *F* value	5.73	4.94	2.94
R^2	0.9255	0.9732	0.8033
Adjusted R^2	0.8634	0.9509	0.7596
Predicted R^2	0.5321	0.7746	0.5948
Adequate precisions	13.2615	22.6227	10.6061

*T: inlet air temperature; F: feed flow rate. *$p \leq 0.05$, **$p \leq 0.01$, ** $p \leq 0.001$.*

converted into non-heme iron which has lower bioavailability (Turhan, 2004).
Heme iron retention ranged from 35.6 to 56.9%, which translates to a heme iron content of 92.19 to 150.46 mg/100 g of powder, which were lower than in others reports (Kikafunda and Sserumaga, 2005; Jamroz et al., 2012). However, some of these studies started from a higher blood iron content.
The model showed that an increase in inlet air temperature conditioned the decrease in heme iron. It was not found any study that consider at heme iron retention during spray drying. According to Tontul and Topuz (2017), when a particle is subjected to higher temperature, rapid evaporation of moisture arises at the surface of the particle and consequently, the formation of a hard crust prevents particle shrinkage during drying. A similar relationship was reported for a thermosensitive compound like ascorbic acid during spray-drying of fruit juices (Singh et al., 2013; Pino et al., 2018; Pino et al., 2020). Heme iron degradation is attributed to oxidative separation of the porphyrin ring, which allows iron to be released from the heme complex. In certain cases, it has been shown that hemoproteins did not release their heme half during denaturation, maintaining most of the iron associated with globin at temperatures below 85°C, while in other cases a decreased in heme iron content was observed at temperatures above 55°C (Lombardi-Boccia, 2006).

3.5. Optimization of the process models

The response variables considered most important: yield, moisture and heme iron retention were optimized. From the contour graph (Fig. 1), the point defined by the inlet air temperature of 124 °C and feed flow rate of 300 mL/h was suggested as the best combination for obtaining the instant beverage. With this combination a product with 92.4% yield, 6.7% moisture and 50.7% heme iron retention were obtained.

3.6. Sensory evaluation

According to the descriptive profile, a blood-based beverage was defined with the following characteristics: clean, reddish-brown, shiny liquid; light strawberry odor; strawberry flavor, very slight sweetness, metallic (iron) aftertaste; consistency of a soft drink, liquid, but with body, soft when swallowing. The product sensory quality was rated very good by the trained tasters.

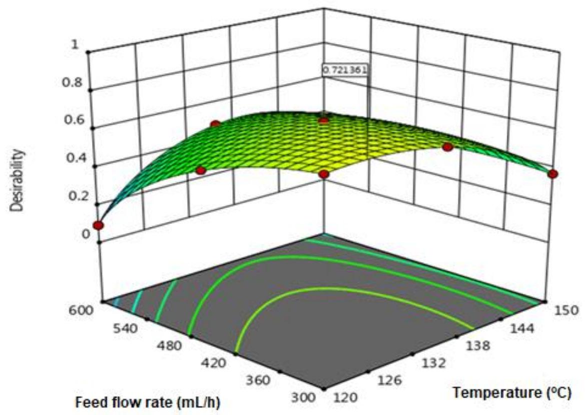

Figure 1. Process optimization response surface plot.

4. CONCLUSIONS

The food industry works to obtain nutritional supplements from animal blood, with the aim of improving the iron status of the population and fighting iron deficiency anemia. The spray-drying study of bovine blood-based supplement revealed the influence of inlet air temperature and feed flow rate on the main response variables. A rise in the inlet air temperature improved process yield, but decreased moisture and heme iron content. While, increasing feed flow rate process caused an increment of moisture content. The best combination for spray-drying the heme iron-fortified beverage was 124 °C inlet air temperature and 300 mL/h feed flow rate. With these conditions, a product with 92.4% yield, 6.7% moisture, 50.7% heme iron retention was obtained. The instant beverage obtained was of good sensory quality for its use as a food supplement.

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