Rheological Properties of Emulsions Stabilized by Green Banana (*Musa cavendishii*) Pulp Fitted by Power Law Model

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ABSTRACT

In this work, the rheological behaviour of emulsions (mayonnaises) stabilized by green banana pulp using the response surface methodology was studied. In addition, the emulsions stability was investigated. Five formulations were developed, according to design for constrained surfaces and mixtures, with the proportion, respectively: water/soy oil/green banana pulp: F1 (0.10/0.20/0.70), F2 (0.20/0.20/0.60), F3 (0.10/0.25/0.65), F4 (0.20/0.25/0.55) and F5 (0.15/0.225/0.625) .Emulsions rheological properties were performed with a rotational Haake Rheostress 600 rheometer and a cone and plate geometry sensor (60-mm diameter, 2° cone angle), using a gap distance of 1mm. The emulsions showed pseudoplastic behaviour and were adequately described by the Power Law model. The rheological responses were influenced by the difference in green banana pulp proportions and also by the temperatures (10 and 25^oC). The formulations with high pulp content (F1 and F3) presented higher shear stress and apparent viscosity. Response surface methodology, described by the quadratic model,showed that the consistency coefficient (K) increased with the interaction between green banana pulp and soy oil concentration and the water fraction contributed to the flow behaviour index increase for all emulsions samples. Analysis of variance showed that the second-order model had not significant lack-of-fit and a significant F-value, indicating that quadratic model fitted well into the experimental data. The emulsions that presented better stability were the formulations F4 (0.20/0.25/0.55) and F5 (0.15/0.225/0.625).

Keywords: green banana pulp, emulsion, rheology, response surface methodology

INTRODUCTION

Banana is one of the most important energy sources for people living in many countries, including Brazil. It is also considered fourth on world's list of most important food crops, after rice, wheat and maize (Anon, 2002). Banana is a seasonal and highly perishable fruit and is often available year around. Due to high starch concentration (over 70% of dry weight), banana processing into flour and starch are important

resource for many industrial purposes (Krzysztof *et al*, 2003). In Brazilian scope, banana production is 7 million tons/year, which corresponds 9.3% world-wide production (FAO, 2004; IBGE, 2007). Banana is a climacteric fruit and, in Brazil, is consumed when the fruit is ripe. For this reason, high fruit quantities are lost during their commercialization due to poor postharvest handling (Izidoro, 2007). These losses can be reduced by rejected fruit processing. Green banana pulp that contains 70-80% starch on a dry weight

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basis, a percentage comparable to corn grain endosperm (Zhang *et al*, 2005), can be used as industrialized products ingredient such as gelatin, cake, bread, pies, yoghurt, ice cream and mayonnaise (Valle and Camargos, 2003).

From a physical point of view, mayonnaise is an oil-in-water emulsion (O/W) and to produce a low fat mayonnaise, it is necessary to decrease the dispersed phase and to increase the water content. According to Liu et al (2007), some fat mimetics such as modified starch, inulin, pectin, microcrystalline cellulose, carrageenan gum and some thickeners are generally used to stabilize the emulsion and to increase the light mayonnaises viscosity.Mayonnaise's rheology have been investigated by several authors because of its importance for formulation selection, process conditions and quality control. Rheological properties may give a quantitative contribution to texture characterization when using different formulations. Mayonnaise shows a yield stress, a pseudoplastic behaviour and time dependent characteristics (Peressini, *et al* 1998; Batista *et al*, 2006). Power Law, Herschel–Bulkley and Casson models have been widely used to describe mayonnaise and salad dressing flow properties (Peressini et al., 1998; Guilmineau and Kulozik, 2007; Batista et al., 2006).

Response surface methodology (RSM) is an effective statistical tool and widely used in process optimization, which includes experimental design, model fitting, validation and condition optimization (Cornell, 2002). Recently many authors reported a modeling approach based on a empirical model obtained by RSM and investigated the influence of the ingredientes concentrations on a wide range of mathematical parameters (Higuti *et al*, 2004; Biazus *et al*, 2005; Ferreira *et al*, 2007; Haminiuk *et al* 2007).

In this work, emulsions samples (mayonnaises) were made with soy oil, water and green banana pulp as stabilizant agent. The stability and emulsion's rheological behaviour were studied using the Power Law model, evaluating by means of response surface methodology the influence of water, oil and green banana pulp concentrations on the rheological parameters.

MATERIALS AND METHODS

Raw material characterization
Green bananas, "Nanica" (*Musa cavendishii*) variety, were obtained from a Central Supply SA-CEASA in Curitiba-Brazil. The *M.cavendishii* variety was chosen due to its availability in Brazil and the accessible price at the markets. Its moisture, pH, tritable acidity, expressed in malic acid and soluble solids were determined according to I.A.L (2005). The bananas ripeness degree was also determined by the ratio ^{o}Brix/titrable acidity in order to standardize the fruits ripening condition collected for this work (Izidoro, 2007).

Pulp preparation
The green banana pulp (GBP) was obtained from the green bananas (*M. cavendishii*), which were washed, cooked under pressure for about 10 minutes, drained, peeled and homogenized in a domestic blender for 5 minutes (Borges, 2003) in a proportion of 1:1 (green banana /water) in order to improve the homogenization. One pulp fraction was used for composition analysis and another one was used to prepare the emulsions.

Emulsions (mayonnaise) preparation
The formulations were prepared with the following ingredients: water, soy oil, green banana pulp (GBP), powdered mustard, vinegar and salt, according to Valle and Camargos (2003). Condiments were not added in order not to disguise the other ingredients flavours. All of these were purchased from a local supermarket. The green banana pulp, water and soy oil proportions are described in Table 1. The vinegar, salt and mustard (powder) proportions were 3.0, 1.5 and 0.5%, respectively for all the samples. The emulsions were prepared using a domestic blender at a constant speed. In the first stage the oil and mustard were mixed for 1 minute. In second stage, the water, vinegar, salt and GBP were mixed for 3 minutes. The emulsions were stored in plastic recipients and kept in refrigerator at 10°C.

Formulations and Experimental Design

The design for constrained surfaces and mixtures module of Statistica 7.1 (Stat-Soft, Tulsa, OK, USA) was used with three variables: water, green banana pulp (GBP) and soy oil, considering that these ingredients proportions presented repercussion in the emulsion structure. Preliminary tests were carried out to establish the minimum

and maximum values to the factors. The design for constrained surfaces and mixtures was applied because the factors underwent certain limitations such as (Cornell, 2002): $0 \leq ai \leq xi \leq bi \leq 1$ i = 1, 2,..q Σ xi = 1, where, ai = upper limit and bi = lower limit.
The experimental design is presented in Table 1.

Table 1- Design for constrained surfaces and mixtures augmented of seven treatments to the water, soy oil and green banana pulp mixtures.

Formulations	Original components			Pseudo-components		
Vertex (V) Centroid (C)	X1	X2	X3	X1	X2	X3
1V (F1)	0.10	0.20	0.70	0.0000	0.0000	1.0000
2V (F2)	0.20	0.20	0.60	0.6660	0.0000	0.3340
3V (F3)	0.10	0.25	0.65	0.0000	0.3330	0.6670
4V (F4)	0.20	0.25	0.55	0.6660	0.3330	0.0100
5V(C) (F5)	0.15	0.225	0.625	0.3330	0.1665	0.5005
5V(C) (F5$_1$)	0.15	0.225	0.625	0.3330	0.1665	0.5005
5V(C) (F5$_2$)	0.15	0.225	0.625	0.3330	0.1665	0.5005

Where X1 + X2 + X3 = 1 or 100%; X1 = water, X2 =soy oil and X3 = green banana pulp (GBP).

The responses were the rheological parameters flow behaviour index (n) and consistency coefficient (K) according to Haminiuk et al.,(2007). These responses were fitted according to the model that showed the higher determination coefficient value and lower chi-square value (χ^2). To represent the fitted response values the linear, quadratic and cubic models were used (Equations 01, 02 and 03). The equations statistical significance was determined by variance analysis (ANOVA) at 5%.

$$\hat{Y} = b1X1 + b2X2 + b3X3 \qquad (01)$$

$$\hat{Y} = b1X1 + b2X2 + b3X3 + b1b2\ X1X2 + b1b3X1X3 + b2b3X2X3 \qquad (02)$$

$$\hat{Y} = b1X1 + b2X2 + b3X3 + b1b2\ X1X2 + b1b3X1X3 + b1b2b3\ X1X2X3 \qquad (03)$$

where: $\hat{Y}$ = estimate rheological parameters response; b = equation coefficients (determined according to Cornell, 2002); X = pseudo-components proportions.

Basic composition analysis

Green banana pulp and formulations composition analysis (Moisture, protein, total fat, crude fibers, ash, pH and acidity) were determined according to I.A.L. (2005) the mineral salts (calcium, iron, magnesium, potassium and sodium) followed the methodology according to AOAC (2000).

Carbohydrates were determined by subtracting the moisture, protein, fat, crude fiber and ash sum percentages from 100% (USP, 2007). Caloric values were determined according to Souci et al. (2000), where the caloric values = (4X protein) + (9X fat) + (4X carbohydrate).

Rheological behaviour

Emulsions rheological properties were performed with a rotational Haake Rheostress 600 rheometer (Haake) and a cone and plate geometry sensor (60-mm diameter, 2° cone angle). The measurements were conducted using a gap distance of 1mm. The sample compartment was controlled at a 10 and 25°C temperatures using a water bath/circulator Haake DC-30 and a Haake Universal Temperature Controler system (UTC) (Haake, Karlsruhe, Germany). The 10°C temperature was chosen for the reason that was the refrigeration temperature and the 25°C has been used by authors studying the mayonnaises and fruit purées rheological behaviour (Guerrero and Alzamora, 1997; Peressini et al., 1998; Branco, 2003; Worrasinchai et al., 2006).
Each experimental run to the upward curve had the duration of 2 min with shear rate range from 0 to $300s^{-1}$, and 2 min to the downward curve with shear rate range from 300 to $0s^{-1}$. Both at decreasing and increasing shear rate, 25 points of shear stress were obtained resulting in a total of 50

data points. Three runs were done for each material, and the resulting shear stress was the three experimental averages values. The experimental data were evaluated and fitted according to the rheological Power Law model (eqn 4), using the average shear stress value for each shear rate, applying the software Origin 7.0 (OriginLab Corporation, MA, USA) to obtain the rheological (n and K) and statistical parameters (R^2, SSR and χ^2) (Haminiuk et al., 2006)

$$\sigma = K.\gamma^n \qquad\qquad (4)$$

where: σ is the shear stress (Pa), K is the consistency coefficient (Pa.s^n) and n is the flow behaviour index (dimensionless). The Power Law model according to Branco and Gasparetto (2003) is a simple model and has a wide technology application.

Optical microscope observation

The glassy flat was coated with mayonnaise sample and placed on Olympus model stage CH30/CH40 (Tokio, Japan). Then adjusted the focus to get clearly the view field. The mayonnaise microstructure pictures were obtained by a camera connected to the microscope (Olympus, model PM-10Ak3, Tokio, Japan). The emulsions were observed in different periods: first day, after 15, 30, 45 and 60 days.

RESULTS AND DISCUSSION

Raw material characterization

Moisture, total soluble solids (°Brix), titrable acidity and the ratio °Brix/titrable acidity analysis were carried out aiming standardize the fruit ripeness degree collected for this work as presented in Table 2.

The moisture values were in agreement with Morton (1987) who found an average 70% to green banana and around 75% to ripe banana and stated that during the maturation period, the pulp moisture content increased due to the transformation with the carbohydrates. As pH and titrable acidity, results were in agreement with Lima et al., (2004) who studied the bananas ripeness degree. In this work, the total soluble solids values were higher then the results found by Silva et al., (2006), which found 3.20 °Brix to green banana, *M. sapientum* variety.

Table 2 - Green bananas (raw material) physical-chemical characteristics.

Parameters	Experimental values
Moisture (%)	71.69 ± 0.12
pH	5.20 ± 0.60
Total soluble solids (° Brix)	5.15 ± 0.31
Titrable acidity (g/mL)*	0.15 ± 0.01
Ratio (°Brix/titrable acidity)	34.80

* expressed in malic acid.

Rheological measurements and surface response

The emulsions flow curves at 10 and 25°C are shown in Figs 1 and 2. Marked points represent the rheogram's experimental data up and down values. It could be observed that the flow behaviour was affected by temperature, which was in agreement with Guerrero and Alzamora (1997) and Haminiuk et al. (2007) studying fruit purées and pulps flows.

According to flow behaviour index data (Tables 3 and 4) all the samples showed shear-thinning (pseudoplastic) behaviour (n < 1) for both the temperatures. Pseudoplastic behaviour was found in previous studies performed with mayonnaises (Ma and Barbosa-Cánovas, 1995; Worrasinchai et al., 2006; Batista et al., 2006) and with bananas purées (Guerrero and Alzamora, 1997). According to Krokida *et al,* (2001), the flow behaviour index (*n*) is slightly affected by the temperature, with a small increase at high temperatures.
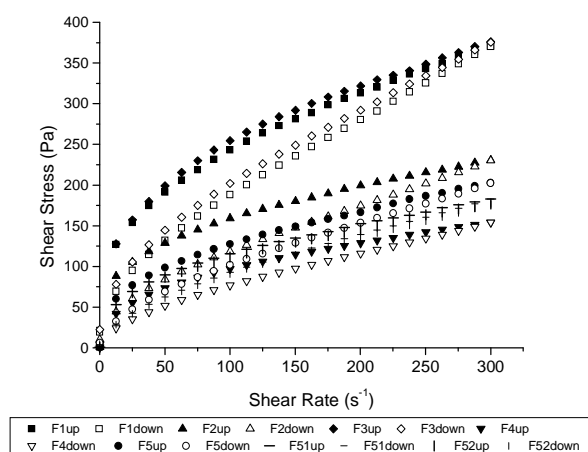
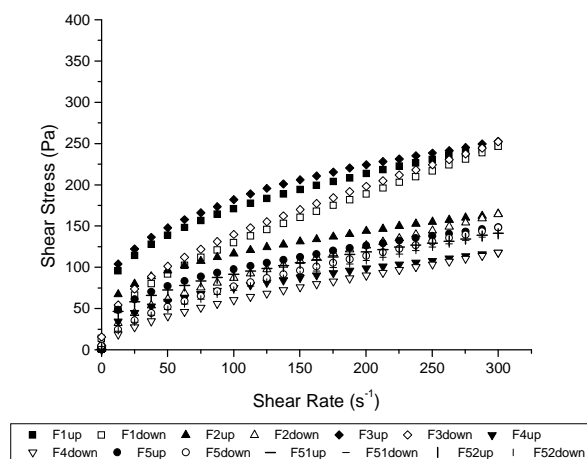**Figure 1** - Emulsions samples flow curves fitted by Power Law model at 10^oC.

Figure 2 - Emulsions samples flow curves fitted by Power Law model at 25^oC

Table 3 - Power Law model parameters at 10^oC.

Formulations (water/oil/GBP)	Consistency coefficient K $(Pa.s^n)$	Flow behaviour index n (dimensionless)	SSR	R^2	X^2
F1(0.10/0.20/0.70)	26.668 ± 0.450 a	0.457 ± 0.015 a	1.121	0.990	29.162
F2(0.20/0.20/0.60)	10.856 ± 0.352 b	0.485 ± 0.011 a	0.770	0.991	3.473
F3(0.10/0.25/0.65)	31.750 ± 0.211 c	0.429 ± 0.012 a	0.844	0.989	13.239
F4(0.20/0.25/0.55)	8.658 ± 0.043 d	0.501 ± 0.010 a	0.212	0.991	1.484
F5(0.125/0.225/0.625)	20.060 ± 0.159 e	0.424 ± 0.013 a	0.787	0.989	11.137
$F5_1$(0.125/0.225/0.625)	20.108 ± 0.042 e	0.423 ± 0.011 a	0.799	0.989	10.327
$F5_2$(0.125/0.225/0.625)	20.856 ± 0.350 e	0.423 ± 0.012 a	0.747	0.989	9.953

Mean ± SD values followed by the same letter in each column are not significant different by Tukey's test.
SSR - Sum of squared residuals. R^2 - Determination coefficient. X^2 - Chi-square.

Table 4 - Power Law model parameters at 25°C.

Formulations (water/oil/GBP)	Consistency coefficient K (Pa.s^n)	Flow behaviour index n (dimensionless)	SSR	R^2	X^2
F1(0.10/0.20/0.70)	22.475 ± 0.347a	0.415 ± 0.021 a	0.785	0.989	10.158
F2 (0.20/0.20/0.60)	9.594 ± 0.173 b	0.467 ± 0.011 a	0.291	0.990	2.074
F3(0.10/0.25/0.65)	27.487 ± 0.443c	0.386 ± 0.012 a	0.612	0.988	4.862
F4(0.20/0.25/0.55)	7.336 ± 0.391d	0.483 ± 0.054 a	0.188	0.991	1.001
F5(0.125/0.225/0.625)	16.049 ± 0.240e	0.402 ± 0.030 a	0.529	0.989	4.635
F5$_1$(0.125/0.225/0.625)	16.551 ± 0.223e	0.399 ± 0.013 a	0.562	0.989	4.113
F5$_2$(0.125/0.225/0.625)	16.195 ± 0.261e	0.402 ± 0.050 a	0.547	0.989	4.551

Mean ± SD values followed by the same letter in each column are not significant different by Tukey's test.
SSR - Sum of squared residuals. R^2 - Determination coefficient. X^2 - Chi-square.

The rheograms fitted by the Power Law model showed high determination coefficient (R^2) and low chi-square (χ^2) values at both temperatures and the (R^2) values ranged from 0.988 to 0.991.
It was noticed that F1 and F3 presented higher shear stress compared with F2, F4 and F5, which could be attributed to the higher green banana pulp content in these samples. These formulations presented similar rheological behaviour to commercial mayonnaise, studied by Worrasinchai et al., (2006) which worked at same shear rate 0 to 300s^{-1}.
The central curves corresponded to the central point samples (F5, F5$_1$ and F5$_2$) and according to Tables 3 and 4 there was no statistical difference between the central point samples (F5, F5$_1$ and

F5$_2$), indicating small experimental error.
Consistency coefficient (K) values decreased with an increase in temperature for all the formulations. According to Krokida et al (2001), the temperature has a major effect on the consistency coefficient (K) on the non-Newtonian fluid food.
Tables 5 and 6 show the rheological parameters n and K analysis of variance at 10 and 25°C, fitted according to the quadratic models. Analysis of variance (F-test) showed that the second order (quadratic) model fitted well into the experimental data. The lack-of-fit tests, which measured the fitness of the model obtained, did not result in a significant F-value, indicating that the model was sufficiently accurate to predict the rheological responses within the ranges studied.

Table 5 - Flow behaviour index (n) and consistency coefficient (K) response analysis of variance at 10°C and 25°C.

Source	Square sum	Degrees of freedom	Mean square	F	Square sum	Degrees of freedom	Mean square	F
n (flow behaviour index)				10°C				25°C
Model	0.004	4	0.005	257.75*	0.025	4	0.006	555.89*
Total error	0.0003	16	0.000		0.0002	16	0.00	
Lack-of-fit	0.00	0	0.000		0.00	0	0.00	
Pure error	0.0003	16	0.000		0.0002	16	0.00	
Total	0.019	20	0.000		0.025	20	0.001	
K (consistence coefficient)								
Model	1182.80	4	295.70	6420,73*	864.58	4	216.14	2006.98*
Total error	0.737	16	0.046		1.173	16	0.1080	
Lack-of-fit	0.000	0	0.00		0.00	0	0.0000	
Pure error	0.737	16	0.046		1.173	16	0.1080	
Total	1183.54	20	59.18		866.30	20	43.315	

* p < = 0.05.

The fitted equations obtained for the rheological parameters n and K at 10 and 25°C are shown in Table 7. All fitted equations showed high determination coefficients values (ranging from 0.98 to 0.99) and low standard error values (ranging from 0.05 to 4.90). The n and K contour plots are given in Figs. 3 and 4 at 10°C and Figs 5 and 6 at 25°C. As observed (Fig. 3 and 4), the shear-thinning emulsions character, represented by response n, at both temperatures was highly influenced by the water fraction, which was confirmed by the higher quadratic coefficient value shown in eqns 5 and 7 (Table 7).

With regard to the consistency coefficient (Figs 5 and 6) the interaction between soy oil and green

banana pulp resulted in higher K values, even so, the soy oil fraction had a greater effect on the consistency coefficient when compared to green banana pulp (eqns 6 and 8). Similar results were observed by Ma and Barbosa-Canovas (1994) and Gladwell et al. (1986), who working with mayonnaise, observed that consistency coefficient magnitude increased with oil concentrations. According to Urbanski *et al* (1982), the emulsions consistency coefficient has a linear relationship with the intumesced polymers. A emulsion,when is compound by polymers, causes large internal frictions, resulting in consistency coefficient (*K*) raise.
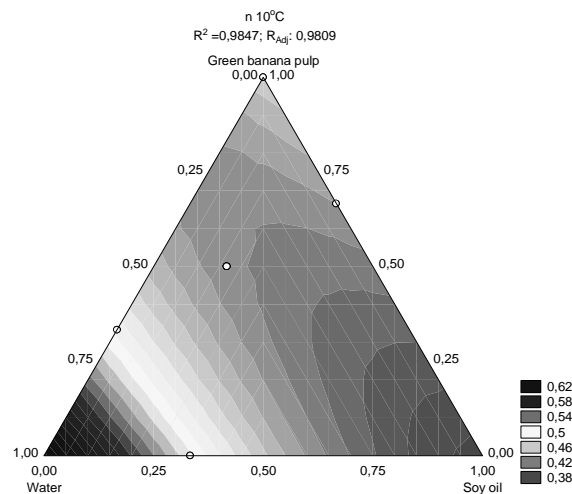

Figure 3 – Flow behaviour index (n) contour plots fitted by the quadratic model at 10°C.
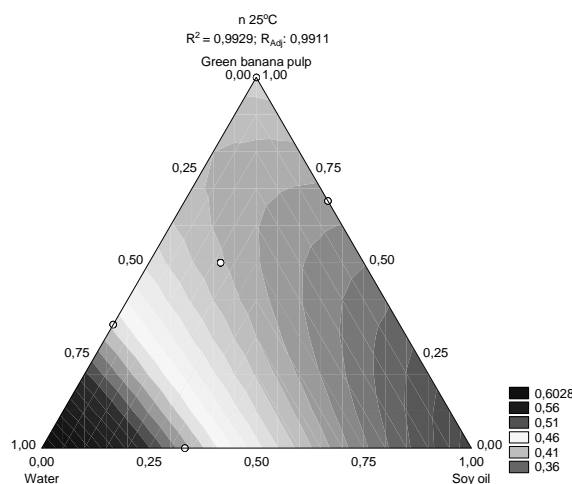

Figure 4 - Flow behaviour index (n) contour plots fitted by the quadratic model at 25°C.
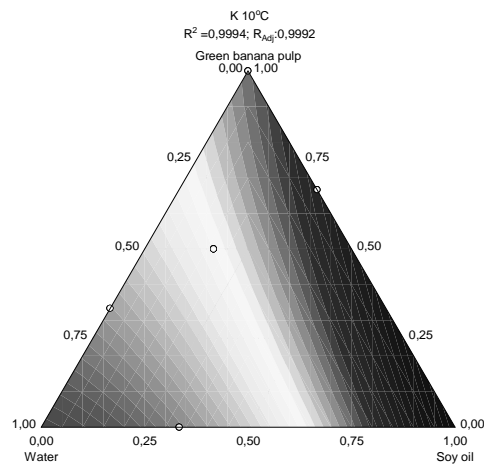
Figure 5 - Consistency coefficient (K) contour plots fitted by the quadratic model at 10°C.
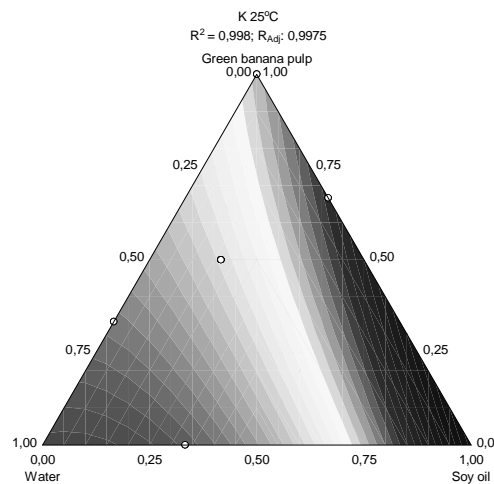

Figure 6 – Consistency coefficient (K) contour plots fitted by the quadratic model at 25°C.

Table 7 - Rheological parameters (n and k) regression equations.

T = 10°C (Eqns 1 and 2) T = 25°C (Eqns 3 and 4)	Eqn	R^2	SE
n = 0,63X1*+0,37X2+0,46X3-0,21X1X2*-0,40X1X3*	5	0.98	0.07
K=1,29X1+41,92X2*+26,67X3*-27,79X1X2*+5,00X1X3*	6	0.99	4.01
n=0,60X1*+0,32X2+0,41X3-0,12X1X2-0,33X1X3	7	0.99	0.05
K=4,53X1+37,52X2*+22,47X3*-36,86X1X2*-4,12X1X3*	8	0.99	4.90

* significative coefficients.

SE = Standard Error, R^2 = Determination Coefficient; X1 = water; X2 = oil; X3, green banana pulp.

Apparent viscosity plot versus shear rate at 10 and 25°C are shown in Figs. 7 and 8. All the formulations apparent viscosity decreased as the temperature and shear rate increased. This behaviour could be explained by the molecules structural breakdown due to the hydrodynamic forces generated and the increased constituent molecules alignment (Asparlan and Haita, 2002; Rao and Tattyakul, 1999). Small hydrodynamic forces at low shear rate are not able to disrupt the flocks and as an effect of shear rate increases, the hydrodynamic forces dominate and disrupt the

flocks, causing a viscosity reduction (McClements, 1999).According to Haminiuk et al. (2007), during food processing, the food structure become weak as temperature increases. Similar results were also obtained to fruit pureés by Guerrero and Alzamora (1997, 1998).
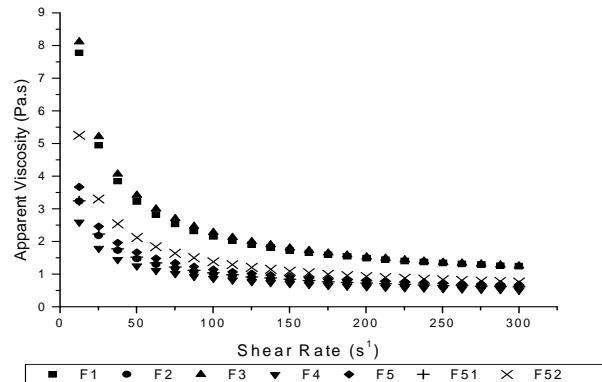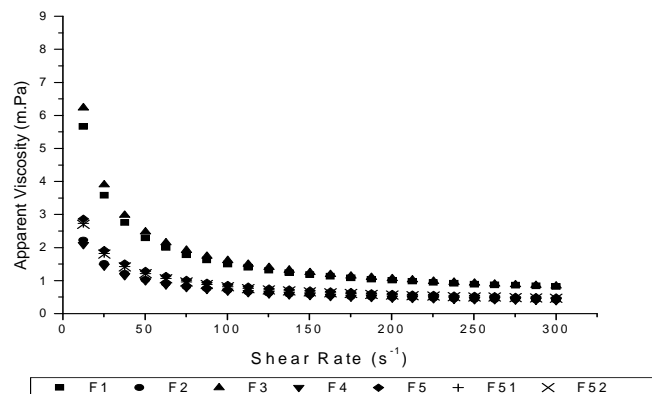

Figure 7 – Apparent viscosity at 10°C.

Figure 8 - Apparent viscosity at 25°C.

Optical microscope observation

In Fig. 9a-e., the emulsions microstructures in the same day that they were prepared are verified.

The small drops correspond to the oil and the empty spaces and according to Worrasinchai et al., (2006) represent the continuous phase, that is, the watery phase. In this work, due to the drops sizes, the all formulations in the first day were steady, therefore, did not have drops coalescence signal.The formulations F1 and F3 presented bigger drops and were more uniform than the others formulations, being able to be classified in accordance with Worrasinchai et al., (2006) as monodispersed emulsions (uniformity in the drops size), whereas, F2, F4 and F5 presented small variety in the drops size (polydispersed). Gutierrez et al., (2002) found that the monodispersed emulsions presented significantly bigger viscosity than polydispersed Emulsions. The same was found in this work through the rheological analyses where the emulsions F3 and F1 presented higher viscosity. Fig. 10a-e show the emulsions microstructures after 60 days storage at 10°C.
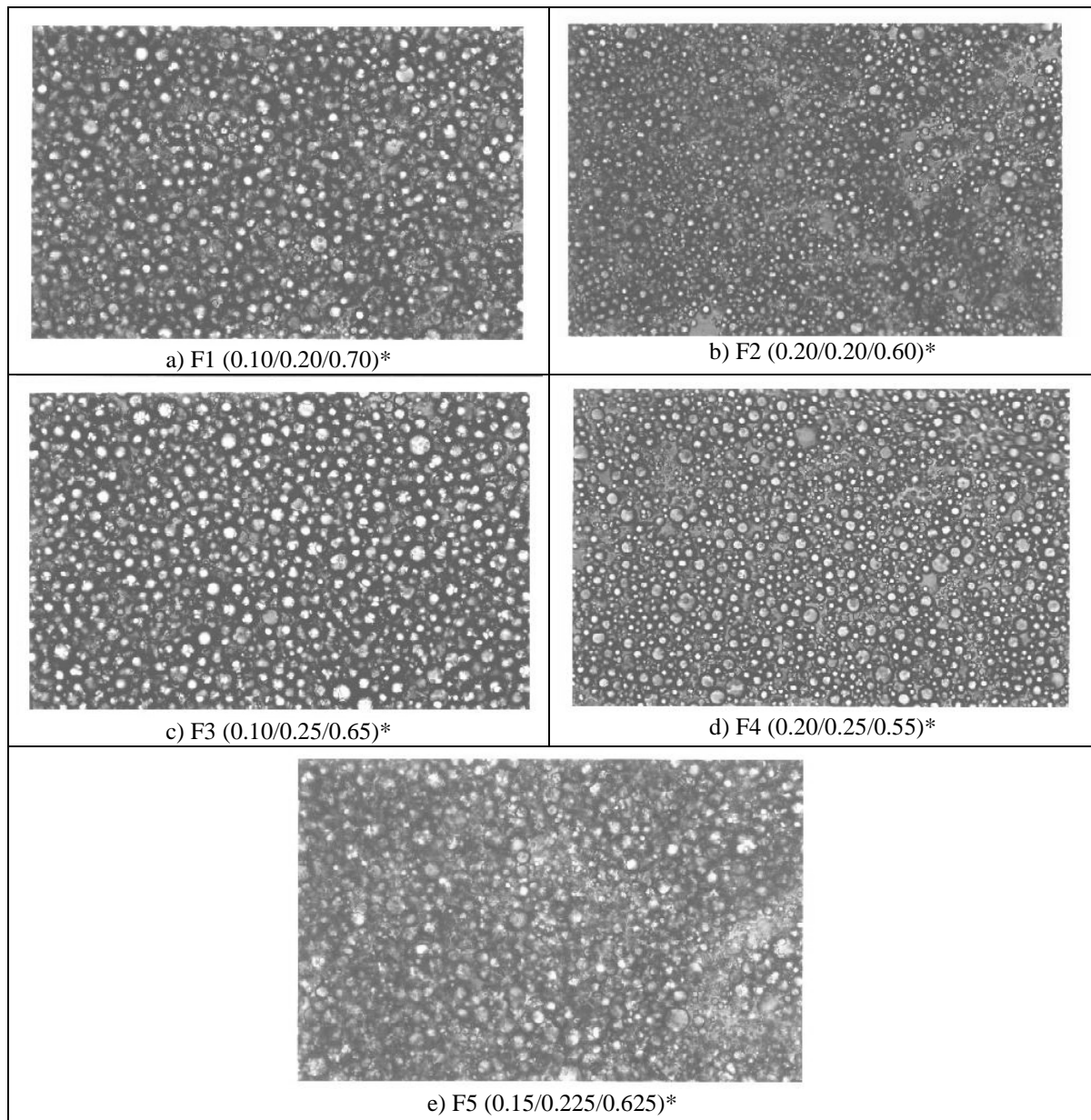
a) F1 (0.10/0.20/0.70)*

b) F2 (0.20/0.20/0.60)*

c) F3 (0.10/0.25/0.65)*

d) F4 (0.20/0.25/0.55)*

e) F5 (0.15/0.225/0.625)*

Figure 9 – Microstructures at 40X to F1 (a), F2 (b), F3 (c), F4 (d) and F5 (e) at first day
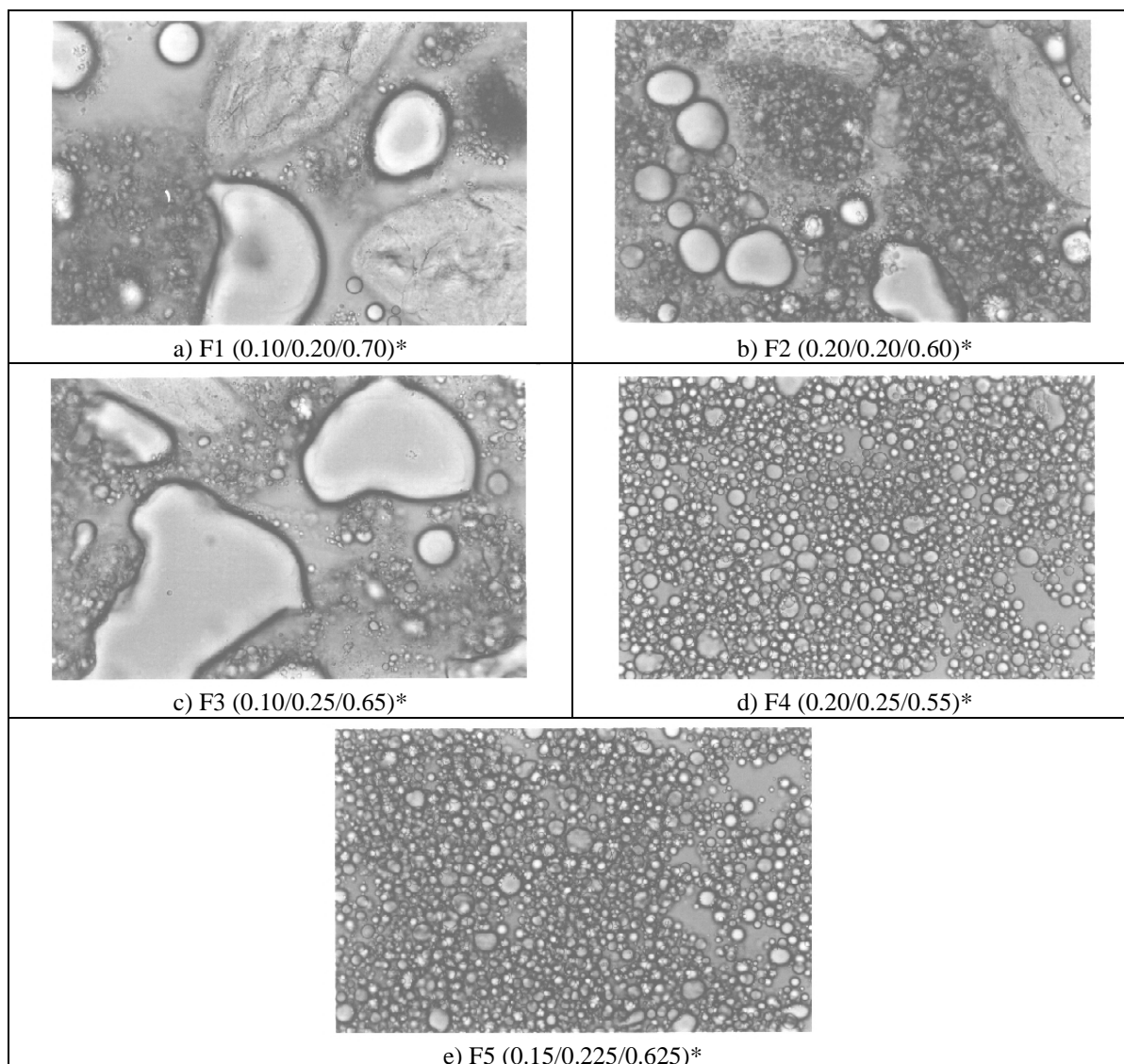* water/soy oil/ green banana pulp proportions.

Figure 10 – Microstructures at 40X to F1 (a), F2 (b), F3 (c), F4 (d) and F5 (e) afters 60 days of preparation.* water/soy oil/ green banana pulp proportions.

After two months F5 and F4 remained steady (Figs. 10d and 10e) and creamy, F2 on the other hand presented notables coalescence signals with consequent instability (Fig 10b). As observed in Figs 10a and c the F1 and F3 formulations were totally unstable with great coalescence signals (large water drops). This could be attributed to the microbiological deterioration of the product. However, there was not a phase separation in both the formulations. In mayonnaises added to β-glucan as fat substitute, Worrasinchai et al., (2006) observed that the formulation without β-glucan presented biggest drops size and was uniform (monodispersed), and the formulation with 25% β-glucan presented polydispersed, where small drops were between the big ones.

CONCLUSIONS

From the present work, it could be concluded that in all the formulations, the mixtures presented shear-thinning (pseudoplastic) behaviour and the rheological parameters were well represented by the Power Law model. With an increase in temperature, a decrease in flow behaviour index (n) and consistency coefficient (K) were observed. Good fit models were developed for flow

behaviour index and consistency coefficient. The formulations with higher GBP content, 70 and 65% (F1 and F3, respectively) were the ones that presented higher shear stress and apparent viscosity. RSM studies showed that the interaction between the soy oil and green banana pulp contributed to the consistency coefficient (K) increase to all the samples. Water, on the other hand, acted on the flow behaviour index (n) increase. Analysis of variance showed that the second-order model had not significant lack-of-fit and a significant F-value, indicating that quadratic model fitted well into the experimental data. The emulsions that presented better stability were the formulations F4 with 55% green banana pulp, 20% water and 25% soy oil and the formulation F5 with 62,5% green banana pulp, 15% water and 22.5% soy oil.

RESUMO

No presente trabalho, foi estudado o comportamento reológico de emulsões adicionadas de polpa de banana verde utilizando a metodologia de superfície de resposta e também foram investigadas a estabilidade das emulsões. Foram desenvolvidas cinco formulações, de acordo com o delineamento para superfícies limitadas e misturas, com as proporções respectivamente: água/óleo de soja/polpa de banana verde: F1 (0,10/0,20/0,70), F2 (0,20/0,20/0,60), F3 (0,10/0,25/0,65), F4 (0,20/0,25/0,55) e F5 (0,15/0,225/0,625). As propriedades reológicas foram realizadas em reômetro Haake Rheostress 600, com sensor de geometria cone e placa (60-mm diâmetro, 2° ângulo de cone), usando uma distância de abertura de 1mm. As emulsões mostraram comportamento pseudoplástico e foram descritas adequadamente pelo modelo Lei da Potência. O comportamento reológico foi influenciado pelas diferentes proporções de polpa de banana verde e também pelas temperaturas (10 e 25^oC). As formulações com alto teor de polpa (F1 e F3) apresentaram maior tensão de cisalhamento e viscosidade aparente. Relativo à metodologia de superfície de resposta, descrita pelo modelo quadrático, pôde-se observar que o coeficiente de consistência aumentou com a interação entre a polpa de banana verde e a concentração de óleo de soja e a água contribuiu com o aumento do índice de comportamento para todas as amostras de emulsões. A Análise de Variância mostrou que o modelo de segundo ordem não apresentou falta-de-ajuste com valor F significativo, indicando que o modelo quadrático representou bem os dados experimentais. As emulsões que apresentaram melhor estabilidade foram as formulações F4 (0,20/0,25/0,55) e F5 (0,15/0,225/0,625).

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