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Use of agricultural by-products in extruded gluten-free breakfast cereals

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ABSTRACT

The objective of this study was to evaluate the effect of the extrusion moisture and temperature on the physical characteristics of breakfast cereals. The chemical composition, microbiological risk and acceptance of the selected breakfast cereal with the best physical quality were assessed to determine the technological viability of the use of these by-products by the food industry. The response surface method and a rotatable central composite design were used, and a desirability test was performed based on adjusted regression models. The breakfast cereal produced under these conditions had protein, lipid and dietary fiber contents of 7.55, 0.97 and 6.12 g $100\,g^{-1}$, respectively. In regards to the sensory analysis, the evaluated breakfast cereal received average acceptance scores ranging from "neither like or dislike" to "like moderately". The use of rice, passion fruit and milk by-products was shown to be an alternative for the production of extruded breakfast cereal.

1. Introduction

Data indicate that 1% of the world population (about 69,065,580), have gluten intolerance (Asbran, 2017). Gluten is found in cereals such as wheat, barley, malt and oats, and this pathology is treated by excluding gluten from the diet (Reips, 2011). Broken rice grains (BRG), passion fruit peel and whey are gluten-free by-products, which makes them appealing for the production of alternative food products for celiac or gluten-intolerant consumers.

Rice (*Oryza sativa*) is one of the three most produced and consumed cereals worldwide. Part of the rice produced is processed, and a by-product named "broken rice" is generated, causing considerable loss of yield in the production of polished rice, the most consumed form of rice in Brazil. The value of this by-product represents only one-fifth of that obtained by the commercialization of the whole grain, although the broken grain contains the same average chemical composition as the whole grain (Silva & Ascheri, 2009). This by-product has been transformed into rice flour, which may be used in the production of vegetable extracts or can serve as the base for new ingredients, such as mixed flours and modified starch (Carvalho et al., 2011; Soares Júnior et al., 2011; Tavares, Soares Júnior, Becker, & Eifert, 2012).

Brazil is the largest producer of passion fruit in the world, with approximately 920,000 tons of the fruit produced per year, corresponding to approximately 70% of the global production (Welle, 2013). Because of its functional properties, passion fruit peel flour (PFPF) has been used in the formulation of many types of foods, such as cookies (Ishimoto, Harada, Branco, Conceição, & Coutinho, 2007), cereal bars (Silva & Ascheri, 2009), pasta (Spanholi & Oliveira, 2009) and breakfast cereals (Vernaza, Chang, & Steel, 2009).

Whey originates from cheese production, a process in which two major proteins, casein and lactalbumin, are separated, and the latter remains in the liquid fraction, constituting whey. This by-product has sparked the interest of researchers world wide due to its nutritional, functional and economic potential. The use of whey in new human food products can generate healthy products, in addition to decreasing its high environmental pollution factor, as it is often discarded untreated on soil or in many river watersheds (Ugwu, Tokiwa, & Aoyagi, 2012).

Extrusion technology allows the use of these by-products (broken rice grains, passion fruit peel and whey) as feedstock and can transform them into various industrialized foods ready for consumption, such as breakfast cereals. Breakfast cereals are important foods for athletes and children due to their innumerous desirable characteristics, such as practicality, convenience, diversified flavors and shapes, and nutritional value (Santos, Caliari, Soares Junior, Viana, & Leite, 2015).

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Considering these reasons, the objective of this study was to evaluate the effect of the extrusion moisture and temperature on the physical characteristics of experimental breakfast cereals formulated with BRG, PFPF and whey powder (WP), at the ratio of 87:03:10. Additionally, the chemical composition, microbiological risk and acceptance of the selected breakfast cereal with the best physical quality were assessed to determine the technological viability of the use of these by-products by the food industry.

2. Material and methods

2.1. Raw materials

The feed stocks for the formulation of the extruded breakfast cereals produced in this study were BRG (mixture of cultivars IRGA 417 and IRGA 424), 2013 harvest, provided by Empresa Arroz Cristal, located in Aparecida de Goiânia, Goiás, Brazil; PFPF, Natural Life brand, located in São José do Rio Preto, São Paulo, Brazil, purchased in the local market at Rio Verde, Goiás, Brazil; and WP provided by Indústria de Laticínios Italac, located in Santa Helena de Goiás, Goiás, Brazil.

2.2. Breakfast cereal processing

The breakfast cereals were prepared with a mixture of BRG, PFPF and WP (87:03:10) obtained in a Y-type homogenizer mixer (Tecnal, TE 201/05, Piracicaba, Brazil) for 15 min. The mixture was packed under different moisture levels (between 10 and 20 g $100\,g^{-1}$), and the temperature of the third zone of the extruder varied between 60 and 110 °C, according to the experimental design.

Thermoplastic extrusion was performed in a simple screw device (Inbramaq, PQ-30, Ribeirão Preto-SP, Brazil). The processing parameters were set as follows: motor rotation of 250 rpm (60 Hz), 4-mm diameter circular matrix opening, pre-matrix with 22 orifices, screw with three inputs, length of 30 cm and bolt compression ratio of 3:1, helical jacket, and feed rate of 335 g min^{-1}. The temperatures of the first and second heating zones were 40 and 60 °C, respectively.

2.3. Physical characteristics of breakfast cereals

The volume of the breakfast cereals was analyzed by the displacement of millet seeds, with 10 replicates for each experiment. The mass was determined using a semi-analytical scale. The specific volume was calculated by the ratio between the mean volume and the mass of the cereals. The expansion index (EI) was gauged by the ratio between the diameter of the extruded material and the diameter of the extruder's output orifice (4 mm). The diameter of the extruded material was measured with a caliper (Digital Caliper, Messen, Danyang, China), and the arithmetic mean was calculated from 10 randomly selected cereals per experiment. The instrumental color parameters of the breakfast cereals were evaluated according to the CIEL L*, a* and b* system in a colorimeter (Color Quest, XE, Reston, USA). An observing angle of 10° and the D65 standard illuminant were used, corresponding to natural daylight.

2.4. Chemical composition of the selected breakfast cereal

The moisture was measured from the mass loss of the sample heated in an oven at 105 °C to constant weight. The proteins were measured using the Kjeldahl method for the determination of total nitrogen. The lipid content was measured using the Soxhlet method; the ash content, by carbonization followed by complete incineration in a muffle at 550 °C; and the total, soluble and insoluble dietary fiber, using the enzyme-gravimetric method. All methods are recommended by the AOAC (2010). The carbohydrates were calculated by the differences method, subtracting from one hundred the values of the moisture, ash, protein and lipid contents. The total energetic value was estimated according to the Atwater conversion values, for which the carbohydrate (minus the dietary fiber content) and protein content was multiplied by four and the lipid content by nine, and the sum of the products was calculated.

2.5. Microbiological risk and acceptance of the selected breakfast cereal

The analyses of coliforms were performed at 35 and 45 °C, according to APHA (2002). The results were evaluated in accordance with the parameters established by RDC resolution no. 12 of January 2, 2001 (Brasil, 2001).

The acceptance test was applied using a seven-point structured hedonic scale (7 = like extremely to 1 = dislike extremely), and it was established that the cut-off score for acceptance of the breakfast cereal would be > 4 (Santos, Caliari, and Soares Junior, 2015; Santos, Caliari, Soares Junior, Viana et al., 2015). First, each tester received the sample, served in a disposable plate with a cup of cold milk (50 mL), so that each tester could evaluate the breakfast cereal with or without the milk, according to his/her preference. The sample was evaluated according to color, smell, texture, taste and purchase intention. For purchase intention, a five-point structured scale was used (1 = certainly would not buy to 5 = certainly would buy) (Stone & Sidel, 1993). The study was approved by the Research Ethics Committee of the Federal Institute of Goiás (Instituto Federal Goiano), under protocol n. 040/2013, and the participants selected to evaluate the sensory characteristics of the product signed an informed consent form confirming that they were aware of the study objective and the risks and benefits.

2.6. Design and statistical analysis

To test the effect of the processing variables on the physical properties of the breakfast cereals, a rotatable central composite design was used, with 11 experiments and three repetitions at the central point. The EI, SV, L*, and chromaticity a* and b* data were evaluated by analysis of variance; multiple regression models were constructed and contour plots were generated to visualize the effect of the independent variables on the responses using the program Statistica (Statsoft, Statistica 7.0, Tulsa, USA). From the significant ($P < 0.10$) mathematical models generated and with the assistance of the Response Desirability Profiling function of the Statistica program, the most desirable breakfast cereal was selected based on the moisture content in the mixture and extrusion temperature used in the third zone of the extruder. The most desirable breakfast cereal was considered to be the one that had the highest EI, SV and chromaticity a* values. The optimization technique was based on the definition of a desirability function restricted to the interval of 0 to 1 for the dependent variables, for which the lower, mean and upper limits adopted were 0, 0.5 and 1.0, respectively (Statsof, 2007).

3. Results and discussion

3.1. Physical characteristics of breakfast cereals

The effect of moisture and temperature on the final aspect of the breakfast cereals became evident in the appearance of the products obtained by the different optimization treatments. The treatments with lower moisture contents and a temperature in the third zone of the extruder lower than 85 °C had light, greyish tones compared to the treatments with a moisture content higher than 15 g $100\,g^{-1}$ and higher temperatures in the third zone of the extruder, resulting in darker cereals with little expansion. The models were significant ($P < 0.10$), with coefficients of determination explaining between 78 and 92% of the responses, except for those of luminosity and chroma b*, which were not significant (Table 1). The color of snacks is a very important characteristic for their commercialization and is influenced by the feedstock that composes their formulation (Akillioglu & Yalcin,

Table 1
Significance level (P) of the linear and quadratic effects and interaction of temperature (x_1) and moisture content (x_2) on the expansion index, specific volume and color parameter (chroma a*), fitted model and correlation coefficient (R^2).

Physical Parameter	Significance Level (ANOVA)				Fitted model	R^2
	T(L)	T (Q)	W (L)	W (Q)		
EI	–	0.01	0.001	0.02	$y = 2.59 - 0.19x_1^2 - 0.22x_2 - 0.16x_2^2$	0.85
SV	–	0.002	0.000	0.003-	$y = 1.58 - 0.22x_1^2 - 0.28x_2 - 0.19x_2^2$	0.92
a*			0.000		$y = 6.92 - 1.32x_2$	0.78

2010). The luminosity (L*) of the breakfast cereals varied between 73.16 and 79.95, and the chromaticity coordinates a* and b* varied from 5.08 to 9.3 and from 15.53 to 18.36, respectively.

The white color of milk results from the dispersion of the light reflected by the fat globules and by the casein and calcium phosphate colloidal particles (Fennema, Parkin, & Damodaran, 2010). WP does not contain the same amount of these components as milk; however, WP is still responsible, together with the BRG, for the characteristic light color of the experimental breakfast cereals formulated with it. The linear effect of moisture content was significant ($P < 0.10$) (Table 1).

The highest chroma a* values (reddest) were found at 85 °C and a moisture content of 15 g 100 g^{-1} (Fig. 1A). According to Lacerda et al. (2010), the Maillard and caramelization reactions are the most likely explanations for products produced at high temperatures and low moisture contents being redder, with a higher content of melanoidins. The EI of the treatments varied between 1.83 and 2.65. The quadratic effects of temperature and moisture content, as well as the linear effect of moisture content, were significant in the model ($P < 0.10$). The area of the plot with the highest EI values (above 2.6) is elliptical and is located at a moisture content of 15 g 100 g^{-1} and 85 °C (Fig. 1B).

The addition of fiber to the formulation of extruded products considerably decreases expansion (Huber, 2001). The largest particles, such as fibers, tend to break the cell walls of the extruded product, reducing the EI (Riaz, 2002), as in the case of the PFPF fibers in the present study (Santos, Caliari, Soares Junior, Viana et al., 2015).

The SV varied between 0.8 and 1.65 mL g^{-1}. The linear and quadratic effects of moisture content were significant ($P < 0.10$), and for the temperature, only the quadratic effect was significant (Table 1). The area of the plot with the highest SV values was wide, although there was no relationship between the moisture content binomial of the by-product mixture and the extrusion temperature (interaction effect) (Fig. 1C). According to Ding, Ainsworth, Tucker, and Marson (2005), water has the opposite effect on expansion, acting as a plasticizer for starchy products, reducing their viscosity and dissipating the

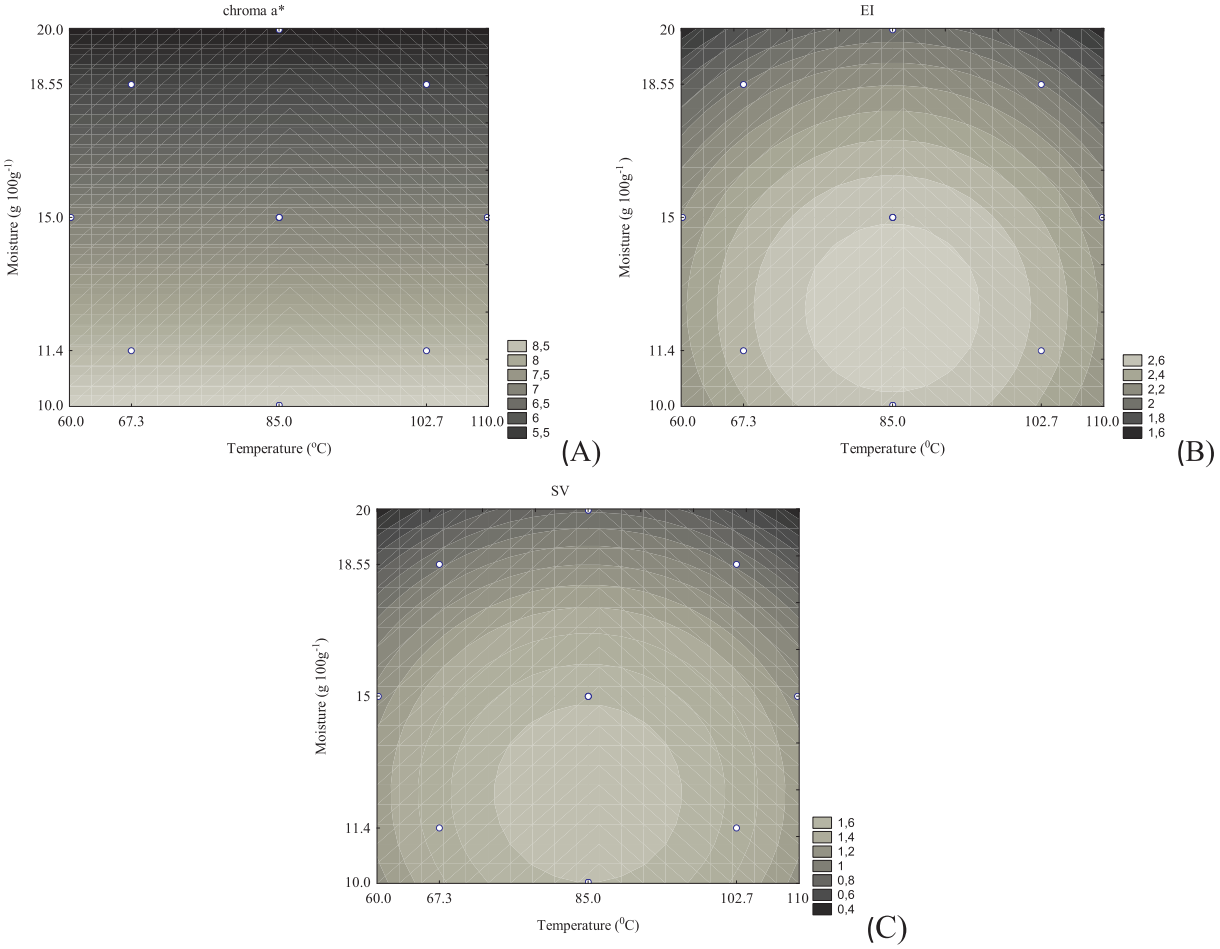

Fig. 1. (A) chroma a*; (B) Expansion index (EI) and (C) specific volume (SV) of breakfast cereals formulated with broken rice grains (BRG), passion fruit peel flour (PFPF) and whey powder (WP) as a function of the moisture content in the mixture (g 100 g^{-1}) and the extrusion temperature (°C) in the third zone of the extruder.

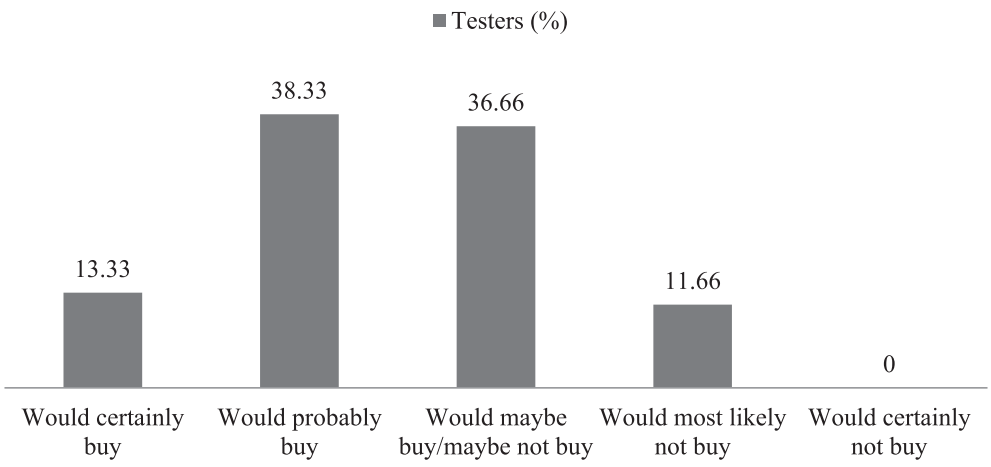

Fig. 2. Purchase intention of the breakfast cereal.

mechanical energy in the extruder; hence, the products becomes denser, and the growth of bubbles is compressed. Expansion and volume are related to the gelatinization of starch caused by heating and the movement of the screw, with consequent generation of friction and shearing inside the extruder jacket Fig. 2.

3.2. Desirability test and validation of the models

The breakfast cereal produced with rice, passion fruit and milk by-products that exhibited the best desirability was obtained with a mixture moisture content of 15 g 100 g^{-1} and a temperature of 85 °C in the third zone of the extruder. The validation tests of the models were performed with the values found in the technological analyses, comparing the expected results with those observed, using two original repetitions and five replicates. The models with R^2 lower than 0.78 were discarded.

3.3. Chemical composition of selected breakfast cereal

The chemical composition and energy value of the selected breakfast cereal were analyzed (Table 2). When present in the formulation, WP increased the moisture content of the product after extrusion, most likely because lactose is capable of retaining water in the product due to its hygroscopic property. The high ash content was caused by the presence of PFPF and WP, which are feed stocks with high ash content, together with the BRG (Santos, Caliari, and Soares Junior, 2015).

The lipid content in the breakfast cereals was low, expressing the lower content of energetic macronutrients. This is an important selection factor for the consumer concerned about health, who prefers products with low lipid contents for the prevention of obesity and corresponding chronic illnesses, such as diabetes and cardiovascular diseases. In comparison to the values found by Silva, Assis, Carvalho, and Simões (2011) in manioc starch and whey powder breakfast cereals (0.7574 g 100 g^{-1}), the lipid contents of the breakfast cereals from this study were higher.

The selected breakfast cereal made with rice, passion fruit and milk by-products can be considered a source of protein (Table 2). The fortification of extruded food formulations with protein from selected sources can improve health and elevate the quality of snacks and breakfast cereals (Day & Swanson, 2013). Fibers are biologically active compounds, and their consumption is of fundamental importance to health. The TDF content of some breakfast cereals were reported by Menezes, Caruso, and Lajolo (2001): "All Bran" breakfast cereal 21.53%; oat, almond and honey breakfast cereal 4.90%; "Corn Flakes" corn breakfast cereal 3.57%; and corn, wheat and oat breakfast cereal 2.15%. The TDF value found in the breakfast cereal produced in this study was high, so it can be considered rich in fiber. In turn, the incorporation of fiber in breakfast cereals can cause texture problems, thus decreasing consumer acceptance. This is due in part to the deterioration of the microstructure, one of the primary quality attributes of extruded breakfast cereals (Chassagne-Berces et al., 2011).

The carbohydrate content and energy value in the produced breakfast cereal were significant (Table 2). When evaluating the effect of the addition of passion fruit flour on the technological properties of organic functional corn flour-based breakfast cereal, Vernaza et al. (2009) found values of 85.37 g 100 g^{-1} of carbohydrates, similar to those obtained in the present study.

Table 2
Chemical composition and energy value of the selected breakfast cereal (extruded with a moisture content of 15 g 100 g^{-1} and a temperature in the third zone of 85 °C).

Component	Breakfast cereal produced with by-products[1]
Moisture[2]	5.38 ± 0.02 (0.31)
Ashes[2]	1.38 ± 0.01 (1.73)
Lipids[2]	0.97 ± 0.02 (3.23)
Protein[2]	7.55 ± 0.07 (1.09)
TDF[2]	6.12 ± 0.01 (0.32)
SDF[2]	2.20 ± 0.01 (0.98)
IDF[2]	3.91 ± 0.01 (0.87)
Carbohydrates[2]	84.72
Energy value[3]	353.33

TDF (total dietary fiber); SDF (soluble dietary fiber); IDF (insoluble dietary fiber).
[1] Mean value with standard deviation and variation coefficient.
[2] g.100 g^{-1}.
[3] kcal.100 g^{-1}.

3.4. Microbiological risk and acceptance of the selected breakfast cereal

The values found in the microbiological analysis of total and thermotolerant coliforms in the studied breakfast cereal were lower than those established by Resolution no. 12 of January 2, 2001 (ANVISA, 2001). The selected breakfast cereal was safe for consumption according to the values obtained in the microbiological analysis, indicating that it was processed according to good manufacturing practices under proper hygienic conditions.

The BRG, PFPF and WP extruded products received means cores for color between "like moderately" and "like it very much". For smell, crunchiness and taste, the results were between "neither like nor dislike" and "like moderately" (Table 3), which is higher than the previously established product acceptance limit (> 4); hence, the results are above the ideal score for the product to achieve the best crunchiness, which is reflected in the value obtained in the sensory test. The

Table 3
Means of scores given by the testers for sensory acceptance of the breakfast cereal.

Attribute	Breakfast Cereal
Color	5.28 ± 1.04
Smell	4.88 ± 1.09
Texture	4.56 ± 1.33
Taste	4.15 ± 1.42

Values represent the mean of 60 testers ± standard deviation.

crunchiness can be improved by the reduction of the moisture content in the breakfast cereal.

It is important to note that the extruded breakfast cereal was not flavored; its sweetness and smell are natural and derive from the WP lactose and its caramelization, respectively. The formation of aromas during this reaction gave the product a caramel scent. In contrast, commercial products are formulated with large amounts of sugar and artificial aromas, the standard known by the judges. Because of child obesity, it is necessary to reduce these ingredients in the formulation of breakfast cereals to help address this important public health problem. Additionally, industries need low-cost options, and the use of WP as a sweetener is a viable alternative for substituting sugar. Moreover, BRG is an important starch source for product expansion, and PFPF is an important source of SDF with functional properties for consumers.

Hough, Buera, Chirife, and Moro (2001) observed that when other attributes please the consumer but the texture or crunchiness does not, the food is immediately rejected. For a product with no crunchiness, not even the proper taste can improve it. The majority of baked or extruded products with a low moisture content, such as breakfast cereals, cookies, wafers and snacks, have a crunchy texture. If the moisture content of these products increases due to the sorption of atmospheric water or mass transport from neighboring components, the result is moistening and soft textures, i.e., the loss of crunchiness (Roudaut, Dacremont, & Mestre, 1998).

According to the purchase intention test 38.33% of the tasters reported that they “would probably buy the product” if it were found on the market, which reinforces the strong acceptance of the studied morning cereal.

4. Conclusion

In conclusion, the extrusion conditions that provided the best physical quality to the agro-industrial by-products WP, PFPF and BRG when used for the production of breakfast cereal (greater expansion, specific volume and better color) were a mixture moisture content of 15 g $100\,g^{-1}$ and an extrusion temperature of 85 °C. The breakfast cereals were rich in TDF, SDF and IDF, but the expansion decreased, and the color darkened. The breakfast cereal produced in the present study can be considered a good alternative to add value to the PFPF and BRG, and for reducing waste, especially in the dairy industry, which currently discards WP, a product with high polluting power. In addition, it is yet another gluten-free product option that can be made available to gluten intolerants, who still have a limited range of products.

Declaration of Competing Interest

The authors have no conflicts of interest to declare.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodchem.2019.124956.

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