Blackberries (*Rubus* sp.) and whole grain wheat flour in cookies: evaluation of phenolic compounds and technological properties

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Revised: 27 January 2019 / Accepted: 31 January 2019 / Published online: 15 February 2019
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Abstract This study evaluated the technological and functional performance of whole grain wheat flour (WGWF), blackberry flour (BF), and blackberry pieces (BP) in cookies, using a Central Rotatable Composite Design ($R^2 > 0.75$, and $p < 0.10$ for model validation). Similar color and fracturability behavior was observed for all cookies with BF and BP, however the phenolic compounds (TPC) and anthocyanins (TAC) levels increased with increasing BF and BP. The formulation selected in the desirability function, containing 7.94% and 4.72% BP and BF, respectively, presented 1553.79 mg GAE/100 g TPC, 63.90 mg CGE/kg TAC. The WGWF and BF can be alternative ingredients to improve color and provide health benefits of cookies.

Keywords Phenolic compounds · Bakery foods · Blackberry · Whole grain wheat flour

Electronic supplementary material The online version of this article (<https://doi.org/10.1007/s13197-019-03628-6>) contains supplementary material, which is available to authorized users.

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Introduction

Several studies have shown the importance of the consumption of whole grain-based baked products, along with ingredients rich in fiber and phenolic compounds. Some authors have studied the addition of blue and red maize flour (Žilić et al. 2016) and baru flour (Pineli et al. 2015) in bakery formulations, and found an increase in the nutritional value of the refined wheat flour-based products such as cookies.

In this sense, the consumption of whole grains, which are recognized as a source of dietary fiber and phenolic compounds, have been stimulated due to their health benefits including the prevention of chronic diseases such as cancer, heart and coronary diseases, type 2 diabetes, metabolic syndrome and also degenerative diseases, such as Parkinson's (Adom et al. 2003; Vitaglione et al. 2008; Anson et al. 2009; Chandrasekara and Shahidi 2012; Abdel-Aal and Rabalski 2013). The successful prevention depends on the concentrations and synergistic interactions of the phenolic compounds present in grains, and to achieve maximum health benefits, these compounds must be ingested from a variety of sources, such as fruits, vegetables, and wholemeal foods (Chandrasekara and Shahidi 2012; Adom and Liu 2002).

Whole grains contain several classes of conjugated phenolic compounds bound to the fibers and aleurone layer, mainly ferulic acids (Adom and Liu 2002; Chandrasekara and Shahidi 2012), while some fruits, as blackberries are rich in anthocyanins, especially cyanidin-3-glycoside, found in free form (Reátegui et al. 2014). Therefore, the combination of these ingredients can improve the health benefits of food products.

Brazil is one of the most important fruit producers with an annual production around 43,000 tons of tropical fruits

(Treichel 2016). However, the tropical fruits have a high moisture content, which along with the high environmental temperatures and relative humidity, can lead to post-harvest losses of approximately 30% (Marques et al. 2009). Thus, the improvement of the shelf-life of tropical fruits can be achieved by the dehydration process, and freeze-drying is considered the most effective method for the preservation of bioactive compounds (Marques et al. 2009).

Blackberries stand out from the wide variety of Brazilian fruits, which have been used in juices, ice cream, jams, pulps, and nutraceutical products, due to their anthocyanins levels, which are correlated with the nutritional quality, antioxidant properties, and sensory attributes for the red-pink color (Tiwari et al. 2009). During processing, peel and seeds rich in bioactive compounds are removed, resulting in a loss of approximately 20% bioactive compounds (Reátegui et al. 2014), thus the full use of blackberries may be advantageous to reduce the processing losses.

The combination of whole grain wheat flour (WGWF) and blackberry in bakery formulations can provide combined effects of dietary fiber, phenolic compounds, and other bioactive compounds. Thus, this study evaluated the performance of the partial replacement of refined wheat flour (RWF) by WGWF, and the addition of whole blackberry flour (BF) and blackberry pieces (BP) on the phenolic compounds levels and technological properties of cookies.

Materials and methods

Raw materials

The following ingredients were used to produce the cookies: wheat grain and RWF donated by the Sul Mineiro S/A mill (Varginha, BRA), palm oil donated by Cargill (São Paulo, BRA), and blackberries *in natura* were purchased from CEAGESP-SP. Sugar, salt, soy lecithin, milk powder, diacetyl tartaric acid ester of mono- and diglycerides (DATEM), baking powder, ammonia bicarbonate and spice mix (ground cinnamon, clove, and nutmeg) were acquired in the local market.

Obtaining the WGWF

In order to improve the grinding efficiency, wheat was conditioned to a moisture level of 15% at 5 °C for 24 h, and the grains were milled in a roller mill (Brabender Quadrumat Senior) passing through the breaking and reduction systems, according to Silva et al. (2016), without passing through the sieve set. The flour was packed in low-density polyethylene bags and stored at 5 °C until analysis.

Obtaining the blackberry flour (BF)

Blackberries were selected considering the ripeness stage, color (intense purple), and structural integrity (absence of injuries), sanitized, freeze-dried (Liotop LP820, BRA) for 48 h, packed (200B Selovac, São Paulo, BRA) under vacuum (93.325.66 N/m²) in low-density polyethylene bags, and frozen at − 18 °C until milling, which was carried out in a knife mill (TE 020 Tecnal, Piracicaba, BRA).

Instrumental color measurements of blackberry flour

Color measurements were carried out in a Mini Scan XE 45/0-L spectrophotometer (HunterLab, Reston, USA), previously calibrated, with illuminant D65, observer angle 10°, in RSIN and CIELab color system (Hunterlab 1998).

Cookies

Control cookie was elaborated according to the formulation reported by Brito et al. (2011), with some modifications: refined wheat flour (139.8 g), whole wheat flour (145.5 g), fat (114.1 g), sugar (141.28 g), salt (4.6 g), corn starch (1.71 g), soy lecithin (1.7 g), milk powder (1.1 g), DATEM (1.1 g), baking powder (4.0 g), ammonia bicarbonate (2.3 g), water (55.0 g), and spice mix (ground cinnamon, ground clove, and ground nutmeg) (0.5 g).

The mixing process was carried out in two phases with the formation of cream, as follows: fat, DATEM and soy lecithin were homogenized for 60 s in a planetary mixer (Kitchen aid, Max Watts 325), at medium speed (144 RPM), with a beater racket type. Sugar was added and homogenized for 3 min at medium speed and then half of water was added under stirring for 1 min. The other ingredients (wheat flour, salt, corn starch, milk powder, baking powder, ammonia bicarbonate, and spice mix) were added, homogenized for 1.5 min at low speed (96 RPM), followed by the addition of the remaining water. The dough was rolled 8 mm thick, and the cookies were baked in a preheated oven at 180 °C top temperature and 160 °C hearth temperature for 12 min.

Experimental design

To evaluate the combined effect of the independent variables WGWF in replacement for RWF, and the addition of BP and BF, a central rotatable composite design was used (Table 1). The independent variables ranged between 14 and 88% for RWF, 0 and 10% for BP and 0 and 5% for BF, respectively for $-\alpha$ (− 1.68) and $+\alpha$ (1.68). The dependent variables were the technological characteristics

Table 1 Central composite rotatable design and parameter results (instrumental color, fracturability, total phenolic compounds (TPC), total anthocyanins content (TAC) and total dietary fibers (TDF)) for cookies with whole grain wheat flour (WGWF), blackberries pieces (BP) and blackberry flour (BF)

Cookie	Coded values			Real values							Moisture (%)	A _w	
	x1	x2	x3	X1 WGWF:RWF (%)	X2 BP (%)	X3 BF (%)	Fracturability ^b		TPC ^c (mgGAE/100 g)	TAC ^d (mgCGE/Kg)			TDF ^e (g/100 g)
							(N)	(g/100 g)					
Cookie	Instrumental color												
	L*	a*	b*	ΔE ^a									
1	48.15 ± 1.92	11.70 ± 0.27	28.45 ± 0.27	12.48	74.72 ± 4.93	928.63 ± 0.02	29.02 ± 0.64	928.63 ± 0.02	29.02 ± 0.64	6.42	6.42		
2	48.48 ± 1.15	9.88 ± 0.19	25.61 ± 0.08	13.05	79.66 ± 9.09	871.96 ± 0.01	16.59 ± 0.55	871.96 ± 0.01	16.59 ± 0.55	10.54	10.54		
3	47.85 ± 2.27	9.35 ± 0.63	24.21 ± 1.98	14.29	94.22 ± 3.15	826.47 ± 0.00	47.06 ± 0.94	826.47 ± 0.00	47.06 ± 0.94	9.18	9.18		
4	43.02 ± 0.89	10.07 ± 0.27	22.58 ± 0.38	19.28	78.30 ± 7.95	1596.86 ± 0.01	45.98 ± 1.24	1596.86 ± 0.01	45.98 ± 1.24	13.01	13.01		
5	44.08 ± 0.61	11.24 ± 0.12	22.89 ± 0.21	18.21	114.97 ± 12.10	1491.67 ± 0.02	35.90 ± 0.82	1491.67 ± 0.02	35.90 ± 0.82	7.94	7.94		
6	41.80 ± 0.71	11.51 ± 0.14	23.31 ± 0.19	20.10	75.83 ± 11.30	1542.84 ± 0.01	34.46 ± 1.22	1542.84 ± 0.01	34.46 ± 1.22	11.75	11.75		
7	39.38 ± 0.51	10.60 ± 0.22	21.02 ± 0.74	23.23	87.87 ± 10.38	1635.59 ± 0.01	68.78 ± 1.57	1635.59 ± 0.01	68.78 ± 1.57	10.41	10.41		
8	44.53 ± 1.50	9.66 ± 0.17	19.81 ± 0.58	19.45	174.96 ± 14.59	1555.20 ± 0.01	43.54 ± 0.59	1555.20 ± 0.01	43.54 ± 0.59	14.40	14.40		
9	45.97 ± 1.66	9.81 ± 0.53	22.35 ± 1.29	16.82	91.26 ± 7.24	982.45 ± 0.00	41.88 ± 1.28	982.45 ± 0.00	41.88 ± 1.28	7.18	7.18		
10	43.76 ± 0.60	10.40 ± 0.35	23.05 ± 0.45	18.41	103.68 ± 7.87	1155.39 ± 0.01	32.18 ± 0.91	1155.39 ± 0.01	32.18 ± 0.91	14.00	14.00		
11	46.82 ± 0.45	11.00 ± 0.11	24.60 ± 0.26	14.99	83.15 ± 3.29	876.18 ± 0.01	19.13 ± 0.14	876.18 ± 0.01	19.13 ± 0.14	8.30	8.30		

Table 1 continued

Cookie	Instrumental color			Fracturability ^b (N)	TPC ^c (mgGAE/100 g)	TAC ^d (mgCGE/Kg)	TDF ^e (g/100 g)
	L*	a*	b*				
12	45.46 ± 0.82	10.27 ± 0.13	22.97 ± 0.29	119.59 ± 13.32	1266.08 ± 0.00	13.35 ± 0.49	11.80
13	47.87 ± 1.61	11.03 ± 0.77	27.46 ± 0.98	63.54 ± 3.76	994.61 ± 0.01	23.12 ± 0.92	9.40
14	40.05 ± 0.47	11.56 ± 0.11	22.04 ± 0.04	144.69 ± 13.62	1511.57 ± 0.02	72.13 ± 0.06	11.65
15	42.54 ± 0.89	10.70 ± 0.29	23.00 ± 0.50	84.31 ± 6.26	1192.55 ± 0.00	31.64 ± 0.30	10.45
16	41.98 ± 1.48	10.63 ± 0.05	22.24 ± 0.32	87.04 ± 4.19	1132.75 ± 0.00	31.71 ± 0.30	10.47
17	46.44 ± 0.16	9.53 ± 0.25	21.74 ± 0.56	82.21 ± 12.46	1072.84 ± 0.00	32.53 ± 0.13	10.54
18	46.30 ± 0.81	9.78 ± 0.09	22.54 ± 0.26	83.14 ± 4.95	1026.08 ± 0.01	32.22 ± 0.21	10.46
R ²	0.7063	0.5781	0.8418	0.7144	0.7753	0.8198	–
p value	0.149	0.396	< 0.001	0.014	0.004	< 0.001	–
Control	60.26 ± 0.80	10.49 ± 0.22	31.21 ± 0.18	29.83 ± 2.42	869.41 ± 0.02	2.22 ± 0.01	2.21

Values are means ± standard deviations of three replicates experiments

^aΔE: total color difference using control as standard. ^bN: Newton. ^cGAE: Gallic acid equivalent. ^dCGE: Cyanidin-3-glucoside equivalent. ^eTDF of cookies was calculated according to the fiber content of the whole grain wheat flour, blackberry pieces, and blackberry flour

and the phenolics compounds (TPC) and total anthocyanins (TAC).

Technological characterization of cookies

Moisture

According to the methodology 44-15.02 of American Association of Cereal Chemists International (AACCI) (2011).

A_w

Performed with the AquaLab apparatus CX-2 (Decagon, Pullman, USA), according to the manufacturer's instructions.

Instrumental color

Measured as described for blackberry flour. The total color difference (ΔE) between the control and the cookies containing whole grain wheat flour and blackberries was calculated as:

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

Fracturability

Determined in a TA.XT2i texture analyzer (Stable Micro Systems, Haslemere, GBR) according to methodology 74-09.01 of AACCI (2011).

Bioactive compounds characterization of cookies

Total phenolics compounds (TPC)

Determined by Folin Ciocalteu method (Roesler et al. 2007).

Total anthocyanins content (TAC)

Determined according to Abdel-Aal and Huck (1999).

Total dietary fiber (TDF)

Determined with the Megazyme® TDF Assay kit (K-TDFR 06/14) according to the methodologies 32-05.01 (AACCI 2011) and 985.29 (AOAC 2006) for RWF, WGWF and for blackberry. The TDF content in cookies was calculated according to the fiber content of this raw material.

Statistical analysis and optimal condition to make cookies with blackberry

Data obtained in the experimental design were analyzed by Response Surface Methodology, using the Statistical Program 5.0 (StatSoft, Inc., Tulsa, OK, USA). The analysis of variance (ANOVA) was used, considering the responses with $R^2 > 0.75$, and $p < 0.10$. The choice of the optimal point was performed according to Derringer and Suich (1980), maximizing the independent variables BF and BP, and the dependent variables b^* , TPC, and TAC, and choosing a target value for fracturability (> 100 N). Desirability values above 0.6 were accepted.

Results and discussion

Characterization of blackberry and wheat flour

As can be seen in Supplementary material, BF exhibited dark purple-red color, with L^* , a^* and b^* values of 30.47 ± 1.14 ; 28.57 ± 0.19 ; and 8.69 ± 0.36 , respectively. Similar values were found by Hirsch et al. (2012) in several blackberry varieties, which ranged from 28 to 31; 9 to 31; and 4 to 11 for the L^* , a^* , and b^* color parameters, respectively. This color is related to the presence of anthocyanins, which play an important protective role against oxidative stress (Stintzing and Carle, 2004).

Regarding to total dietary fiber, the mean values for refined, whole grain and blackberry flour were 2.59 ± 0.13 , 13.03 ± 0.26 and 56.24 ± 2.14 g/100 g, on a dry basis, respectively, which is in accordance with the USDA Table (2015).

Technological characterization of cookies

The results of the technological characterization of cookies containing whole grain wheat flour and blackberries and the control sample are shown in Table 1, with their respective R^2 and p values.

The moisture and A_w values were not affected by the independent variables within the range studied, with mean values of 1.52 ± 0.71 and 0.38 ± 0.04 g/100 g, respectively (Table 1). A_w was lower than 0.6, which is the desired limit to maintain the crispness of cookies, according to Jardim (2010).

With respect to instrumental color, at the concentrations studied, the blends containing WGWF, BP, and BF did not significantly interfere with the L^* and a^* color parameter of cookies, but affected the more purplish tones (lower b^* values) with the increase in blackberries concentrations (Fig. 1a and Table 2). Similar behavior was observed by Singh et al. (2015) with increase in level of black carrot fiber incorporation in eggless gluten-free rice muffins.

In order to better understand the effect of the addition of blackberry flour on cookies, ΔE were calculated.

Fig. 1 Response surface for the color b^* as a function of the addition of blackberry pieces (BP) and blackberry flour (BF) and response surfaces for the Delta E as a function of the addition of whole grain wheat flour (WGWF), blackberry pieces (BP), and blackberry flour (BF)

Table 2 Mathematical models of the statistically significant ($p < 0.10$) dependent variables for the addition of whole grain wheat flour (WGWF), blackberries pieces (BP) and blackberry flour (BF) for obtaining cookies

Dependent variables	Mathematical model	Fcal/Ftab
b^*	$22.43 - 1.13x_2 - 1.68x_3 + 0.42x_2^2 + 0.76x_3^2$	7.12
ΔE^a	$18.03 + 1.15x_2 + 2.74x_3 - 0.66x_2^2 - 0.93x_1x_3$	5.35
TPC ^b (mgGAE/100 g)	$11.42 + 0.71x_1 + 1.05x_2 + 2.10x_3 + 0.81x_3^2 + 0.87x_1x_2 - 0.93x_1x_3$	2.65
TAC ^c (mgCGE/Kg)	$33.31 - 4.03x_1 + 9.07x_2 + 9.37x_3 + 5.74x_3^2$	6.08

^a ΔE : total color difference using control as standard. ^bTPC: total phenolics content (gallic acid equivalent). ^cTAC: total anthocyanins content (cyanidin-3-glucoside equivalent)

According to Tiwari et al. (2008), $\Delta E > 3$ indicates color differences which can be observed by the naked eye. The cookies of the present study had $\Delta E > 12$ in comparison with the control, thus the increase in blackberries in both forms made the cookies with a darker red-purplish color, as observed in Fig. 1b–d. Aksoylu et al. (2015) evaluated the effects of blueberry, grape seed powder and poppy seed incorporation in cookies. Although the ΔE was not calculated, a decrease in L^* , which can be attributed to the promotion of nonenzymatic browning reactions during baking and also to the presence of dark color arising from natural pigments from fortification agents, such as anthocyanins.

It is worth emphasizing an increasing demand for color-enhancing ingredients in substitution of synthetic dyes, and in this context, anthocyanins, chlorophylls, carotenoids, and betalains can play an important role as antioxidants, besides conferring color to the products (Stintzing and Carle 2004).

The fracturability was not significant, with values ranging from 64 N to 175 N (Table 1). When compared to the control samples, higher values were observed for all trials, probably because the increase in BF concentrations led to a more homogeneous and compact structure of the cookies due to their smaller particles, requiring a greater break force. Kaur et al. (2017) also observed an increase of fracturability with increasing amount of flaxseed flour in cookies, since the increase in fiber concentration interferes with the rheological properties of the dough.

Bioactive compounds characterization of cookies

Table 2 shows that the total phenolic compounds levels of the cookies were significantly affected by the three independent variables ($R^2 = 0.7753$, $F_{cal} > F_{tab}$ and $p < 0.01$), with a greater effect of BF when compared to the variables BP and WGWF (Fig. 2b, c). TPC levels ranged from 826 to 1636 mg GAE/100 g (Table 1)

Fig. 2 Response surfaces for the total phenolic compounds as a function of the addition of whole grain wheat flour (WGWF), blackberry pieces (BP), and blackberry flour (BF) and response

surfaces for the total anthocyanins content as a function of the addition of whole grain wheat flour (WGWF), blackberry pieces (BP), and blackberry flour (BF)

indicating the great contribution of BF, once the higher the BF addition, the higher the TPC, as can be seen in Fig. 2b, c. Our results were higher than those found by Pineli et al. (2015) in cookies containing baru flour, which is rich in phenolic compounds (86.16 ± 0.43 mg GAE/100 g). As reported by Adom and Liu (2002), the major portion of phenolic compounds in wheat are in the conjugated form (75%), which should be hydrolyzed for the analysis. This step was not performed in this study, which aimed to evaluate the phenolic compounds in the free form, found in the blackberry or released during baking of the WGWF-based cookies.

Abdel-Aal and Rabalski (2013) also studied the phenolic compounds of WGWF, and evaluated the changes in the profile of free and conjugated phenolic acids of whole-grain breads, cookies, and muffins during baking. They found a reduction of up to 36.2% in the conjugated form, and up to 17.1-fold increase in free ferulic acids, probably due to the high temperature used in the process. Another study showed that the chia flour addition had a positive impact on the TPC levels whole wheat based bread. The increase was proportional to the chia addition and this result was attributed to the presence of chlorogenic and caffeic acids, myricetin, quercetin, and kaempferol (Sayed-Ahmad et al., 2018).

The total anthocyanins content ranged from 16.59 ± 0.55 to 72.13 ± 0.06 mg CGE/kg (Table 1) and increased significantly ($p < 0.10$) with the addition of BF and BP (Fig. 2d–f). On the other hand, the increase in WGWF concentration had a negative impact on this response, as shown in Fig. 2. According to ANOVA, the R^2 value was 0.8198, $F_{cal} > F_{tab}$ and a p value < 0.01 . Table 2 presents a second-order mathematical model. Similar values were found by Žilić et al. (2016) in cookies made with blue and dark-red corn flour cooked at 200 °C for 10 min (from 45.7 ± 1.3 to 93.3 ± 0.1 mg CGE/kg). However, when 0.2 g/100 g citric acid was added to the formulations and the oven temperature was reduced, values up to six times higher than the values of the present study were observed even increasing the exposure time (150 °C/12 min) (461.5 ± 6.5 mg CGE/kg). According to those authors, citric acid affects the TAC either by reducing the pH of the system or by acylation the sugar residues or flavil cation.

As reported by Stintzing and Carle (2004), there is a high correlation between the anthocyanins content and the antioxidant capacity of the vegetables, which was also observed in the present study, since the formulations 14 and 7 containing the highest TAC levels presented low b^* and high a^* values (Table 1).

Regarding to increase of dietary fiber, Table 1 show that among the 18 formulations of this study, 12 presented total dietary fiber above 3.0 g/30 g portion, thus these cookies

can be considered fiber sources according to U.S. Food and Drug Administration (FDA 2017). The control cookie presented lower fiber contents (0.66/30 g). The addition of whole wheat flour and grape pomace (skin and partially defatted seeds) was also responsible for the increase in total fiber content in cookies (Karnopp et al. 2015). In addition, corroborating with our results, an A_w values lower than 0.6 were observed, which can be explained by the ability of the fibers to bind to the free water.

When correlating fiber values with TPC levels, the BF-based cookies presented similar results to biscuits supplemented with inulin in combination with soybean, amaranth, carob, or apple and oat fibers studied by Vitali et al. (2009), who also found an increase in the antioxidant activity of the cookies with increasing the fiber content.

Validation

The replacement of 51% RWF by WGWF (0.00) and the addition of 7.94% BP (0.98) and 4.72% BF (1.49) was considered the optimal point according to the desirability function (desirability of 0.62), conferring cookies with higher nutritional value and functional properties provided by fibers and phenolic compounds, including anthocyanins, besides the higher BF levels, which provided a better coloring to the cookies, making them more attractive.

This formulation was used for the validation of the model (in triplicate). A control formulation was also made, and the TPC and TAC levels in the dough and cookies were analyzed to evaluate the effect of thermal processing on these compounds.

The values of b^* , ΔE , phenolics compounds and anthocianins obtained by the experimental validation are presented in Table 3, which are very close to the values predicted by the desirability function, with a low relative error ($p < 10\%$). Therefore, the mathematical models were capable of predicting the effects of each independent variable (within the range studied) on the analyzed responses.

With respect to the effect of thermal processing on the phenolic compounds, the baking process increased the TPC content by 196.75% (from 789.71 ± 0.50 to 1553.79 ± 0.64 mg GAE/100 g) in cookies. Similar results were observed by Žilić et al. (2016) in dark-red corn flour, who attributed this increase to more solubility of bounded phenolic acids after baking.

Several mechanisms occurring during thermal processing have been suggested, resulting in an increase in the free phenolic acids, including the release of bound phenolic compounds in the food matrix, phenolic polymerization, and oxidation, thermal degradation, depolymerization of high molecular weight phenolics or even the formation of intermediates during the Maillard reaction. Although these

Table 3 Experimental validation according to the optimized conditions predicted by the desirability test of cookies containing whole grain wheat flour (WGWF), blackberries pieces (BP) and blackberry flour (BF)

Independent variable	Optimum value Coded value/real value	Dependent variable	Observed value	Predict value	RE % ^a
WGWF (X1)	0.00 (145.50 g)	<i>b</i> *	19.36 ± 1.49	21.23	− 8.85
BP (X2)	0.98 (22.65 g)	ΔE	22.54 ± 1.06	23.23	− 2.98
BF (X3)	1.49 (13.46 g)	TPC (mgGAE/100 g) ^b	1553.79 ± 0.64	1619.31	− 4.22
		TAC (mgCGE/Kg) ^c	63.90 ± 2.32	60.45	5.70

Values are means ± standard deviations of three replicates experiments

^aRE: Relative error. ^bTPC: total phenolic compounds (gallic acid equivalent). ^cTAC: total anthocyanins content (cyanidin-3-glucoside equivalent)

changes are complex and dependent on many factors, the baking process can be considered a good way of improving the bioavailability of phenolic acids in whole grain-based products (Abdel-Aal and Rabalski 2013).

With respect to the anthocyanins levels, a retention of 27.87% was observed in the heat-treated cookies. According to Damodaran et al. (2007), anthocyanins can be degraded by various mechanisms that lead to the formation of dark and insoluble compounds, with temperature and pH being the most important factors. This may explain the lower values for the parameter *b** found in the color analysis.

Thus, further studies about the increased retention of these compounds in products subjected to high baking temperatures are required, and the use of extracts containing anthocyanins may be a promising alternative, as evaluated by Chávez-Santoscoy et al. (2016), who observed a high retention capacity of anthocyanins when using black bean bark extract in cookies formulations.

Conclusion

The results showed that wheat and blackberry in its whole form can be an effective alternative to obtaining cookies with functional potential, by increasing fiber and phenolic compounds, with health benefits. The TPC and TAC content increased 80% and 2778%, respectively, and dietary fiber was 830% higher, when compared to control cookies. In this way, blackberry has the potential for the industrialization and commercialization of higher value-added products, such as bakery foods. The CCRD and desirability tools were essential and allowed to elaborate cookies with healthier characteristics and adequate technological properties.

Acknowledgements This work was supported by the CNPq (Grant number 148510/2013-2) and CAPES. The authors thank Moinho Sul Mineiro and Cargill for the donation of wheat grain and refined wheat flour and palm oil, respectively.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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