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Effect of hydrocolloids on the physicochemical characteristics of yellow mombin structured fruit

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Abstract

The technology for the production of restructured fruit with high contents of fruit pulp using hydrocolloids as binding agents has not been fully developed. This study evaluated the effect of mixtures of sodium alginate, low methoxy pectin, and gelatin on the characteristics of yellow mombin (*Spondias mombin* L.) fruit gels. The results of the central composite design showed that the models obtained, except for those of water activity and soluble solids, were predictive. Gelatin was the most important factor affecting firmness, pH, and the color parameters of the structured fruit pulp.

Keywords: alginate; gelatin; pectin; response surface methodology.

1 Introduction

The Northeast region of Brazil is known for its large scale production of various tropical and sub-tropical fruits since the growth conditions in this region, such as high temperatures, light, and adequate humidity, are favorable for their cultivation. Among the exotic fruits pertaining to the genus *Spondias*, which are very much appreciated in this region, there are yellow mombin (*Spondias mombin* L.), umbu (*Spondias tuberosa* Arruda Camara), and caja-umbu fruits (Narain et al., 2007). In the Brazilian food industry, the yellow mombim has mostly been used to produce pulp, juice, and ice creams, and has high economic potential, owing to its consumer appeal and exotic and pleasant flavor, besides its high nutritional value as a source of vitamins and functional compounds as carotenoids.

The production of restructured fruit with high contents of fruit pulp using hydrocolloids as binding agents could be a viable option for the use of this fruit, and it would enlarge the already existing market resulting in higher added value products that can be used in many food formulations, such as in dairy and baking industry. Structured fruits are formulated with high concentration of fruit pulp using hydrocolloids (gelatin, sodium alginate, pectin) to form a product with soft texture that can be consumed in the way it is presented or can be used as an confectionery ingredient or consumed as fresh fruit (Raab & Oehler, 1976; Vijayanand et al., 2000; Grizotto et al., 2007; Azoubel et al., 2011).

The objective of this study was to evaluate the effects of different hydrocolloid (sodium alginate, pectin, and gelatin) concentrations on the characteristics of fruit gels made from pulp with high soluble solids level (50°Brix) using the Response Surface Methodology (RSM). RSM has been used in several studies on restructured fruit, like mango (Mouquet et al., 1992; Gill et al., 2004), pineapple (Grizotto et al., 2007) and *Passiflora cincinnata* (Azoubel et al., 2011) pulp.

2 Materials and methods

2.1 Plant materials

Three yellow *mombin* genotypes were selected: IPA 6.1; IPA 11.2, and IPA14. The fruits were washed, sanitized, and the pulp was extracted using a depulper (Bonina Compact, Brazil). They were then packed in plastic bags and frozen at –22°C.

2.2 Restructuring process

The technological co-adjutants used as food grade hydrocolloids to prepare the restructured yellow mombim were: commercial sugar (Cristal Primavera, Brazil), sodium alginate (Vetec Química, Brazil), low methoxy pectin (CP Kelco, Brazil), and 180 Bloom gelatin (Rebière Gelatinas, Brazil); glycerol ($C_3H_5(OH)_3$) (Vetec Química, Brazil) was used as the solute to suppress the water activity and anhydrous calcium hydrogen phosphate ($CaHPO_4$) (Vetec Química, Brazil, analytical grade) as the source of calcium.

The amount of hydrocolloids used was determined according to the experimental design, as presented in Table 1. Initially, glycerol was added to the fruit pulp at a rate of 10 g/100 g (or 10% of the pulp weight) and, based on the soluble solids content, the amount of sugar required to reach 50°Brix was calculated. This mixture, previously heated to 60°C, was transferred to a plastic beaker, and the dry mixture of hydrocolloids (alginate+pectin+gelatin) and sugar was then added and mixed (400 rpm) using a laboratory mixer (Nova Técnica, NT 137, Piracicaba, Brazil). After mixing for 10 minutes, 2 g of $CaHPO_4$ suspended in 5 mL of distilled water were added and mixed for 5 more minutes. With the aid of 5 cm diameter Petri dishes (depth 1 cm), the structured fruits were molded into a solid cylinder shape and maintained under refrigeration at 10°C for 24 hours to complete the gelling process.

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2.3 Physicochemical analyses

The physicochemical analyses were performed in triplicate, and the following parameters were determined: firmness, water activity, soluble solids (°Brix), pH, and color.

The firmness of the structured fruit was measured using a TA.XT2 texturometer (Stable Micro Systems, Godalming, EUA), with a 75 mm diameter cylindrical probe and 25 kg load cell, according to the method described in the TA.XT2 application manual SWTI/P35. The TA.XT2 settings were: force in compression mode; 60 s -"hold until time", 1 mm/s test speed; and 20 mm of distance from the sample.

Once the trigger force of 5 g was reached, the maximum force was registered and the probe compressed the sample to 20% of its original height for 60 s at this distance, and it was then withdrawn from the sample. The firmness values, expressed in grams, represented the mean of three peaks of maximum force, and the measurements were carried out on three different samples that were maintained at room temperature in Petri dishes. Water activity (a_W) was determined using a portable hygrometer (Decagon, PawKit, Pullman, USA) at 25°C. A bench digital refractometer (Cambridge Instuments Inc., Reichert-Jung Abbe Mark II, Buffalo, USA) and a potentiometer (Tecnal, Tec-3MO, Piracicaba, Brazil) were used to determine soluble solids and pH, respectively. The color parameters (L*, a* and b*) were measured using a portable colorimeter (ColorTec, PCM, Clinton, USA). The average color difference (ΔE*) between the fresh and the structured yellow *mombin* pulp was calculated according to Equation 1.

$$\Delta E^* = \sqrt{\left(L^* - L_o^*\right)^2 + \left(a^* - a_o^*\right)^2 + \left(b^* - b_o^*\right)^2} \quad (1)$$

Where:

ΔE* is the total difference in color;

L_o* and L* are the luminosity values of the fresh and structured pulps samples, respectively;

a_o* and a* are the intensity of red color of the fresh and structured pulps samples, respectively;

b_o* e b*are the intensity of the yellow color of the fresh and structured pulps samples, respectively.

2.4 Experimental design

A central composite rotatable design (Rodrigues & Iemma, 2009) was used in the structuring process of yellow *mombin* using three factors: alginate, pectin, and gelatin concentrations. Five levels of each variable were chosen, including the center point and two axial points. A total of 17 combinations were performed for each genotype, including three replications of the center point (Table 1). The inclusion of axial points, in addition to the repetitions of the central point, is aimed at setting a model to experimental responses of the second order.

It was assumed that a mathematical function, ϕ, exists for the response variable Y (firmness, water activity, pH, soluble solids, and ΔE), in terms of three independent process variables (x_1, x_2, and x_3, which are alginate, pectin, and gelatin concentrations, respectively) – Equation 2:

$$y = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 \quad (2)$$

The *Statistica* 7.0 package (Statsoft, 1995) was used to obtain the regression coefficients, analysis of variance, and to create three dimensional graphs.

3 Results and discussion

Table 1 presents the results of firmness (F), water activity (a_w), pH, soluble solids (SS), and color difference (ΔE) obtained from the central composite design trials of the structured yellow *mombin* pulps for the three genotypes. The modeling and the statistical analysis of each of these response values are discussed bellow.

3.1 Firmness (F)

The statistical analysis revealed that all terms (linear, quadratic, and cross-product terms) were significant at 95% confidence level in relation to the restructured fruit using yellow *mombin* IPA 11.2 genotype pulp. For the IPA 14 genotype samples, the effects of alginate concentration (linear and quadratic), the quadratic effect of gelatin concentration, and the effects of all interactions between the hydrocolloids were not significant ($p \leq 0.05$).

As for the structured fruit using the genotype IPA 6.1 pulp, since the effect of pectin (quadratic) and the interaction between this hydrocolloid and alginate led to values close to 0.05, they were considered in the model. In addition, the effect of gelatin (linear and quadratic) was significant, and therefore it has to be considered in the prediction model.

As shown in Table 2, the significance of the regression was verified by analysis of variance (ANOVA), and lack of fit (95% confidence level) was determined by the F test. As for the structured IPA 11.2 genotype pulp, the regression model showed lack of fit and a non-significant regression, while for IPA 14 and IPA 6.1 genotypes, the regression was significant and the lack of fit was not significant.

The fitted model for the structured genotype IPA 14, which explained 92% of the firmness variability is described by Equation 3, while for the structured IPA 6.1 genotype, the fitted model (Equation 4) had an R^2 of 0.77, which is considered a not very high value.

$$F(g) = -275.55 + 295.47P + 75.89P^2 + 35.05G \quad (3)$$

$$F(g) = -450.11 - 172.69A - 136.36A^2 - 37.31P^2 + 81.00G - 2.13G^2 + 121.53AP \quad (4)$$

Where F is firmness (g); A is alginate concentration (% or $g.100g^{-1}$); P is pectin concentration (% or $g.100g^{-1}$); G is gelatin concentration (% or $g.100g^{-1}$).

The generated surfaces are shown in Figure 1. It can be seen that firmness of the structured fruit pulps was most

Table 1. Central composite design trial results of firmness (F), pH, water activity (a_w), soluble solids (SS), and color difference of the structured fruit with different concentrations of alginate (A), pectin (P), and gelatin (G).

Trial	A (g/100g)	P (g/100g)	G (g/100g)	IPA 11.2					IPA 14
				F (g)	pH	a_w	SS	ΔE	F (g)
01	0.50 (−1)	0.80 (−1)	10.00 (−1)	244.11±3.86	3.68±0.00	0.86±0.01	54.35±1.71	16.06±0.57	293.93±2.26
02	1.50 (+1)	0.80 (−1)	10.00 (−1)	159.80±2.34	3.79±0.00	0.87±0.00	55.64±0.00	13.53±0.94	258.56±8.58
03	0.50 (−1)	2.20 (+1)	10.00 (−1)	116.43±4.68	3.77±0.00	0.86±0.00	55.69±0.06	11.09±0.53	338.41±3.67
04	1.50 (+1)	2.20 (+1)	10.00 (−1)	159.35±9.68	3.83±0.00	0.86±0.00	58.14±0.00	11.40±0.64	333.61±2.34
05	0.50 (−1)	0.80 (−1)	20.00 (+1)	1150.29±68.48	4.04±0.01	0.87±0.00	60.64±0.00	14.11±0.08	590.13±19.81
06	1.50 (+1)	0.80 (−1)	20.00 (+1)	64.39±6.01	4.07±0.00	0.86±0.00	58.14±0.00	15.34±0.22	524.19±12.95
07	0.50 (−1)	2.20 (+1)	20.00 (+1)	344.75±38.24	4.05±0.00	0.86±0.01	62.64±0.00	14.15±0.15	740.21±13.34
08	1.50 (+1)	2.20 (+1)	20.00 (+1)	339.23±7.95	4.10±0.01	0.83±0.00	60.64±0.00	18.13±0.24	608.23±8.66
09	1.00 (0)	1.50 (0)	15.00 (0)	798.98±0.00	3.84±0.00	0.87±0.00	58.23±0.00	14.49±0.04	509.07±0.00
10	1.00 (0)	1.50 (0)	15.00 (0)	838.59±0.00	3.86±0.00	0.87±0.00	58.14±0.00	12.43±0.58	523.97±0.00
11	1.00 (0)	1.50 (0)	15.00 (0)	798.87±0.00	3.96±0.00	0.86±0.00	63.23±0.00	12.43±1.28	549.57±0.00
12	0.16 (−1.68)	1.50 (0)	15.00 (0)	366.27±68.83	3.82±0.00	0.87±0.01	63.23±0.00	12.79±0.40	464.93±6.09
13	1.84 (+1.68)	1.50 (0)	15.00 (0)	465.21±37.38	3.93±0.00	0.86±0.00	62.94±0.29	11.79±0.80	651.27±28.64
14	1.00 (0)	0.32 (−1.68)	15.00 (0)	919.71±123.29	3.85±0.01	0.87±0.00	65.64±0.00	13.96±0.17	364.95±1.25
15	1.00 (0)	2.68 (+1.68)	15.00 (0)	824.14±12.25	3.91±0.00	0.86±0.01	73.14±0.00	15.11±0.09	523.42±14.98
16	1.00 (0)	1.50 (0)	6.60 (−1.68)	221.60±6.40	3.61±0.01	0.86±0.00	70.64±0.00	12.63±1.30	185.67±2.04
17	1.00 (0)	1.50 (0)	23.40 (+1.68)	1041.15±6.48	4.00±0.00	0.86±0.00	68.14±0.00	13.88±0.09	872.09±28.64

Trial	IPA 14				IPA 6.1				
	pH	a_w	SS	ΔE	F (g)	pH	a_w	SS	ΔE
01	3.71±0.01	0.86±0.00	60.40±0.00	16.87±0.08	132.43±7.80	3.36±0.01	0.88±0.01	60.56±0.00	17.50±0.03
02	3.81±0.01	0.85±0.00	60.40±0.00	14.70±0.02	192.02±1.25	3.37±0.00	0.89±0.00	53.06±0.00	18.06±0.01
03	3.81±0.00	0.86±0.00	60.48±0.00	18.43±0.07	213.87±0.47	3.38±0.00	0.88±0.00	60.56±0.00	16.82±0.20
04	3.85±0.00	0.86±0.00	60.48±0.00	14.53± 0.20	234.67±6.32	3.41±0.00	0.88±0.00	56.56±0.00	16.44±0.21
05	3.90±0.01	0.87±0.00	60.48±0.00	13.87±0.50	336.31±10.22	3.81±0.00	0.88±0.01	53.31±0.35	18.58±0.34
06	3.94±0.00	0.86±0.00	60.48±0.00	14.50±0.02	321.63±4.76	3.77±0.01	0.88±0.00	60.56±0.00	18.94±0.23
07	3.99±0.02	0.86±0.00	60.48±0.00	14.41±0.06	227.55±0.94	3.66±0.01	0.88±0.00	55.56±0.00	18.52±0.13
08	3.73±0.01	0.86±0.00	60.48±0.00	13.71±0.23	533.07±10.53	3.67±0.00	0.87±0.00	60.56±0.00	18.46±0.26
09	3.80±0.00	0.87±0.00	69.31±1.77	14.47±0.13	421.78±0.00	3.58±0.00	0.89±0.00	58.06±0.00	18.70±0.19
10	3.81±0.00	0.87±0.00	60.48±0.00	14.83±0.45	455.66±0.00	3.62±0.00	0.89±0.00	58.06±0.00	18.06±0.24
11	3.81±0.00	0.87±0.00	73.06±0.00	12.51±0.63	407.10±0.00	3.58±0.00	0.89±0.00	58.06±0.00	18.06±0.24
12	3.82±0.00	0.88±0.00	61.81±1.77	15.38±0.39	324.23±5.93	3.57±0.01	0.90±0.00	58.06±0.00	19.13±0.15
13	3.91±0.00	0.88±0.00	60.48±0.00	14.42±0.51	437.29±2.58	3.59±0.01	0.88±0.00	56.06±0.71	18.34±0.02
14	3.89±0.00	0.88±0.00	60.48±0.00	15.17±0.43	433.70±1.09	3.58±0.01	0.88±0.00	58.06±0.00	17.96±0.09
15	3.93±0.01	0.87±0.00	60.48±0.00	16.00±0. 20	371.18±3.98	3.61±0.00	0.90±0.00	58.06±0.00	18.26±0.04
16	3.74±0.01	0.88±0.00	57.98±0.00	20.50±0.16	172.54±6.32	3.29±0.00	0.89±0.00	55.56±0.00	14.63±0.01
17	3.93±0.01	0.88±0.00	68.06±0.00	16.19±0.01	480.60±9.36	3.68±0.00	0.88±0.00	58.06±0.00	19.44±0.17

influenced by gelatin and that the firmness values increased as concentration increased. In addition, Table 1 shows that the highest values of firmness were obtained when higher concentrations of gelatin were used for all genotypes, and that the IPA 6.1 genotype resulted in structured products with lower values of firmness in most of the trials.

According to Grizotto et al. (2007), gels showed good firmness when a value around 1.5 kg was obtained for structured concentrated pineapple pulp, whereas a firmness around 1.3 kg was considered satisfactory for concentrated papaya (Grizotto et al., 2005). However, comparing the values of firmness obtained in the present study with those from the literature cited, it was observed that the genotype IPA 11.2 resulted in a structured product with firmness closer to that considered acceptable for this type of product. Furthermore, the structured genotype IPA 6.1 had the lowest values of firmness, which is considered low for this type of product.

Carvalho et al. (2011) found values between 9.00 and 1103.20 g for structured mixed yellow monbim and papaya, and Azoubel et al. (2011) found values between 99.79 and 1834.36 g for structured *Passiflora cincinnata* fruit pulp. These authors observed that firmness of the structured fruit pulp was strongly influenced by gelatin, and that the firmness values increased with an increase in concentration. In the present study, a similar behavior was observed.

Karki (2011), studying the production of five blueberry fruit leather (product similar to structured fruit) from different cultivars (Blue Magic, Burlington, Jersey, Puru, and Reka) using honey, lemon juice, and pectin found firmness values between 345.5 and 759.2 g. The results showed significant differences

Table 2. Analysis of variance for firmness of structured yellow mombin genotypes IPA 11.2, IPA 14, and IPA 6.1 structured fruits.

Source of variation	IPA 11.2		
	DF	MS	F_{cal}
Regression	9	168393.22	2.15
Residual	7	78304.14	
Lack of fit	5	109416.00	208.61
Pure error	2	524.50	
Total	16		R^2= 0.73
Source of variation	**IPA 14**		
	DF	MS	F_{cal}
Regression	3	155311.40	41.76
Residue	13	3719.18	
Lack of fit	11	4319.10	10.29
Pure error	2	419.65	
Total	16		R^2 = 0.92
Source of variation	**IPA 6.1**		
	DF	MS	F_{cal}
Regression	6	29036.52	4.88
Residue	10	5946.61	
Lack of fit	8	7278.23	11.74
Pure error	2	620.15	
Total	16		R^2 = 0.77

DF: degree of freedom; MS: mean square.

Table 3. ANOVA model adjusted to the pH of structured yellow mombin genotypes IPA 11.2, IPA 14, and IPA 6.1.

Source of variation	IPA 11.2		
	DF	MS	F_{cal}
Regression	1	0.2495	68.23
Residual error	15	0.0037	
Lack of fit	13	0.0036	0.87
Pure error	2	0.0041	
Total	16		R^2= 0.91
Source of variation	**IPA 14**		
	DF	MS	F_{cal}
Regression	7	0.0127	7.13
Residual error	9	0.0018	
Lack of fit	7	0.0023	67.92
Pure error	2	0.00003	
Total	16		R^2 = 0.75
Source of variation	**IPA 6.1**		
	DF	MS	F_{cal}
Regression	3	0.1118	76.57
Residual error	13	0.0015	
Lack of fit	11	0.0016	3.05
Pure error	2	0.0005	
Total	16		R^2 = 0.95

DF: degree of freedom; MS: mean square.

($p<0.05$) in the texture parameter hardness between the blueberry cultivars. These results confirmed that the values of IPA 6.1 found can be considered satisfactory for the production of this type of product.

Cavalcanti (2012) observed firmness values between 34.67 and 377.67 g and between 63.66 and 999.03 g for red mombin structured fruit and a mixture of red mombin and acerola structured fruits, respectively. In these structured products, it was could be observed that gelatin was the hydrocolloid that most influenced firmness. The yellow mombin structured fruit showed values within the range previously reported for those fruits.

3.2 pH

Based on the statistical analysis at a 95% confidence level, it was observed that the pH was a simple function of gelatin concentration. As for the structured IPA 14 genotype, only the quadratic term of gelatin had no significant effect, while for the structured IPA 6.1 genotype, only the effects of linear and quadratic terms of gelatin and the interaction between pectin and gelatin were significant.

According to the analysis of variance (ANOVA) results (Table 3), the models showed a significant regression and not significant lack of fit for both IPA 11.2 and IPA 6.1 genotypes, while for IPA 14 genotype, a lack of fit was observed. Therefore, the fitted models for IPA 11.2 (Equation 5) and IPA 6.1 (Equation 6) are:

$$pH = 3.48 + 0.03G \quad (5)$$

$$pH = 2.81 + 0.08G - 0.01G^2 - 0.002PG \quad (6)$$

The generated surfaces are shown in Figure 2. It can be seen that the pH of the structured fruit pulps was most influenced by gelatin, as it was observed for firmness.

Grizotto et al. (2007), investigating the parameters for structuring concentrated pineapple pulp with high content of soluble solids using sodium alginate, pectin, and glycerol, found pH values between 3.24 and 3.94. Oliveira et al. (2010) developed three formulations for structured concentrated cupuaçu pulp using hydrocolloids such as gelatin and pectin, which were subjected to drying in an oven with air circulation at 50°C for 6 hours, and found pH values between 3.95 and 3.99. When structuring *Passiflora cincinnata* with high content of soluble solids (50 °Brix), Azoubel et al. (2011) found pH values between 3.43 and 3.79. In the present study, the pH values of the structured fruits ranged from 3.29 to 4.10, and most of them were within the range observed by the authors mentioned above.

Carvalho et al. (2011) evaluated the effect of pectin, gelatin, and sodium alginate on the characteristics of structured mixed fruit gel of yellow mombin pulp and papaya using response surface methodology. They found pH values between 4.18 and 5.54. Cavalcanti (2012) reported pH values between 3.94 and 4.36 and between 3.67 and 4.27 for red mombin structured fruit and a mixture of red mombin and acerola structured fruit, respectively. In the present study, the pH values found are close to those reported in the literature and are within a normal and appropriate range for these products.

3.3 Water activity (a_w)

The models obtained did not show a significant regression (95% confidence level), indicating that they were not capable of describing the variations in the water activity (a_w). Both the

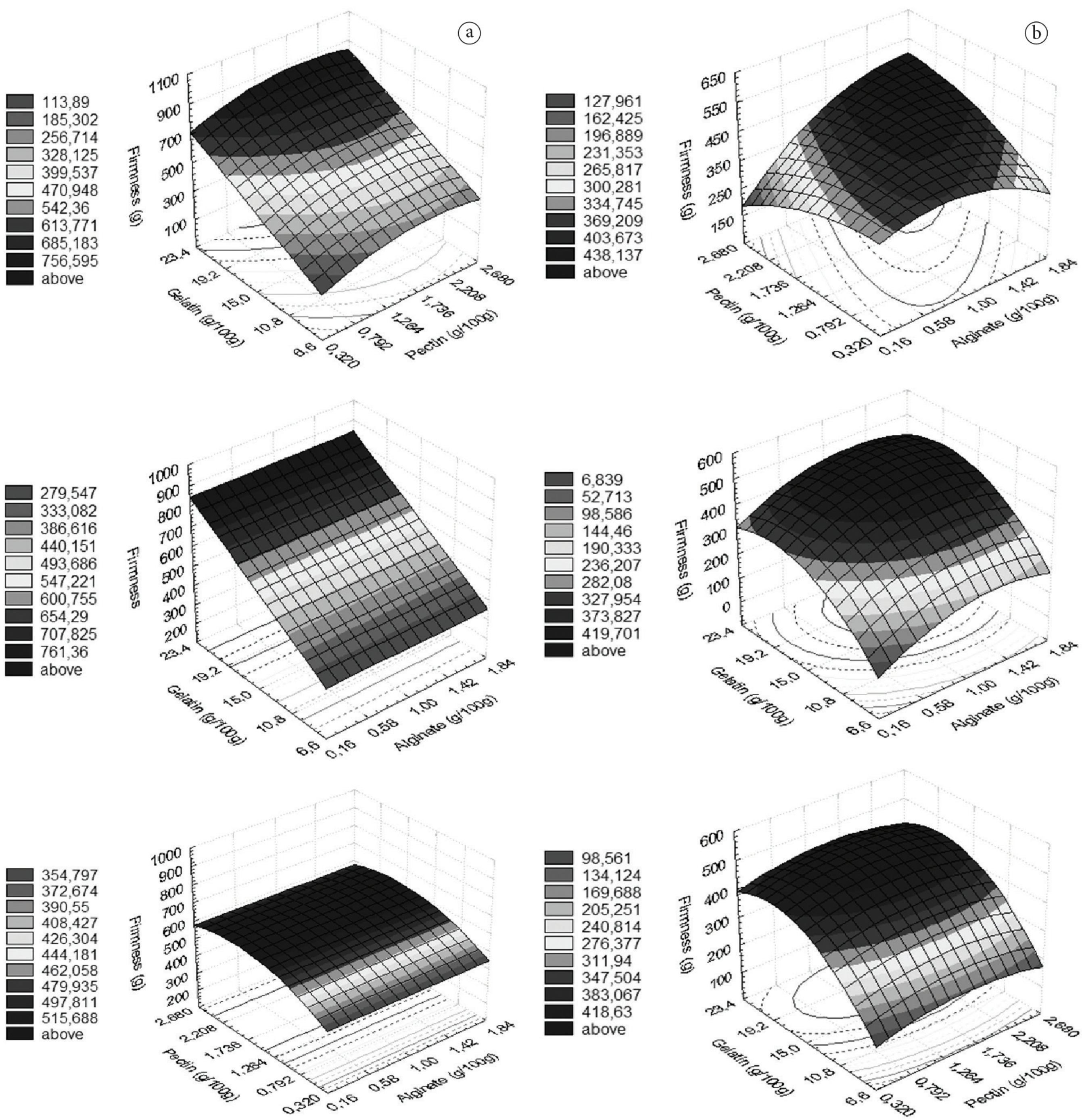

Figure 1. Response surfaces for firmness of structured IPA 14 (a) and IPA 6.1 (b) genotypes (the other independent variable in each figure is fixed in its central value).

standard error calculation and ANOVA showed that there were no significant terms, implying that the hydrocolloid concentrations have no influence on the a_w of the structured fruits from all genotypes. Similar results were found by Azoubel et al. (2011) for *Passiflora cincinnata* structured pulp. However, as observed by Grizotto et al. (2007), the functional dependence of water activity on the pectin, alginate, and glycerol concentrations is too complex for the simple models usually employed in RSM. The a_w values obtained were within the intermediate range of 0.65 to 0.90, as reported by Chirife & Buera (1994), and in agreement with the values found by Grizotto et al. (2007) for pineapple structured pulp.

Oliveira et al. (2010), Carvalho et al. (2011), and Cavalcanti (2012) found water activity values between 0.55 and 0.60; 0.56 and 0.89; 0.7, and 0.84; 0.74 and 0.87 for cupuaçu, a mixture

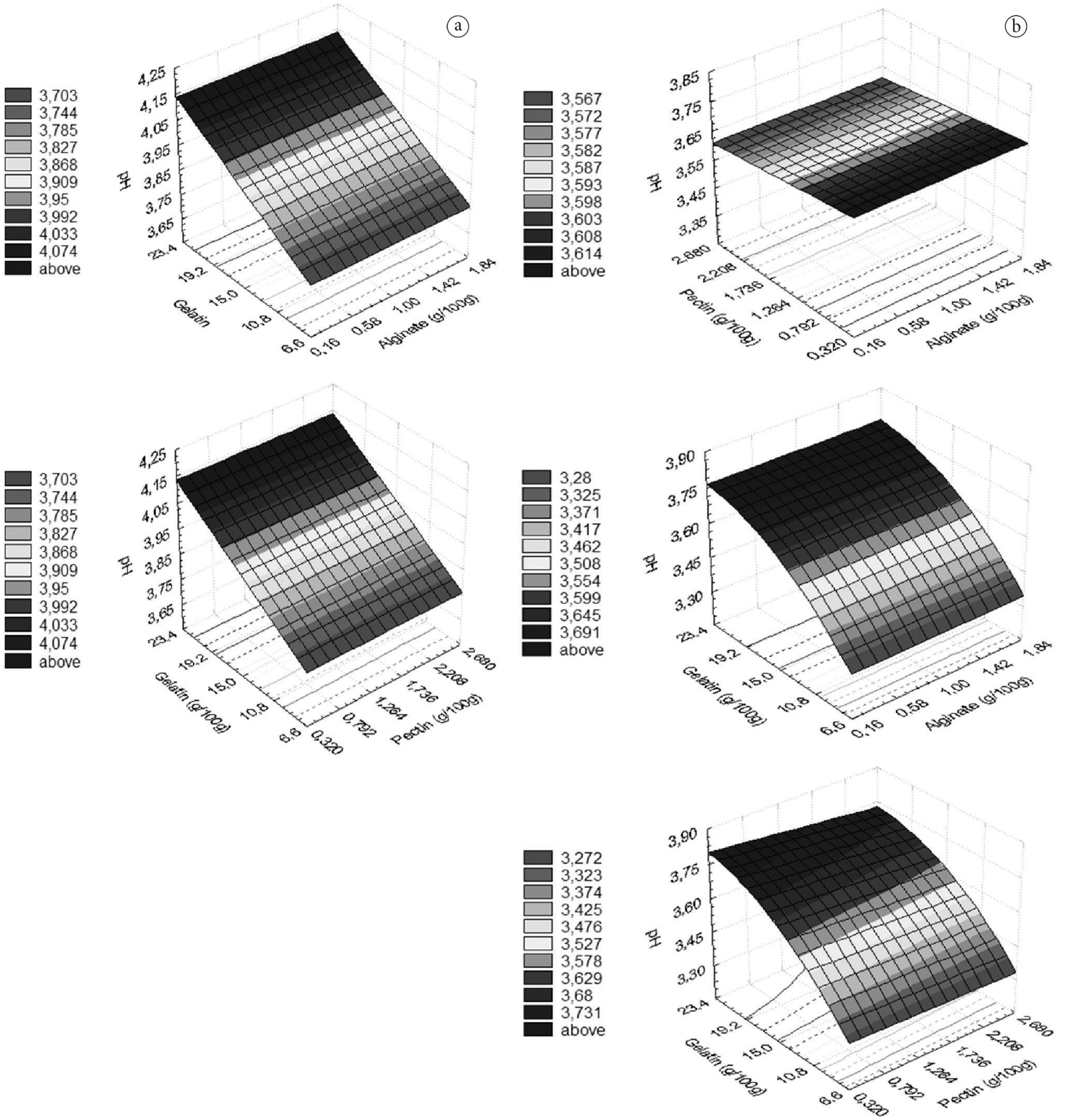

Figure 2. Response surfaces for pH of structured IPA 11.2 (a) and IPA 6.1 (b) genotypes (the other independent variable in each figure is fixed in its central value).

of yellow mombin and papaya, red mombin, and a mixture red mombin and acerola structured fruits, respectively.

3.4 Soluble solids (SS)

The models obtained did not show a significant regression (95% confidence level), indicating that it was not capable of describing the variations is soluble solids (SS). Both the standard error calculation and ANOVA showed that there were no significant terms, implying that the hydrocolloid concentrations have no influence on the SS of the structured fruits from all genotypes pulps. These results showed significantly larger variations in SS when the factor levels were varied than for the replicates trials for both IPA 11.2 and IPA 6.1 genotypes.

Oliveira et al. (2010), Carvalho et al. (2011) and Cavalcanti (2012) found soluble solids values between 58.67 and 61.33; 47.66 and 81.67; 30.33 and 54.33; 37.02 and 51.45 for structured cupuaçu fruit; yellow mombin mixed with papaya; red mombin; and red mombin mixed with acerola, respectively. The values found in the present study were within the range reported by the authors above mentioned.

3.5 Color difference (ΔE)

Color difference has been widely used to describe color changes during the processing of fruit and vegetable products (Maskan et al., 2002; Shih et al., 2009; Adekunte et al., 2010). The color variables are related to the types and quantities of some components present in foods (Ameny & Wilson, 1997; Sass-Kiss et al., 2005).

The significance of regression was determined by ANOVA, and lack of fit (95% confidence level) was determined using the F test, as shown in Table 4. It was observed for the structured genotype IPA 6.1 that the regression was significant and the lack of fit was not significant.

The statistical analysis revealed no significant terms for both IPA 11.2 and IPA 14 genotypes at a 95% confidence level. The three-fold replicate center point showed much larger variations in ΔE when the factor levels were varied than those of the replicates trials. As for IPA 6.1 genotype, the statistical analysis revealed that only the effects of gelatin (linear and quadratic) were significant ($p \leq 0.05$) for this response. The fitted model is described by Equation 7 ($R^2 = 0.86$).

$$\Delta E = 11.04 + 0.78G - 0.02G^2 \tag{7}$$

The generated surfaces are shown in Figure 3. It can be seen that an increase in the amount of gelatin, independent of the amount of sodium alginate and pectin, resulted in an increase in ΔE. Since the objective of this study was to obtain a product similar to the fresh pulp, and thus to preserve the original characteristics of the fruit, the smaller the ΔE, the better the result. This was possible using minimum amounts of alginate (0.16 g.100g^{-1}), pectin (0.32 g.100g^{-1}), and gelatin (6.6 g.100g^{-1}).

McHugh & Huxsoll (1999) studied the effect of moisture and temperature on the colorimetric properties of extruded peach and peach/starch gels. The authors observed for that as moisture content increased, the product lightness (L), redness (+a), and yellowness (+b) values decreased significantly ($p < 0.01$) for peach gels. For peach/starch gels, it was observed a decrease in L and b when temperature increased. These color changes were attributed to carotenoid degradation and non-enzymatic browning. Maskan et al. (2002) also observed color change during concentration of grape juice, cooking juice with starch, and drying of structured grape pulp and found that color changes occurred during the structured phase of the concentration of grape juice, in which the parameters a and b increased and L decreased. The authors believed that this change was due to degradation of anthocyanins in grape juice during heating and during drying of structured pulp. In the case of structured yellow *mombin*, an additional drying process was not performed, and the color differences obtained may be due to the heating step of the pulp as a result of degradation of some sensitive carotenoids.

Table 4. ANOVA model adjusted for the ΔE of the structured yellow mombin Genotype IPA 6.1.

Source of variation	DF	MS	Fcal
Regression	2	8.31	26.69
Residual error	14	0.31	
Lack of fit	12	0.34	2.46
Pure error	2	0.14	
Total	16		$R^2 = 0.86$

DF: degree of freedom; MS: mean square.

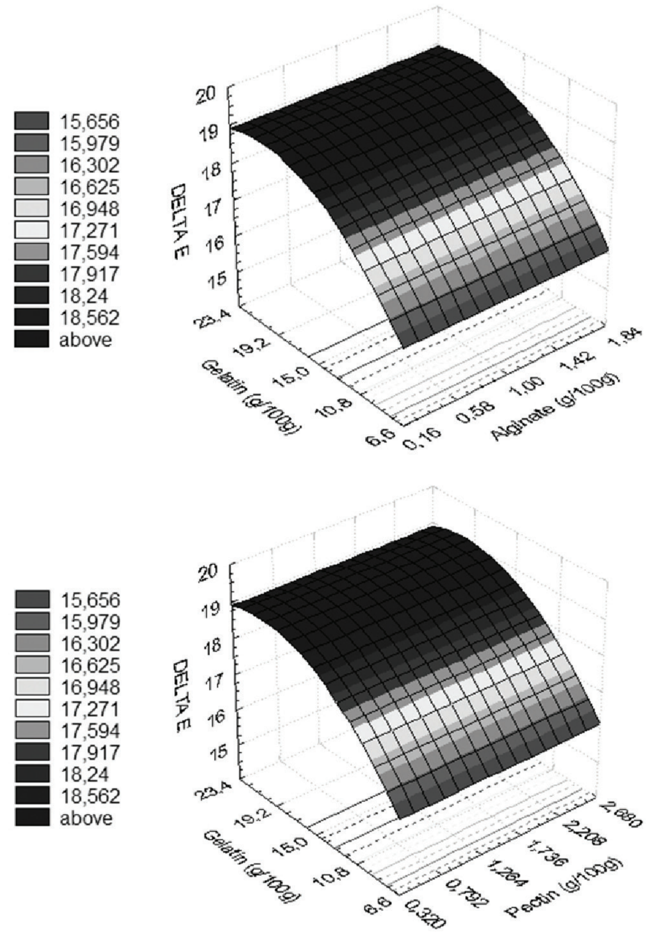

Figure 3. Response surfaces for ΔE of structured IPA 6.1 genotype (the other independent variable in each figure is fixed in its central value).

Cavalcanti (2012) observed in red mombin structured fruit that gelatin was the only hydrocolloid which had a positive contribution. The higher the concentration of gelatin, the greater the color difference. As for the mixture of red mombin and acerola structured fruit it was observed that the red mombin fruit pulp showed a negative contribution to color difference. Lower concentration of red mombin fruit pulp led to the highest difference in the structured product color.

4 Conclusion

The structured yellow *mombin* IPA 11.2 and IPA 14 genotypes showed the highest values of firmness, and they are considered good for structuring yellow *mombin*. Gelatin influenced the pH of structured yellow *mombin* IPA 11.2 and IPA 6.1 genotypes, while for IPA 14 genotype, it was not possible to verify the influence of hydrocolloids. The empirical models obtained for water activity and soluble solids were not considered predictive, but it was observed that the water activity values were within the intermediate moisture range. The color difference model for IPA 6.1 genotype was not considered predictive also, but the models for the structured IPA 11.2 and IPA 14 genotypes showed that gelatin was the hydrocolloid that most influenced the change in the product color. The results showed that there is a good prospect for production of structured fruits with yellow *mombin* pulp.

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