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Use of sesame oil cake (*Sesamum indicum* L.) on corn expanded extrudates

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ABSTRACT

In the production of oil from sesame (*Sesamum indicum* L.) seeds, a coproduct is obtained which is rich in protein and fiber contents. Mixtures of semi-defatted sesame cake (SDSC) (0–20%) and corn grits were processed in a single screw extruder at screw speed ranging from 324 to 387 rpm to improve the nutritional value of corn expanded extrudates. Chemical composition of raw and extruded materials, sectional expansion index (SEI), texture properties, color, paste viscosity, microstructure and sensory analysis of the extrudates were performed. The addition of SDSC increased protein, fat and ash content of corn extrudates, whereas carbohydrate content was reduced. The addition of SDSC reduced the sectional expansion of the corn extrudates and increased puncture force. SDSC–corn extrudates were darker than non-SDSC–corn extrudates. Increasing SDSC increased the number of cells similar to those of commercial corn extrudates with small cells. Sensory analysis showed 20% SDSC-corn extrudates to be acceptable and nutritional balanced. The use of SDSC on corn extrudates up to 20% is an alternative to improve nutritional value keeping good sensory characteristics.

1. Introduction

Sesame (*Sesamum indicum* L.) is a oleaginous plant of high nutritious value with a high amount of proteins composed mainly of sulfur-amino acids (methionine), essential fatty acids, vitamins and minerals, amongst them, calcium which is found in high concentration (Arriel, Araujo, Soares, Beltrão, & Firmino, 2006). Sesame seeds also contain a large group of fat-soluble antioxidants (sesamin, sesamol, sesamolin and tocopherols), which play an important role on health-promoting effects (Rangkadilok et al., 2010), acting especially against oxidative processes in cells.

Sesame is a fast cycle and draught tolerant crop cultivated in the arid region of the Brazilian Northeast, where families produce their food in the family farming system. Although sesame consumption in Asian countries such as India and China is high, the Brazilian consumption is reasonably limited due to cultural habits.

In the process of extraction of sesame oil by mechanical press, semi-defatted sesame cake (SDSC) with about 50% of protein and high calcium concentration (1500 mg/100 g) is obtained (Ariel et al., 2006). When calcium content of SDSC is compared to traditional calcium sources, such as cow milk (123 mg of calcium/100 mL of milk) (Franco, 1999), the advantage of SDSC in terms of calcium concentration is clear although its bioavailability should be evaluated. Sesame cake is also a very interesting source of crude fiber (10.8 g/100 g) (Mohdaly, Smetanskaa, Ramadanc, Sarhanb, & Mahmoudb, 2011).

The thermoplastic extrusion technology has been successfully used to develop ready to eat new products, as a result of physical and chemical modification due to combination of shear, heat and pressure in short time (Camire, Camire, & Krumhar, 1990). When starchy materials at low water content are processed by extrusion, puffed extrudates are obtained resulting in low product density and crispy texture (Bouvier, Bonneville, & Goullieux, 1997). The main raw material used in the production of puffed extrudates is corn grits which is abundant and cheap. The presence of high starch content is fundamental for the expansion and formation of small air bubbles that enhance sensory characteristics such crispness and crunchiness (Ding, Ainsworth, Plunkett, Tucker, & Marson, 2006).

Many cereal-based foods, such as expanded extrudates from corn, breakfast cereals from wheat, oat and barley, and baked products such as cookies, bread, crackers are considered good carriers of dietary fiber (Duarte, Carvalho, & Ascheri, 2009). However, incorporation of fiber deteriorates the quality characteristics, such as expansion, loaf volume, spread and texture (Onwulata, Konstance, Strange, Smith, & Holsinger, 2000). Some studies have attempted to improve the functionality of fiber-based ingredients by thermal and thermo-mechanical treatments such as extrusion cooking (Gajula, 2007). Apart from functional and nutritional improvements due to extrusion of fiber and protein based ingredients, the sensory characteristics of the final product could also be positively affected.

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In recent years, many studies have showed an extensive use of pulse proteins, such as lentils, peas, and chickpeas used to increase the biological value protein of cereal-based products (Han, Janz, & Gerlat, 2010; Ryland, Vaisey-Genser, Arntfield, & Malcolmson, 2010; Shirani & Ganesharanee, 2009). An interesting study aimed at examining changes in food consumption, satiety and perceived bowel health while consuming a diet rich in chickpeas was conducted by Murty, Pittaway, and Ball (2010). The authors showed that perceived satiety increased while participants consumed chickpeas and also found bowel function improvement.

There is a growing interest in the evaluation of the residues generated by food processing (Altan, McCarthy, & Maskan, 2008a, 2008b; Conti e Silva, Cruz, & Arêas, 2010; Stojceska, Ainsworth, Plunkett, Ibanoglu, & Ibanoglu, 2008). The use of oleaginous species and/or their byproducts in extruded products in the scientific literature is scarce, although Mukhopadhyay and Bandyopadhyay (2003) used the extrusion to study the effect on the anti-nutritional factor tannin in sesame meal. They found that extrusion was effective to reduce the anti-nutritional factor, tannin, from sesame meal. In another study, the physical properties of directly expanded extrudates formulated from partially defatted peanut flour (PDPF) and different types of starch were investigated (Suknark, Phillips, & Chinnan, 1997). The conditions that lead to high expansion, low bulk density, and low shear strength (hardness) of tapioca and corn starch were 20–30% PDPF at 18–19% moisture content and 5–30% PDPF at 18–19% moisture content, respectively.

The aim of this work was to study the effect of screw speed and semi-defatted sesame cake on the extrusion of corn extrudates and to characterize their nutritional, texture features, internal microstructure and sensory attributes.

2. Materials and methods

2.1. Materials

Commercial corn grits were kindly donated by Granfino Food Industry S.A. (Nova Iguaçu, Brazil) and sesame grain, variety “BRS Seda”, was donated by Embrapa Cotton (Campina Grande, Brazil). In order to obtain sesame cake, an expeller extruder CA59G Oekotec (IBG Monforts, Germany) fitted with a 5 mm circular die was used to process sesame cake at room temperature (25 ± 2 °C), which was further dried at 60 °C and milled in a disk mill 3600 Perten Instruments (Huddinge, Sweden) to produce coarse flour that was placed in a plastic bag, sealed and maintained in a freezer (−15 °C) until extrusion process to avoid oxidative changes.

2.2. Chemical analyses

The chemical composition of corn grits, semi-defatted sesame cake (SDSC), and the 10 and 20% of SDSC extrudates were determined according to AOAC standard methods: protein content method n. 46-13 (AOAC, 1995), fat content method n. 945.38 (AOAC, 2005), dietary fiber content method n. 985.29 (AOAC, 2005), ash content method n. 923.03 (AOAC, 2005), moisture content was determined in oven at 105 °C until constant weight and carbohydrate by difference. The aminoacid profile was also determined on the extrudates according to the methodology described by AOAC (2005), method 994.12, modified by Cohen and Michaud (1993) using high performance chromatographer Alliance 2695 (Waters, Milford, USA) equipped with a fluorescent detector Alliance 2475 (Waters, Milford, USA). Protein hydrolysis was carried out using 6 M chloridric acid solution per 20 h at 110 °C. After hydrolysis, derivatization reaction was performed using an AccQ Fluor Reagent Kit® (Waters, Milford, USA). After derivatization, samples were incubated at 55 °C per 10 min. Amino acid profile, except for tryptophan and sulphur amino acids, was determined using a column AccQ.Tag® 3.9 mm × 150 mm (Waters, Milford, USA), 5 μL injection volume and elution flow of 1 mL/min. Standard amino acids (NCI0180, Pierce Biotechnology, Inc., Rockford, USA) were used to construct a calibration curve.

2.3. Extrusion conditions

The blends of corn grits and varied content of SDSC (0 to 20%) were extruded in a RX 50 Inbramaq single screw extruder (Ribeirão Preto, Brazil). The screw was 200 mm long, 60 mm in diameter and compression ratio of 1:1. The die set was designed with two parts: an internal die of 54 holes of 2.82 mm diameter each placed in between the end of the screw head and the four round holes of 1.8 mm diameter each with 10 mm length. The screw speed ranged from 324 to 387 rpm. The powders were fed into the extruder at 15% moisture using an adjusted vibrating channel at a rate of 20 kg/h. The size of the extrudates was adjusted to 30 mm long by controlling the facial cutter speed to 39 rpm.

The extrudates were dried in an oven with circulating air at 50 °C for 24 h until the final moisture of 5% (±1%) and then stored in plastic bags for further analyses and the rest was milled in a disk mill 3600 (Perten Instruments, Huddinge, Sweden) followed by a second milling passage in another grinder hammer mill 3100 (Perten Instruments, Huddinge, Sweden) to obtain a fine flour that was then sieved in a vibrating sieve shaker Rotap RX-29 (W.S. Tyler, Mentor, USA) to obtain particles sized between 106 and 212 μm. The expanded extrudates were used for the following analyses: sectional expansion index, texture analyses, morphological characterization and sensory evaluation, while the milled/sieved extrudates were analyzed for paste viscosity.

2.4. Experimental design and data analysis

A 2^2 central composite design was carried out using response surface methodology (RSM) (Box, Hunter, & Hunter, 1978) to show the interaction of two independent variables, denominated SDSC content (x_1,%) and screw speed (x_2, rpm). The experimental design was composed of thirteen trials (six runs, with two axial points and five repetitions of the central point). For each variable, extreme levels were established according to preliminary experiments. The coded levels and experimental values are shown in Table 1. Dependent variables (Y_i) were sectional expansion index (SEI), textural and paste viscosity parameters. Each dependent variable was correlated to the independent variables using a second-degree polynomial model (Eq. 1), which takes into account the linear, quadratic and interaction effects of these variables.

$$Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_{11} {X_1}^2 + \beta_{22} {X_2}^2 + \beta_{12} X_1 X_2 + \varepsilon \quad (1)$$

Y_i was the response; X_1 is% of SDSC, X_2 is screw speed, β_o is the intercept; β_1 and β_2 the linear coefficients; β_{11} and β_{22} the quadratic coefficients, and β_{12} the interaction coefficients.

The stepwise forward multiple regression analysis shown in Eq. (1) was carried out using *Statistica*® version 5.0 (Statsoft, Tulsa, USA). The significance of the individual terms and also of the interaction terms in the polynomial was determined statistically at the

Table 1
Coded levels and experimental values for the 2^2 central composite design.

Independent variables	Levels				
	$-\alpha$[a]	-1	0	$+1$	$+\alpha$[a]
SDSC[b] (%) (X_1)	0.0	2.9	10.0	17.1	20.0
Screw speed (rpm) (X_2)	324	333	356	378	387

[a] $\alpha = 1.414$.
[b] SDSC = semi-defatted sesame cake.

probability level of at least 5% ($P \leq 0.05$). The analysis of variance (ANOVA) tables were generated for each of the response functions.

Extrusion processing parameters and product responses (Table 2) were analyzed by using a graphical method of RSM in order to obtain extrudates with acceptable properties of expansion, textural parameters and paste viscosity. Response variables with R^2 higher than 0.7 and regression coefficients are presented in Table 6 and predictive models were used to graphically represent them as shown in Figs. 1, 3 and 4.

2.5. Sectional expansion index

The sectional expansion index (SEI) of dried extrudates were conducted on 10 extrudates of 3 cm in length as described by Alvarez-Martinez, Koundury, and Harper (1988) using a caliper to measure the diameter in three points of cylindrical shape extrudates. The calculation of SEI followed the equation shown as follow:

$$\text{Sectionalexpansionindex(SEI)} = \left[\frac{D}{D_0}\right]^2 \quad (2)$$

Where D is the diameter of the extrudate after cooling and D_0 is the diameter of the die.

2.6. Texture analysis

The texture of the dried extrudates with approximately 5% moisture content was analyzed on a Texture Analyzer TA.HDi (Stable Micro Systems, Surrey, England) fitted with a load cell of 50 kg and a stainless steel cylindrical probe of 2 mm diameter. The extrudates were placed in an adjustable three point snap fixture (TA-92) and punctured at cross head speed of 1 mm/s until the probe completely passed the extrudate. The texture evaluation of all extrudates was conducted at a fixed distance of 6 mm, although the diameter varied according to the experiments. The measurement of 10 specimens was recorded. According to Bouvier et al. (1997), the following criteria were applied to evaluate crispness:

– Spatial frequency of structural ruptures (mm^{-1}):

$$N_{sr} = \frac{N_o}{d} \quad (3)$$

Table 2
Effects of extrusion conditions on process and product responses.

Extrusion conditions			Product responses						
Run	SDSC content, X_1 (%)	Screw speed, X_2 (rpm)	SEI	F (N)	W_c (N. mm)	PV (cP)	Breakdown (cP)	Setback (cP)	ΔE
1	17.1	333	12.9	0.1516	0.6368	135.0	109.5	155.0	6.77
2	2.9	333	20.0	0.1202	0.5248	238.0	138.5	288.5	4.18
3	17.1	378	13.0	0.1823	0.8758	99.5	87.5	136.0	6.81
4	2.9	378	23.1	0.1121	0.4795	203.5	105.0	252.0	3.52
5	10.0	324	16.5	0.1580	0.7343	272.5	158.0	259.5	4.55
6	10.0	387	19.0	0.1373	0.5548	211.0	127.5	212.5	3.97
7	0	356	25.5	0.0916	0.3753	63.0	42.5	132.5	0.00
8	20.0	356	6.5	0.1721	0.7358	83.5	71.5	45.5	8.35
9	10.0	356	16.0	0.1508	0.6006	221.5	143.5	222.5	4.15
10	10.0	356	15.8	0.1516	0.6368	226.0	144.5	236.5	3.79
11	10.0	356	15.2	0.1603	0.7019	192.0	130.0	231.5	3.79
12	10.0	356	14.5	0.1502	0.6093	135.5	108.0	203.0	4.48
13	10.0	356	14.3	0.1764	0.7232	166.5	106.5	211.0	4.22

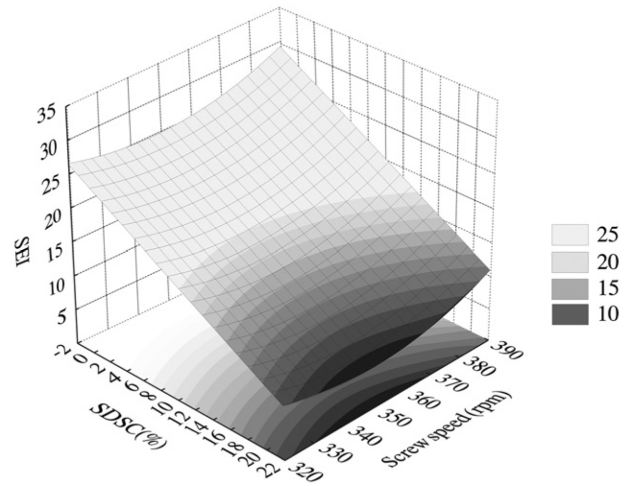

Fig. 1. Response surface plot for SEI as a function of screw speed and SDSC addition.

– Average specific force of structural ruptures (N):

$$F_{sr} = \sum \frac{\Delta F}{N_0} \quad (4)$$

– Average puncture force (N):

$$F = \frac{A}{d} \quad (5)$$

– Crispness work (N mm):

$$W_c = \frac{F}{N_{sr}} \quad (6)$$

N_0 is the total number of peaks in the texture analyzer force–deformation curve output, d is the distance of puncture (mm), ΔF is the individual force drops for each peak (N), A is the area under the force deformation curve (mm^2), N_{sr} is the frequency of ruptures, F_{sr} is the average specific force of ruptures, F is the average puncture force and W_c is the crispness work.

The instrumental texture parameters of two commercial corn puffed extrudates coated with cheese flavor (brands "A" and "B") were also compared to the experimental data.

2.7. Paste viscosity

The paste viscosity of corn grits, SDSC flour and expanded extrudates were investigated according to Carvalho, Takeiti, Onwulata, and Pordesimo (2010), in duplicate. A Rapid Visco Analyser (RVA, Newport Scientific Pty Ltd., Warriewood, Australia) was used to measure the paste viscosity of samples as a function of temperature. Approximately 3 g of extrudate specimen flour (14% of water content, wb) adjusted to 10% solids concentration was added to 25 g distilled water and this was loaded into the RVA. The time–temperature profile included initially mixing and holding the specimen with the paddles rotating at 160 rpm at 25 °C for 4 min (to investigate the cold-swelling starch peak), heating to 95 °C at a constant rate of 14 °C/min, holding at 95 °C for 3 min, and then cooling to 25 °C in 5 min at the same rate. The readings from the paste curve generated were cold viscosity (CV) (maximum viscosity reading at 25 °C), peak viscosity at 95 °C (PV) (first viscosity reading data when the temperature reached 95 °C), breakdown viscosity and setback viscosity following the methodology described by Duarte et al. (2009).

2.8. Microstructure analysis

Morphological observations of two fractured internal radial sections were visualized using a scanning electron microscope (SEM) LEO 440i (Leica Electron Microscope Ltd., Germany). The samples were previously dried in oven (WTB Binder, Tuttlinger, Germany) at a temperature of 105 °C overnight, glued on a metallic stub and metalized with a gold/palladium alloy in a Sputter Coater (mod. SC7620, Polaron, UK) at a coating rate of 0.51 Å/s, for 180 s, at 3 mA, 1 V and 2×10^{-1} Pa. The image acquisition was performed by LEO software, 3.01 version (Leica Electron Microscope Ltd, Germany).

The internal radial structure of the extrudates was also acquired using a benchtop office scanner HP Scanjet 3500C (Palo Alto, USA) set to 600 pixels resolution and digital colored images were compared to SEM microphotograph.

2.9. Color evaluation

The color of the grinded extrudates (fraction between 106 and 212 μm) were measured in a Hunter ColorQuest XE (Hunter Associates Laboratory Inc., Reston, USA) as lightness (L), redness (a) and yellowness (b). For each sample six measurements were taken in average. The adopted control sample was extrudate with 0% of SDSC and the total color change (ΔE) was calculated as:

$$\Delta E = \sqrt{(L-L_0)^2 + (b-b_0)^2 + (a-a_0)^2} \tag{6}$$

2.10. Sensory evaluation

In order to evaluate the effect of sesame type on the extrusion of expanded extrudates through sensory analyses, another experiment was conducted in the same extrusion conditions of SDSC–corn extrudates hence two concentrations of whole sesame seeds (WSS) added with corn grits: 5%, WSS–corn (05:95), and 10%, WSS–corn (10:90), were produced and then compared.

A hedonic preference test was carried out to access the sensory acceptability of the extruded products. The corn expanded extrudates added of 10% sesame cake, SDSC–corn (10:90), and 20% sesame cake, SDSC–corn (20:80) were evaluated on overall liking by 120 consumers on 9-point hedonic scales: 1—disliked extremely; 5—neither liked nor disliked; 9—liked extremely. The preference test assessment of two extrudates made from whole sesame seed (WSS-corn expanded added of 5% and 10%) were also compared to the experimental data.

Table 4
Mineral content (mg/100 g) of semi-defatted sesame cake (SDSC) and corn grits.

	Na	Mg	P	K	Ca	Fe	Zn
SDSC	6.6	607.2	931.8	1089.3	1660.7	39.0	9.4
Corn grits	4.0	213.0	748.7	1190.8	10.4	0.7	8.4
Brand A	824.0	ND	ND	ND	ND	ND	ND
Brand B	1016.0	ND	ND	ND	ND	ND	ND

ND: Non Determined.

The consumers were divided in two groups of 60 subjects each, where the second group received prior the test a card with information about the products and the sesame nutritional properties. The card showed the following instructions: "You will receive samples of corn expanded snacks added of whole sesame seed and semi-defatted sesame cake. The sesame seed is rich in oleic and linolenic acids and antioxidants. It also contains phytosterol that blocks the production of cholesterol being used as a reducer of blood cholesterol. In the extraction of the oil from its seeds, sesame nutrients were concentrated contributed a significant amount of calcium and protein to be added to snacks".

Within the group who received the informative card, preference data were submitted to a cluster analysis using the Euclidean distances and Ward's aggregation method according to overall acceptability scores (Hottenstein, Taylor, & Carr, 2008).

The participants were regular consumers of this type of products. The session was conducted in individual booths which were illuminated by white light and the samples were presented following a balanced design to reduce the first order and carry-over effects.

3. Results and discussion

3.1. Chemical composition

The chemical composition of corn grits, semi-defatted sesame cake (SDSC), corn extrudates added of 10 and 20% SDSC and commercial brands A and B is presented in Table 3.

As expected, the addition of SDSC increased protein, fat and ash content of corn extrudates, whereas carbohydrate content reduced. Maia, Calvete, and Telles (1999) added sesame cake flour as a nutritional protein complement in extruded bean flour, and also found an increment in the chemical composition of the mixed flour, particularly for protein and fat content.

Dietary fiber content of SDSC was much higher (32×) when compared to corn grits, although it was not analyzed in the extrudates. Elleuch et al. (2011) described different dietary fibre sources, including sesame coat ranging from 31.6 to 42 g/100 g (dry basis). In addition, these authors also reported that fibre-rich by-products, which are rich in both dietary fibre and bioactive compounds, benefit food processors, since consumers have preferred natural supplements.

As shown in Table 4, SDSC is an excellent source of calcium and iron when compared to corn grits and it has 55 times more iron and

Table 3
Chemical composition of corn grits (g/100 g), semi-defatted sesame cake (SDSC), SDSC–corn extrudates (0:100; 10:90 and 20:80) and commercial corn puffed extrudates (brands A and B).

	Corn grits	SDSC	SDSC-corn extrudates (0:100)	SDSC-corn extrudates (10:90)	SDSC-corn extrudates (20:80)	Brand A[a]	Brand B[a]
Moisture	11.0 ± 0.0	8.1 ± 0.1	5.0 ± 0.2	5.7 ± 0.2	5.7 ± 0.4	4.8	5.0
Protein[b]	9.2 ± 0.3	35.0 ± 0.3	10.7 ± 0.2	13.8 ± 0.3	16.4 ± 0.8	6.4	4.0
Fat	0.7 ± 0.0	11.2 ± 0.2	0.4 ± 0.0	3.1 ± 0.0	3.7 ± 0.0	20.8	18.8
Dietary fiber	0.7 ± 0.0	22.7 ± 0.0	ND	ND	ND	ND	ND
Ash	0.5 ± 0.0	8.6 ± 0.0	0.9 ± 0.0	1.5 ± 0.0	1.5 ± 0.0	1.3	1.5
Carbohydrate	77.9	14.4	83.0	75.9	72.7	66.7	70.7

ND: Non determined.
[a] Nutrition facts provided by the manufacturer.
[b] The coefficient used to calculate protein was 5.7 and 6.25 for corn grits and SDSC, respectively. In the case of the corn extrudates, the protein coefficient was 5.7.

Table 5
Pattern of amino acids requirements suggested by FAO/WHO/UNU (1985) and amino acid profiles of corn grits, semi-defatted sesame cake (SDSC) and SDSC–corn extrudates.

Essential aminoacids ($g\ 100\ g^{-1}$of protein)	FAO/WHO/UNU (1985) infants	FAO/WHO/UNU (1985) adults	Corn grits	SDSC flour	SDSC–corn (10:90)	SDSC–corn (20:80)
Treonine	3.40	0.90	1.44 ± 0.00	4.95 ± 0.04	1.70 ± 0.02[a]	2.05 ± 0.01[a]
Methionine	2.50	1.70	NA	NA	NA	NA
Valine	3.50	1.30	2.58 ± 0.00[a]	7.75 ± 0.06	2.85 ± 0.04[a]	3.40 ± 0.00[a]
Leucine	6.60	1.90	7.73 ± 0.01	11.85 ± 0.16	6.70 ± 0.01	6.95 ± 0.01
Isoleucine	2.80	1.30	1.82 ± 0.00[a]	6.70 ± 0.10	2.15 ± 0.00[a]	2.65 ± 0.00[a]
Phenylalanine	6.30	1.90	3.41 ± 0.01	10.70 ± 0.14	3.65 ± 0.06[a]	4.40 ± 0.01[a]
Lysine	5.80	1.60	0.61 ± 0.00[b]	4.25 ± 0.06[a]	0.90 ± 0.01[b]	1.20 ± 0.00[b]
Histidine	1.90	1.60	3.33 ± 0.00	3.95 ± 0.04	1.50 ± 0.02[a]	1.70 ± 0.00[a]
Tryptophan	1.10	0.50	NA	3.50 ± 0.05	NA	NA

NA: Non Analyzed.
[a] Limitant aminoacids for infants.
[b] Limitant aminoacids for both infants and adults.

159 times more calcium than corn. The concentration of these elements is higher than the conventional food source, such as milk (123 mg/100 g) for calcium and green leafy vegetables for iron content (0.6 to 3.1 mg/100 g) (TACO, 2006). Han et al. (2010) developed a gluten-free snack using pulse flours and concluded that the percent daily values per serving of iron in the chickpea crackers were 3–6 times higher than commercial products (0–2% range). In the case of calcium, gluten-free snack showed 22 mg/100 g per serving (30 g) corresponding to 1% daily value. Commercial brands of corn extrudates showed very high sodium content ranging from 824 to 1016 mg/100 g, which exceeds the dietary reference intake of sodium for children from 4 to 8 years, which is 1.2 g/day (National Academy of Science, 2011). Usually, this amount of salt is added to the snack in order to improve flavor since there is almost no sodium in the corn grits, which is the main ingredient of commercial corn puffed extrudate. Fat content showed a substantial increase from 0.4 to 20.8% in the commercial corn extrudates, which was due to the post-extrusion fat/seasoning coating.

The amino acid composition of corn grits, SDSC and SDSC-corn extrudates (10 and 20%) is shown in Table 5. Essential amino acid contents present in the extrudates were superior to the recommend daily ingestion for an adult, except for lysine in both 10% and 20% SDSC. As expected, lysine contents in both extrudates were higher when compared to corn grits.

Usually, the consumption of leguminous vegetables, such as peas and beans, in mixtures with cereal sources is recommended in order to supply tryptophan and to avoid deficiency in diets lacking animal proteins. In the case of using SDSC, although tryptophan was not analyzed in the extrudates, it can be envisaged that addition of it would comfortably supply tryptophan intake, since tryptophan content in SDSC is three and seven times higher than the recommended daily intake, respectively for infant and adult (FAO/WHO/UNU, 1985). Conti e Silva et al. (2010) studied the influence of thermoplastic extrusion on the nutritive value of bovine rumen protein and neither raw nor extruded proteins had any limiting amino acid. Although the extrusion process reduced true digestibility, the protein digestibility-corrected amino acid scores for both proteins were 100%, and these authors concluded that thermoplastic extrusion did not affect the protein quality of bovine rumen.

3.2. Sectional expansion index

Sectional expansion is one of the measurements that shows clearly the effect of changes in starch conversion as a result of extrusion process. SEI values of corn grits extrudates with added SDSC varied from 6.5 to 25.5 (Table 2). Usually highly expanded extrudates is a product of high shear, pressure and temperature conditions found in the extruder, hence, high melt viscosity is able to hold air bubbles inside the starch matrix when expelled out of the die. The addition of low molecular weight material in a mixture with starch causes reduction of overall expansion (Fan, Mitchell, & Blanshard, 1996).

The regression model (Table 6) for SEI was significant ($P<0.05$) and the addition of SDSC affected SEI more than screw speed. The multiple correlation coefficient (R^2) was 0.95, indicating a good fit to the models. Thus, Fig. 1 shows that adding SDSC decreased expansion, especially at 330–360 rpm range, but as screw speed increased, the mechanical shearing may caused a decrease of the molten starch viscosity favoring bubble growth and then lead to extrudates with higher expansion as reported by Della Valle, Vergnes, Colonna, and Patria (1997) and Moraru and Kokini (2003). Similar results were also related by Suknark et al. (1997) and Lazou and Krokida (2010) for expanded corn extrudates with added partially defatted peanut flour (10% fat) and lentil, respectively. According to Suknark et al. (1997), increasing peanut flour resulted in an increase in fat and protein content which reduced the expansion of the extrudates. The effect of protein on characteristics of extrusion product depends on both type (native or denatured) and concentration of protein that influence water-binding capacities which affect starch gelatinization (Faubion & Hoseney, 1982). In addition, the expansion ratio decreased as a result of increasing protein content because it has limited or non-puffing capacity compared with starch, hence by diluting starch content the expansion was reduced. In the case of the

Table 6
Coefficients of regression for the response equations (Eq. 1)[a] for the independent variables.

	SEI	F (N)	W_c (N mm)	PV (cP)	Breakdown (cP)	Setback (cP)	ΔE
β_0	1.53E+01***	1.51E−01***	6.16E−01***	1.88E+02***	2.20E+02***	1.26E+02***	4.08E+00***
β_1	−5.51E+00***	2.70E−02**	1.28E−01**	–	4.67E+01***	–	2.21E+00***
β_{11}	–	−9.09E−03*	–	−5.49E+01*	5.48E+01***	−3.23E+01*	3.22E−01*
β_2	8.50E−01*	–	–	–	–	–	–
β_{22}	1.36E+00**	–	–	–	–	–	3.65E−01*
β_{12}	–	9.70E−03**	7.11E−02*	–	–	–	–
R^2	0.95	0.95	0.85	0.74	0.87	0.80	0.85

***significant at the 0.1% level; **significant at the 1% level; *significant at the 5% level.
[a] Where X_1 = SDSC content (%) and X_2 = screw speed (rpm).

extrusion of lentil-corn blends, expansion ratio decreased with feed rate, moisture and lentil content. Besides protein content, SCSD had a considerably amount of fat (11.2%) and dietary fibre (22.7%) that did not provide enough viscous material inside the barrel which reduced the expansion. Similar results was described by Duarte et al. (2009), where addition of soy bean hull on the extrusion of corn grits reduced SEI in directly expanded extrudates.

3.3. Texture properties

The texture attributes (hardness and crispness) of expanded extrudates are results of the human being perception associated with the expansion and cell structure of the product (Ding, Ainsworth, Tucker, and Marson (2005). The internal cell structure of puffed extrudates can be visualized using image techniques such as scanning electron microscopy or X-ray tomography which can be correlated with their crispness (Chaunier, Della Valle, & Lourdin, 2007).

Typical compression curve of the extruded snacks is presented in Fig. 2. As observed by Bouvier et al. (1997), the crispness is related to cell structure demonstrating its fragility and "ease of breakdown". The structure of the crispy products tends to collapse due to their fragile and weak structures. This structural property depends mainly of distribution, cells size and thickness of its walls. Structure breakdown generates small and numerous expanded peaks associated to the sound effects.

By increasing SDSC content, the force sharply increased almost three times compared to SDSC-Corn (0:100). The drops in force peaks for SDSC 10 and 20% extrudates were much higher than SDSC 0%, which could be attributed to the cell wall thickness. The addition of SDSC, rich in protein and fiber, may act as reinforcement of the cell structure, thus offering resistance to the puncture force probe. The lowest puncture force was observed for brand B during the penetration course, which showed cell wall weakness of similar texture behavior to SDSC-Corn (0:100) extrudate. Similar results have also been reported for other corn based extrudates added of fiber and protein (Lazou & Krokida, 2010; Yanniotis, Petraki, & Soumpasi, 2007).

The texture parameters are shown in Table 2. Average puncture force (F) values varied from 0.0916 (no SDSC addition) to 0.1823 N (high content of SDSC) and crispness work (W_c) ranged from 0.4795 (low SDSC addition) to 0.8758 N mm (high content of SDSC). The interaction of SDSC addition and screw speed was statistically significant ($P<0.05$) (Table 6), that it means the increase of puncture force (hardness) and crispness work were associated with addition of SDSC and high screw speed.

Regression analysis showed that SDSC content significantly affected ($P<0.01$) the puncture force (F) of extruded products (Table 6) and this also occurred in crispness work (W_c). Response surface plots showed that SDSC addition increased puncture force (F) (Fig. 3) and crispness work (W_c) (Fig. 4) and screw speed had no significance ($P>0.05$) on F and on W_c values, but there was a significant interaction between them for both texture parameters ($P<0.05$). SDSC addition (protein and fiber source) resulted in more rigid structures and high values of puncture force at higher screw speed. Similar results have also been reported by Lazou and Krokida (2010). The presence of fibers also contributed to increase the product hardness due to reduction of cell size, probably causing premature rupture of gas cells, which reduced the overall expansion and resulted in less porous microstructure (Altan et al., 2008a, 2008b), i.e., this means that highest fiber content produced less crispy extrudate.

In order to compare the texture profile of commercial corn extrudates with SDSC–corn extrudates (Table 7), two commercial brands identified as brand "A" and brand "B" were evaluated. Although N_{sr} values were not statistically different among the extrudates ($P<0.05$) (data not shown), brand "B" had the lowest value which could be related to the presence of large internal cells, thus resulting in smaller number of cells. Rupture frequency (N_{sr}) of commercial brand "A" had the same result of SDSC–corn extrudate (20:80). Crispness work (W_c) of brand "B" had similar results compared to SDSC–

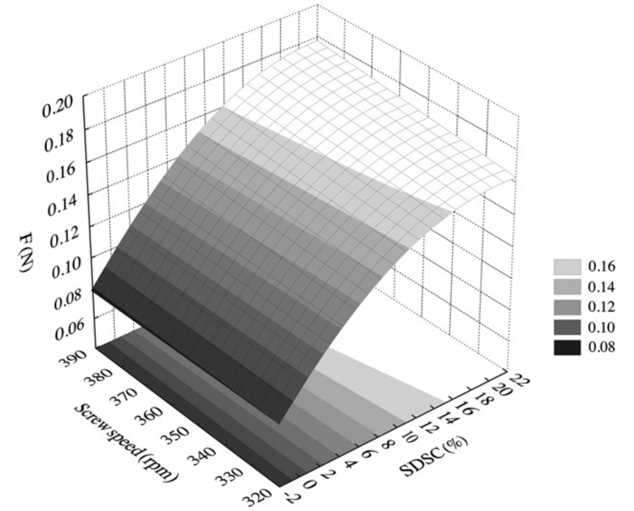

Fig. 3. Response surface plot for compression force (F) as a function of screw speed and SDSC addition.

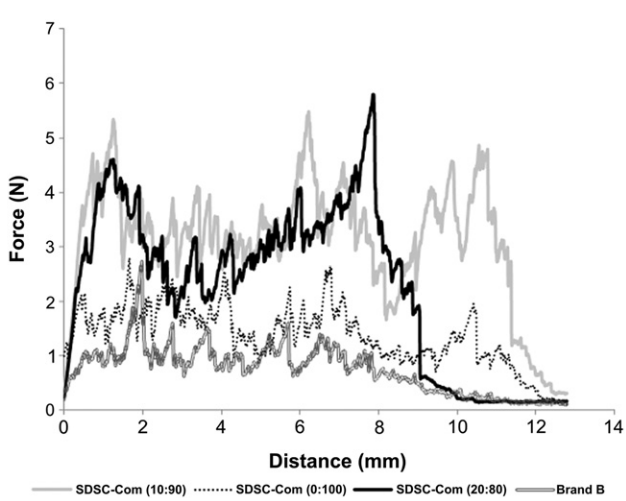

Fig. 2. Typical compressive curve of SDSC-corn extrudates and commercial brand "B".

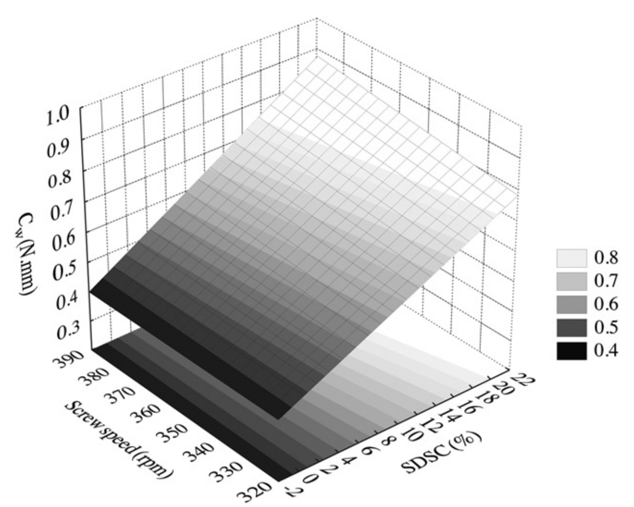

Fig. 4. Response surface plot for crispness work (W_c) as a function of screw speed and SDSC addition.

Table 7
Comparison of texture parameters between commercial samples and SCSD-corn expanded extrudates.

Samples	F (N)	N_{sr} (mm^{-1})	W_c (N mm)
Brand "A"	0.0963^b	0.2480^a	0.3969^c
Brand "B"	0.1412^a	0.2217^a	0.6466^{bc}
SDSC–corn (10:90)	0.1508^a	0.2547^a	0.6006^{bc}
SDSC–corn (20:80)	0.1721^c	0.2464^a	0.7358^a

^{abc}Different letters in the same column show significant statistical difference (Tukey's test, $P<0.05$).

corn extrudate (10:90). Capriles, Soares, and Arêas (2007) developed low calorie expanded corn extrudates and compared them to commercial corn extrudates, concerning texture and sensory acceptability. Theses authors did not find significant difference ($P<0.05$) in sensory acceptability and texture instrumental evaluation indicating that was possible to produce puffed corn extrudates with low fat content.

3.4. Paste viscosity

Paste viscosity analyses revealed the changes in starch structures subjected to previous process that involves heat and shear. In particular, it is quite sensitive to small changes during food extrusion when formulation, temperature, feed rate and screw speed may vary (Whalen, Bason, Booth, Walker, & Williams, 1997).

Pasting properties of SDSC–corn extrudates are presented in Table 2 and paste viscosity curves of the raw materials and corn extrudates are presented in Fig. 5. Peak viscosity, breakdown viscosity and setback viscosity values varied from 63 to 238 mPa s, 42.5 to 158.0 mPa s and 45.5 to 288.5 mPa s, respectively.

Paste viscosity of raw corn grits showed, high peak viscosity at 95 °C over 1000 cP and high setback viscosity (Fig. 5a) and SDSC flour presented a bimodal shape viscosity at 95 °C with a mild drop during cooling step, but increased again till 25 °C, and followed by another reduction in viscosity. This behavior could be attributed to the presence of native protein that under heat and shearing resulted in the denaturation and molecular rearrangement thus increasing the free volume of polypeptide chains. Similar findings were also found by Carvalho, Onwulata, and Tomasula (2007) who worked with paste viscosity of whey protein isolate mixed with different starch.

The paste viscosities of selected extrudates are shown in Fig. 5b. The viscosity profile of all extruded materials presented a similar curve with absence of peak viscosity at 95 °C, indicating that the extrusion condition was severe leading to a complete starch broken down. The paste viscosity of SDSC–corn extrudates showed cold viscosity typical of puffed extrudates, but the statistical analysis demonstrated that the experimental data of the cold viscosity readings were not statistically significant ($P<0.05$). The presence of cold viscosity peak, typical of high shearing and temperature, during extrusion process has been reported by Carvalho et al. (2010).

Regression analysis showed that only SDSC content had a significant effect on peak viscosity, breakdown and setback viscosities ($P<0.05$), however peak viscosity (PV) presented low R^2 value (0.74) and therefore was not considered for discussion. Setback decreased in the presence of SDSC whereas breakdown viscosity increased. Higher insoluble fiber content in the mixture increased starch breakdown due to its fractions acting as shearing material that was not easily melted during extrusion process (Oksman, Mathew, Bonderson & Kvien, 2006).Similar findings were also reported by Duarte et al. (2009) who worked with directly expanded corn grits and soybean hull extrudates. These authors found that breakdown and setback viscosity were affected by addition of soybean hull, which was also observed in the present work. Both, breakdown and setback viscosities were reduced with the addition of soybean fibers. Screw speed did not affect the paste viscosity readings ($P>0.05$) (Table 6). In contrast, Duarte et al. (2009) found that screw speed increased the setback viscosity values, and a positive interaction between screw speed and temperature on paste viscosity.

3.5. Color evaluation

Color is an important quality characteristic directly related to consumer acceptance and it is used to quantify the effect of extrusion cooking. Total color change in the extruded products ranged between 3.52 and 8.35 (Table 2). The effect of SDSC and screw speed on the total color change (ΔE values) on extrudates is shown in Table 2.

Results of regression analyses (Table 6) showed that color change was most dependent on SDSC content ($P<0.05$), with only a slight increase in color change when screw speed increased. The extrudates of high SDSC content were darker than the extrudates with non-SDSC ($P<0.05$), which could be explained by the high content of brown pigments, particularly present in the sesame coat. Similar findings were also reported by Liu, Hsieh, Heymann, and Huff (2000) who extruded oat–corn blend and concluded that addition of oat led to a decrease of lightness in the extrudates. Screw speed also had the same effect ($P<0.05$) on the total color change value of the extrudates, which could be related to an increase in shearing that lead to a non-

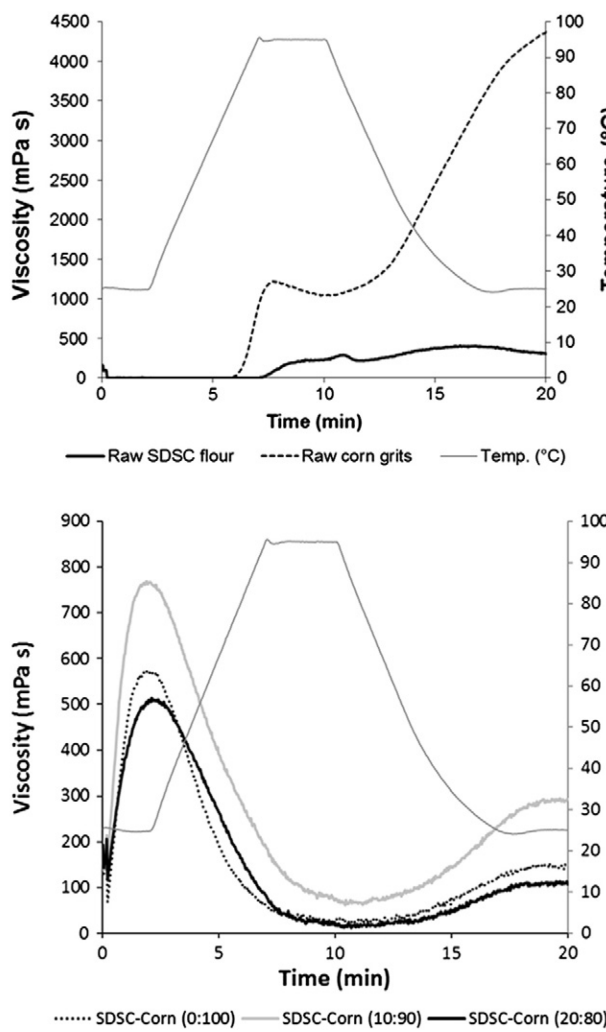

Fig. 5. Paste viscosity curve of raw corn grits and raw SDSC flour (top) and SDSC–corn extrudates (bottom).

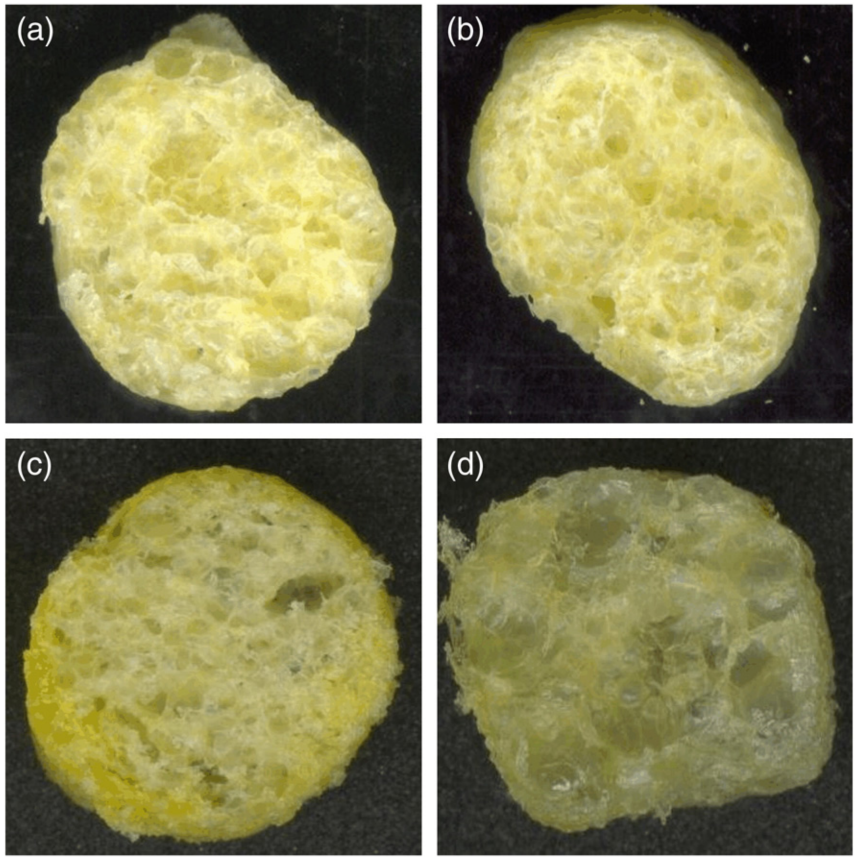

Fig. 6. Macrostructures of SDSC–corn extrudates and commercial corn extruded products: (a) 10:90 mixture at a screw speed of 356 rpm; (b) 20:80 mixture at a screw speed of 356 rpm; (c) **"**A" commercial product and (d) "B" commercial product (magnification 5×).

enzymatic browning reaction. Lue, Hsieh, and Huff (1994) reported an increase in darkness of corn extrudates added with sugar beet fiber processed at variable screw speeds (200 and 300 rpm) and attributed mainly to pigments present in the fiber ingredient and secondly to an increase of specific mechanical energy at high screw speed.

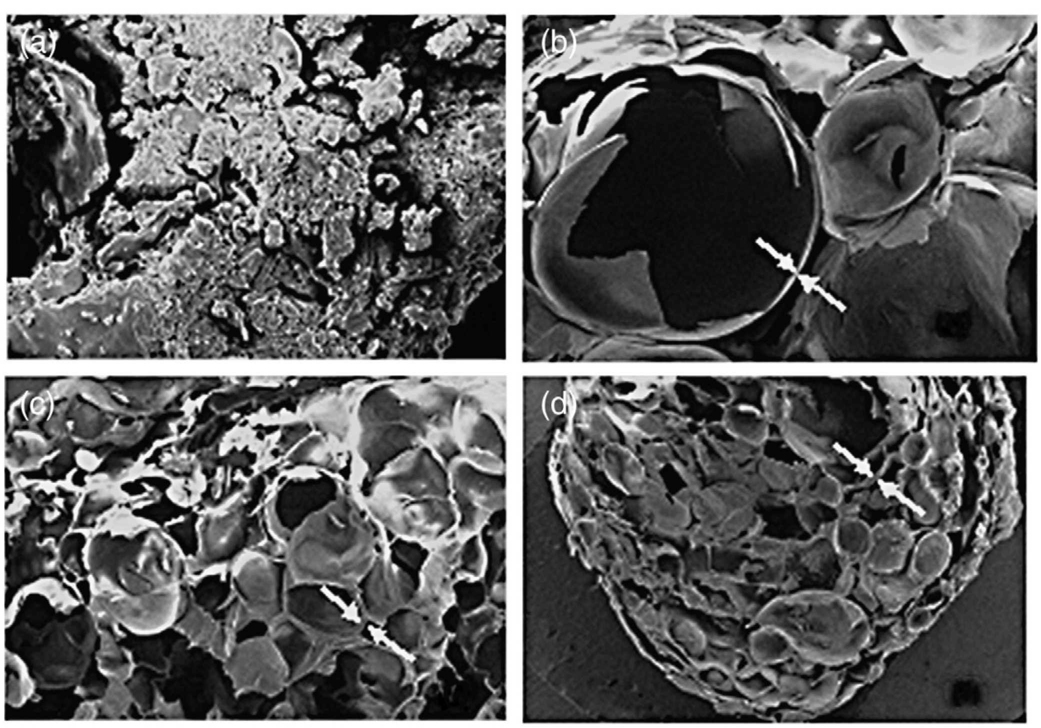

Fig. 7. SEM images of SDSC flour and extrudates obtained at 356 rpm using SDSC–corn mixtures of: (a) SDSC, (b) 0:100, (c) 10:90, (d) 20:80 (magnification 40×). Arrows indicate thickness of cell walls.

Table 8
Overall acceptability scores of SCSD– and WSS–corn expanded extrudates.

	WSS–corn (05:95)	WSS–corn (10:90)	SDSC–corn (10:90)	SDSC–corn (20:80)
Group without information (N = 60)	6.77 aA	5.10 cA	6.05 bA	5.80 bB
Group with information (N = 60)	6.93 aA	5.42 bA	6.45 aA	6.67 aA

Different lowercases letters within line indicates significant ($P<0.05$) differences between samples on Fisher (L.S.D.) test.
Different uppercases letters within column indicates significant ($P<0.05$) differences between groups on Fisher (L.S.D.) test.

3.6. Macroscopic and microscopic evaluation

The external shape and internal cell structure of SDSC-corn extrudates and commercial corn puffed extrudates are presented in Fig. 6.

SDSC–corn extrudate (20:80) (Fig. 6b) had slightly smaller cells than SDSC–corn extrudate (10:90) (Fig. 6a) and also showed a homogeneous cell distribution that could be compared to commercial extrudate “A” (Fig. 6c). Commercial product “B” (Fig. 6d) presented an irregular external shape and larger internal cells of thin walls, indicating fragile structure probably due to an excessive shearing condition. In addition, internal cell distribution and size are related to the mechanical tests, particularly to the number of frequency of ruptures (N_{sr}). N_{sr} indicates that the corn extrudate with 20% of SDSC had similar values to “A”, a commercial extrudate (Table 7), that looked similar (Fig. 6b and c). This morphology corroborates with the texture findings previously discussed.

The internal structure of the SDCS–corn extrudates was also observed by using electron scanning microscopy (Fig. 7). The morphology of SDSC flour revealed a dense, compact and heterogeneous mass. However, the corn extrudates with SDSC did not show remnants of SDSC flour, but instead a well mixed phase with corn was observed. By comparing corn extrudate and SDSC–corn samples (Fig. 7), it is clear that increasing SDSC content, the radial expansion ratio was reduced, but cells increased in number and diminished in size, which may be attributed to the presence of dietary fiber (22.7%) in SDSC flour that acted as a nucleating agent and increased the number of air cells. Yanniotis et al. (2007) related the effects of pectin and wheat fiber addition on physical and structural properties of expanded corn extrudates and concluded that pectin decreased radial expansion less than wheat bran, which is rich in insoluble fiber. Moreover, the expansion ratio, the moisture content and the porosity decreased as the fiber concentration increased, while hardness increased as a consequence of starch matrix rupture as insoluble fiber is less plastic or deformable than pectin.

Cell wall thickness also increased with SDSC addition (Fig. 7a, b and c) which resulted in an increase of high compression force (F) and crispness work (W_c) (Table 7). Similar results were demonstrated by Lazou and Krokida (2010) who found that addition of lentil flour enhanced the thickening of the cell walls of the corn extrudates. Moreover, the number of air cells decreased and the size of the air cells increased with increased levels of lentil flour..

3.7. Sensory analysis

The global overall liking means showed higher acceptability scores for the corn extrudates evaluated by informed consumers (Table 8). Means compared through statistical tools showed significant difference ($P<0.05$) on overall acceptability of corn extrudate with 20% SDSC between the different groups of consumers. These findings indicated that there was a positive influence acceptability of expanded extruded snacks after the presentation of the nutritional benefits of sesame seeds, especially for snack with 20% SDSC. The nutritional properties of the product were considered by consumers for a higher acceptance scores.

When all the consumers within the groups were considered, overall acceptability was significantly ($P<0.05$) lower for corn extrudate with 10% whole sesame seed (WSS). This result was similar for both groups of consumers, except that this sample was significantly different ($P<0.05$) from the other snacks (5% WSS, 10% SDSC and 20% SDSC) in the group of consumers who received the information card. The 5% WSS snack had higher scores but there were no significant differences between this sample and the extrudates with 10 and 20% semi-defatted sesame cake, with average scores varying only from 6.45 to 6.93. In general, the informed subjects were considered “liking lightly”.

Cluster analysis is a way of grouping cases of data based on the similarity of responses to several variables. The aim is to better interpret consumer preference data in order to identify consumer groups according to the similarity of their individual responses. After cluster analysis on overall acceptability data among the consumers who received the nutritional information, three different segments were identified (Table 9). The biggest segment (22) all extrudates scored higher that considering the samples felt between “liked moderately” and “liked very much”, for the snacks with 5%WSS and 20% SDSC. The second segment (20) preferred the snack added of 20% SDSC to the others, but “disliked very much” the snacks with whole seed sesame. The third segment (18) preferred the snacks with lower levels of addition of sesame, both whole seeds and semi-defatted cake.

The segmentation analysis showed that a greater number of consumers preferred the corn extrudate with 20% SDSC between consumers who received the information about sesame nutritional properties. The consumer groups identified according to their individual responses showed more clearly that the products with added semi-defatted sesame cake were well accepted and considered “liked very much”, especially the extrudate with higher proportions, which presented average scores varying from 5.33 to 8.00. These findings indicate the potential of utilization of sesame cake to produce acceptable corn.

4. Conclusion

Addition of 10% SDSC increased in protein content fourfold compared to commercial corn puffed extrudates. Although the lysine

Table 9
Overall liking scores after segmentation of informed consumers group.

Cluster	WSS–corn (05:95)	WSS–corn (10:90)	SDSC–corn 10:90)	SDSC–corn (20:80)	N	Intra-class variance
1	7.78a	4.39b	6.94a	5.33b	18	7.31
2	8.18[a]	7.09b	7.32b	8.00a	22	5.52
3	4.80b	4.50b	5.05b	6.40a	20	8.42

Different lowercase letters within line indicates significant ($P<0.05$) differences between samples on Fisher (L.S.D.) test.

content of SDSC flour was much higher than corn grits, the extruded SDSC-corn products did not have an adequate aminoacid profile balance. The addition of SDSC reduced the sectional expansion of the corn extrudates and increased compression force, which was corroborated with the microstructure. The paste viscosity of SDSC–corn extrudates had the presented similar profile of typical puffed extrudates, presenting cold viscosity peak as a result of solubility in ambient temperature. SDSC–corn extrudates were darker than non-SDSC–corn extrudates. Sensory analyses showed that there was a positive influence on extrudates acceptability after information on the presentation of the nutritional benefits of sesame seeds, especially for 20% SDSC-corn extrudate was presented. There is the potential of using semi-defatted sesame cake to produce corn extrudates of good acceptability.

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References

Altan, A., McCarthy, K. L., & Maskan, M. (2008). Twin-screw extrusion of barley–grape pomace blends: Extrudate characteristics and determination of optimum processing conditions. *Journal of Food Engineering*, *89*, 24–32.

Altan, A., McCarthy, K. L., & Maskan, M. (2008). Evaluation of snack foods from barley–tomato pomace blends by extrusion processing. *Journal of Food Engineering*, *89*, 231–242.

Alvarez-Martinez, L., Koundury, K. P., & Harper, J. M. (1988). A general model for expansion of extruded products. *Journal of Food Science*, *53*, 609–615.

Arriel, N. H. C., Araujo, A. E., Soares, J. J., Beltrão, N. E. M., & Firmino, P. T. (2006). *Cultivo do gergelim: Sistemas de produção.* Campina Grande: Embrapa Cotton.

Bouvier, J. M., Bonneville, R., & Goullieux, A. (1997). Instrumental methods for the measurement of extrudate crispness. *Agro-Food Industry Hi-Technology*, *8*, 16–19.

Box, G. E. P., Hunter, W. G., & Hunter, J. S. (1978). *Statistics for experimenters: An introduction to design, data analysis and model building.* New York: John Wiley & Sons.

Camire, M. E., Camire, A., & Krumhar, K. (1990). Chemical and nutritional changes in foods during extrusion. *Critical Reviews in Food Science and Nutrition*, *29*, 35–57.

Capriles, V. D., Soares, R. A. M., & Arêas, J. A. G. (2007). Development and assessment of acceptability and nutritional properties of a light snack. *Ciência Tecnologia Alimentos*, *27*, 562–566.

Carvalho, C. W. P., Onwulata, C. I., & Tomasula, P. M. (2007). Rheological properties of starch and whey protein isolate gels. *Food Science and Technology International*, *13*, 207–216.

Carvalho, C. W. P., Takeiti, C. Y., Onwulata, C. I., & Pordesimo, L. O. (2010). Relative effect of particle size on the physical properties of corn meal extrudates: Effect of particle size on the extrusion of corn meal. *Journal of Food Engineering*, *98*, 103–109.

Chaunier, L., Della Valle, G., & Lourdin, D. (2007). Relationships between texture, mechanical properties and structure of cornflakes. *Food Research International*, *40*, 493–503.

Cohen, S. A., & Michaud, D. M. (1993). Synthesis of a fluorescent derivatizing reagent, 6-aminoquinolyl-N-hydroxysuccinimidyl cargamate, and its application for the analysis of hydrolysate amino acids via high-performance liquid chromatography. *Analytical Biochemisstry*, *211*, 279–287.

Conti e Silva, A. C., Cruz, R. J., & Arêas, J. A. G. (2010). Influence of thermoplastic extrusion on the nutritive value of bovine rumen protein. *Meat Science*, *84*, 409–412.

Della Valle, G., Vergnes, B., Colonna, P., & Patria, A. (1997). Relations between rheological properties of molten starches and their expansion behaviour in extrusion. *Journal of Food Engineering*, *31*, 277–295.

Ding, Q. B., Ainsworth, P., Plunkett, A., Tucker, G., & Marson, H. (2006). The effect of extrusion conditions on the functional and physical properties of wheat-based expanded snacks. *Journal of Food Engineering*, *73*, 142–148.

Ding, Q. B., Ainsworth, P., Tucker, G., & Marson, H. (2005). The effect of extrusion conditions on the physicochemical properties and sensory characteristics of rice-based expanded snacks. *Journal of Food Engineering*, *66*, 283–289.

Duarte, G., Carvalho, C. W. P., & Ascheri, J. L. R. (2009). Effect of soybean hull, screw speed and temperature on expanded maize extrudates. *Brazilian Journal of Food Technology*, *12*, 205–212.

Elleuch, M., Bedigian, D., Roiseux, O., Besbes, S., Blecker, C., & Attia, H. (2011). Dietary fibre and fibre-rich by-products of food processing: Characterisation, technological functionality and commercial applications: A review. *Food Chemistry*, *124*, 411–421.

Fan, J. T., Mitchell, J. R., & Blanshard, J. M. V. (1996). The effect of sugars on the extrusion of maize grits .2. Starch conversion. *International Journal of Food Science and Technology*, *31*, 67–76.

FAO/WHO/UNU (1985). Energy and protein requirements. *Report of a joint FAO/WHO/UNU expert consultation. WHO technical report series, vol. 724, Geneva*.

Faubion, J. M., & Hoseney, R. C. (1982). High-temperature short-time extrusion cooking of wheat-starch and flour. 2. Effect of protein and lipid on extrudate properties. *Cereal Chemistry*, *59*, 533–537.

Franco, G. (1999). *Tabela de composição química dos alimentos* (9th ed.). Rio de Janeiro: Ed. Livraria Atheneu.

Gajula, H. (2007). Fiber-enriched wheat flour precooked using extrusion processing: rheological, nutritional and sensory properties. Master´s thesis, Kansas, USA: Kansas State University.

Han, J., Janz, J. A. M., & Gerlat, M. (2010). Development of gluten-free cracker snacks using pulse flours and fractions. *Food Research International*, *43*, 627–633.

Hottenstein, A. W., Taylor, R., & Carr, B. T. (2008). Preference segments: A deeper understanding of consumer acceptance or a serving order effect? *Food Quality and Preference*, *19*, 711–718.

Lazou, A., & Krokida, M. (2010). Structural and textural characterization of corn–lentil extruded snacks. *Journal of Food Engineering*, *100*, 392–408.

Liu, Y., Hsieh, F., Heymann, H., & Huff, H. E. (2000). Effect of process conditions on the physical and sensory properties of extruded oat-corn puff. *Journal of Food Science*, *65*, 1253–1259.

Lue, S., Hsieh, F., & Huff, H. E. (1994). Modeling of twin-screw extrusion-cooking of corn meal and sugar–beet fiber mixtures. *Journal of Food Engineering*, *21*, 263–289.

Maia, G. A., Calvete, Y. M., & Telles, F. J. S. (1999). Eficiência da farinha desengordurada de gergelim como complemento protéico da farinha extrudada de caupi. *Pesquisa Agropecuária Brasileira*, *34*, 1295–1303.

Mohdaly, A. A. A., Smetanskaa, I., Ramadanc, M. F., Sarhanb, M. A., & Mahmoudb, A. (2011). Antioxidant potential of sesame (*Sesamum indicum*) cake extract in stabilization of sunflower and soybean oils. *Industrial Crops and Products*, doi:10.1016/j.indcrop. 2011.02.018.

Moraru, C. I., & Kokini, J. L. (2003). Nucleation and expansion during extrusion and microwave heating of cereal foods. *Comprehensive Reviews in Food Science and Food Safety*, *2*, 121–138.

Mukhopadhyay, N., & Bandyopadhyay, S. (2003). Extrusion cooking technology employed to reduce the anti-nutritional factor tannin in sesame (*Sesamum indicum*) meal. *Journal of Food Engineering*, *56*, 201–202.

Murty, C. M., Pittaway, J. K., & Ball, M. J. (2010). Chickpea supplementation in an Australian diet affects food choice, satiety and bowel health. *Appetite*, *54*, 282–288.

National Academy of Science (2011). Dietary reference intakes: Recommended intakes for individuals. From. http://www.iom.edu/Activities/Nutrition/SummaryDRIs/~/media/Files/Activity%20Files/Nutrition/DRIs/New%20Material/5DRI%20Values%20SummaryTables%2014.pdf accessed May 29, 2011

Oksman, K., Mathew, A. P., Bondeson, D., & Kvien, I. (2006). Manufacturing process of cellulose whiskers/polylactic acid nanocomposites. *Composites Science and Technology*, *66*(15), 2776–2784.

Onwulata, C. I., Konstance, R. P., Strange, E. D., Smith, P. W., & Holsinger, V. H. (2000). High-fiber snacks extruded from triticale and wheat formulations. *Cereal Foods World*, *45*, 470–473.

Rangkadilok, N., Pholphana, N., Mahidol, C., Wongyai, W., Saengsooksree, K., Nookabkaew, S., et al. (2010). Variation of sesamin, sesamolin and tocopherols in sesame (*Sesamum indicum* L.) seeds and oil products in Thailand. *Food Chemistry*, *122*, 724–730.

Ryland, D., Vaisey-Genser, M., Arntfield, S. D., & Malcolmson, L. J. (2010). Development of a nutritious acceptable snack bar using micronized flaked lentils. *Food Research International*, *43*, 642–649.

Shirani, G., & Ganesharanee, R. (2009). Extruded products with Fenugreek (*Trigonella foenum-graecium*) chickpea and rice: Physical properties, sensory acceptability and glycaemic index. *Journal of Food Engineering*, *90*, 44–52.

Stojceska, V., Ainsworth, P., Plunkett, P., Ibanoglu, E., & Ibanoglu, S. (2008). Cauliflower by-products as a new source of dietary fibre, antioxidants and proteins in cereal based ready-to-eat expanded snacks. *Journal of Food Engineering*, *87*, 554–563.

Suknark, K., Phillips, R. D., & Chinnan, M. S. (1997). Physical properties of directly expanded extrudates formulated from partially defatted peanut flour and different types of starch. *Food Research International*, *30*, 515–583.

TACO (2006). *Tabela Brasileira de Composição de Alimentos.* Campinas: NEPA/Unicamp (n. 02).

Whalen, P. J., Bason, M. L., Booth, R. I., Walker, C. E., & Williams, P. J. (1997). Measurement of extrusion effects by viscosity profile using the rapid ViscoAnalyser. *Cereal Foods World*, *42*, 469–475.

Yanniotis, S., Petraki, A., & Soumpasi, E. (2007). Effect of pectin and wheat fibers on quality attributes of extruded cornstarch. *Journal of Food Engineering*, *80*, 594–599.