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Reduced-Calorie Filling Cream: Formula Optimization and Mechanical Characterization

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Filling creams are generally fat and sugar based; they are important components in different confectionary foods, in which they provide taste, texture and adhesion of the baked items. The objective of this research was to develop and optimize a reduced-calorie filling cream. The effect of the fat replacer system (a mixture of simplesse, microcrystalline cellulose and maltodextrin) and the fat substitution level (from 0 to 100 %) on filling cream properties was studied.
A D-optimal mixture design with five components (water, margarine, simplesse, microcrystalline cellulose and maltodextrin) was chosen which resulted 25 formulations. The remaining ingredients, sugar, dextrose monohydrate and skimmed milk powder, were kept constant (55 % of the total mixture).
Mechanical properties, water activity, density and color were used as response variables in the regression model built to determine the optimal levels of ingredients. The best formulation was chosen through the desirability function. Lubricated squeezing flow (LFS) experiments were performed to study the mechanical behaviors of reduced-calorie filling creams.
LFS results showed that reduced-calorie filling creams behave as a pseudoplastic liquid or as a viscoelastic liquid or as a viscoelastic foam, depending on both fat replacer system and fat substitution level. Moreover mechanical properties are related to the spreading and consistency properties as perceived by the consumers.
Quadratic models were used to optimize the response variables. The optimized formulation had 3.5 kcal/g, so it was possible to reduce the caloric content at least of 30 % with good results.

1. Introduction

Filling creams are basically sugar and fat mixtures, even if also other ingredients are included in the recipe (Manley, 2001). Sugars are generally the main ingredients; sucrose is the most used one (Birkett, 2009). It acts both as sweetener and as bulking agent and also affects some sensory properties such as sweetness, hardness and dryness of the final product. Dextrose is less sweet than sucrose and dissolves in the mouth with a significant and pleasant cooling effect, but it can lead to splitting problems because of a water activity problem (Manley, 2001). Sugars in general do not chemically react with fats, but they affect mechanical properties (Helstad, 2006). Fat content in filling creams varies from 30 to 60 % , and has an enormous effect on the sensory and rheological properties . Basically the consistency of a filling cream is determined by the solids content of the fat (Manley, 2001). When margarine and/or butter are used, the product exhibits a pseudo-plastic behaviour. Different instrumental approaches were used in order to characterize semi-solid products, as, rheological analysis (Carbone et al., 2011), mechanical determination (Thomareis et al., 2011) and a combined mechanical-rheological approach (Chung et al., 2012).
In order to reduce the caloric content, fat can be substituted by a fat replacer system which determinates the appropriate texture characteristics of the cream (Manley, 2001). Generally, a three-ingredients system could be necessary for a good fat mimetic: a thickening agent, a soluble bulking agent, and an insoluble microparticulate (Jones, 1996). Some microparticulates can be used as fat substitutes due to their ability to

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form gels and to confer smoothness, such as microcrystalline cellulose, which is insoluble in water (Jones and Jonnalagadda, 2006). Simplesse, a microparticulate protein-based, can be used for products that are prepared at low temperature, such as creams, dressings and dairy products (Daniel 2010). Maltodextrins act as bulking agent, thickener and stabilizer (Hull, 2010) and could partially replace fats, but only at low substitution level. In order to define the optimal combination of ingredients of a fat replacer system, a mixture experimental model could be used that has no constant and squared terms (Gacula, 1993). In particular, when the range of ingredients variation is restricted or resources are limited, a D-optimal design, that focuses on estimating model coefficients, could be used (Mostefa et al., 2006).
The objective of this work was to develop reduced-calorie filling creams. New filling creams containing different fat replacers, at different levels substitution, were designed, developed and characterized.

2. Material and methods

2.1 Experimental design

A D-optimal mixture design with five components (water, simplesse, microcrystalline cellulose, maltodextrin, and margarine) was used and their sum represented the 45 % of the total. The proportions for each ingredient were expressed as a percentage of the mixture, and for each treatment combination, the sum of the component proportions was equal to one hundred, where:

$$x_1 + x_2 + x_3 + x_4 + x_5 = 100 \quad (2.1)$$

The percentage of each ingredient used was chosen according to the literature (Jones, 1996) and preliminarily tested. In particular, ranges for each ingredient were determined as follows: water (x_1) 11 – 65 %, maltodextrin (x_2) 0 – 25 %, microcrystalline cellulose (x_3) 0 – 10 %, simplesse (x_4) 0 – 35 %, margarine (x_5) 0 – 89 %.
In order to replace fat content at different levels, the following mixture constraints were imposed:

$$0 \leq x_2 + x_3 + x_4 \leq 89 \quad (2.2)$$

$$11 \leq x_1 + x_2 + x_3 + x_4 \leq 100 \quad (2.3)$$

A quadratic model (Gacula, 1993) was used and 25 experimental points were determined (Table 1), five points were replications.

Table 1: Fat replacer system composition

Formulation	W	MD	MC	S	M
1	65.00	11.52	4.55	18.92	0.00
2	65.00	11.52	4.55	18.92	0.00
3	65.00	0.00	0.00	35.00	0.00
4	41.78	23.22	0.00	35.00	0.00
5	65.00	18.07	10.00	0.00	6.93
6	42.52	4.38	9.74	35.00	8.36
7	65.00	25.00	0.00	0.00	10.00
8	39.30	25.00	6.50	13.98	15.22
9	39.30	25.00	6.50	13.98	15.22
11	55.74	0.00	0.00	22.13	22.14
13	30.09	6.95	0.00	35.00	27.96
14	32.06	24.21	10.00	0.00	33.73
16	38.45	8.48	0.00	14.91	38.16
17	38.45	8.48	0.00	14.91	38.16
18	53.75	0.00	4.34	0.00	41.92
19	53.75	0.00	4.34	0.00	41.92
22	16.86	14.19	6.78	0.00	62.18
23	16.86	14.19	6.78	0.00	62.18
24	11.11	0.00	10.00	13.50	65.39
25	11.11	0.00	0.00	0.00	88.89

2.2 Materials

The following ingredients were used: margarine (M) (Flo'c, Unigrà s.r.l.), dextrose monohydrate (J.T. Beker), powdered sucrose (Eridania), skimmed milk powder (Irish rived by Morgan Chemicals S.p.a.), deionised water (W) and soy lecitine (Lecinova). Microionized whey proteins (S) (Simplesse 100, Kelco), gently supplied by Giusto Faravelli, microcrystalline cellulose (MC) (Tabulose, Blanver Farmoquimica LTDA), maltodextrin 6 DE (MD) (Glucidex, Roquette Preres SA) were also used to partially or completely replace the fat phase.

2.3 Sample preparation

Samples were prepared by mixing all the ingredients, according to the designed formulations, at room temperature for 20 min. Then, the mixture was whipped using a Kenwood chef device. Samples were stored at 4°C 24 hours, then analysed at 20°C.

2.4 Methods

Preliminary characterization. Water activity was measured through an AcquaLab device (Decagon Devices, Inc., 4TE series) at 20 ± 3°C that uses the chilled-mirror dewpoint technique to measure the water activity of a sample. Color parameters were measured by a colorimeter Minolta Chroma Meter II Reflectance Cr-300, set on L*, a*, and b* system. A small plexiglass cylinder, of known volume ($1cm^3$) and weight (1g), was used to measure sample density. The cylinder was filled with the sample and weighed. Density was expressed as weight (g)/volume (cm^3) ratio. Three replicates of each sample were made.
Mechanical properties.Lubricated squeezing flow experiment at constant diameter of the sample was performed with an Instron Universal Machine (Instron Ltd., mod. 4467) equipped with a 100 N load cell. Cylindrical samples (D = 40mm; h =8 mm) were tested at 3 constant crosshead rate (1, 5, 10 mm/min),at room temperature (20 °C ±2). Measurements were made in triplicate.

2.5 Data analysis

ANOVA was performed to evaluate formulation effect on data (Design-Expert v.8.00 software, Stat-Easy Inc. Minneapolis, USA). As response variables, a_w, density, color and mechanical parameters were used. The latter were obtained as parameters of the model reported by Launay and Michon (2008), that was used for experimental data fitting (Statistica 98, StatSof. Italia).
Only the variables significantly different were used in models generated to determine the optimal levels of ingredients. The following regression model was used:

$$Y=B_1X_1+B_2X_2+B_3X_3+B_4X_4+B_5X_5+B_{12}X_1X_2+B_{13}X_1X_3+B_{14}X_1X_4+B_{15}X_1X_5+B_{23}X_2X_3+B_{24}X_2X_4+B_{25}X_2X_5+B_{34}X_3X_4+B_{35}X_3X_5+B_{45}X_4X_5+error \quad (2.4)$$

where Y was the response variable, X was the percentage of each ingredient, B was the coefficient generated from the model, subscript represented the ingredients.
Areas of overlap, where all responses were simultaneously optimized, were determined. The best formulation was chosen through the desirability function (Di Monaco et al., 2010). Optimal conditions were ascertained by preparing the sample with the highest desirability in the optimized region and by determining significant differences between observed and predicted values (paired *t* -test, $p\leq0.05$) (SPSS v. 17.0 for windows).

3. Results and Discussion

3.1 Preliminary characterization

Filling creams presented different a_w values (Figure 1.a), from 0.76 - 0.86. a_w was higher for samples with a high water content and low fat replacer content (1 - 2 - 3 - 5 – 7 - 19). The presence of maltodextrin and a right water-powder ratio (4 - 13 - 14) determined lower a_w. Indeed, hydrocolloids structure the water and a_w decreases (Jones, 1996). Density values are reported in figure 1.b. Density of several samples was within the range 0.75 - 1.15 gcm^{-3}, as described by Manley (2001). Samples containing a high amount of simplesse (1 – 2 - 3) showed the lowest density and were not able to be used as filling cream. Samples with high cellulose microcrystalline content (7 - 8) were too dense, probably because of its ability to form a three-dimensional network (Jones, 1996) and also because it does not contribute to incorporate air during whipping. This excludes the possibility of replacing fat with only cellulose microcrystalline. The color coordinates that most characterize filling creams were L* and b*, in particular the brightest (high L*) and lightest (low b*) filling creams were the first ones with the lowest density values, ie with more entrained air (data not shown).

3.2 Mechanical properties

Elongational viscosity (η_b) as a function of biaxial strain (ε_b) and biaxial strain rate ($\dot{\varepsilon}_b$), for full fat filling creams and just one defatted filling cream, was showed in Figure 2. All filling creams showed a shear thinning behavior with a viscosity that decreased as the biaxial strain rate increased (Figure 2a) but for some formulations the elongational viscosity decreased with a different rate depending on biaxial strain (Figure 2.b). Experimental data were fitted by using a no- linear regression model, as reported by Launey and Michon (2008) and A, n, m parameters were estimated (Table 2).

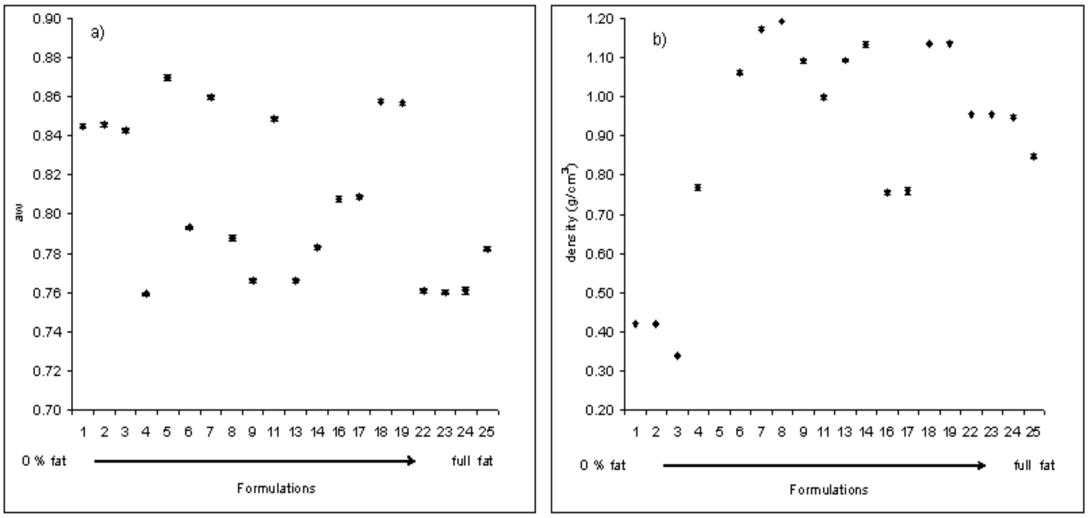

Figure 1: Aw (a) and density (b) of filling cream with different fat content and fat replacer system

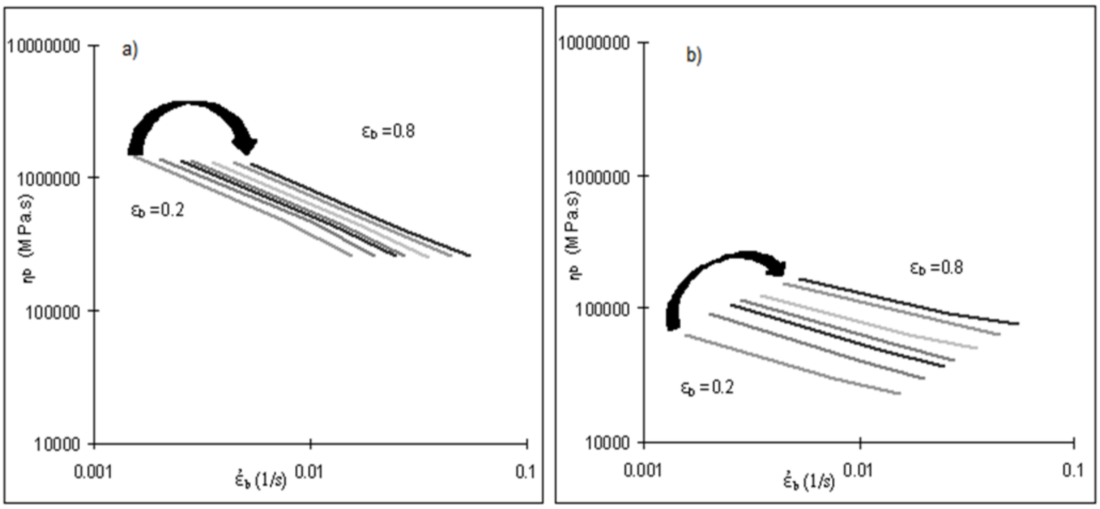

Figure 2: Elongational viscosity (η_b) vs biaxial strain rate ($\dot{\varepsilon}_b$), at different biaxial strains (ε_b), of filling creams with full fat content (formulation 25) (a) and low fat content (formulation 8)(b)

The A value regarded the consistency of the product (Launey and Michon, 2008). The full fat sample (25) had the higher value of A (Table 2). Filling cream with 10-15% of fat reduction (22), showed similar properties to full fat filling cream.The value of m was purely descriptive and had no unequivocal rheological meaning, even if it could depend on the viscoelastic property of a material (Launey and Michon, 2008). m depended both on fat content and fat replacer composition; it was higher for samples in which maltodextrin formed a gel. Also n parameter increased as fat content decreased, but it was mainly influenced by fat replacer composition. Samples with high m and n values were hardly spreadable. Among formulations with 55-70% of fat reduction, only sample 16 resulted spreadable as full fat filling, but with a lower consistency. Meanwhile the 13 sample presented a marked viscoelastic character, not present in the full fat filling. Formulation 8 with low fat content, was characterized by high n and m values, but low A values. Among free fat formulations, sample 4 was the most similar to the full fat filling. Generally, fat replacer reduced A values, and increased m and n parameters even if the last ones were mainly influenced by fat replacer composition.

Table 2: Estimated mechanical parameters (average ±S.E.) of some filling creams

Formulations	A (Pa)	m (Pa)	n (Pa.s)
25	9.21±0.04	1.34±0.03	0.28±0.01
22	8.55±0.05	1.94±0.04	0.16±0.01
16	7.76±0.07	1.81±0.05	0.3±0.01
14	7.54±0.1	2.79±0.08	0.37±0.02
13	8.28±0.16	2.98±0.12	0.51±0.03
8	7.68±0.14	2.83±0.11	0.58±0.02
4	8.11±0.16	2.88±0.13	0.41±0.03
2	6.05±0.12	2.19±0.10	0.37±0.02

3.3 Formula optimization

The response affected by the formulation were used as response variables in regression models built to determine the optimal levels of ingredients. Estimated parameters of prediction models for each response variable were listed in Table 3.

Table 3: Final Equations in Terms of Real Components

Component	A (Pa)	n (Pa.s)	m (Pa)	a_w	density (g/cm^3)	L*	a*	b*
W	-34.1	-0.93	2.08	0.96	14.5	-91.18	-70.3	171.59
MD	18	10.36	-82.7	0.61	48.4	-599	-224.76	509.35
MC	-610.26	-50.29	-80.5	0.71	244.45	-2731.98	-1123.76	2193.53
S	-13.04	1.44	20.7	0.63	7.54	17.37	-27.75	101.26
M	7.94	0.28	0.5	0.75	2.05	73.71	-8.71	25.85
W*MD	121	N.S.	113.24	N.S.	-1.13	15.62	5.38	-12.6
W*MC	879	N.S.	-21.18	N.S.	-2.93	33.31	13.55	-28.28
W*S	147.2	N.S.	-28.7	N.S.	-0.52	6.33	2.38	-6.23
W*M	60.2	N.S.	6.37	N.S.	-0.26	3.42	1.29	3.05
MD*MC	348.16	N.S.	498.6	N.S.	-3.16	38.91	14.44	-25.53
MD*S	-131.2	N.S.	88.57	N.S.	N.S.	1.95	N.S.	N.S.
MD*M	-54.8	N.S.	66.71	N.S.	0.22	3.74	1	-2.22
MC*S	484.81	N.S.	145.4	N.S.	-2.13	24.88	9.84	-16.73
MC*M	720	N.S.	110	N.S.	-2.96	34.95	13.64	-27.24
S*M	N.S.	N.S.	-26.75	N.S.	0.08	-1.52	0.47	0.91
R^2	0.99	0.74	1	0.98	1	1	0.99	1
p	<0.0001	0.04	<0.0001	<0.0001	<0.0001	<0.0001	0.0004	<0.0001

Response variables were explained through linear and quadratic models (Table 3). In particular, quadratic models were used to explain almost all parameters considered, except for a_w and n,. n was the worst parameter estimated. Meanwhile m was estimated very well by the model chosen and it was influenced by MD and MC content. The best formulation of the fat replacer system was found, through the desirability function, imposing as constraints the maximization of A, the minimization of a_w, n value between 0.25 - 0.4, m between 1.5 - 2.5, estimated caloric content between 2.5 - 3.5 kcal/g and density between 0.7 - 1.Three optimized formulations were found with the same predicted caloric content, the same water and margarine content, the same water-fat replacer ratio, but different content of each fat replacer (Table 4).

Table 4: Composition and characteristics of optimal formulations with the highest desirability (0.78 - 0.73)

Solutions	1	2	3
W	33.49	35	29.88
MD	9.74	4.23	6.44
MC	0.06	10	9.63
S	29.38	23.03	18.55
M	27.34	27.74	35.5
A	8.1	8.48	7.93
n	0.4	0.4	0.27
m	2.5	1.78	2.5
a_w	0.77	0.79	0.78
density	1	0.96	0.92
L*	84.53	85.26	86.71
b*	12.91	11.7	12.08

These results underlined the strong interaction among components of the fat replacer system (Table 3). At the first formulation containing a high percentage of simplesse and of maltodextrin corresponded a filling cream with a high m value. A lower m and a higher A values were obtained by adding MC and reducing the MD, content (formulation 2). The filling cream with the third formulation was similar to the first one for A and m, but different for n. Formulation 1, with the highest desirability, was used to validate the model. The results from paired t-test showed no significant differences ($p < 0.05$) between predicted and measured parameters (results not reported). The optimal filling cream had 3.5 kcal/g, obtaining a caloric content reduction of about 31 %.

4. Conclusions

D-Optimal design was useful to study the effect of fat reduction on properties of filling creams. The strengths of this method lie in reducing the number of formulations to run. Results obtained confirmed that it is often impossible to replace fat with a single compound, considering that the fat plays different roles in food. Evaluated filling creams presented different structure (pseudoplatic liquid, liquid foam, viscoelastic liquid), depending on fat and fat replacer content.
The quadratic model explained the effect of almost all ingredients of the fat replacer system. Through the desirability function it was possible to develop a reduced fat filling cream.

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