ISSN 0101-2061 (Print)
ISSN 1678-457X (Online)
Food Science and Technology

DOI: https://doi.org/10.1590/fst.22518

Optimization of beef patties produced with vegetable oils: a mixture design approach and sensory evaluation

Paulo Ricardo LOS[1]*, Gabriela Vollet MARSON[2], Sílvia Deboni DUTCOSKY[3], Alessandro NOGUEIRA[1,4], Marina Tolentino MARINHO[4], Deise Rosana Silva SIMÕES[4]

Abstract

The exaggerated consumption of fast food and ready to eat products is a common practice which results in an unbalanced intake of saturated fats. In order to improve the fat composition of beef patties, mixture design was used to optimize the inclusion of pomace olive oil (POO) and canola oil (CO). Cooking yield, moisture retention, diameter reduction, color, texture and sensorial parameters were accessed. Models showed, with a 94.5% of variance explained, that the inclusion of POO and CO should be limited in order to maintain a low acidity index and texture parameters comparable to commercial burgers of similar composition. Preference test, consumer profile, acceptability, penalty analysis and Check-all-that-apply (CATA) results indicated that a parcial replacement of pork fat (PF) can be considered. In sum, formulations with improved fat composition (50 or 33% replaced animal fat by POO and CO) were obtained.

Keywords: beef hamburgers; CATA; consumer profile; just about right; penalty analysis; pomace olive oil; unsaturated fats; processed meat.

Practical Application: replacement of animal fat by vegetable oils.

1. Introduction

Brazil is the third largest beef consumer in the world, summing up 25.7 kg per capita, followed by United States of America (25.6 kg per capita) (Organisation for Economic Co-operation and Development, 2017). A recent study appointed that, in the USA, where the consumption is similar to Brazil, 22% of the meat consumed is processed (Daniel et al., 2011). Also, in a study held in Canada, market share of ready-to-consume processed products have been rising (Moubarac et al., 2014). Among processed meats, beef patties are tasty, cheap and versatile, which makes it a popular meal option for many people (Mapiye et al., 2014). Patties present attractive sensory characteristics along with high nutritional value proteins, vitamins, minerals and usually high content of lipids (Nascimento et al., 2005), mainly saturated fatty acids which have been related to several diseases (Mapiye et al., 2012). Despite its fat composition, ready-to-eat frozen food and fast food products are popular (Borba et al., 2013), and must be seen as relevant food with potential of nutritional improvement (Mapiye et al., 2014). Considering this situation, researchers in food science and technology are studying the development of more nutritious patties, increasing the product value and responding to the consumer demand for healthier products (Arihara, 2006; Zhang et al., 2010; Carli, 2012; Hathwar et al., 2012; Olmedilla-Alonso et al., 2013; Keenan et al., 2014; Grasso et al., 2014). For the study and improvement of beef patties formulations, mixture design methodology has been a useful tool (Liu et al., 2010; Kurt & Kilinççeker, 2011; Baugreet et al., 2017).

To reduce the consumption of saturated fats, oils can be used, especially the ones that are rich in essential fatty acids (ω-3, ω-6 and ω-9), which perform beneficial effects on the organism, for instance, reducing chronic and degenerative diseases (Turatti, 2000; Borba et al., 2013). Although it has been proved that the level proportion of HDL (High Density Lipoprotein) and LDL (Low Density Lipoprotein) cholesterol are not influenced by the intake of saturated fats alone, it is important to include poli and unsaturated fats on the diet, which contain essential fatty acids, wherein the ratio less than 4:1 of ω-6/ ω-3 is recommended (Hyman, 2008).

During a product development, the consumer's opinion regarding the product is important and needs to be established in the sensory analysis context. In CATA method, a list of attributes is given to the consumers, who then select the terms that apply for the sample. The method allows the use of hedonic scores and Just-About-Right (JAR) scales, without biasing the results, and giving an overall assessment of the product (Ares et al., 2015; Jaeger et al., 2015).

Regarding this information, and the poor intake of the population on the poli and unsaturated fats, the aim of the present

Received 08 Aug., 2018
Accepted 06 Jan., 2020

[1] *Programa de Pós Graduação em Ciência e Tecnologia de Alimentos, Universidade Estadual de Ponta Grossa – UEPG, Ponta Grossa, PR, Brasil*
[2] *Programa de Pós Graduação em Engenharia de Alimentos – DEA, Faculdade de Engenaharia de Alimentos – FEA, Universidade Estadual de Campinas – UNICAMP, Campinas, SP, Brasil*
[3] *About Solution, Curitiba, PR, Brasil*
[4] *Departmento de Engenharia de Alimentos, Universidade Estadual de Ponta Grossa – UEPG, Ponta Grossa, PR, Brasil*
*Corresponding author: pauloricardolos@yahoo.com.br

study was to develop beef patties with a healthier lipid profile by using oils with essential fatty acids, such as POO (pomace olive oil) and CO (canola oil). In this paper, an appropriate blend of fat, in terms of physicochemical, textural and sensorial quality of beef patties, was investigated through a mixture design. The sensory assessment of preference, acceptability, JAR and CATA analysis were chosen to analyze the consumer's opinion about the products, indicating their market viability.

2 Materials and methods

2.1 Design of experiment

A mixture design experiment is a type of response surface methodology in which independent variables are ingredients of a mixture, and the response variables act as a function of proportions of individual components (Myers et al., 2016). For optimization regarding fat content, a 10-run (F1 – F10) simplex centroid mixture design was carried out. Each mixture was replicated twice for error estimation. Each formulation had the same base, 80.0% of the beef patty's total mass: 50% beef; 15.2% ice chips; 8.0% water; 4.0% textured soy protein and 2.8% additives and spices (1.6% salt, 0.4% monosodium glutamate, 0.1% garlic powder, 0.1% onion powder, 0.1% ground black pepper, 0.5% polyphosphates). To that, 20.0% of fat (from different sources and proportions defined by the mixture design) were added, completing the formulation. The independent variables were as follows: POO (Pomace olive oil) (A), PF (pork fat) (B) and CO (canola oil) (C), according to Table 1. The dependent variables were the texture parameters, color (L*, a*, b*), cooking yield, moisture retention, diameter reduction and acidity index.

2.2 Beef burger production

Lean ground beef (sirloin tip or knuckle), spices and additives were supplied by a local market using a 4,7 mm diameter meat grinder. This cut was chosen because of its low fat content (10%). Burger samples were prepared in 1-kg batches and, along with spices and additives, were divided in 10 parts and manually mixed for 10 minutes, in sanitized containers. The mixture was shaped into a burger using a manual burger-forming PVC (Polyvinyl Chloride) mold (Tupperware). Burgers had an approximate diameter of 9 cm and weight of 50 g. All burgers were packed in PVC film and aluminum foil and directly kept frozen (-18 °C) in a dark environment, until analysis. Three brands of commercial frozen beef patties (HC1, HC2 and HC3) produced with vegetable hydrogenated fat and animal fat were obtained in a local market for physicochemical comparative analysis with the formulations. Those samples were packaged and kept in the same conditions and amount of time as the manufactured burgers did.

Table 1. Proportion of fat content in mixture simplex centroid design.

Formulations	POO (%)	CO (%)	PF (%)
F1	100	-	-
F2	-	-	100
F3	-	100	-
F4	50	-	50
F5	50	50	-
F6	-	50	50
F7	33.3	33.3	33.3
F8	66.7	16.7	16.7
F9	16.7	16.7	66.7
F10	16.7	66.7	16.7

2.3 Sample preparation

Frozen patties were cooked in a titanium pan (200 ± 10 °C) for 2.5 minutes at each side until the temperature of the center reached 71 °C (using a T-handle digital thermometer). The temperature of the pan was verified with an infrared thermometer (Infrared IR 77L) following the FDA (Food & Drug Administration) and ESDA (Exploratory Spatial Data Analysis) recommendation (minimum temperature in the center of 71 °C for 15 seconds) (García et al., 2009). The samples were served at consumption temperature (50 ± 3 °C) in white polyethylene plates coded with three random digits. The presented sample corresponded to 1/4 of the hamburger patty and the edges were removed to standardize size (4 ± 0.5 cm). Spring water was available for palate cleansing in all tests.

2.4 Physicochemical analysis

Fat samples of burger patties extracted by the Bligh-Dyer Method (Bligh & Dyer, 1959), were analyzed regarding their acidity index (AI) by the AOCS method. Acidity index results were expressed as a percentage of free fatty acids (FFA) considering the equivalent-gram of oleic acid (Association of Official Analytical Chemists, 2005). These analysis were made with the cooked and raw burgers. Cooking yield, moisture retention and diameter reduction were calculated according to method described by Piñero et al. (2008) and Choi et al. (2009).

Color analysis was performed using a colorimeter MiniScan EZ colorimeter (Hunter Lab, Reston, Virginia, USA), with two replicates on each side at 25 °C, obtaining the parameters L*, a* and b*, representing the lightness, the red-green and the blue-yellow spectrum, respectively (Mapari et al., 2006; López-Álvarez et al., 2005).

Texture assessment was performed in a texture analyzer (Stable Micro Systems TA.XT plus) at 25 °C for all tests. The force and the work needed to move the were estimated with a Warner–Bratzler blade, with 25 mm shear force using 2.5 ± 0.1 cm x 5.0 ± 0.1 cm rectangles. For the textural profile analysis (TPA – hardness, adhesiveness, elasticity, cohesiveness, chewiness e resilience), cylinders of 2 ± 0.1 cm were cut and were analyzed six times at a 30% compression rate using probe P36 (36 mm high) in a two cicles' compression, with a load cell of 50 kg and speed rate of 2 mm/s.

2.5 Sensory analysis

Sensory assessments were conducted in compliance with "State University of Ponta Grossa Ethics Committee" approved under number CAAE: 673.493, in the sensory analysis laboratory, built following the recommendations of ISO 8589 (International Organization for Standardization, 2007).

In order to select the 4 best, ten formulations were submitted to preference analysis in a nine points hedonic scale (1- I dislike extremely; 9 - I like extremely) (Meilgaard et al., 1991). Because of the elevated number of samples, an experimental design of balanced incomplete blocks type III (DIB - III) was applied, in which each assessor evaluates a block of 4 samples, and every sample appeared in pairs at least two times per block (Cochran & Cox, 1992). In this preference test, 150 assessors participated, totalizing 60 assessments per sample. In addition, a consumer profile questionnaire was applied to all assessors, regarding the age, gender, and frequency of consumption.

From the results of the preference test, 3 samples and a standard (without fat replacement) were chosen to subsequent analysis, totalizing the 4 samples for the CATA test (Varela & Ares, 2012).

The test consisted in the assessment of one sample at a time. The CATA attributes were defined by a team of students, professors and researchers, which have experience in testing the product and by testing the 4 samples, defined which attributes were important to the characterization of the samples. For the CATA test, a total of 114 assessors were attended.

2.6 Statistical analysis

Physicochemical data was collected and analyzed by surface response methodology. A simplex centroid mixture design allows the modeling of a third order equation that describes the formulations for each response.

All data underwent analysis of variance (ANOVA 2-wa.y) and multiple comparison of means (Tukey Test with $p<0.05$). Acceptability and CATA were analyzed by XLStat program (trial version, Addinsoft).

The hedonic scores were evaluated to normality, by Kolmogorov-Smirnov test, a p value bellow 0.05 was established to reject the null hypothesis (Zielinski et al., 2014). The data matrix was composed of burger samples (n=4) and assessors (n=114), totaling 456 data points.

A segmentation k-means analysis was performed to verify the behavior of the consumers regarding acceptability. By the covariance matrix, the samples scores' data were submitted to PCA, to identify the behavior of the burger samples by preference mapping. A PCA bi-plot (samples and consumers) was used to show preferences of consumers for each sample (Schilling & Coggins, 2007).

CATA data was arranged in a frequency matrix, attributes with relative frequency below 20% were not considered for further analysis. Cochran Q test was performed to verify the significant differences among samples regarding the CATA terms. Multivariate approach by Correspondence Analysis was performed showing the attributes that better correlated with each sample (Meyners et al., 2013).

3 Results and discussion

3.1 Physicochemical and color analysis

In Table 2, physicochemical parameters are presented. Samples F2, F3 and F9 presented the highest CY of approximately 73%. Piñero et al. (2008) found similar results (70.86 ± 3.54%). Lowest CY was about 66%, found in some of the produced patties.

Formulation F9 presented high MR and similar results were verified for F1. Lower MR of formulations F2, F4, F6, F7, F8 and F10.

DR was higher to HC3 in comparison with F1. These results are in agreement with those found by Piñero et al. (2008). In sum, the results of CY, MR and DR shows that, in general, the chosen formulations were comparable to commercial brands regarding these physicochemical aspects mainly when partial replacement of PF was done.

Color is one the most important quality parameters of processed meat products and is related to consumer acceptability and purchase (Bastos et al., 2014). Regarding the color results (Table 2), it can be observed that for all formulations lightness was. This may have happened because of the use of vegetable oils which makes the L* increase due to oil loss during cooking that stays in the surface. A low a* value was obtained for F2 (5.49 ± 1.10) when compared to F7, because F2 contains

Table 2. Physicochemical and color parameters for hamburger patties formulations and commercial brands after cooking.

Samples	Lipids (g/ 100g)	Acidity Index (% FFA)	CY (%)	MR (%)	DR (%)	L*	a*	b*
F1	$9.09±0.37^{E}$	$0.86 ± 0.00^{E}$	$70.40 ± 1.23^{F}$	$38.04 ± 0.10^{A}$	$15.20 ± 2.8^{C}$	$45.70 ± 2.7^{AB}$	$5.87 ± 0.37^{ABCD}$	$16.01 ± 0.55^{A}$
F2	$18.35 ± 1.33^{A}$	$1.15 ± 0.41^{D}$	$74.70 ± 0.33^{B}$	$30.04 ± 0.61^{C}$	$18.40 ± 4.1^{B}$	$48.80 ± 3.8^{A}$	$5.49 ± 1.10^{D}$	$15.48 ± 0.88^{C}$
F3	$11.07 ± 0.64^{F}$	$0.79 ± 0.31^{F}$	$71.80 ± 1.20^{C}$	$36.38 ± 0.05^{AB}$	$17.30 ± 1.7^{AB}$	$47.60 ± 2.0^{AB}$	$5.56 ± 0.45^{CD}$	$15.44 ± 0.29^{C}$
F4	$12.95 ± 0.52^{C}$	$0.86 ± 0.00^{E}$	$67.80 ± 1.51^{G}$	$34.51 ± 2.92^{ABC}$	$17.50 ± 1.3^{AB}$	$46.34 ± 2.6^{AB}$	$6.01 ± 0.21^{ABC}$	$15.71 ± 0.35^{B}$
F5	$10.50 ± 0.80^{D}$	$2.01 ± 0.00^{A}$	$70.80 ± 3.08^{D}$	$27.70 ± 0.93^{BC}$	$17.80 ± 4.8^{AB}$	$47.60 ± 1.7^{A}$	$5.78 ± 0.27^{BCD}$	$15.54 ± 0.41^{C}$
F6	$11.38 ± 0.23^{F}$	$1.44 ± 0.00^{C}$	$70.90 ± 1.35^{D}$	$34.86 ± 1.42^{ABC}$	$17.30 ± 0.3^{AB}$	$47.50 ± 2.6^{AB}$	$5.98 ± 0.76^{ABCD}$	$15.66 ± 0.63^{C}$
F7	$12.66 ± 1.96^{G}$	$2.01 ± 0.00^{A}$	$66.30 ± 3.29^{H}$	$30.59 ± 1.67^{C}$	$20.20 ± 1.7^{A}$	$45.20 ± 1.2^{ABC}$	$6.59 ± 0.42^{A}$	$16.38 ± 0.47^{A}$
F8	$14.56 ± 0.41^{B}$	$1.44 ± 0.00^{C}$	$68.30 ± 0.89^{F}$	$34.76 ± 3.13^{ABC}$	$18.50 ± 1.4^{B}$	$46.10 ± 2.4^{AB}$	$5.93 ± 0.54^{AB}$	$15.90 ± 0.48^{B}$
F9	$12.38 ± 3.57^{G}$	$1.15 ± 0.41^{D}$	$76.70 ± 0.78^{A}$	$39.23 ± 1.10^{A}$	$17.10 ± 0.6^{AB}$	$48.00 ± 1.5^{A}$	$5.61 ± 0.36^{CD}$	$15.75 ± 0.60^{C}$
F10	$12.56 ± 0.67^{G}$	$1.58 ± 0.20^{B}$	$65.00 ± 0.78^{H}$	$34.19 ± 0.88^{ABC}$	$18.60 ± 2.9^{B}$	$45.30 ± 2.5^{ABC}$	$6.04 ± 0.41^{ABC}$	$15.66 ± 0.33^{C}$
p value	0.000	0.000	0.000	0.000	0.056	0.000	0.000	0.000

Note: F1 to F10: Formulations of burgers; CY: cooking yield; MR: moisture retention; DR: diameter reduction. L*: lightness; a*: red spectrum; b*: blue spectrum; ^{ABCDEFGH} Different letters in the same column indicate significant statistical differences between samples (Tukey Test, $p < 0.05$).

only PF in the formulation and this may have contributed for this loss in red color. García et al. (2009) produced low fat hamburger patties (10%) and obtained lower values for the red parameter. No significant differences were found for b* value among the formulations. Average color values (L*, a* and b*) were comparable to those already published for beef patties (Shrestha et al., 2010).

Fat content and AI data for cooked and raw patties can be seen respectively at Table 2 and 3. Samples F7 (equal proportion of the three fats sources) and F5 (no PF) showed a higher acidity level index for cooked patties compared to F1, F2, F3, F4 and F9, probably due to the high vegetable oils concentration on these two formulations, which are less stable than animal fat regarding their composition. This tendency of data cannot be seen for raw burgers. The only difference detected was when comparing F5 to HC3, this later presenting a higher AI. For some cooked samples (F1 and F4) the FFA percentage were significantly lower than those of raw meat. On both formulations, CO was not present. This can happen because FFA can be lost or can react during cooking (Rodriguez-Estrada et al., 1997). Increased FFA content in cooked patties was found for samples F7 and F8. Because the AI values were very little, despite the significant difference between cooked and raw patties, an important lipid oxidation did not occur, as found by Shrestha et al. (2010).

Table 3. Lipids and acidity index for raw hamburger patties formulations and commercial brands.

Samples	Lipids (g/ 100g)	AI (% FFA)
F1	10.16 ± 1.84^{C}	1.44 ± 0.00^{AB}
F2	13.22 ± 1.41^{AB}	1.58 ± 0.20^{AB}
F3	14.88 ± 0.54^{A}	1.15 ± 0.00^{AB}
F4	13.28 ± 0.32^{A}	1.15 ± 0.00^{AB}
F5	9.54 ± 0.32^{D}	1.01 ± 0.02^{B}
F6	12.15 ± 6.31^{B}	1.29 ± 0.20^{AB}
F7	9.67 ± 2.21^{D}	1.15 ± 0.00^{AB}
F8	11.08 ± 0.56^{B}	1.15 ± 0.00^{AB}
F9	8.98 ± 0.54^{E}	1.44 ± 0.41^{AB}
F10	10.52 ± 0.87^{C}	1.29 ± 0.20^{AB}
p value	0.000	0.000

Note: ^{ABCDE} Different letters in the same column indicate significant statistical differences between samples (Tukey Test, $p < 0.05$).

Cooked patties with total PF replacement by oils (e.g.: F1, F3 and F5) exhibited a lower fat content after cooking when compared to F2 (only PF) which resulted in better fat retention, due to the inherent characteristics of that ingredient. Fat content of all raw samples was not statistically different, showing that the general formulation proposed in this paper makes the formulated samples comparable to those three commercial brands chosen for the study.

Appart from a slight difference found for F1 (only PF) which presented the highest toughness (lower shear force) and F7 and F8 with higher work of shearing, no differences were found among formulations (Table 4). When fat replacers are used, the shear force required to cut through the sample is often lower (Bastos et al., 2014). In this paper we didn't expect that change because only the fat type was changed while maintaining lipid content, and so, no changes in tenderness were found. And, in beef patties with less fat (10%) the work of shearing (toughness) is 3 times higher than those of this work formulations' (García et al., 2009), which is comprehensible once in this work we have 20% fat patties

F6, F8 and F9 presented lower chewiness and probably because of its fat composition. In agreement with resilience results, patties F3 and F4 presented higher values of chewiness.

Both attributes elasticity (related to the food recovery between the end of the first bite and the start of the second bite) and adhesiveness (force necessary to pull the compression away from the sample), showed no significant differences (Kruk et al., 2014).

Cohesiveness was higher for F6. Rodríguez-Carpena et al. (2011) found that fat replacement by unsaturated oils in patties did not affect the cohesiveness and hardness of the final product.

3.2 Surface Response Methodology (SRM)

Mixture design methodology has been used to predict physicochemical properties of hamburgers and other meat products and the ingredients interactions for the responses (Shahiri & Mazaheri, 2014; Mastromatteo et al., 2009; Sarteshnizi et al., 2015). Analysis of variance (F-test) showed that the third order model is well adjusted to the experimental data for the response AI. The adjusted coefficient of determination (R^2) implies that 93.1% of the behavior variation could be explained by the fitted

Table 4. Texture profile of burgers formulations.

	Toughness (kg s)	Tenderness (kg)	Hardness (g)	Elasticity*	Cohesiveness*	Chewiness (g)	Resilience*	Adhesiveness (g s)
F1	5.32 ± 2.53^{b}	0.88 ± 0.16^{a}	1021 ± 176^{bc}	0.92 ± 0.03^{a}	0.81 ± 0.01^{ab}	760 ± 118^{bcd}	0.35 ± 0.02^{cde}	-1.11 ± 0.52^{a}
F2	8.65 ± 0.54^{ab}	1.09 ± 0.11^{a}	913 ± 190^{bc}	0.90 ± 0.04^{a}	0.81 ± 0.02^{ab}	661 ± 110^{bcd}	0.37 ± 0.01^{abcd}	-1.22 ± 0.93^{a}
F3	8.00 ± 1.01^{ab}	0.99 ± 0.11^{a}	1086 ± 168^{bc}	0.92 ± 0.03^{a}	0.81 ± 0.02^{ab}	804 ± 107^{bcd}	0.33 ± 0.02^{e}	-2.07 ± 0.44^{a}
F4	6.84 ± 0.14^{ab}	0.89 ± 0.03^{a}	1193 ± 245^{ab}	0.90 ± 0.02^{a}	0.79 ± 0.02^{ab}	849 ± 149^{abc}	0.33 ± 0.02^{e}	-2.03 ± 1.95^{a}
F5	7.31 ± 0.22^{ab}	0.99 ± 0.11^{a}	1032 ± 198^{bc}	0.93 ± 0.03^{a}	0.81 ± 0.01^{ab}	768 ± 130^{bcd}	0.36 ± 0.02^{bcde}	-2.63 ± 0.88^{a}
F6	6.76 ± 1.20^{ab}	0.93 ± 0.04^{a}	762 ± 231^{c}	0.92 ± 0.03^{a}	0.81 ± 0.01^{a}	567 ± 167^{cd}	0.36 ± 0.02^{abcde}	-0.72 ± 0.52^{a}
F7	9.25 ± 0.43^{a}	1.10 ± 0.17^{a}	1000 ± 214^{bc}	0.93 ± 0.04^{a}	0.81 ± 0.02^{ab}	749 ± 127^{bcd}	0.36 ± 0.02^{abcde}	-1.35 ± 1.17^{a}
F8	9.11 ± 1.07^{a}	1.22 ± 0.15^{a}	798 ± 168^{c}	0.91 ± 0.04^{a}	0.81 ± 0.02^{ab}	583 ± 100^{cd}	0.36 ± 0.02^{abcde}	-1.36 ± 0.50^{a}
F9	8.35 ± 0.20^{ab}	1.02 ± 0.10^{a}	696 ± 194^{c}	0.91 ± 0.04^{a}	0.81 ± 0.01^{ab}	511 ± 147^{d}	0.39 ± 0.02^{ab}	-1.87 ± 1.35^{a}
F10	8.66 ± 0.15^{ab}	1.12 ± 0.11^{a}	1195 ± 172^{ab}	0.92 ± 0.02^{a}	0.80 ± 0.01^{ab}	878 ± 105^{abc}	0.35 ± 0.02^{cde}	-3.25 ± 1.77^{a}

Note: ^{abcde} Same letter on the column indicates no significant difference for the samples ($p < 0.05$); *Dimensionless values.

model. The value of the correlation coefficient is in agreement to other values reported on the literature (Shahiri & Mazaheri, 2014). Therefore, this parameter was chosen to be used in SRM.

Considering the validated model for the AI, the response surface is shown in Figure 1. The darker the color, the higher the AI. As the replacement of PF by POO and CO rises, the AI also does. This means that for formulation with little replacement (<20%) or an unbalanced mixture of POO and CO (edges), the AI is smaller. The use of the two vegetable oils in higher concentrations results in a higher AI. The mainly unsaturated oils used in this work, CO and POO, are less stable to oxidation compared to PF, which is predominantly saturated. Although the optimized equation for AI suggests a higher PF content, it can predict the best AI for different fat composition patties: $y = 0.86x_1 + 0.96x_2 + 0.78x_3 - 0.39x_1x_2 + 4.71x_1x_3 + 2.04x_2x_3 + 6.70x_1x_2x_3$.

Therefore, these results show that the change in fat composition of the patties, with the exception of the AI, did not affect physicochemical and textural parameters.

Shahiri & Mazaheri (2014) evaluated the replacement of fat with starchy ingredients and a relatively high number of significant responses were obtained. Differently from this work, the addition of starchy ingredients maybe have a greater effect on physical, texture and color parameters because of its interactions with other ingredients. Even though the mixture design model for AI was able to predict this parameter when varying the fat content of hamburgers, it was not able to define alone the best formulation and sensory characteristics of the final product are yet very important. Then, to determine the best formulation, a sensory analysis was performed.

3.3 Sensory analysis

Preference test

The preference test results (data not shown) for variance analysis (ANOVA 2-way) and Tukey test indicated a significant difference between the formulations ($p < 0.05$). The higher scores were obtained by F4, F8 and F9, and Tukey test showed no significant differences between these samples. The formulations F3 and F1 presented the lowest scores. Due to the use of oils, a change in the flavor could be detected, as well as an increase in the hardness. Similar results were found by Choi et al. (2009) and Melo & Clerici (2015).

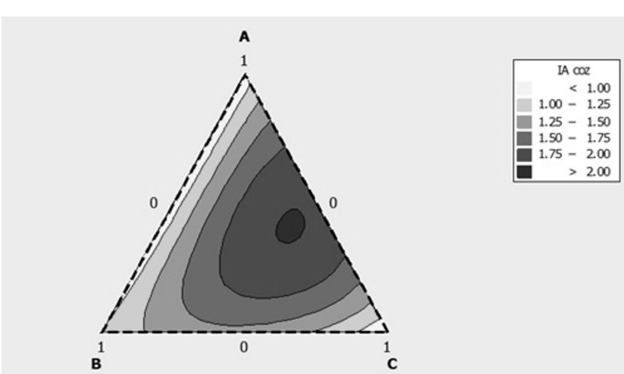

Figure 1. Mixture Contour plot for acidity index of beef patties. Note: A: Pomace olive oil; B: Pork fat; C: Canola oil.

Oliveira et al. (2013) found that a replacement of 100% of animal fat in hamburger patties can be rejected by consumers; however, the partial replacement showed good preference. Regarding this information and the results obtained, the three most preferred formulations were F4, F8 and F9 with hedonic scores of 6.43, 6.38, 6.31 respectively and the formulation F2 with hedonic scores of 6.23, containing 100% PF as a control, often found commercially, were chosen to further analysis.

Consumer profile

The results of consumer profile showed that from 150 assessors, 80% are 18 to 25 years old, 70% female and 30% male. From the answers, 45% of the assessors consume frozen hamburger patties frequently, indicating a high consumption of this product by the young population. Regarding the purchase intent, results showed that 41% of the assessors exhibit interest in buying food with fat replacements, opening a new market sector for this kind of product.

Acceptability analysis

The segmentation by k-means analysis segmented the consumers in three different groups. The consumers' behavior of each group are shown in Figure 2, the segment one is the smallest representing 21% of consumers, that had a similar behavior of segment 2 (31% of consumers), showing a different approach regarding the F9 hamburger. The third segment represents 48% of consumers, which equally liked the four formulations (F2 = 7.18; F4= 7.44 ; F8 = 7.47 ; F9 = 7.22). It can be seen that F4 formulation obtained positive scores for all the segments, with overall hedonic score of 6.75.

Based on these results, the preference mapping was performed, selecting the consumers as variables (vectors). Figure 3 shows that the F4 hamburger was well accepted by all segments, and 76.4% of variability between products and consumers was explained. For López-López et al. (2010), and Martínez et al. (2012) showed that a replacement of less than 20% of PF by different oils did not show any difference in overall acceptability. In the present study, 20% of fat was replaced in patties, increasing the differences between the samples, consequently modifying the acceptability.

CATA

The attributes with frequency above 20% were selected for CATA analysis, including salty taste, barbecue taste, rubbery, soft, juicy, chewy, intermediate quality, good quality, cheap, intermediate price, homogeneous batter, "want more" flavor and fat after flavor. The attributes below 20% frequency were the plastic flavors, onion, soy, spicy, artificial, garlic, bacon and burnt; raw meat and stable odors; stiff, crumbly batter, satiety sensation, healthy burger, expensive burger, poor quality, gives me pleasure and acid after taste.

Cochran Q test was performed on the 13 terms, (Table 5), the F9 can be considered juicier, has more fat after flavor and is less rubbery. F2 is less juicy, less soft and has lowest barbecue odor. F8 is the most rubbery and F4 is the softer,

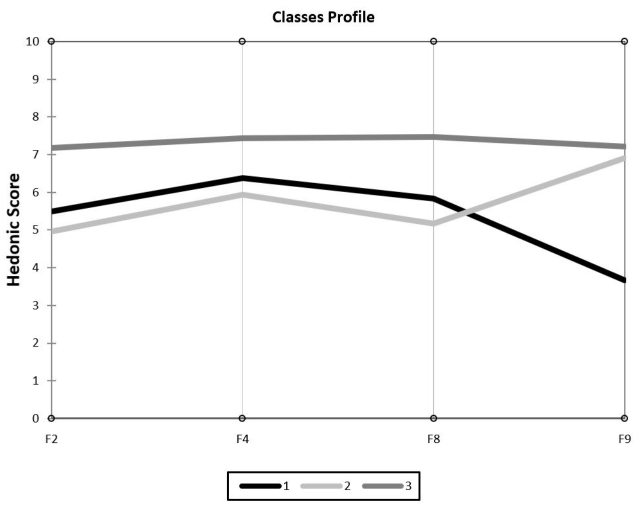

Figure 2. Consumers segmentation by k-means analysis.

easy to chew and was indicated most often with the want more term. Correspondence analysis was performed, confirming the Cochran results (Figure 4).

Analyzing the first component in CA plot, related to formulation F2 it can be seen that the formulation is characterized by rubbery, intermediate quality, fat after flavor and barbecue odor, some of these attributes can be related to the low acceptability mean. The rubbery attribute can be related to the low moisture retention observed for this formulation, influencing consumers' acceptability.

On the other hand, the formulation F4 was defined to be easier to chew, soft, juicy and desired flavor, attributes that can influence higher acceptability by consumers. The easy to chew and homogeneous batter can be related to texture parameters of low chewiness and low resilience respectively. Also this formulation received 50% POO, giving it a high nutritional quality and taste to the product.

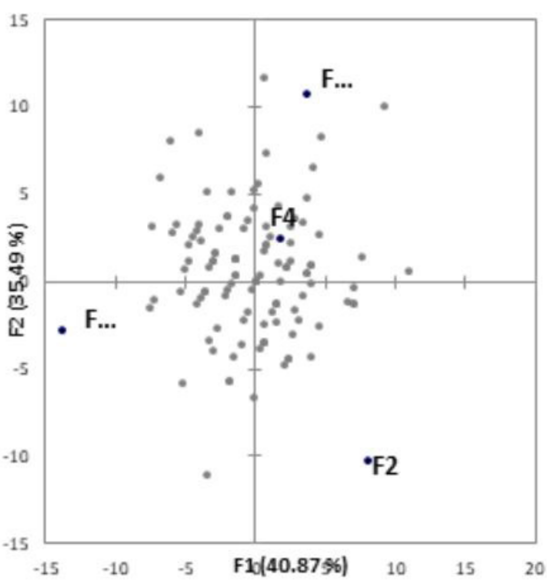

Figure 3. Preference mapping for hamburger patties with fat replacement.

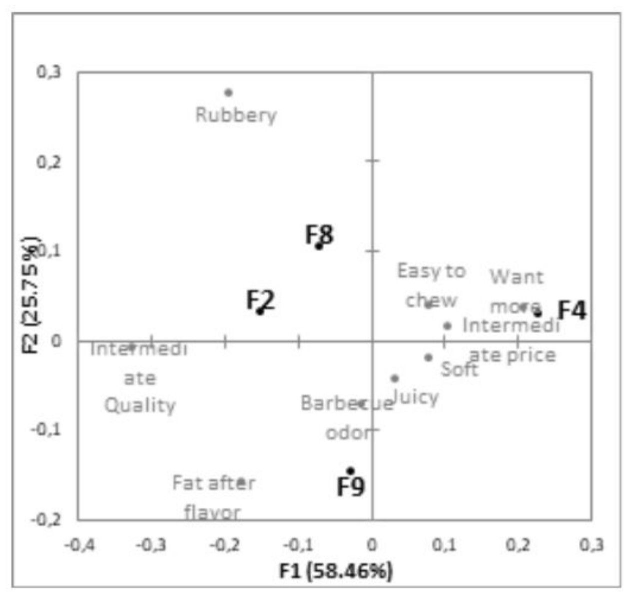

Figure 4. Sensory characterization by CATA analysis.

Table 5. Frequency of CATA terms.

Attributes	p-values	F2	F4	F8	F9
Good Quality	0.240	0.447^{a}	0.561^{a}	0.482^{a}	0.482^{a}
Rubbery	**0.012**	**0.246^{ab}**	**0.175^{ab}**	**0.298^{b}**	**0.149^{a}**
Salty taste	0.221	0.421^{a}	0.491^{a}	0.456^{a}	0.386^{a}
Soft	**0.005**	**0.421^{a}**	**0.605^{b}**	**0.456^{ab}**	**0.570^{ab}**
Barbecue odor	**0.002**	**0.149^{a}**	**0.228^{ab}**	**0.289^{b}**	**0.333^{b}**
Juicy	**0.018**	**0.421^{a}**	**0.553^{ab}**	**0.465^{ab}**	**0.596^{b}**
Easy to chew	**0.005**	**0.500^{a}**	**0.702^{b}**	**0.535^{a}**	**0.579^{ab}**
Intermediate Quality	**0.005**	**0.298^{b}**	**0.123^{a}**	**0.246^{ab}**	**0.272^{b}**
Cheap	0.665	0.237^{a}	0.202^{a}	0.263^{a}	0.246^{a}
Homogeneous batter	0.299	0.377^{a}	0.404^{a}	0.316^{a}	0.316^{a}
"Want more"	**0.007**	**0.184^{a}**	**0.333^{b}**	**0.184^{a}**	**0.219^{ab}**
Fat after flavor	**0.002**	**0.333^{ab}**	**0.219^{a}**	**0.228^{a}**	**0.404^{b}**
Intermediate price	0.160	0.228^{a}	0.333^{a}	0.228^{a}	0.272^{a}

Note: ^{abc}Different letters at same line indicate significant different percentages for the attribute ($p < 0.05$) by Cochran Q test.

The formulation F9 is highly related to a barbecue odor, fat after flavor, intermediate quality, soft, juicy and easy to chew. The attribute soft is related to the low hardness obtained in the texture parameters, also the high moisture retention is observed by the relation with the juicy attribute, highly correlated to the formulation.

The formulation F8 is related to a rubbery term, a high toughness in the texture parameters was observed, proving by the correspondence analysis, where the assessors indicated a rubbery product.

4 Conclusions

The formulations presented differences regarding its physical, chemical, instrumental and sensory analysis. The mixture design was able to predict the response of AI by the special cubic model, explaining 94.5% of the variation in the experimental data for this parameter. The results showed that the formulations F9 containing 66.7% of PF and 16.7% of POO and 16.7% of CO were similar to commercial burgers for the textural parameters. The segmentation by k-means analysis segmented the consumers in three different groups. The sensory assessment pointed that even with the segmentation in three groups, the formulation F4 containing 50% PF and 50% POO had a good acceptability, showed by the preference map. The penalty analysis pointed that the seasoning excess penalized all the formulations, especially the F9 formulation. The CATA analysis related the F4 formulation to a burger with soft texture, easy to chew and desired flavor, the F9 formulation had the characteristics of being juicy, less rubbery and had a fat after flavor. The formulations F4 and F9 can be considered a good choice for animal fat replacement of 50% and 33% respectively, in the manufacture of frozen hamburger beef burgers. Furthermore, these two formulations consisted of a more nutritious choice, with a low acidity index and high content of unsaturated fats.

Acknowledgements

The authors are grateful to the National Council for Scientific and Technological Development (CNPq) and the Coordination for Improvement of Personnel in Higher Level (CAPES) for financial support and scholarships and Professor Isabel Cristina Vollet Marson for the English review.

References

Ares, G., Antúnez, L., Bruzzone, F., Vidal, L., Giménez, A., Pineau, B., Beresford, M. K., Jin, D., Paisley, A. G., Chheang, S. L., Roigard, C. M., & Jaeger, S. R. (2015). Comparison of sensory product profiles generated by trained assessors and consumers using CATA questions: Four case studies with complex and/or similar samples. *Food Quality and Preference*, 45, 75-86. http://dx.doi.org/10.1016/j.foodqual.2015.05.007.

Arihara, K. (2006). Strategies for designing novel functional meat products. *Meat Science*, 74(1), 219-229. http://dx.doi.org/10.1016/j.meatsci.2006.04.028. PMid:22062731.

Association of Official Analytical Chemists – AOAC. (2005). *Official methods of analysis of the Association of Official Analytical Chemists* (18th ed.). Gaithersburg: AOAC International.

Bastos, S. C., Pimenta, M. E. S. G., Pimenta, C. J., Reis, T. A., Nunes, C. A., Pinheiro, A. C. M., Fabrício, L. F. F., & Leal, R. S. (2014). Alternative fat substitutes for beef burger: technological and sensory characteristics. *Journal of Food Science and Technology*, 51(9), 2046-2053. http://dx.doi.org/10.1007/s13197-013-1233-2. PMid:25190862.

Baugreet, S., Kerry, J. P., Allen, P., & Hamill, R. M. (2017). Optimisation of protein-fortified beef patties targeted to the needs of older adults: a mixture design approach. *Meat Science*, 134, 111-118. http://dx.doi.org/10.1016/j.meatsci.2017.07.023. PMid:28779717.

Bligh, E. G., & Dyer, W. J. (1959). A rapid method of total lipid extraction and purification. *Canadian Journal of Biochemistry and Physiology*, 37(8), 911-917. http://dx.doi.org/10.1139/o59-099. PMid:13671378.

Borba, C. M., Oliveira, V. R., Montenegro, K. R., Hertz, P. F., & Venzke, J. G. (2013). Physical and chemical quality of beef and chicken burgers submitted to different heat treatments/Avaliacao fisico-quimica de hamburguer de carne bovina e de frango submetidos a diferentes processamentos termicos. *Brazilian Journal of Food and Nutrition*, 24(1)

Carli, C. G. (2012). Avaliação física, sensorial e microbiológica de hambúrgueres suplementados de farinha de linhaça dourada. In *Seminário de Iniciação Científica e Tecnológica da UTFPR - Sicite 2012*. Curitiba: UTFPR.

Choi, Y.-S., Choi, J.-H., Han, D.-J., Kim, H.-Y., Lee, M.-A., Kim, H.-W., Jeong, J.-Y., & Kim, C.-J. (2009). Characteristics of low-fat meat emulsion systems with pork fat replaced by vegetable oils and rice bran fiber. *Meat Science*, 82(2), 266-271. http://dx.doi.org/10.1016/j.meatsci.2009.01.019. PMid:20416740.

Cochran, W. G., & Cox, G. M. (1992). *Experimental designs* (2nd ed., 611 p.). New York: John Whiley & Sons, Inc.

Daniel, C. R., Cross, A. J., Koebnick, C., & Sinha, R. (2011). Trends in meat consumption in the United States. *Public Health Nutrition*, 14(4), 575-583. http://dx.doi.org/10.1017/S1368980010002077. PMid:21070685.

García, M. L., Calvo, M. M., & Selgas, M. D. (2009). Beef hamburgers enriched in lycopene using dry tomato peel as an ingredient. *Meat Science*, 83(1), 45-49. http://dx.doi.org/10.1016/j.meatsci.2009.03.009. PMid:20416684.

Grasso, S., Brunton, N. P., Lyng, J. G., Lalor, F., & Monahan, F. J. (2014). Healthy processed meat products–Regulatory, reformulation and consumer challenges. *Trends in Food Science & Technology*, 39(1), 4-17. http://dx.doi.org/10.1016/j.tifs.2014.06.006.

Hathwar, S. C., Rai, A. K., Modi, V. K., & Narayan, B. (2012). Characteristics and consumer acceptance of healthier meat and meat product formulations—a review. *Journal of Food Science and Technology*, 49(6), 653-664. http://dx.doi.org/10.1007/s13197-011-0476-z. PMid:24293684.

Hyman, M. (2008). *Ultrametabolism*. New York: Atria Publishing Group.

International Organization for Standardization – ISO. (2007). *ISO 8589: Sensory analysis - general guidance design of test*. Genebra: ISO.

Jaeger, S. R., Hunter, D. C., Kam, K., Beresford, M. K., Jin, D., Paisley, A. G., Chheang, S. L., Roigard, C. M., & Ares, G. (2015). The concurrent use of JAR and CATA questions in hedonic scaling is unlikely to cause hedonic bias, but may increase product discrimination. *Food Quality and Preference*, 44, 70-74. http://dx.doi.org/10.1016/j.foodqual.2015.04.001.

Keenan, D. F., Resconi, V. C., Kerry, J. P., & Hamill, R. M. (2014). Modelling the influence of inulin as a fat substitute in comminuted meat products on their physico-chemical characteristics and eating quality using a mixture design approach. *Meat Science*, 96(3), 1384-1394. http://dx.doi.org/10.1016/j.meatsci.2013.11.025. PMid:24361558.

Kruk, Z. A., Kim, H. J., Kim, Y. J., Rutley, D. L., Jung, S., Lee, S. K., & Jo, C. (2014). Combined effects of high pressure processing and addition of soy sauce and olive oil on safety and quality characteristics of chicken breast meat. *Asian-Australasian Journal of Animal Sciences*, 27(2), 256-265. http://dx.doi.org/10.5713/ajas.2013.13417. PMid:25049950.

Kurt, S., & Kilinççeker, O. (2011). Mixture optimization of beef, turkey, and chicken meat for some of the physical, chemical and sensory properties of meat patties. *Poultry Science*, 90(8), 1809-1816. http://dx.doi.org/10.3382/ps.2010-01306. PMid:21753219.

Liu, F., Dai, R., Zhu, J., & Li, X. (2010). Optimizing color and lipid stability of beef patties with a mixture design incorporating with tea catechins, carnosine and α-tocopherol. *Journal of Food Engineering*, 98(2), 170-177. http://dx.doi.org/10.1016/j.jfoodeng.2009.12.023.

López-Álvarez, M. A., Hernández-Andrés, J., Valero, E. M., & Nieves, J. L. (2005). Colorimetric and spectral combined metric for the optimization of multispectral systems. In *Proceedings of the 10th Congress of the International Colour Association (AIC'05)* (pp. 1685-1688). USA: Association Internationale de la Couleur.

López-López, I., Cofrades, S., Yakan, A., Solas, M. T., & Jiménez-Colmenero, F. (2010). Frozen storage characteristics of low-salt and low-fat beef patties as affected by Wakame addition and replacing pork backfat with olive oil-in-water emulsion. *Food Research International*, 43(5), 1244-1254. http://dx.doi.org/10.1016/j.foodres.2010.03.005.

Mapari, S. A., Meyer, A. S., & Thrane, U. (2006). Colorimetric characterization for comparative analysis of fungal pigments and natural food colorants. *Journal of Agricultural and Food Chemistry*, 54(19), 7027-7035. http://dx.doi.org/10.1021/jf062094n. PMid:16968059.

Mapiye, C., Aalhus, J. L., Vahmani, P., Rolland, D. C., McAllister, T. A., Block, H. C., Uttaro, B., Proctor, S. D., & Dugan, M. E. R. (2014). Improving beef hamburger quality and fatty acid profiles through dietary manipulation an exploitation of fat depot heterogeneity. *Journal of Animal Science and Biotechnology*, 5(1), 54. http://dx.doi.org/10.1186/2049-1891-5-54. PMid:25810905.

Mapiye, C., Aldai, N., Turner, T. D., Aalhus, J. L., Rolland, D. C., Kramer, J. K. G., & Dugan, M. E. R. (2012). The labile lipid fraction of meat: from perceived disease and waste to health and opportunity. *Meat Science*, 92(3), 210-220. http://dx.doi.org/10.1016/j.meatsci.2012.03.016. PMid:22546816.

Martínez, B., Miranda, J. M., Vázquez, B. I., Fente, C. A., Franco, C. M., Rodríguez, J. L., & Cepeda, A. (2012). Development of a hamburger patty with healthier lipid formulation and study of its nutritional, sensory, and stability properties. *Food and Bioprocess Technology*, 5(1), 200-208. http://dx.doi.org/10.1007/s11947-009-0268-x.

Mastromatteo, M., Lucera, A., Sinigaglia, M., & Corbo, M. R. (2009). Combined effects of thymol, carvacrol and temperature on the quality of non conventional poultry patties. *Meat Science*, 83(2), 246-254. http://dx.doi.org/10.1016/j.meatsci.2009.05.007. PMid:20416746.

Meilgaard, M., Civille, V., & Carr, B. (1991). *Sensory evaluation techniques*. Boca Raton: CRC Press.

Melo, L. S. M., & Clerici, M. T. P. S. (2015). Desenvolvimento e avaliação tecnológica, sensorial e físico-química de produto cárneo, tipo hambúrguer, com substituição de gordura por farinha desengordurada de gergelim. *Alimentos e Nutrição Araraquara*, 24(4), 361-368.

Meyners, M., Castura, J. C., & Carr, B. T. (2013). Existing and new approaches for the analysis of CATA data. *Food Quality and Preference*, 30(2), 309-319. http://dx.doi.org/10.1016/j.foodqual.2013.06.010.

Moubarac, J.-C., Batal, M., Martins, A. P. B., Claro, R., Levy, R. B., Cannon, G., & Monteiro, C. (2014). Processed and ultra-processed food products: consumption trends in Canada from 1938 to 2011. *Canadian Journal of Dietetic Practice and Researc*, 75(1), 15-21. http://dx.doi.org/10.3148/75.1.2014.15. PMid:24606955.

Myers, R. H., Montgomery, D. C., & Anderson-Cook, C. M. (2016). *Response surface methodology: process and product optimization using designed experiments*. USA: John Wiley & Sons.

Nascimento, M. D. G. F., Oliveira, C. Z. F., & Nascimento, E. R. (2005). Hambúrguer: evolução comercial e padrões microbiológicos. *Boletim do Centro de Pesquisa e Processamento de Alimentos*, 23(1). http://dx.doi.org/10.5380/cep.v23i1.1271.

Oliveira, D. F., Coelho, A. R., Burgardt, V. C. F., Hashimoto, E. H., Lunkes, A. M., Marchi, J. F., & Tonial, I. B. (2013). Alternativas para um produto cárneo mais saudável: uma revisão. *Brazilian Journal of Food Technology, Campinas*, 16(3), 163-174. http://dx.doi.org/10.1590/S1981-67232013005000021.

Olmedilla-Alonso, B., Jiménez-Colmenero, F., & Sánchez-Muniz, F. J. (2013). Development and assessment of healthy properties of meat and meat products designed as functional foods. *Meat Science*, 95(4), 919-930. http://dx.doi.org/10.1016/j.meatsci.2013.03.030. PMid:23623320.

Organisation for Economic Co-operation and Development – OECD. (2017). *Meat consumption (indicator)*. Retrieved from http://dx.doi.org/10.1787/fa290fd0-en

Piñero, M. P., Parra, K., Huerta-Leidenz, N., Arenas de Moreno, L., Ferrer, M., Araujo, S., & Barboza, Y. (2008). Effect of oat's soluble fibre (β-glucan) as a fat replacer on physical, chemical, microbiological and sensory properties of low-fat beef patties. *Meat Science*, 80(3), 675-680. http://dx.doi.org/10.1016/j.meatsci.2008.03.006. PMid:22063581.

Rodríguez-Carpena, J. G., Morcuende, D., & Estévez, M. (2011). Partial replacement of pork back-fat by vegetable oils in burger patties: Effect on oxidative stability and texture and color changes during cooking and chilled storage. *Journal of Food Science*, 76(7), C1025-C1031. http://dx.doi.org/10.1111/j.1750-3841.2011.02327.x. PMid:22417539.

Rodriguez-Estrada, M., Penazzi, G., Caboni, M. F., Bertacco, G., & Lercker, G. (1997). Effect of different cooking methods on some lipid and protein components of hamburgers. *Meat Science*, 45(3), 365-375. http://dx.doi.org/10.1016/S0309-1740(96)00123-4. PMid:22061474.

Sarteshnizi, R. A., Hosseini, H., Bondarianzadeh, D., & Colmenero, F. J. (2015). Optimization of prebiotic sausage formulation: Effect of using β-glucan and resistant starch by D-optimal mixture design approach. *Lebensmittel-Wissenschaft + Technologie*, 62(1), 704-710. http://dx.doi.org/10.1016/j.lwt.2014.05.014.

Schilling, M. W., & Coggins, P. C. C. (2007). Utilization of agglomerative hierarchical clustering in the analysis of hedonic scaled consumer acceptability data. *Journal of Sensory Studies*, 22(4), 477-491. http://dx.doi.org/10.1111/j.1745-459X.2007.00121.x.

Shahiri, H. T., & Mazaheri, M. T. (2014). Optimization of physicochemical properties of low-fat hamburger formulation using blend of soy flour, split-pea flour and wheat starch as part of fat replacer system. *Journal of Food Processing and Preservation*, 38(1), 278-288. http://dx.doi.org/10.1111/j.1745-4549.2012.00774.x.

Shrestha, S., Cornforth, D., & Nummer, B. A. (2010). Process optimization and consumer acceptability of salted ground beef patties cooked and held hot in flavored marinade. *Journal of Food Science*, 75(7), C607-C612. http://dx.doi.org/10.1111/j.1750-3841.2010.01728.x. PMid:21535526.

Turatti, J. M. (2000). Óleos vegetais como fonte de alimentos funcionais. Óleos *e Grãos*, 56, 20-27.

Varela, P., & Ares, G. (2012). Sensory profiling, the blurred line between sensory and consumer science. A review of novel methods for product characterization. *Food Research International*, 48(2), 893-908. http://dx.doi.org/10.1016/j.foodres.2012.06.037.

Zhang, W., Xiao, S., Samaraweera, H., Lee, E. J., & Ahn, D. U. (2010). Improving functional value of meat products. *Meat Science*, 86(1), 15-31. http://dx.doi.org/10.1016/j.meatsci.2010.04.018. PMid:20537806.

Zielinski, A. A. F., Haminiuk, C. W. I., Nunes, C. A., Schnitzler, E., van Ruth, S. M., & Granato, D. (2014). Chemical composition, sensory properties, provenance, and bioactivity of fruit juices as assessed by chemometrics: a critical review and guideline. *Comprehensive Reviews in Food Science and Food Safety*, 13(3), 300-316. http://dx.doi.org/10.1111/1541-4337.12060.