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ORIGINAL PAPER

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OPTIMIZATION OF MANGO-PINEAPPLE JELLY SPHERE PRODUCTION BY FROZEN REVERSE SPHERIFICATION USING A FULL FACTORIAL DESIGN

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ABSTRACT

Background. The bite-sized jelly sphere with a gelatinous exterior and fruit puree interior is a type of innovative fruit-based dessert. This study aimed to produce jelly spheres with a gelatinous exterior and mango-pineapple puree interior by using frozen reverse spherification.

Materials and methods. A full factorial design (2^3) was applied to study the effects of mango-pineapple ratio (x_1), immersion time in sugar solution (x_2), and concentration of sugar solution (x_3) in the production of mango-pineapple jelly spheres using frozen reverse spherification. The responses studied were the physicochemical properties (color, total soluble solids, and texture) and sensory evaluation of mango-pineapple jelly spheres.

Results. Mango-pineapple ratio had a positive effect on a^* and b^* while having a negative effect L^* value on the jelly sphere. Total soluble solids of jelly spheres were influenced by both immersion time in sugar solution and concentration of sugar solution. Immersion time in sugar solution had a positive effect on the peak force of the compression cycle and deformation at peak load while having a negative effect on the total soluble solid of jelly spheres. On the other hand, the concentration of sugar solution had a positive effect on the sensory evaluation in terms of flavor, texture, and overall acceptability. The desirability function approach was used to optimize the factors, and an overall desirability of 0.89 for all responses was achieved with 1.28:1 mango-pineapple ratio, 30 mins immersion time in sugar solution, and 22°Brix sugar solution. A proximate analysis of the optimized mango-pineapple jelly spheres had an energy content of 73.18 kcal/100 g and showed nutrient values of 81.11% moisture, 0.10% ash, 0.46% protein, 0% fat, 0.97% total dietary fiber, and 17.35% digestible carbohydrate.

Conclusion. The development of the optimal mango-pineapple jelly sphere allows food producers to produce a dessert that is low in calories, with a good appearance and consumer acceptability.

Keywords: fruit, spherification, full factorial design, encapsulation

INTRODUCTION

Consumption of fruit has regularly been associated with a decreased risk of degenerative diseases such as cancer and coronary heart disease, due to the presence of health-promoting phytochemicals such as carotenoids, flavonoids, phenolic compounds, and vitamins (Codoner-Franch et al., 2013; Ribeiro et al., 2007). Mango is valued as a source of bioactive compounds with potential health-promoting activity, such as dietary fibre, various carotenoids and polyphenols (Palafox-Carlos et al., 2012). It is a good source of

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essential vitamins and dietary minerals such as Vitamin A, Vitamin C, calcium, potassium, magnesium and iron (Ribeiro et al., 2007). Pineapple, on the other hand, contains an excellent source of vitamin A, B, and C as well as the minerals calcium, phosphorous, magnesium, potassium, iron, copper, and manganese (Yuris and Siow, 2014).

Spherification is a technique that is commonly used in molecular gastronomy to form spherical elements that contain a physical outer gel membrane with a liquid core (Gibbs and Myhrvold, 2011). Spherification was first patented in 1946 as a technique to create a matrix type encapsulation of lipid-based flavors and ingredients for the manufacture of edible artificial cherries and other soft fruits (Peschardt, 1946). Reverse spherification is a type of spherification that involves high calcium or calcium-fortified liquid foods being put into a sodium alginate bath (Gibbs and Myhrvold, 2011). Frozen reverse spherification is a refinement of reverse spherification with the extra step of pre-freezing liquid foods with a calcium content in a mold, before immersing it in a sodium alginate bath (Potter and Ruhlman, 2010).

The optimization technique is an efficient and systematic tool to find the best solution from the set of all possible ones. The ultimate aim of optimization is to produce a product with a desirable combination of properties. Hence, the optimization procedure involves the selection of critical product attributes (Ekpong et al., 2006). Consumer acceptance is of prime importance in food product development; thus, food product optimization often involves sensory evaluation (Abdullah and Cheng, 2001; Acosta et al., 2008). Desirability function is a type of optimization technique that is useful in finding an optimal experimental condition for multiple responses established as ideal by combining all responses into one measurement (Viera et al., 2012).

One fruit-based dessert that is available on the market is flavored fruit jelly. Maleki et al. (2020) use bayberry syrup while Gaikwad et al. (2019) produce sweet water balls using mango flavors. On the other hand, reverse spherification has been applied in the production of radish alginate hydrogel beads (Tsai et al., 2017), while Bubin et al. (2019) produced pitaya pearls.

These fruit-based desserts generally contain artificial flavors, artificial colors, and preservatives with little nutritional value (Kipfer, 2011). As frozen reverse spherification is a technique of molecular gastronomy which is relatively new, scientific study about this process is scarce. Hence, preliminary research is needed to obtain information about frozen reverse spherification as a basis for future studies. Mango and pineapple have been chosen to make the fruit puree. Mango and pineapple are exotic fruits with attractive sensory characteristics that are not yet commonly found in global markets but have the potential to be popularized globally (Rawson et al., 2011). The objectives of this study were to optimize the production of bite-sized jelly spheres with a gelatinous exterior and mango-pineapple puree interior by frozen reverse spherification. The effects of different mango-pineapple ratios, immersion time in sugar solution, and concentration of sugar solution on the physicochemical and sensory properties of the mango-pineapple jelly sphere were investigated.

MATERIALS AND METHODS

Materials

Locally grown ripe mangoes (*Mangifera indica* L. cv. Chokanan) and Josephine pineapples (*Ananas comosus* L. var. *comosus* cv. Josephine) were purchased from a local market (AEON, Klang Valley, Malaysia). Food grade sodium alginate (R&M chemicals, UK) and calcium lactate (V.I.S. Food Tech, Malaysia) were used without further purification. Caster sugar (Central Sugars Refinery, Malaysia) was used to make the packing media for the jelly spheres produced.

Experimental design and statistical analysis

The formulations were optimized using a two-level factorial experimental design with 3 variables, which were mango-pineapple ratio (1:1–4:1), immersion time in sugar solution (5–30 mins), and concentration of sugar solution (10–22°Brix). As the central point of the experimental design was repeated twice, the total number of experimental points was 10. These included 8 experimental points with combinations of the three factors across two levels of each and 2 central points. Table 1 shows the coded formulation with different levels of variables (low level: –1, central point: 0, high level: +1) in a randomized run order.

The effects of the variables (mango-pineapple ratio, immersion time in sugar solution, and concentration of sugar solution) on the responses [flavor, texture, overall acceptability, peak force, deformation at peak load, TSS, color (L^*, a^*, and b^*)] were determined by ANOVA, and performed using Statgraphics Centurion XVII software (Statpoint Technologies, USA, 2014).

A two-factor interaction model was selected, with its empirical model shown as:

$$Y_e = b_0 + b_1X_1 + b_iX_i + b_{12}X_1X_2 + \ldots + b_{ij}X_iX_j + \ldots$$

where:

Y_e – estimated response,
b_0 – model constant,
b_i – model coefficient reflecting simple effects,
b_{ij} – model coefficient reflecting interactive effects,
X_i – coded input variables.

The coefficient, b, was calculated by multiple linear regression, and its significance was estimated using ANOVA.

Table 1. Run orders of formulations and magnitude of factors of the experiments of the factorial design

Run order	Factors		
	mango-pineapple ratio x_1	immersion time in sugar solution x_2 mins	concentration of sugar solution x_3 °Brix
1	1:1 (–1)	5 (–1)	22 (+1)
2	4:1 (+1)	5 (–1)	10 (–1)
3	1:1 (–1)	30 (+1)	10 (–1)
4	4:1 (+1)	30 (+1)	22 (+1)
5	1.86:1 (0)	17.5 (0)	16 (0)
6	1:1 (–1)	5 (–1)	10 (–1)
7	1.86:1 (0)	17.5 (0)	16 (0)
8	4:1 (+1)	5 (–1)	22 (+1)
9	4:1 (+1)	30 (+1)	10 (–1)
10	1:1 (–1)	30 (+1)	22 (+1)

Raw material preparation process

The mangoes and pineapples were rinsed with running water to remove any dirt, peeled and cut into small pieces (20 × 20 × 20 mm). The mango and pineapple pieces were blended separately using a commercial blender (Total Image, Malaysia). Calcium lactate was added at 1% (w/w) into the mango and pineapple puree, respectively. The pineapple puree was filtered to remove coarse fibers by using a kitchen strainer. After that, different ratios of mango-pineapple puree (1:1, 1.86:1, 4:1) were prepared by weighing and homogenizing different proportions of mango puree and pineapple puree according to the formulations (Table 1). The mango-pineapple puree was added to a plastic hemispheres mold (3 g per sphere) using a plastic dropper and was subjected to freezing at –18°C overnight. Prior to the experiment, it was transferred to a refrigerated temperature, before being left to thaw at room temperature for 30 min (Bubin et al., 2019). Sodium alginate was mixed at 0.5% (w/w) in distilled water using an ultra turrax mixer (IKA, Germany) with a speed of 800 rpm for 5 min. It was then allowed to hydrate for 24 h before it was used as a spherification bath. After that, the spheres produced were then placed in glass jars with metal screw lids (capacity: 200 mL, height: 80 mm, diameter: 68 mm, capsize: 63 mm) containing sugar solutions of different concentrations (10°Brix, 16°Brix, 22°Brix). The concentration of sugar solution was adjusted to the desired °Brix with the aid of a digital refractometer (Milwaukee MA871, USA).

Jelly sphere making process

The sodium alginate solution was poured into a round flat bottom pan, which was placed in a 25°C water bath throughout the gelling process. Pre-frozen mango-pineapple puree was immersed in a sodium alginate bath for different immersion times in sugar solutions (5 mins, 17.5 mins, 30 mins). A jelly membrane was formed during the period of immersion. The sodium alginate bath was stirred gently using a stirring rod to prevent the spheres from sticking to each other (Young, 2013). After the immersion time in sugar solution was completed, the mango-pineapple jelly spheres were removed from the sodium alginate bath using a slotted spoon and transferred into a container filled with distilled water. The mango-pineapple jelly spheres were transferred into a glass jar containing a sugar solution (20 spheres per jar). The glass jars containing the mango-pineapple jelly spheres were stored in a chiller at 4°C before analysis.

Physicochemical analyses of jelly spheres

Physicochemical analyses were conducted on three separate samples (homogenized if required) of 10 run orders. The color of the puree in the jelly spheres was measured by using a colorimeter (HunterLab ColorFlex EZ, USA) along with the software, EasyMatch QC. Total soluble solids (TSS) of the puree in the jelly spheres was measured by using a digital bench-top refractometer (Milwaukee MA871, USA). Texture analysis of the mango-pineapple jelly spheres was done by referring to the instruction manual of the texture analyzer (Brookfield CT3, USA).

Sensory evaluation of mango-pineapple jelly spheres

The hedonic test was conducted in the sensory booth of the food science laboratory at UCSI University. Panels were comprised of forty untrained volunteers who were students of the university. Ten mango-pineapple jelly sphere samples were presented in sampling cups that were labeled with randomized three-digit codes. As the number of samples to be evaluated was large, the samples were divided into two equal blocks, with five samples in each block, including one center point. Each block was presented in a random order for each panelist. The samples were tasted during two sessions on the same day to prevent panelists from becoming tired (Royer et al., 2006). The panelists were asked to fill in questionnaires to assess the flavor, texture and overall acceptability using a 9-point hedonic scale (1 – dislike extremely, 2 – dislike very much, 3 – dislike moderately, 4 – dislike slightly, 5 – neither like nor dislike, 6 – like slightly, 7 – like moderately, 8 – like very much and 9 – like extremely).

Proximate analysis of jelly spheres produced in optimized conditions

Proximate analysis of the mango-pineapple jelly spheres was carried out. Moisture content was determined using the oven drying method (National Forage Testing Association, 2006). Ash, protein, and total dietary fiber were determined according to the AOAC method, 923.03, 955.04, and 985.29, respectively, with slight modifications (AOAC, 2005). Fat content was determined using the Soxhlet extraction method (Nielsen, 2010). Digestible carbohydrate was determined by calculating the mass of food material remaining after subtracting the weight for moisture, ash, protein, total dietary fiber, and fat. Energy content was calculated by using the conversion factors of 2 cal/g total dietary fiber, 4 cal/g of protein, 4 cal/g of total carbohydrate, and 9 cal/g of total fat.

RESULTS AND DISCUSSION

The physicochemical properties of the mango-jelly spheres in terms of color (Lightness, redness, and yellowness), total soluble solids, and texture (firmness and elasticity) are shown in Table 2. The lightness coordinate, L^*, ranged significantly from 50.59 to 54.77 (Table 2). Mango-pineapple ratio is the main factor that increased the L^* coordinate (Fig. 1a).

Run order 6 (mango-pineapple ratio of 1:1) presented the highest values for L^* while run orders 4, 8, and 9 (mango-pineapple ratio of 4:1) presented the lowest values for L^*. The lightness data could be fitted into a linear equation, and the total explained variance was 88.67%:

$$\text{Color } (L^*) = 55.63 - 1.33 \times \text{mango-pineapple ratio} \quad (1)$$

It was observed that increasing the mango-pineapple ratio resulted in a higher a^* (Fig. 1b). The values of a^* obtained ranged from 5.52 to 7.57 (Table 2). Run order 9 (mango-pineapple ratio of 4:1) showed the highest values for a^*, while run order 3 (mango-pineapple ratio of 1:1) showed the lowest values for a^*. The multiple regression analysis of a^* showed that the model could explain 98.90% of all variance in the data. The following equation was obtained from the analysis:

$$\text{Color } (a^*) = 4.85 + 0.68 \times \text{mango-pineapple ratio} \quad (2)$$

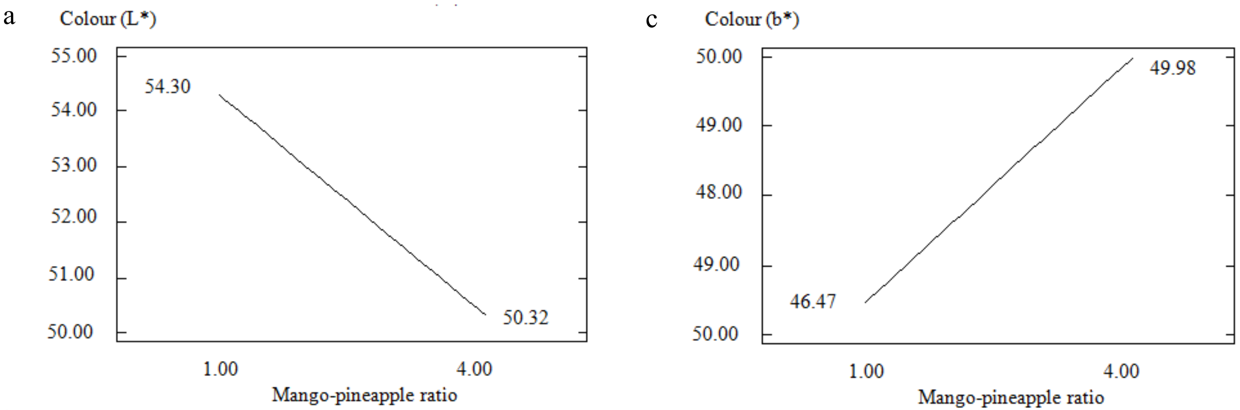
The yellowness coordinate, b^*, increased by increasing the mango-pineapple ratio (Fig. 1c). The values obtained for b^* ranged from 45.49 to 51.22 (Table 2). Run order 2 (mango-pineapple ratio of 4:1) exhibited the highest values for b^*, while run order 3 (mango-pineapple ratio of 1:1) exhibited the lowest values for b^*. The data were fitted into a linear equation ($p \leq 0.05$) with a determination coefficient of 75.55%:

Table 2. Physicochemical parameters of the mango-pineapple jelly spheres

Run order	Factors			Responses					
	x_1	x_2	x_3	color L^*	color a^*	color b^*	total soluble solids °Brix	peak force of compression cycle g	deformation at peak load mm
1	1.00	5.00	22.00	54.62 ±0.03^{e}	5.52 ±0.00^{b}	47.93 ±0.08^{e}	16.90 ±0.10^{g}	15.67 ±3.05^{a}	3.80 ±0.80^{bc}
2	4.00	5.00	10.00	50.70 ±0.01^{b}	7.47 ±0.01^{f}	51.22 ±0.02^{i}	10.23 ±0.15^{b}	16.33 ±1.53^{a}	3.47 ±0.31^{b}
3	1.00	30.00	10.00	54.57 ±0.07^{de}	5.42 ±0.01^{a}	45.49 ±0.05^{a}	9.20 ±0.10^{a}	27.67 ±0.58^{b}	5.33 ±0.29^{c}
4	4.00	30.00	22.00	50.62 ±0.01^{ab}	7.56 ±0.01^{g}	49.54 ±0.01^{g}	13.97 ±0.15^{e}	29.33 ±2.52^{b}	5.87 ±0.12^{c}
5	1.86	17.50	16.00	51.04 ±0.05^{c}	6.74 ±0.01^{e}	47.66 ±0.05^{d}	11.63 ±0.06^{d}	26.33 ±0.58^{b}	5.17 ±0.97^{c}
6	1.00	5.00	10.00	54.77 ±0.04^{f}	5.57 ±0.01^{c}	47.47 ±0.05^{c}	10.13 ±0.06^{b}	14.33 ±0.58^{a}	3.00 ±0.10^{a}
7	1.86	17.50	16.00	51.05 ±0.01^{c}	6.69 ±0.02^{d}	47.44 ±0.04^{c}	11.63 ±0.06^{d}	26.33 ±0.58^{b}	5.23 ±0.50^{d}
8	4.00	5.00	22.00	50.59 ±0.02^{a}	7.50 ±0.01^{f}	49.39 ±0.04^{f}	16.13 ±0.15^{f}	16.67 ±1.15^{a}	4.27 ±0.21^{c}
9	4.00	30.00	10.00	50.64 ±0.01^{ab}	7.57 ±0.00^{g}	50.45 ±0.05^{h}	10.13 ±0.06^{b}	30.00 ±1.00^{b}	5.67 ±0.42^{d}
10	1.00	30.00	22.00	54.52 ±0.01^{d}	5.44 ±0.01^{a}	45.66 ±0.03^{b}	10.70 ±0.10^{c}	28.33 ±0.58^{b}	5.63 ±0.23^{d}

x_1 – mango-pineapple ratio (grams of mango puree per gram of pineapple puree), x_2 – immersion time in sugar solution, mins, x_3 – concentration of sugar solution, °Brix.

$^{a–g}$Mean value with different superscript in the same column indicates a significant difference at $p \leq 0.05$, as measured by Tukey's HSD test.



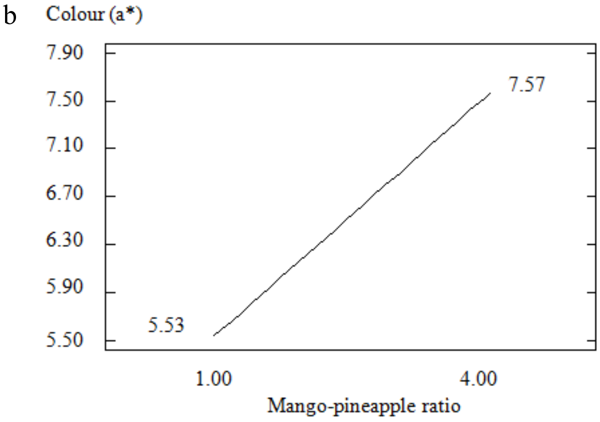


Fig. 1. Effects of mango-pineapple ratio on color: a – lightness (L^*), b – greenness-redness (a^*), c – blueness-yellowness (b^*) of mango-pineapple jelly spheres

$$\text{Color } (b^*) = 45.30 + 1.17 \times \text{mango-pineapple ratio} \quad (3)$$

The results indicated that mango-pineapple jelly spheres were light in color, towards redness and yellowness based on the color scale. The color characteristics of the mango-pineapple jelly spheres may be attributed to carotenoids in mango and pineapple, which have red, orange, and yellow pigments (Rodriguez-Amaya, 1999). Production of the jelly spheres using puree with a higher mango-pineapple ratio resulted in a darker colored product with a higher intensity of redness and yellowness. This shows that mango was the major contributor to the color of the finished product. This is in agreement with the work of Bubin et al. (2019) on the production of pitaya pearls, where the resulting color was due to the pigment present in the red pitaya that contributed to red purple color.

The TSS varied significantly ($p \leq 0.05$) from 9.20°Brix to 16.90°Brix (Table 2). Run order 1 (5 mins immersion time in sugar solution, 22°Brix concentration of sugar solution) showed the highest TSS value, while run order 3 (30 mins immersion time in sugar solution, 10°Brix concentration of sugar solution) showed the lowest TSS value. The estimated response surface plot revealed that the TSS of the mango-pineapple jelly sphere increased as the concentration of sugar solution was increased, especially when the immersion time in sugar solution was short (Fig. 2a).

According to the multiple regression analysis, the model for TSS data was significant statistically ($p \leq 0.05$) and could explain 89.89% of all variance of the TSS results. The higher the immersion time in sugar solution and concentration of sugar solution used, the higher the TSS value of the samples (Fig. 2b). However, their linear interaction seemed to decrease the TSS value:

$$\begin{gathered}\text{TSS} = 4.28 + 0.10 \times \text{immersion time in sugar} \\ \text{solution} + 0.59 \times \text{concentration of sugar solu-} \\ \text{tion} - 0.01 \times \text{immersion time in sugar solution} \times \\ \text{concentration of sugar solution}\end{gathered} \tag{4}$$

The membrane of jelly spheres (calcium alginate) is permeable to small molecules, and thus exchange of molecules across the membrane can occur (Vega et al., 2012). The decrease in TSS in this study with a longer immersion time in sugar solution might be due to the diffusion of soluble solids in the sodium alginate bath during spherification (Rahman, 2007). The increase in TSS when the mango-pineapple jelly spheres were stored in sugar solution at a higher concentration was due to the migration of soluble solids from the sugar solution with a higher solute concentration region into the jelly spheres with a lower solute concentration region (Vega et al., 2012).

The positive effect of the concentration of sugar solution on TSS was the most evident when the immersion time in sugar solution was shorter. This was probably due to the lower degree of obstruction that the solute experienced at a short immersion time in sugar solution. As the concentration of polymer chains per given volume was low, more solutes were able to

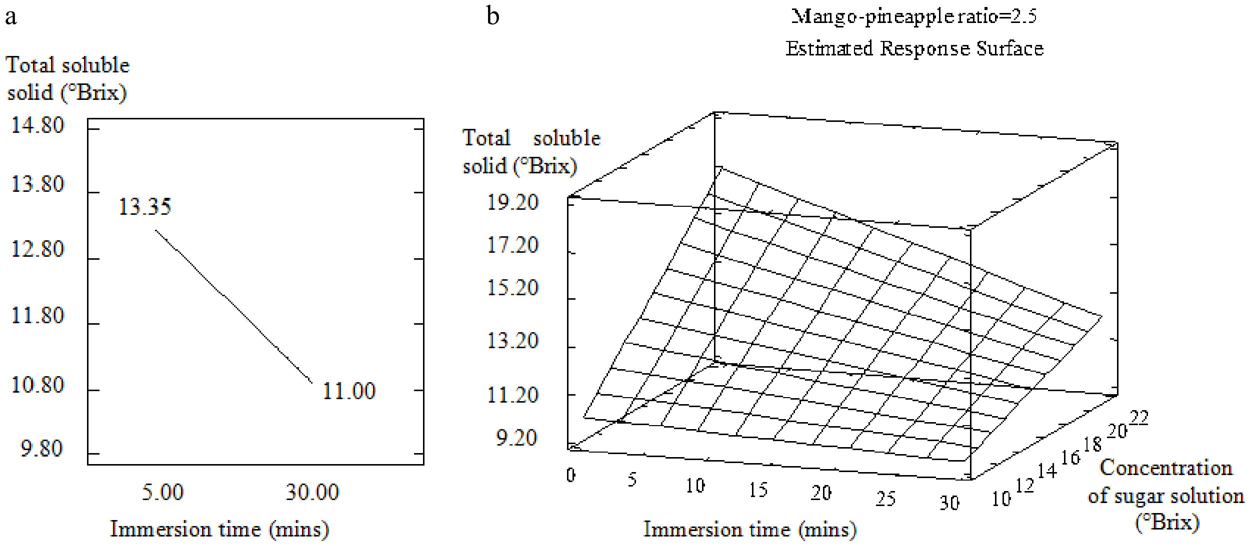


Fig. 2. Effects of (a) immersion time in sugar solution and (b) interactions of two factors of immersion time in sugar solution and sugar concentration on the total soluble solids of mango-pineapple jelly spheres

diffuse across the calcium alginate membrane (Amsden, 1998). Since more solutes diffused from the sugar solution into the jelly spheres, a higher TSS was observed in the content of jelly spheres at a shorter immersion time in sugar solution with a higher concentration of sugar solution.

On the other hand, the peak force of the compression cycle, which is the force necessary to break the gel structure, represents the firmness and hardness of the membrane of the jelly spheres (Pons and Fiszman, 1996). Hardness indicates the stability of the beads during processing, transportation and storage (Maleki et al., 2020; Tsai et al., 2017). On the other hand, Bubin et al. (2019) reported that a lower hardness, cohesiveness and rupture force with a high springiness causes the beads to burst and become chewed, portraying a chewing gum-like texture (Bubin et al., 2019). Immersion time in sugar solution was of prime importance in the peak force of the compression cycle and showed a significant positive effect.

The values obtained for the peak force of the compression cycle, which is the firmness of the jelly sphere, ranged from 14.33 g to 30.00 g (Table 2). Run orders 1, 2, 6, and 8 (5 mins immersion time in sugar solution) exhibited the lowest values for peak force of the compression cycle. As expected, run orders with a higher immersion time in sugar solution had higher values for peak force of the compression cycle (Table 2; Fig. 3a).

The multiple regression analysis of the peak force of the compression cycle showed that the model could explain 91.32% of all variance in data. These results were used to calculate the predictive equation:

$$\text{Peak force of compression cycle} = 13.94 + 0.52 \times \text{immersion time in sugar solution} \tag{5}$$

On the other hand, deformation at peak load is the distance at which the probe penetrated before breaking of the jelly sphere occurs (Conner, 2013). It is an indication of the jelly sphere's elasticity, in which a shorter distance indicates a brittle jelly sphere, and a larger distance indicates a more elastic jelly sphere (Genovese et al., 2010).

The elasticity indicated by the deformation at peak load values was significantly different ($p \leq 0.05$) when immersion time in sugar solution was different. The values obtained for deformation at peak load ranged from 3.00 mm to 5.87 mm (Table 2). Similar to the results of peak force of the compression cycle, run orders 1, 2, 6, and 8 (5 mins immersion time in sugar solution) exhibited the lowest values for deformation at peak load (Table 2; Fig. 3b).

Run orders with a higher immersion time in sugar solution exhibited higher values for deformation at

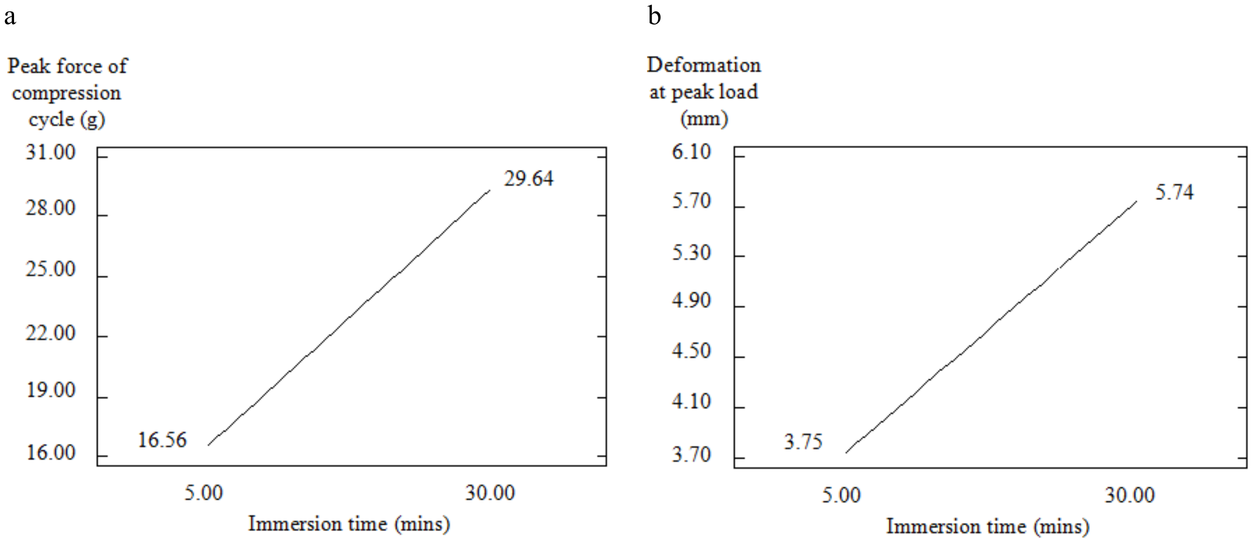


Fig. 3. Effects of immersion time in sugar solution on the (a) firmness (peak force of compression cycle) and (b) elasticity (deformation at peak load) of mango-pineapple jelly spheres

peak load. The multiple regression analysis of deformation at peak load showed that the model could explain 83.80% of all variance in the data. These results were used to calculate the predictive equation:

$$\text{Deformation at peak load} = 3.35 + 0.08 \times \text{immersion time in sugar solution} \tag{6}$$

The results of a longer immersion time in sugar solution leading to harder and more elastic jelly spheres in this study were in agreement with a study by Lee and Rogers (2012). They reported that the hardness of jelly spheres increased as immersion time in sugar solution increased, until reaching maximum gel strength. This could be due to more calcium ions diffusing outwards and reacting with the guluronic acid zones, forming egg-box junctions at the interface and ultimately leading to gelation, until a point at which the guluronic acid zones are saturated with calcium ions (Potter et al., 1994).

A comparison of the sensory evaluation results of mango-pineapple jelly spheres is shown in Table 3, in which all the responses have no significant difference under different runs ($p > 0.05$). The scores for texture, flavor and overall acceptability were lower compared to the flavored sweet water balls, in which, with a 25% sugar syrup content, it had a score of 8.56 for texture, 8.8 for taste and 8.16 overall acceptability (Gaikwad et al., 2019). The results showed that different concentrations of sugar solution were of prime importance and showed significant positive effects (Fig. 4a, 4b, 4c). These results were used to calculate the predictive equations:

$$\text{Flavor} = 4.13 + 0.12 \times \text{concentration of sugar solution} \tag{7}$$

$$\text{Texture} = 4.84 + 0.08 \times \text{concentration of sugar solution} \tag{8}$$

$$\text{Overall acceptability} = 4.53 + 0.10 \times \text{concentration of sugar solution} \tag{9}$$

The scores obtained for flavor, texture, and overall acceptability ranged from 5.15 to 7.15, 5.45 to 7.15, and 5.40 to 7.25, respectively. Run order 10 (22°Brix concentration of sugar solution) gained the highest scores. In contrast, samples of run order 3, which were immersed in a solution with the lowest sugar content (10°Brix concentration of sugar solution), gained the lowest scores for all these three sensory attributes. However, the scores do not have significant differences among one another ($p > 0.05$).

Table 3. Sensory attributes of the mango-pineapple jelly sphere

Run order	Factors			Responses		
	x_1	x_2	x_3	flavor	texture	overall acceptability
1	1.00	5.00	22.00	6.85 ±1.12	6.10 ±1.63	6.50 ±1.38
2	4.00	5.00	10.00	5.60 ±1.81	5.75 ±1.85	5.75 ±1.28
3	1.00	30.00	10.00	5.15 ±1.64	5.45 ±1.85	5.40 ±1.45
4	4.00	30.00	22.00	6.45 ±1.85	6.70 ±1.20	6.70 ±1.67
5	1.86	17.50	16.00	5.80 ±1.76	6.20 ±1.59	6.05 ±1.48
6	1.00	5.00	10.00	5.55 ±1.30	5.50 ±1.65	5.65 ±1.25
7	1.86	17.50	16.00	5.80 ±1.60	6.10 ±1.85	5.75 ±1.84
8	4.00	5.00	22.00	6.75 ±1.78	6.55 ±1.83	6.60 ±1.85
9	4.00	30.00	10.00	5.20 ±1.80	5.90 ±1.92	5.50 ±1.74
10	1.00	30.00	22.00	7.15 ±1.17	7.15 ±1.12	7.25 ±1.06

x_1 – mango-pineapple ratio (gram of mango puree per gram of pineapple puree), x_2 – immersion time in sugar solution, mins, x_3 – concentration of sugar solution, °Brix.

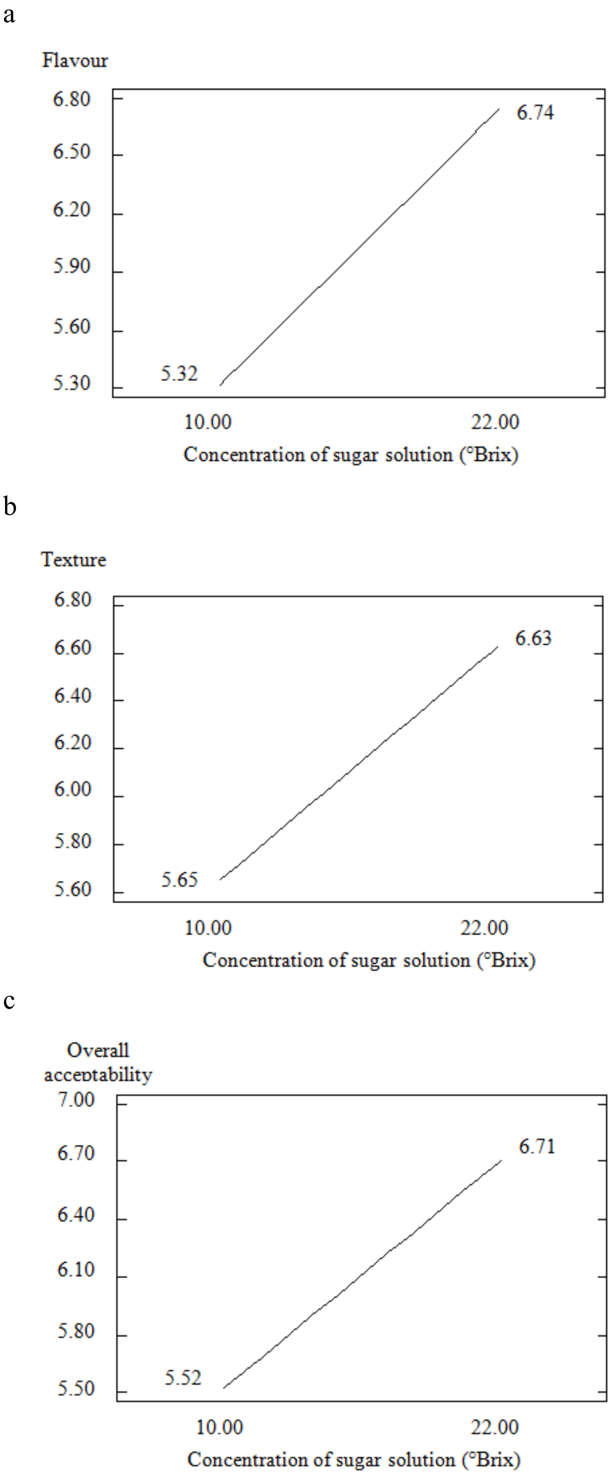


Fig. 4. Effects of sugar solution concentration on the sensory evaluation: a – flavor, b – texture, c – overall acceptability of mango-pineapple jelly spheres

The results from the hedonic test indicated that most of the panelists preferred mango-pineapple jelly spheres that were stored in sugar solutions of a higher concentration (22°Brix) in terms of flavor, texture, and overall acceptability. The optimization procedure was conducted to maximize the flavor, texture, overall acceptability, peak force of compression cycle, deformation at peak load, pH, TSS, and color coordinates (L^*, a^*, and b^*). The optimal settings were determined to be 1.28:1 mango-pineapple ratio, 30 mins immersion time in sugar solution, and 22°Brix sugar solution, with an overall desirability of 0.89.

The fact that the parameters to assess texture, goal of peak force of compression cycle and deformation at peak load were set to maximize as higher values for both responses indicates that the jelly sphere is firmer and more elastic. The goals of L^*, a^*, and b^* values of mango-pineapple jelly sphere were set to maximize as a brighter color product with a higher intensity of redness and yellowness to be more appealing to consumer. For all the five sensory attributes, the goal of optimization was to maximize the values as a higher score indicates a better preference of the sensory panelists towards a certain characteristic of the product.

The optimal settings were 1.28:1 mango-pineapple ratio, 30 mins immersion time, and 22°Brix sugar solution, with a desirability quotient and specified range. In this study, the overall desirability was 0.89. Table 4 shows the comparison between predicted and actual values for all 9 responses of physicochemical properties. There was no significant difference ($p > 0.05$) among the predicted and actual values of peak force of the compression cycle. The actual value for deformation at peak load was 4.01% higher than the predicted value. This inconsistency may be due to modelling deficiencies as well as random error during texture analysis. The significant differences ($p \leq 0.05$) between predicted and actual values of total soluble solid and color coordinates (L^* value, a^* value, and b^* value) may be attributed to variations among different batches of mangos and pineapples.

Table 5 shows the proximate analysis of optimized mango-pineapple jelly spheres. The energy content per 100 g of the optimized mango-pineapple jelly spheres was calculated to be 73.18 kcal. The energy content of optimized mango-pineapple jelly sphere was lower

Table 4. Physicochemical properties: comparison of predicted and actual values

	Predicted	Actual
Peak force of compression cycle, g	29.64^a	31.33 ± 1.15^a
Deformation at peak load, mm	5.74^a	5.97 ± 0.06^b
Total soluble solid, °Brix	12.23^a	13.00 ± 0.10^b
Color *L**	53.49^b	47.58 ± 0.02^a
Color *a**	5.94^a	8.78 ± 0.00^b
Color *b**	47.18^b	44.82 ± 0.02^a

Each value in the column represents mean ±standard deviation; $n = 3$.

$^{a–b}$Mean values with different superscripts in the same row indicate a significance difference at $p < 0.05$.

Table 5. Proximate analysis of optimized mango-pineapple jelly spheres

Component	Percentage
Moisture	81.11 ±0.04
Ash	0.10 ±0.07
Protein	0.46 ±0.10
Fat	0.00 ±0.00
Total dietary fiber	0.97 ±0.05
Digestible carbohydrate	17.35 ±0.10

than 80 kcal/100 g maximum limit as recommended by the FDA (Food..., 2014) for low-calorie foods.

The high moisture content of 81.11 ±0.04% obtained for the optimized mango-pineapple jelly spheres implied that this product has a relatively short shelf life, and refrigeration is needed to avoid microbial spoilage (Nwofia et al., 2012). The mineral content of the optimized mango-pineapple jelly spheres was indicated by the ash content (0.10 ±0.07%) (Vunchi et al., 2011). The optimized mango-pineapple jelly spheres contained 0.46 ±0.10% of protein, suggesting that the product is not a rich source of protein. As expected, the product contained zero fat, which was lower than the 0.5 g/100 g maximum limit recommended by the FDA (Food..., 2014) for fat-free foods. Also, the sample contained 0.97 ±0.05% total dietary fiber, which was an extra component when compared with commercialized fruity juice balls (0%). The digestible carbohydrate of the optimized mango-pineapple jelly spheres was calculated as 17.35 ±0.10%. This was the primary component that contributed to the energy content of the product.

CONCLUSION

In this study, bite-sized jelly spheres with a gelatinous exterior and mango-pineapple puree interior were successfully produced using frozen reverse spherification. The effects of certain factors on the responses were evaluated by using a two-level full factorial design with a central point repeated twice. Results showed that the mango-pineapple ratio had a significant effect ($p \leq 0.05$) on the color (L^*, a^*, and b^* values) of the mango-pineapple jelly spheres. Immersion time in sugar solution was found to have a significant effect ($p \leq 0.05$) on peak force of the compression cycle, deformation at peak load, and TSS of the product. The concentration of the sugar solution in which the jelly spheres were stored affected the product's flavor, texture, overall acceptability for sensory evaluation and TSS. An overall desirability of 0.89 for all responses can be achieved with optimal settings of the factors, including 1.28:1 mango-pineapple ratio, 30 mins immersion time in sugar solution, and 22°Brix sugar solution, with selection based on maximizing texture and color. The mango-pineapple jelly sphere can be consumed as a dessert on its own or be incorporated into other desserts or beverages.

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