

Microencapsulates of *Stenocereus pruinosus* fermented juice concentrate and their bioactive compounds using maltodextrin, gum arabic, and mesquite gum as carrier agents

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Abstract

Pitaya juice contains high amounts of pigments, especially betalains. In order to obtain the pitaya pigments to be encapsulated, a simplex-lattice-design was used. Pitaya fermented juices were mixed with mesquite gum (MG), gum arabic (GA), maltodextrin (MDX) or their combinations (5% w/v) and encapsulated by spray drying (160°C). Microcapsules were analyzed in color, bioactive compounds and some physicochemical characteristics. All formulations allowed the obtention of powders (yield 64–84%). All powders had moisture content below 6%, water activity around 0.208, and a pale-red color (Hue and Chroma around to 16° and 32, respectively). Powders with MG and GA had the highest red index values. The MG-GA combination retained the higher amount of betalains (3.28 ± 0.09 mg/g powder, particularly betaxanthins). The phenolic compounds content of powders ranged between 8.01 and 10.77 mg Gallic acid equivalents/g powder and a maximum antioxidant activity of 15.05 mg trolox equivalents/g powder, particularly the ternary blend (MG-GA-MDX).

Introduction

Pigments, particularly those obtained from natural sources have gained importance in the food industry, since they could replace synthetic colorants, which have been associated with some ailments when they are consumed frequently. According to some studies, they could alter the children's behavior, increasing respiratory allergies and in extreme cases show genotoxic activity (Amchova et al., 2015). The most common natural pigments are chlorophylls, carotenoids, flavonoids, anthocyanins and betalains (Delgado-Vargas, 2002). The ingestion of natural pigments may promote healthy benefits since they can prevent or help in the treatment against ailments such as cancer, neurodegenerative and cardiovascular diseases, among others (Delgado-Vargas, 2002; Sarı et al., 2019).

Betalains are water-soluble pigments commonly found in the plant vacuoles. They are divided in betaxanthins (orange-yellow) and betacyanins (red-purple) (Chandrasekhar et al., 2015; Delgado-Vargas, 2002). Betalains possess high antioxidant activity and may have antimicrobial properties against some microorganisms (Choo, 2018).

Pitaya (*Stenocereus pruinosus*) fruits are endemic to Mexico. Pitayas have a berry shape with middle large thorns, small and edible black seeds, and mucilaginous flesh with white, yellow, pink, orange, red or purple colors (García-Cruz et al., 2017). The pitaya pulp is the largest part in the fruit and represents the edible portion (García-Cruz et al., 2013). The consumption of pitaya could provide to humans the benefits of betalain compounds due to their high amount as well as other benefits provided by flavonoids, carotenoids, sterols, triterpenes, iron (Fe), and ascorbic acid (García-Cruz et al., 2017; Ramírez-Rodríguez et al., 2020). However, the short shelf life of the fruit and short period of production may limit their consumption (Ochoa-Velasco & Guerrero Beltrán, 2013). On the other hand, since pitaya is a climatic fruit, it last only for few days in fresh fashion. In addition, the environmental conditions (temperature, pH, light and oxygen) and its high sugar content may cause the loss of color of betalains in the juice (Khan and Giridhar, 2014).

Encapsulation of natural compounds, such as pigments, has shown to extend the pigments stability, being spray drying one of the most used method due to the low cost, simplicity and short time of processing (Bakry et al., 2016; Santos et al., 2018). The operational parameters and mixture of encapsulates plays an important role through encapsulation and drying. Therefore, some researchers suggest that a pretreatment applied to the extract of the material, before spray drying, could increase the amount and stability of betalains before encapsulation (Castro-Enríquez et al., 2020; Kumar and Giridhar, 2017; Quirós et al., 2019; Sravan Kumar et al., 2014).

A pretreatment of fermentation of the material to be spray dried could help the drying process due to the reduction of fermentable sugars. The fermentation of low molecular weight (low glass transition temperature) compounds such as sugars will avoid that the powder be adhered to the walls of the dryer during the process (Bhandari et al., 1997; Santos et al., 2018). *Saccharomyces cerevisiae* yeast is commonly used for making this fermentation, hydrolyzing sugars and pectic substances in the juice. *S. cerevisiae* release pectinolytic enzymes for hydrolyzing pectins in the system (Poondla et al., 2015); despite, commercial enzymes can also be used for hydrolyzing pectic substances in liquid food systems such as fruit juices. Commercial enzymes have the disadvantage of requiring special means for their production, which result in high costs.

The addition of carrier agents to the liquid to be spray dried improve the yield of the obtained powder due to the reduction of stickiness and the increase of the glass transition temperature of the final product. The most common carrier/encapsulation agents are starches, gums, lipids, and proteins (Jiménez-González & Guerrero-Beltrán, 2021). Furthermore, the use of different carrier agents may result in a final product with physicochemical properties that are characteristic of each agent; however, in some cases, the combination of carrier agents could improve the properties of the powders such as the retention of color. To the scientific knowledge, no research has been reported about the encapsulation of betalains using mesquite gum as carrier or its combinations with other agents such as gum arabic and, or maltodextrin.

The aim of this study was to evaluate the effect of the combination of three encapsulation agents (mesquite gum, gum arabic, maltodextrin) for obtaining powders, by spray drying, of fermented red pitaya juice.

Materials And Methods

Materials

A local grower from Puebla, Mexico provided the pitaya (*Stenocereus pruinosus*) fruit. After arrival, fruits were sorted for separating damaged fruits. Fruits were left to complete their maturity by checking color and firmness as ripening indicators. Fruits were washed, disinfected with a sodium hypochlorite solution (1% v/v) and surficial water removed using paper towel. Then, peel was removed by hand, pulp placed into polyethylene bags and stored at -20°C for later use.

Pre-treatment of pitaya juice

Inoculum

Saccharomyces cerevisiae strain DBVPG6765 was acquired from the Food Microbiology Laboratory collection of the Universidad de las Americas Puebla (UDLAP), Cholula, Puebla, Mexico. The yeast inoculum was stored in vials in glycerol [1:1, v /v] at -20°C until use. Every time that the fermentation of pitaya juice was performed, one vial of yeast inoculum was suspended in 50 mL of sterilized Sabouraud Dextrose Broth (Microtech Scientific, BD Difco) and incubated at 25°C in a shaking bath until the culture reach the early stationary phase; this value was determined by optical density using a Jenway 7305 spectrophotometry (Cole-Parmer, Jenway, United Kingdom) at 660 nm reading every hour until the value of the absorbance was the same for at least three times. In the growing stationary phase, yeasts plate counts were performed to determine the colony forming units (CFU) of yeast per mL of broth; this was around 2.16×10^7 CFU/mL.

Fermentation of juice and concentration

Pulp was thawed during 24 h at refrigeration conditions (4°C). The homogenized pulp was filtered for removing seeds and large particles. The inoculum was added to the juice fruit at a ratio of 1:100 (v/v). The inoculated-fruit juice blend was placed in two glass beakers; therefore, fermentation was made at 27°C for 72 h in a shaking bath at 80 rpm under dark conditions to avoid pigment degradation. The fermented juice was centrifuged at 6,000 rpm for 10 min at 4°C. Finally, juice was concentrated in a rotatory evaporator (Büchi, R-300, Flawil, Switzerland) at 35°C and 33 mmHg until reaching 6°Bx (6% w/w of total soluble solids). Therefore, the concentrated juice was adjusted to 5°Bx.

Experimental design

Single, double, and ternary mixtures interactions of the coating agents were used for the encapsulation of concentrated juice. The independent variables considered in this study were gum arabic (GA) (CEDROSA S.A. de C.V.), maltodextrin (MDX) (Ingredion S.A. de C.V.) and natural mesquite gum (MG) purified according to the Beristain et al. (2002) procedure. Seven formulations of concentrated juice-encapsulated agent were used.

Results were adjusted to the following polynomial model (Eq. 1):

$$y = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 + \beta_{123} x_1 x_2 x_3$$

1

where y values are the different responses (yield, moisture content, water activity (a_w), Hue, Chroma, total betalains, phenolic compounds, antioxidant activity), β_n values are the coefficients and x_1 , x_2 , x_3 are the concentration of maltodextrin, mesquite gum, and gum arabic, respectively.

Concentrated juice-encapsulated agent

All concentrated juice-encapsulation agent (CJEA) blends were obtained by taking 12.5 g of gum (or mixture) and made up to 250 mL to get a concentration of 5% (w/v) of gum (or preparing the amount of powder solution to be spray dried). Blends of CJEA at the corresponding gum and amount of gum were homogenized at maximum speed using a magnetic stirrer at room temperature until the encapsulating material was completely incorporated.

Spray drying

For encapsulation, 250 mL of the blends of CJEA were fed in a mini spray dryer (Büchi, Mod. B-290, Switzerland) at flow rate of 2.79 ± 0.18 mL/min (3.15 ± 0.18 g/min), air flow of 3.5 m/s (100%), pressure of 1.05 bar, and inlet temperature of 160°C. A nozzle of 0.7 mm in diameter was used. A constant aspiration power of 100% along the process was applied (Ochoa-Velasco et al., 2017). The obtained powder was weighed immediately after finishing the drying process. The encapsulated pigments were stored at room temperature in amber glass bottles for later analysis.

Physical characteristic of concentrated juice

The *concentrated juice* was physicochemical analyzed in total soluble solids (Hand refractometer, Atago F7, Tokyo, Japan), moisture content by gravimetric method at 105°C until constant weight, viscosity (Brookfield viscometer, DV-I, Stoughton, USA), density, and color parameters (L^* , a^* , b^*) with a portable CR-400 colorimeter (Konica Minolta, Osaka, Japan) with a standard illuminant D65 and a 2° standard observer. Hue ($Hue = \tan^{-1}(b^*/a^*)$), and Chroma ($Chroma = (a^{*2} + b^{*2})^{1/2}$) and red index ($RI = 90.909 \times (a^*/L^*)$, a modification of yellow index calculation considering maximum value of a^* as 110 and L^* as 100) (Rhim et al., 1999), were calculated.

Yield and physicochemical characteristics of powders

Yield

The powder yield was calculated according to Eq. (2).

$$Yield(\%) = \frac{PW}{EA} \times 100$$

2

where PW is the weight of powder (g) obtained from the spray drying process, EA is the encapsulation agent (g) plus the total solids (g) in the concentrated juice.

Moisture content and water activity (a_w). Moisture content was determined by drying about two grams of powder at 75°C until constant weight. The a_w was determined using an AQUALAB hygrometer (AQUALAB, Pullman, WA, USA).

Bulk and tapped densities. The powder was weighted (approximately 2 g) and placed into a 10 mL graduated cylinder. The bulk density was calculated by dividing the mass of powder by the volume

occupied in the cylinder. The tapped density was calculated after tapping the cylinder for 1 min on a flat surface; therefore, density was recalculated with the mass and the new volume.

Color. Color of the powder was measured with a quartz cylindrical cell ($\phi = 45$ mm, 17 mm depth) for measuring the L^* , a^* and b^* color parameters.

Particle size. The particle size distribution was measured using a Laser Diffraction Particle Size Analyzer (Bluewave, Microtrac, USA).

Bioactive compounds in concentrated juice and powders

For concentrated juice, an aliquot of sample was taken directly for analysis. On the other hand, For microencapsulated pigments, 200 mg of the powder was dissolved in 20 mL water and vortexed for 1 h at high speed. All samples were centrifuged at 6,000 rpm at 15°C for 15 min and filtered through Whatman paper No.1.

Betalain quantification

For betalains quantification, a spectrophotometric method was used as described by Herbach et al. (2006). The calculations were made with the maximum absorption values at 535 and 483 nm for betacyanins and betaxanthins, respectively. The total betalains content was the sum of betacyanins and betaxanthins calculated according to Eq. (3).

$$\text{Betacyanins or Betaxanthins} \left[\frac{\text{mg}}{\text{g}} \right] = \left[\frac{A(DF)(MW)Vd}{\epsilon LWd} \right]$$

3

where A is the maximum absorption value at 535 and 483 nm, DF is the dilution factor, Vd is the volume of sample in mL (concentrated juice or rehydrated powder), Wd is the weight in grams of the sample, L is the quartz cell pathway (1 cm). The molecular weight (MW) and molar extinction coefficient (ϵ) for betacyanin are 550 g/mole and 60,000 L/mole-cm in water, respectively; and for betaxanthins are 350 g/mole and 48,000 L/mole-cm in water, respectively.

Antioxidant activity (DPPH)

Antioxidant activity was determined by the inhibition of the DPPH (2,20-diphenyl-1-picrylhydrazyl) (Sigma-Aldrich, USA) radical. DPPH assay with modifications was done by adding 200 μL of sample to 2 mL of 0.1 mM DPPH (absorbance 0.9 ± 0.05 at 517 nm). After 30 min, the absorbance was read at 517 nm (Brand-Williams et al., 1995). The percentage of inhibition was calculated using Eq. (4). Results (Eq. (5)) were reported as Trolox (Sigma-Aldrich, USA) equivalents (TE) from the standard equation plot at different Trolox concentrations.

$$\text{Inhibition}(\%) = \frac{Abs_0 - Abs_t}{Abs_0} * 100$$

$$TE \left(\frac{mg}{mL} \right) = \left(\frac{A - b}{m} \right) * DF * 100$$

where Abs_0 is the absorbance of the DPPH reagent at time 0, Abs_t is the absorbance at the steady state for DPPH, A is the absorbance of the sample, b is the intercept (1.107), m is the slope (0.780 L/mg) with $R^2 = 0.992$, and DF is the dilution factor of the sample.

Total phenolic compounds

The total phenolic compounds content was determined by the Singleton & Rossi (1965) method with a few modifications. Briefly, 200 μ L of sample was mixed with 2 mL of water and 200 μ L of Folin-Ciocalteu's reagent (Sigma-Aldrich, USA); then, the mixture was incubated for 3 min in the dark. After this time, 1 mL of 2M Na_2CO_3 was added. After 30 min of incubation in the dark, the absorbance was measured at 765 nm in a UV/Vis spectrophotometer. The results were reported as Gallic acid equivalents (GAE) from the standard equation plot at different Gallic acid concentrations. Total phenolic compounds were calculated with Eq. (6).

$$GAE \left(\frac{mg}{100mL} \right) = \left(\frac{A - b}{m} \right) * DF * 100$$

where A is the absorbance of the sample, b is the intercept (0.0008), m is the slope (0.006 1/mg) with $R^2 = 0.998$, and DF is the dilution factor of the sample. Results were reported as mg of Gallic acid per 100 mL of sample.

Statistical analysis

ANOVA and Tukey test ($P = 0.05$) were performed to observe the differences between the means over the independent variables using Statistix 8.1 software. Respond surface of special cubic mixture design model was developed using the Design Expert program 7.0.0 (Stat Ease Inc., USA).

Results And Discussion

Characteristics of fermented pitaya juice

Table 1 shows the physicochemical characteristics of juice after fermentation (enzymatic liquefaction). The fermented juice showed a total consumption of reducing/fermentable sugars analyzed with Fehling's solution (data not shown). The juice had 7.5% of total solids ($^{\circ}Bx$) and moisture content of $92.42 \pm 1.19\%$

(w/w). The viscosity of 31 could optimize the spray drying process by preventing the clogging of the nozzle (Sun-Waterhouse & Waterhouse, 2015). Color of the fermented juice was bright red, characteristic of pitaya fruit; however, it was different of non-fermented juice reported by other authors (García-Cruz et al., 2013; García-Cruz et al., 2017). The fermented juice was rich in antioxidant compounds such as betalains, containing a slighter amount of betaxanthins compared to betacyanins, similar to unfermented fruit reported by García-Cruz et al. (2013); however, the fermentation process might reduce the amount of these compounds (García-Cruz et al., 2013). The fermented pitaya juice had a total amount of betalains similar to pulps of *Stenocereus pruinosus* (García-Cruz et al., 2013), *Stenocereus stellatus* pitayas (Pérez-Loredo et al., 2016). In addition, the juice retains phenolic compounds with antioxidant activity (1431.50 ± 36.94 mg GAE/100 g db).

Table 1

Characteristics of powders

Yield, moisture content and aw

The Yield, moisture content, and a_w of microencapsulates are shown in Table 2.

Yield. All yields (64.62–84.73%) obtained in this research about encapsulating of pitaya juice had significant differences ($P < 0.05$) and were higher than 50%; similar to those obtained for the spray dried beetroot juice with blends of GA and MDXs of different dextrose equivalents (Bazaria & Kumar, 2017). The tendency is showed in Fig. 1a. The polynomial model (Eq. 1) gave a good fit ($R^2 = 0.990$) for the data of yields (Table 3, Fig. 2). A decrease in the powder yield with the use of MDX and MG is observed. The reduction in yield could be attributed to a deficient drying process and the attachment of the droplets to the wall of the drying chamber. It is important to say that some researchers have mentioned that yields up to 50%, obtained by spray draying, are considered for an efficient process (García-Lucas et al., 2016). Coimbra et al. (2021) pointed out that three types of interactions could happen between the encapsulation agent and the core of the encapsulated; these are: i) polymer-bioactive compounds interactions, ii) polymer-polymer interaction, and iii) synergic effect between two or more polymers to obtain better physicochemical properties. The former explains how binary mixtures of gums such as the MDX:GA and MG:GA mixtures had the highest yields.

Table 2

Figure 1

Table 3

Figure 2

Moisture content. The moisture content values ranged from 1.05 ± 0.12 to 6.70 ± 0.10 (Table 2). No significant differences ($P > 0.05$) were observed within single encapsulating agents. The blends of binary

and ternary agents (Table 2, Fig. 1b) showed statistical differences ($P < 0.05$); however, the model (Eq. 1) fitted to experimental data ($R^2 = 0.980$) satisfactorily (Table 3, Fig. 2). The differences in moisture content could be attributed to the different temperature gradients between the atomized liquid and the hot air since the atomized droplets size depend on the differences of the liquid viscosities and molecular weight caused by the encapsulation materials. García-Lucas et al. (2016) pointed out that moisture contents below of 4% were chemical and microbiological safe in some fruit products. Most the values obtained in this research can be classified as safe and stable (Table 2) about physicochemical reactions and microbial growth.

Water activity (a_w). All values of a_w of powders in this research were below 0.208. Water activity values of powder below 0.6 can be considered stables (da Silva et al., 2013). Statistical differences ($P < 0.05$) were observed in a_w of powder among encapsulation agents (Table 2). The differences could be due to the molecular structure difference in encapsulation agents, particularly due to the ramifications and hydrophilic functional groups (Akhavan Mahdavi et al., 2016) of the encapsulation material (different agents). Higher a_w values were observed in powders with MDX, followed by powders with MG and GA. It can be seen in Fig. 1c, how the addition of different encapsulation agents to the mixture decreases a_w values. As a result, these formulations might extend the shelf life of encapsulated pigments.

Densities of powders

The densities of powers of fermented pitaya juice are shown in Table 2. *Bulk density (ρ_b)*. It varies from 0.197 to 0.220 g/cm³. Powders with MDX and GA had the lowest and the highest values, respectively. Similar behavior was observed by Mahdavee Khazaei et al. (2014) in the encapsulation of saffron petals juice with MDX 7DE and GA. The rest of the formulations of powders showed similar ρ_b values with no significant difference ($P > 0.05$) among them. *Tapped density (ρ_T)*. A different tendency was observed in tapped densities. Values ranged from 0.197 to 0.330 g/cm³. The powder with MDX had the lowest values of tapped density. It has been mentioned that, in presence of MDX, the air inside of particles could be expanded (Utpott et al., 2020); consequently, a reduction in density may occur. The powders of GA, MDX-GA, and MDX-GA-MG had the higher tapped densities ($P > 0.05$). All formulations of powders that contain MG, as part of the encapsulating mixture, were similar in densities, with the exception of the ternary combination.

Color of powders

L^* , a^* , b^* color parameters values are shown in Table 4. The three, lightness (L^*), red-green (a^*) and yellow-blue (b^*), color parameters presented significant differences ($P < 0.05$) among the single, double or triple encapsulating agents. Both the a^* and b^* values of powders were positive; meaning that they are located in the first quadrant of CIELab color space (Baquero-Peña & Guerrero-Beltrán, 2017; Ochoa-Velasco et al., 2017). The powders obtained in this work were lighter in color (lower a^* , b^* and *Chroma* values) compared to those obtained by García-Lucas et al. (2016) for pitaya juice encapsulated with MDX and pectin at different temperatures. They collected the powder in the cyclone and the powder attached

to the drying chamber, exposed to high temperatures for more time; therefore, very probably powders darkened due to some reactions such as caramelization. The *Hue* values of powders were near to 16°, similar to those of the juice. The color saturation (*Chroma*) remains close to the value of the juice. *Chroma* and *Hue* does not take into account the *L** values; however, the *L** values are the parameter that more evident change may have, compared to the juice *L** value. The red index (Table 4) indicate that color reduced approximately 30% due to the dilution of the color because of creamy-white encapsulations agents. In the case of the contour plots (Fig. 1d and e), good fits with the model ($R^2 = 0.900$ and 0.880 , for *Hue* and *Chroma*, respectively (Table 3)) were obtained. The use of GA, as the only agent, reduced *Hue* values. On the contrary, the use of single encapsulation agents increased *Chroma* values; however, they were reduced in the binary and ternary blends of gums in the powders.

Table 4

Particle size

The particle size of powders of pitaya juice are illustrated in Fig. 3. It can be seen that all agents, including binary and ternary blends, had polymodal size distributions. A clearly secondary peak was observed for the MG-GA (Fig. 3f) formulation, which can be characteristic of agglomeration of particles. The particles exhibited wide range with diameters ranging from 0.75 to about 209.3 μm . The lower mean particle size was observed in powder with GA ($D [4,3] = 5.04 \mu\text{m}$). The higher mean particle size was around 11.2 μm for the MG-GA powder formulation. Some authors suggest that bigger microparticles might retain better the pigments (Garrido Makinistian et al., 2020). The agglomeration of powders results in an increase of the mean particle size, especially when two combined agents are used as encapsulations materials. Span or particle size distribution was lower in powders of the ternary blend, MG, and GA as encapsulating agents, which indicate that sizes are more homogeneous, and consequently provide better dispersibility properties (Ding et al., 2020). A peak in smaller was observed in powders of MDX and MDX-GA. Some reports have suggested that the reduction in particle size in powders could improve solubility and bioavailability due to the higher surface area (Vasile et al., 2020). On the other hand, very small particles and greater surface area might increase the molecular interaction and a degradation of the encapsulated compounds may occur (Otálora et al., 2018).

Figure 3

Bioactive compounds of microencapsulated pigments

Total betalains

Table 5 shows the bioactive compounds of powders of fermented pitaya juice. The total amount of betalains ranges from 2.92 to 3.28 mg/g of powder in dry basis (db). Similar values were reported by Bazaria & Kumar (2016) in the encapsulation of concentrated beetroot juice with whey protein. The polynomial model did not fit well experimental data ($R^2 = 0.750$), indicating that the model only explains 75% of the experimental values (Fig. 1f, Fig. 2, Table 3). Less amounts of betalains were observed in powders with MDX, MDX-GA and MDX-MG-GA in comparison with the other powders ($P < 0.05$). On the

contrary, high amount of betalains was observed in the powder of MG-GA. An increase in betalains content may indicate that the blend of both encapsulating agents could protect pigments better than using only one encapsulating agents. In comparison with GA, used for making powders, MG has only been used as encapsulation material for encapsulation few compounds; is has been used for preventing the oxidation of orange peel oil (Beristain et al., 2002). MG, in combination with zein, make a good combination to encapsulate grape seed extracts (Davidov-Pardo et al., 2013). Jiménez-Aguilar et al. (2011) used MG for avoiding the losses of anthocyanins from blueberry.

Table 5

Phenolic compounds

Table 5 shows the amount of total phenolic compounds in powders of fermented pitaya juice. The amount of phenolic compounds were higher than betalains, very probably due to others compounds present in the juice or formed during fermentation (Hur et al., 2014) or some interferences like ascorbic acid (Sánchez-Rangel et al., 2013). The total phenolic compounds ranged from 8.01 to 10.77 mg GAE/g powder in db. The difference in phenolic compounds loses could be attribute to the contribution of each encapsulation agent to the glass transition temperature of the encapsulation mixture, and an inherent change in heat capacity that affect the drying rate (Ghosh Dastidar and Chakrabarti, 2019). In addition, Some researchers have suggested that thermal processes could induce the alteration in the molecular structure of phenolic compounds, which could cause degradation (Bazaria and Kumar, 2016; Kuhn et al., 2020). The contour plot (Fig. 1g) shows the behavior of phenolic compounds according to the different encapsulation agents. Figure 2 show the experimental values fitted to the predict values ($R^2 = 0.910$, Table 3). It can be noticed that the powder with MG and MG-GA show higher amounts of phenolic compounds. In contrast, the powders with GA and MDX-MG had the lower amount of phenolic compounds ($P < 0.05$).

Antioxidant activity

Table 5 shows the antioxidant activity in powders of fermented pitaya juice. It can be noticed that phenolic compounds influence more in antioxidant activity than betalains. The polynomial model showed a good fitting ($R^2 = 0.930$) with the experimental data (Fig. 2, Table 3). The antioxidant activity had significant differences ($P < 0.05$) in powders, which could depend on the encapsulation material (Table 5). These differences could be attributed to functional groups interactions, molecular structures and ramification that may help to the pigments stability (Zhang et al., 2020). Lower values of antioxidant activity were observed in powders with GA. On the other hand, high antioxidant activity was observed in powders when MG was added to the mixture, being the MG, MG-GA, and ternary MDX-MG-GA blends with approximately 12.40 to 15.05 mg TE/g powder in db. Recent studies reported that MG contains high content of phytochemicals present naturally in the gum compared to GA, exhibiting better antioxidant activity (Vasile et al., 2019). Only a slight reduction of antioxidant activity was observed when MDX and MG were combined (10.70 mg TE/g powder in db) (Fig. 1h).

Conclusions

Microencapsulation of fermented red pitaya juice by spray drying using mesquite gum, gum arabic and maltodextrin as encapsulating materials allows the obtention of powders. High yields were obtained for all formulations (64–84%). The use of simplex lattice design shows the difference in the combinations of encapsulation agents. All powders obtained might be microbiological and chemical stable due to the low values of moisture and a_w ($< 6\%$ and < 0.208 , respectively). Powders retained the color of the juice, and they might be used as colorant in foods. Microcapsules retain bioactive compounds. Betaxanthins were found in greater amount in comparison to betacyanins. Antioxidant activity were governed especially by other phenolic compounds rather than betalains. Further studies need to be done to evaluate the potential of powders as colorant applied in food systems.

Declarations

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FUNDING DECLARATION

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CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

AUTHORS CONTRIBUTION

The authors J.A. Guerrero-Beltrán and O. Jiménez-González contribute to design and plan the experiments. The authors O. Jiménez-González performed the technical part (measurements, procedure, and analysis). The authors J.A. Guerrero-Beltrán and O. Jiménez-González analyzed data and interpreted data. The authors J.A. Guerrero-Beltrán and O. Jiménez-González discussed the results and wrote the manuscript.

DATA AVAILABILITY

All data obtained and analyzed from this research are included in this article.

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Tables

Table 1-5 are available in the Supplementary Files section.

Figures

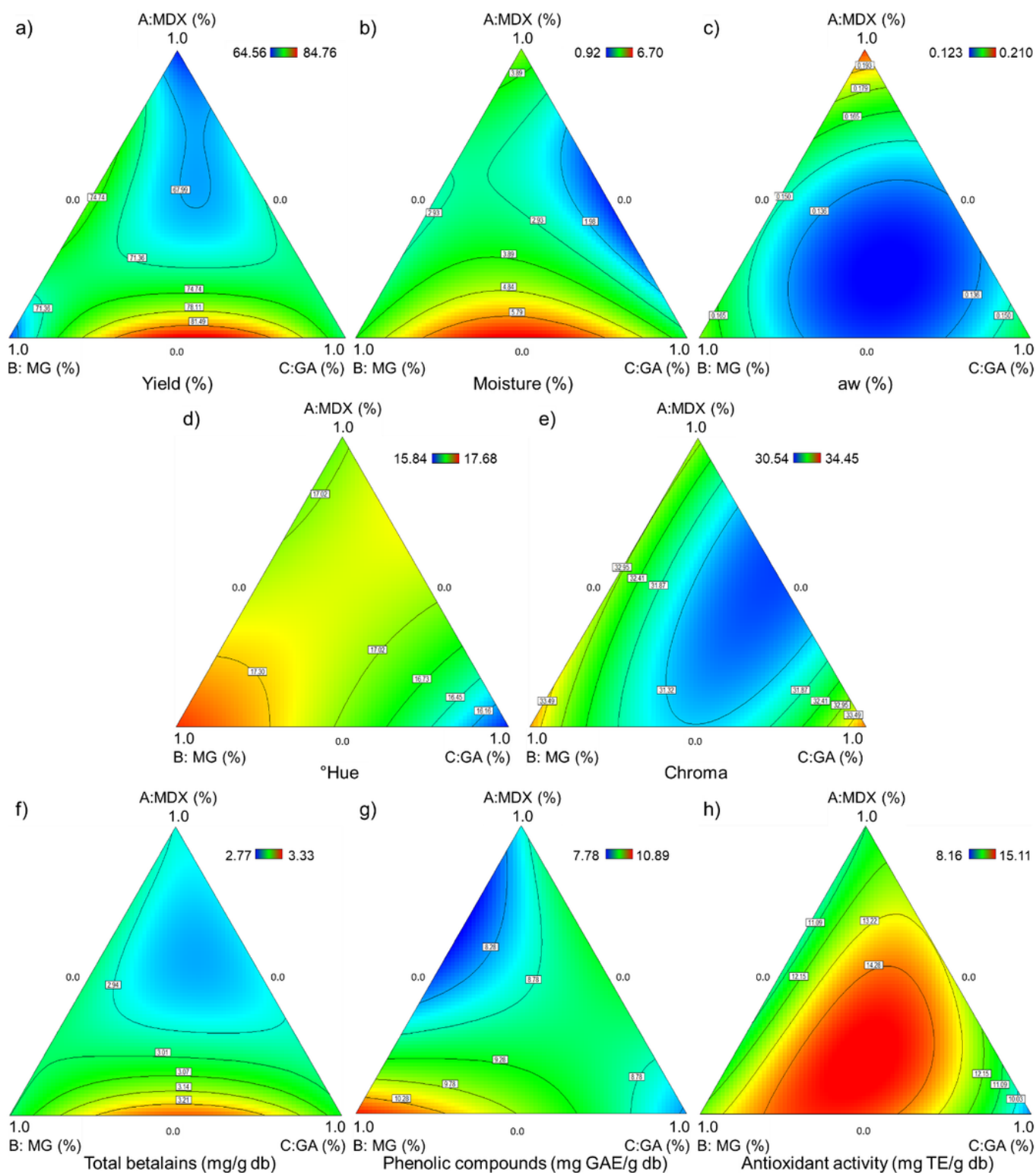


Figure 1

Contour plots of influence of encapsulating materials (maltodextrin, MDX, mesquite gum, MG, and gum arabic, GA) on a) Yield, b) Moisture content, c) a_w , d) Hue, e) Chroma, f) Total betalains, g) Phenolic compounds, h) Antioxidant activity.

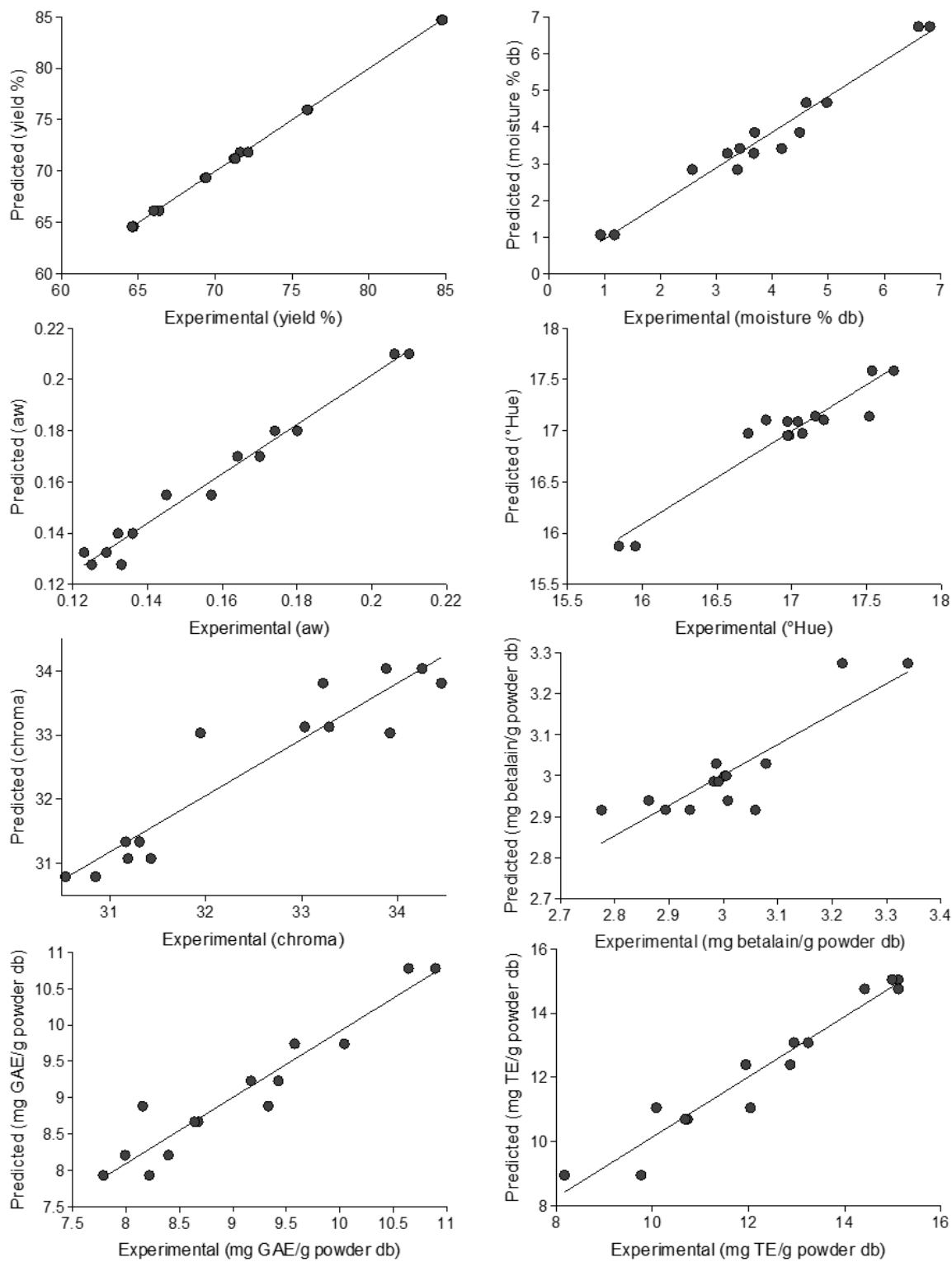


Figure 2

Polynomial models for yield, moisture content, water activity, color properties (Hue, Chroma) and antioxidant characteristics (betalains, polyphenols and antioxidant activity).

Figure 3

Particle size of different formulations of hydrolyzed pitaya juice by fermentation a) MDX, b) MG, c) GA, d) MDX-MG, e) MDX-GA, f) MG-GA, g) MDX-MG-GA, h) Boxplots of particle size (lower and upper quartiles appear as a box, and minimum and maximum values as whiskers).

Supplementary Files

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