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ORIGINAL ARTICLE

Production of oven-baked wheat chips enriched with red lentil: an optimization study by response surface methodology

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Abstract Chips are the most common snacks in human diet and generally are produced by frying. However, due to their high carbohydrate, fat and salt content, they are considered as unhealthy snacks. In this study, it is aimed to develop red lentil enriched chips for use as a healthy and nutritious snack food. Due to the health concerns about high fat content of the fried chips, the samples were oven-baked instead of frying. Response surface methodology was used to investigate the effect of process parameters (red lentil flour ratio, baking temperature and time) on physicochemical, textural, nutritional, and bioactive properties of the chips. The samples were also evaluated in terms of taste, odor, crispness, and general acceptance by the panelists. The highest antioxidant capacity, total phenolic content and hydroxymethyl furfural content was achived with the sample supplememented with 50% red lentil flour and baked at the highest temperature and time used in the study (190 °C, 9 min). Red lentil flour supplementation increased protein and resistant starch content of the chips. The highest resistant starch content of the samples and lowest in vitro glycemic index value were achieved with the sample prepared with 50% red lentil flour supplementation. These results of this study proved that red lentil is a good source to be used for enrichment of oven-baked wheat chips as a novel snack food with high nutritional values and low in vitro glycemic index.

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Introduction

Snacks can be defined as a small portion of food consumed between regular meals and have become an important part of the daily diet of the world's population (Thakur and Saxena 2000; Njike et al. 2016). Chips are the most common snacks consumed by people of all age groups (Thakur and Saxena 2000). However, due to the high carbohydrate, fat and salt content, they are considered as unhealthy snacks. There are several studies considering the negative consequences of energy dense and low nutrient food consumption on the health including overweight, obesity, diatebetes, and nutrient deficiencies (Maetens et al. 2017; WHO 2016). According to the World Health Organization (WHO), obesity prevelanace is dramatically rising and obesity is categorized as a global health epidemic. In 2016, more than 1.9 billion adults aged 18 years and older (39% of adults) were overweight, 41 million children under the age of 5 years were overweight or obese (WHO 2018). Due to increase in the prevalence of obesity, cardiovascular and other lifestyle related diseases, awareness of the consumers about their food choices has changed and there is a demand for developing healthy and nutritional snacks as well as foods. Legumes are important sources of diet providing energy, dietary fibre, protein, minerals and vitamins required for human health (Boye et al. 2010; Hall et al. 2017; Sozer et al. 2017; Rathod et al. 2017; Sattar et al. 2017; Portman et al. 2018, 2019). Several materials were studied to enhance the functional properties of chips; grape seed extract (Rababah et al. 2011), flaxseed flour (Yuksel et al. 2014), sorghum flour (Kaplan et al. 2020), and yellow

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corn, soybean flour, soy protein isolate (Jiang et al. 2019). Kaplan et al. (2020) performed in vitro gylcemic index and bioactive properties of deep-fried sorghum-based gluten free chips. The authors found that the addition of sorghum flour positively affected the bioactive properties and negatively affected the glycemic index of chips. In another study, Kılınççeker et al. (2015) investigated the physicochemical and sensory properties of chicken meatballs produced using yellow lentil flour and chickpea flour.

Red lentil is a leguminous crop that is an excellent source of protein, carbohydrate, fiber, minerals, and nutrient (Dogan et al. 2013) and can be a potential ingredient for the development of snacks with specified functional properties. There are some studies investigating the effect of lentil flour addition on the quality of snacks (Dogan et al. 2013; Chan et al. 2019). However, to the best of our knowledge, there is no study on the effect of process parameters on the quality of red lentil enriched wheat chips. Teterycz et al. (2020) produced pasta using red lentil flour and pea flour. They reported that the pasta containing red lentil flour had the highest protein and dietary fibre content among the samples.

The objective of this study is to develop healthy and nutritious wheat chips enriched with red lentil. Due to the health concerns about high fat content of the common chips, the chips samples were oven-baked instead of frying. The effect of process parameters on physicochemical, textural, nutritional, and bioactive properties of the chips were investigated. Response surface methodology was used to determine the optimum processing parameters (red lentil flour ratio, baking temperature and baking time) to obtain the highest phenolic content, antioxidant capacity and resistant starch content with a low HMF content. Sensory analyzes of the samples in terms of taste, odor, crispness, and general acceptance were also carried out.

The physical and chemical properties that may occur during the storage of chips which may adversely affect the acceptability of the chips by the consumer. To evaluate the changes during storage, chips sample produced using the optimum processing parameters were also subjected to stability test and ash, colour, total phenolic content, antioxidant capacity, HMF content, and texture of the sample were investigated.

Materials and methods

Materials

Corn flour, wheat flour samples, red lentil, onion, garlic powder, salt, and cumin were purchased from a national market in Kayseri, Turkey. All chemicals were analytical reagent grade, unless otherwise specified.

Production of red lentil flour and chips

For the preperation of red lentil flour, lentil samples (100 g) were mixed with 300 mL of water and boiled for 15 min and dried at 100 °C for 5 h. After drying, lentil samples were ground and sieved to pass 212 µm. A "base flour" was prepared by mixing wheat flour (80%), corn flour (20%), onion powder (2%), garlic powder (2%), cumin (2%), and salt (2%). Red lentil flour and water (water content of all the dough was fixed at 60%) was added to this mixture (base flour) for the preparation of the chips dough. The mixture (red lentil flour + base flour + water) was kneaded in a kneading machine (Kitchen Aid, Professional 600 MI, USA) and wrapped with stretch film and allowed to rest at room temperature for half an hour. The dough was sheeted using a dough sheeter (Rondo, Dog SS0615, Switzerland) to obtain a 1.0 mm thickness. The chips were cut in 5 cm diameter and baked in an oven (Simfer, M-4257, Turkey). The experimental design was generated with response surface methodology (RSM) using Design Expert Program (Stat-Ease, USA). Red lentil flour concentration, baking time and temperature were selected as the independed variables. Three levels for each factor were selected and red lentil ratio was varied from 0 to 50% at a base flour mixture, baking temperature was varied from 170 to 180 °C and baking time was varied from 6 to 9 min. Chips samples were ground to pass 212 µm for the analysis except for texture and sensory analysis.

Proximate analysis of the samples

Moisture, protein, and ash content of the flour and chips samples were determined according to the approved methods of AACCI 44-15A, 46-11A, and 08–01, respectively (AACC International, 2009).

Colour properties

Colour of the flour and chips samples were determined using Konica Minolta (Chroma Meter CR-5, Japan) colour determination device. Samples were placed to the device and L^*, a^* and b^* values were determined. The L^* value gives information on lightness and darkness of the sample. + a^* values are red intensity, − a^* values show the green intensity; + b^* values are yellow intensity, − b^* values show the blue intensity of the samples.

Determination of resistant starch content

Resistant starch (RS) of the flour and chips samples were determined using the Megazyme Resistant Starch Kit (Megazyme Int., Ireland) according to the approved

method of AACCI 32–40 (AACC International. 2009). In brief, samples were incubated with α-amylase and amyloglucosidase (16 h, 37 °C) to digest non RS. The RS is recovered by centrifugation and then dissolved in KOH and hydrolyzed to glucose with amyloglucosidase. Glucose is measured with GOPOD reagent by spectrophotometer (Shimadzu UV-1800, Japan).

Determination of in vitro *glycemic index value*

The samples were digested according to the method described previously (Englyst et al. 1992). For this purpose samples (100 mg) were weighed into 50 mL tubes with 10 glass beads (5 mm diameter) added to each tube. Two milliliters of 0.05 M hydrochloric acid (HCl) and 10 mg of pepsin (Sigma, P7000) were added, and the tubes were incubated at 37 °C in a shaking water bath for 30 min. Then, 4 mL of sodium acetate buffer (0.5 M, pH 5.2) was added to each tube. One milliliter of freshly prepared enzyme solution containing 0.104 g pancreatin (Sigma-Aldrich, P7545) and 14.45 U amyloglucosidase (3300 U/mL, Megazyme Int., Ireland) was added and the tubes were incubated vertically at 37 °C in a shaking water bath. Aliquots (100 µL) were taken at 0, 10, 20, 30, 60, 90, 120, and 180 min intervals and mixed with 1 mL of absolute ethanol. These solutions were centrifuged at 800 g for 10 min, and glucose content of the supernatant was measured with glucose oxidase–peroxidase (GOPOD) reagent (Megazyme Int., Ireland) by using spectrophotometer (Shimadzu 1601, Japan) at 510 nm wavelength. Total starch hydrolysis (%) in the samples was calculated as follows;

$$\text{Total Hydrolysis (\%)} = \left[\frac{\left(\text{Released Glucose Weight} \times \frac{160}{182}\right)}{\text{Total Starch Weight}}\right] \times 100$$

Several researchers showed a high correlation between the rate of starch digestion and the glycaemic response by various in vitro digestion methods that imitate the in vivo methods (Granfeldt et al. 1994; Englyst et al. 1996, 2003; Goñi et al. 1997; Regand et al. 2011). The in vitro glycemic index is also called as "Estimated Glycemic Index".

Goni et al. (1997) stated that the kinetics of in vitro digestion is followed by a nonlinear model with a first order equation of $C = C_\infty\left(1 - e^{-kt}\right)$, where C_∞ is the percentage of starch hydrolyzed at time t (min), C_∞ is the equilibrium percentage of starch hydrolyzed after 180 min, and k is the kinetic constant. Total starch hydrolysis (%) values of the samples were plotted against time (min) and the area under the curve was calculated using Microsoft Excel. Hydrolysis index (HI) represents the rate of starch digestion in the samples in relation to the digestibility of starch in a reference material, white bread (75.4% starch content). The HI was calculated as follows;

$$HI = \frac{\textit{Area under the curve of the sample}}{\textit{Area under the curve of reference sample (white bread)}}$$

The in vitro GI was calculated by using the equation of Goni et al. (1997);

$$GI = 39.71 + 0.549 \times HI$$

Determination of total phenolic content and antioxidant capacity

Total phenolic content of the flour and chips samples were measured using the Folin-Ciocalteu method described by Spanos and Wrolstad (1990). Prior to the analysis sample extract was prepared by mixing 2 g of sample and 80% of methanol at appropriate concentrations. The samples were mixed for 1 h in a shaker and then centrifuged at 11,200 g for 5 min. Sample extract (200 µL) was mixed with 1.5 mL of Folin-Ciocalteu solution (0.2 N) and stood for 5 min. At the end of the incubation, 4 mL of sodium carbonate solution (75 g/L) was added to the tubes and the tubes were incubated in dark at room temperature for 2 h. The absorbance of the solution was determined at 765 nm (Shimadzu UV-1800, Japan). Gallic acid (Merck, Germany) was used as calibration reference standard (0–1 mg gallic acid/mL methanol). The results were expressed as mg gallic acid per 100 g of sample.

Antioxidant capacity of the samples was determined using DPPH radical scavenging method (Anton et al. 2009). Sample extract (200 µL) was mixed with 2 mL of 80% methanol and 2.5 mL of DPPH (1, 1-diphenyl-2-picrylhydrazyl) solution (0.1 mM in methanol) and incubated in dark for 30 min The absorbance value of the samples was measured at 517 nm (Shimadzu UV-1800, Japan) at the end of the incubation. Trolox (Sigma-Aldrich, USA) was used as the reference standard (0.1–0.5 mM in 60% methanol) and the results were expressed as milimol Trolox equivalent per 100 g of sample.

Determination of hydroxymethyl furfural by HPLC

Hydroxymethyl furfural (HMF) analysis was carried out using HPLC. Chips samples (1 g) were mixed with 10 mL of distilled water and homogenized using ultrasonic water bath. The samples were centrifuged at 9,000 g for 10 min and 1.5 mL of the supernatant was taken to an ependorf tube. Carez I (1.5 mL) and Carez II (1.5 mL) solutions were added, and the sample was centrifuged at 17,500 g for 10 min. The remaining clear fraction was passed through

the 0.45 μm filter and transferred to the vials. A C18 column (4.6 × 250 mm) filled with octadecylsilane modified silicate was used. The injection volume was 20 μL and ultrapure water and acetonitrile (95:5) containing 1% acetic acid were used as mobile phase (1 mL/min). Column temperature was kept constant at 25 °C. Chromotograms were determined at 284 nm at Diode Array Detector (DAD). HMF standards (2.5–20 ppm) were used to prepare the calibration curve.

Texture and sensory analysis

The hardness values of the chips samples were determined using the Texture Analyzer (TA.XT Plus, Stable Micro System Ltd., UK) and the Kramer 5-blade shear probe (HDP/KS-5). A load cell of 30 kg was used. One piece of chips was placed vertically on the bottom side of the Kramer shear probe and the probe was lowered onto the sample at a speed of 5 cm/min. The maximum force required to break the chip was obtained from deformation curve (Bozkurt and Bayram 2006). Sensory analyzes of the chips samples were carried out by a group of 10 panelists. Samples were evaluated in terms of taste, odor, crispness (by hand) and general acceptance.

Statistical analysis and optimization

All experiments were performed in duplicate and mean values were recorded. Standard deviations were calculated and stated in Tables 2, 3. The effect of the independent variables (red lentil flour concentration, baking time and temperature) on the physicochemical, textural, nutritional, and bioactive properties of the chip samples were determined by regression equations created by Design Expert (Stat-Ease, Minneapolis, MN, USA). In order to describe the relationship between the independent variables (red lentil flour ratio, baking temperature and time) and dependent variables (quality properties), the response values were fitted by second order polynomial (quadratic) regression models. Response surface methodology (RSM) was used to optimise the chips preperation conditions (red lentil ratio, baking time and temperature). The regression equations were solved using the software to find the optimal red lentil ratio, baking time and temperature to achive high antioxidant capacity, high protein, total phenolics and resistant starch contents, while hydroxymethyl furfural content was minimum. The correlation coefficients were calculated between the sensory properties (taste, odor, crispness, general acceptance) and the physicochemical, textural, nutritional, and bioactive properties of the chips.

Determination of storage stability of the chips

The chips sample prepared at the optimal conditions (red lentil ratio, baking time and temperature) was packaged in polyvinylidene chloride (PVDC) coated cellophane packages under modified atmosphere (N_2) and stored in a cooling oven at 20 °C (Nuve EV 018, Turkey) for 60 days for the stability tests. Samples were taken at the 15th, 30th and 60th days and analysed in terms of hardness, antioxidant capacity, total phenolic content, and colour.

Results and discussion

Physicochemical, bioactive and colour properties of the red lentil and base flour samples

Protein, ash, resistant starch, total phenolic content, antioxidant capacity and colour values of the flour samples are shown in Table 1. Ash content of the red lentil flour was 2.9%, whereas base flour had higher ash content (7.3%). Protein content of the red lentil flour (22.1%, dry base (db)) was higher than that of the base flour (9.6%, db). Total phenolic content of the red lentil flour and base flour were like each other (74.9 and 85.3 mg GAE/100 g, respectively). Furhermore, resistant starch of red lentil flour and base flour were found 5.4% and 0.6%, respectively. Lentil flour had a L^* value of 74.0 and an a^* value of 3.5. Base flour had higher L^* value (87.1) and lower a^* value (0.9). Lower L^* and higher a^* value of lentil flour compared to the base flour shows the darker colour of lentil flour. Lower L^* and higher a^* value of lentil flour compared to the base flour shows the darker colour of lentil flour. Antioxidant capacity of lentil flour sample was higher (42.3%) than that of the base flour (26.0%). The results of red lentil flour were compatible with the literature (Boye et al. 2010; Zou et al. 2011; Dogan et al. 2013; Du et al. 2014; Rathod et al. 2017; Li and Ganjyal 2017; Sattar et al. 2017; Portman et al. 2018; Chan et al. 2019).

Physicochemical and colour parameters of the chips

Ash, protein and colour values of the chips samples are shown in Table 2. The ash contents were varied between 3.25% and 4.62% (db). The lowest ash content (3.25%) was achieved in the sample containing 50% red lentil flour and baked at 180 °C for 6 min (F13). The sample prepared without addition of red lentil flour and baked at 190 °C for 7.5 min had the highest ash content (4.62%, F3). As the ash content of the red lentil flour was lower than that of the base flour, the addition of red lentil flour caused decreases in the ash content of the samples. Regression analysis was showed that the red lentil flour ratio (coded as A) and

Table 1 Physicochemical properties, bioactive properties and color parameters of red lentil flour and base flour used in the chips formulation

		Lentil flour	Base flour
Physicochemical properties	Ash (%, db)	2.9 ± 0.05	7.3 ± 0.21
	Protein (%, db)	22.1 ± 0.23	9.6 ± 0.02
	Resistant starch (%)	5.4 ± 0.02	0.6 ± 0.10
Bioactive properties	Total phenolic content (mg GAE/100 g)	74.9 ± 0.56	85.3 ± 1.06
	Antioxidant capacity (% inhibition)	42.3 ± 0.25	26.0 ± 0.39
Color parameters	L^*	74.0 ± 0.08	87.1 ± 0.16
	a^*	3.5 ± 0.05	0.9 ± 0.03
	b^*	25.6 ± 0.06	14.2 ± 0.21

Base flour mixture: 80% wheat flour, 20% corn flour. Onion powder, garlic powder, cummin and salt was added as 2% of the flour

baking time (coded as C) had significant effect on the ash content of the chips samples at linear level ($p < 0.0001$ and $p = 0.0168$, respectively), and red lentil flour ratio had the highest influence on ash content of the samples (Table 3). The positive coefficients of the terms (Table 3) were indicated that ash content was gradually decreased with the increase of red lentil flour ratio and baking time.

The protein contents were varied between 8.35 and 15.49% (db). The lowest protein content (8.35%) was achieved in the sample prepared without addition of red lentil flour and baked at 180 °C for 6 min (F5). The highest protein content (15.49%, F12) was achieved in the sample containing 50% red lentil flour and baked at 190 °C for 7.5 min. As the protein content of the red lentil flour was higher than that of the base flour, the addition of red lentil flour caused increases in the protein content of the samples. Regression analysis was showed that the red lentil flour ratio (coded as A), temperature (coded as B) and time (coded as C) had significant effects on the protein content of the chips samples at linear level ($p < 0.0001$, $p = 0.0376$ and $p = 0.0302$, respectively). Similar to the ash content results, red lentil flour ratio had the highest influence on protein content of the samples (Table 3). Positive coefficients of the terms (Table 3) were indicated that protein content gradually increased with the increase of red lentil flour ratio and baking time.

Color is one of the most important parameters for the quality and acceptability of baked products (Jiang et al. 2019). L^*, a^* and b^* values of the chips samples varied between 52.60 and 76.24 (100 represents the brightest white), 3.66–14.69 (higher value represents more intense redness), and 26.88–31.28 (higher value represents a more intense yellowness) respectively. The highest L^* and a^* values were achieved in the samples prepared with the addition of 25% red lentil flour and baked at 190 °C for 9 min. The lowest L^* and a^* values were achieved in the samples prepared without addition of red lentil flour and baked at 180 °C for 6 min. According to the regression analysis, the p values of the model for L^* and a^* values indicated that the model were reliable ($p = 0.0362$ and 0.0455, respectively). However, for b^* values, the model was not reliable ($p = 0.0041$) (Table 3). The linear effect of temperature (coded as B) and baking time (coded as C) had significant on the L^* and a^* values of the chips samples, and baking time had the highest influence ($p = 0.0041$ and 0.0028, respectively). Positive coefficients of the terms (Table 3) indicated that the increase in temperature and baking time caused an increase in the darkness (L^*) and redness (a^*) of the samples, as expected.

Bioactive properties of the chips

Bioactive properties of the chips samples in terms of total phenolic content and antioxidant capacity are shown in Table 2. Total phenolic content of the samples was vaired between 66.77 mg GAE/100 g and 151.97 mg GAE/100 g. The chips sample produced with the addition of 25% of red lentil flour and baked at 170 °C for 6 (F11) min had the lowest total phenolic content, whereas the one prepared with the addition of 25% of red lentil flour and baked at 190 °C for 9 min (F15) had the highest total phenolic content. Regression analysis showed that baking temperature (coded as B) and time (coded as C) had significant effect on the total phenolic content of the chips samples at the linear level ($p = 0.0114$ and $p = 0.0018$, respectively). Antioxidant capacity of the samples varied between 20.54 and 57.73%. The sample prepared with the addition of 25% of red lentil flour and baked at 190 °C for 6 min (F8) had the lowest antioxidant capacity. Similar to the total phenolic content, the highest antioxidant capacity was achieved with the sample prepared with the addition of 25% of red lentil flour and baked at 190 °C for 9 min

Table 2 Properties of the chips samples

Sample	Ratio (%)	Temp. (°C)	Time (min)	Ash (%)	Protein (%)	L^*	a^*	b^*	TPC (mg GAE/100 g)	AC (%)	HMF	RS (%)	In vitro GI	Hardness (kg)
F1	0	170	7.5	4.42 ± 0.05	8.46 ± 0.23	75.78 ± 0.16	4.36 ± 0.11	27.25 ± 0.13	88.75 ± 0.47	26.28 ± 0.88	3.11 ± 0.08	0.94 ± 0.03	99.4 ± 0.14	10.763 ± 0.529
F2	25	180	7.5	4.02 ± 0.04	11.62 ± 0.06	75.03 ± 0.13	4.24 ± 0.05	29.66 ± 0.10	103.14 ± 0.34	32.18 ± 0.37	1.35 ± 0.07	2.56 ± 0.01	84.5 ± 0.47	13.301 ± 1.707
F3	0	190	7.5	4.62 ± 0.03	9.46 ± 0.06	69.20 ± 0.07	7.75 ± 0.07	28.06 ± 0.18	124.71 ± 1.43	41.63 ± 0.44	58.81 ± 0.91	0.90 ± 0.03	98.9 ± 0.08	15.078 ± 1.784
F4	25	180	7.5	3.97 ± 0.04	11.62 ± 0.17	70.54 ± 0.07	6.65 ± 0.05	29.70 ± 0.18	97.32 ± 0.98	31.80 ± 1.06	3.23 ± 0.17	2.13 ± 0.03	92.5 ± 0.43	13.764 ± 0.848
F5	0	180	6	4.55 ± 0.01	8.35 ± 0.28	76.24 ± 0.13	3.66 ± 0.05	26.88 ± 0.17	83.62 ± 1.34	21.92 ± 0.29	1.60 ± 0.14	1.07 ± 0.02	95.5 ± 0.06	32.623 ± 1.080
F6	50	170	7.5	3.52 ± 0.01	15.25 ± 0.34	69.63 ± 0.05	7.00 ± 0.04	30.20 ± 0.22	101.90 ± 0.52	33.45 ± 0.79	2.58 ± 0.02	3.25 ± 0.01	73.9 ± 0.49	7.546 ± 1.124
F7	50	180	9	3.45 ± 0.03	14.81 ± 0.17	67.85 ± 0.12	7.76 ± 0.07	31.28 ± 0.10	102.04 ± 0.47	52.87 ± 0.60	2.46 ± 0.04	2.64 ± 0.04	84.9 ± 0.12	12.299 ± 1.139
F8	25	190	6	3.66 ± 0.00	11.42 ± 0.34	74.59 ± 0.13	4.07 ± 0.02	27.40 ± 0.12	96.56 ± 0.53	20.54 ± 0.09	0.95 ± 0.02	1.83 ± 0.02	89.6 ± 0.25	25.310 ± 2.401
F9	25	180	7.5	3.97 ± 0.03	11.86 ± 0.17	70.20 ± 0.17	7.36 ± 0.08	30.22 ± 0.12	115.40 ± 0.82	37.65 ± 0.30	4.02 ± 0.03	1.75 ± 0.02	93.2 ± 0.38	17.306 ± 2.631
F10	25	170	9	4.00 ± 0.02	11.26 ± 0.23	69.43 ± 0.14	8.04 ± 0.08	30.56 ± 0.20	116.08 ± 0.57	42.07 ± 0.65	5.99 ± 0.03	1.99 ± 0.02	90.3 ± 0.27	5.949 ± 0.343
F11	25	170	6	3.62 ± 0.01	10.34 ± 0.06	74.06 ± 0.29	3.86 ± 0.13	26.18 ± 0.45	66.77 ± 0.79	25.85 ± 0.42	0.69 ± 0.08	2.03 ± 0.02	89.1 ± 0.30	35.370 ± 1.960
F12	50	190	7.5	3.45 ± 0.02	15.49 ± 0.45	66.54 ± 0.16	8.97 ± 0.10	29.09 ± 0.06	118.82 ± 0.49	47.26 ± 0.44	6.13 ± 0.32	3.52 ± 0.00	89.0 ± 0.63	7.591 ± 0.456
F13	50	180	6	3.25 ± 0.01	13.42 ± 0.34	73.32 ± 0.36	3.86 ± 0.07	28.00 ± 0.14	77.59 ± 0.59	27.72 ± 0.44	0.91 ± 0.00	2.82 ± 0.02	75.5 ± 0.28	14.441 ± 0.725
F14	0	180	9	4.60 ± 0.03	8.66 ± 0.06	66.72 ± 0.13	9.45 ± 0.06	30.94 ± 0.13	138.14 ± 0.89	26.31 ± 0.53	61.84 ± 0.70	1.01 ± 0.00	99.3 ± 0.62	13.046 ± 0.674
F15	25	190	9	3.95 ± 0.08	11.34 ± 0.00	52.60 ± 0.11	14.69 ± 0.05	30.68 ± 0.09	151.97 ± 0.96	57.73 ± 0.16	80.92 ± 0.36	1.88 ± 0.02	87.5 ± 0.60	10.891 ± 0.991

TPC, Total phenolic content (mg GAE/100 g); *AC*, Antioxidant capacity (% inhibition); *HMF*, Hydroxymethyl furfural (mg/kg); *RS*, Resistant Starch; *GI*, Glycemic index

Table 3 Significance of the regression models (p values) and the effects of variables on the properties of the chips samples

Source of variance	Ash (%)	Protein (%)	L^*	a^*	b^*	TPC	AC	HMF	RS (%)	In vitro GI	Hardness
Linear											
A (Ratio, %)	< 0.0001*	< 0.0001*	0.2579	0.6172	0.0139	0.3037	0.0467*	0.0004*	0.0009*	− 0.0018*	0.7408
B (T, °C)	0.6713	0.0376*	0.0260*	0.0409*	0.5116	0.0114*	0.0699	0.0002*	0.9410	0.7045	0.1268
C (time, min)	0.0168*	0.0302*	0.0041*	0.0028*	0.0002	0.0018*	0.0048*	0.0001*	0.6635	0.7680	− 0.0244*
Interaction											
AB	0.2124	0.2638	0.5777	0.6727	0.1242	0.4167	0.9037	0.0026*	0.7235	0.2007	0.1509
AC	0.4463	0.1338	0.5206	0.5750	0.4865	0.2211	0.1483	0.0015*	0.8280	0.0996	0.0014*
BC	0.6881	0.1587	0.0316	0.0969	0.3401	0.7883	0.1451	0.0005*	0.9164	0.3719	0.0347*
Quadratic											
A^2	0.1343	0.0796	0.5960	0.7515	0.2915	0.7208	0.8733	0.1139	0.9110	0.6064	0.0010*
B^2	0.1913	0.4625	0.1633	0.2005	0.0218	0.3808	0.2824	0.0090*	0.9566	0.8747	0.4668
C^2	0.0753	0.0054*	0.3031	0.6691	0.3773	0.6359	0.7340	0.0133*	0.3867	0.7172	0.2753
Model	0.0005*	< 0.0001*	0.0362*	0.0454*	0.0041	0.0278*	0.0497*	0.0002*	0.0367*	0.0459*	0.0048*

TPC, Total phenolic content (mg GAE/100 g); *AC*, Antioxidant capacity (% inhibition); *HMF*, Hydroxymethyl furfural (mg/kg); *RS*, Resistant Starch; *GI*, Glycemic index

(F15). According to the regression analysis red lentil flour ratio (coded as A) and baking time (coded as C) had significant effect on the antioxidant capacity at the linear level ($p = 0.0467$ and $p = 0.0048$, repectively). Among the independent variables, baking time had the highest influence on the total phenolic content and antioxidant capacity of the values. As the high temperature cooking causes degradation of some phenolic compounds, a decrease in antioxidant capacity can occur. However, some of the Maillard reaction products especially melanoidins may increase the activity (Ramirez-Jimenez et al. 2000). The high value of total phenolic content and antioxidant capacity achieved in the F15 sample may be associated with this phenomenon. The total phenolic content (a) and antioxidant capacity (b) 3D plots are shown in Fig. 1.

Hydroxymethyl furfural (HMF) contents of the chips

Hydroxymethyl furfural (HMF) is one of the typical compounds formed during the Maillard reaction and have received attention due to the common occurrence in heat treated products. There are some studies indicating that HMF is cytotoxic at high concentrations and irritant to eyes, skin, respiratory track and mucous membranes (Capuano and Fogliano 2011; Miao et al. 2014). However, the toxicity of HMF is still need to be discussed, as there are some studies such as the study of Severin et al. (2010) indicating that HMF did not have a risk to human health. In this study, we have measured the HMF content of the chips samples as well. The HMF contents of the samples varied between 0.69 mg/kg and 80.92 mg/kg (Table 2). The lowest HMF content was achieved in the sample prepared with the addition of 25% red lentil flour and baked at 170 °C for 6 min (F11). The sample prepared with the addition of 25% red lentil flour and baked at 190 °C for 9 min (F15) had a very high HMF content (80.92%). Regression analysis showed that all of the independent variables (red lentil ratio, baking temperature and baking time) had significant effect on the HMF content of the chips samples at linear, interaction and quadratic levels. Baking time had the highest influence ($p = 0.0001$) on the HMF content. Positive coefficients of the terms (Table 3) indicated that the increase in red lentil ratio, baking temperature and baking time caused an increase in the HMF content of the samples. There are some factors affecting HMF formation, one of them is baking time and temperature (Capuano and Fogliano 2011; Miao et al. 2014). Higher baking temperature and time induces the formation of HMF (Capuano and Fogliano 2011), which is also investigated in this study.

Resistant starch content and in vitro *glycemic index value of the chips*

Resistant starch content and in vitro glycemic index (GI) value of the samples are shown in Table 2. RS content varied between 0.90% and 3.52% and the lowest RS content was achieved with the samples prepared without addition of red lentil flour as expected. The samples prepared with the addition of 50% red lentil flour had higher RS content among the samples (2.64–3.52%). Resistant

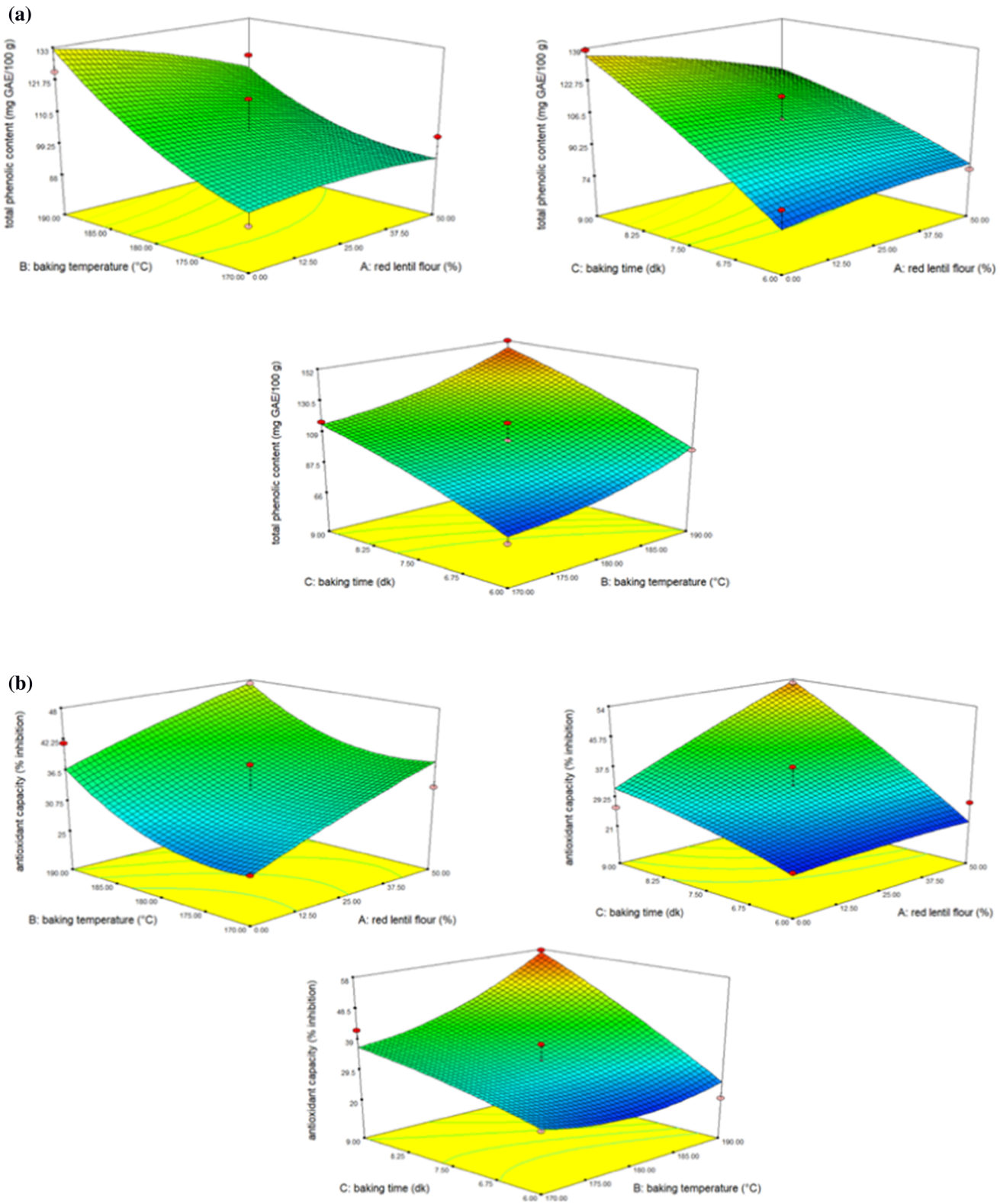

Fig. 1 3D plots of the **a** total phenolic content and **b** antioxidant capacity of the samples

starch content 3D plots are shown in Fig. 2. In vitro GI values varied between 73.9 and 99.4. The lowest in vitro GI value (73.9 ± 0.49) was achieved with the sample prepared with the addition of 50% red lentil flour and baked at 170 °C for 7.5 min (F6) and the highest in vitro GI value (99.4 ± 0.14) was achieved with the sample

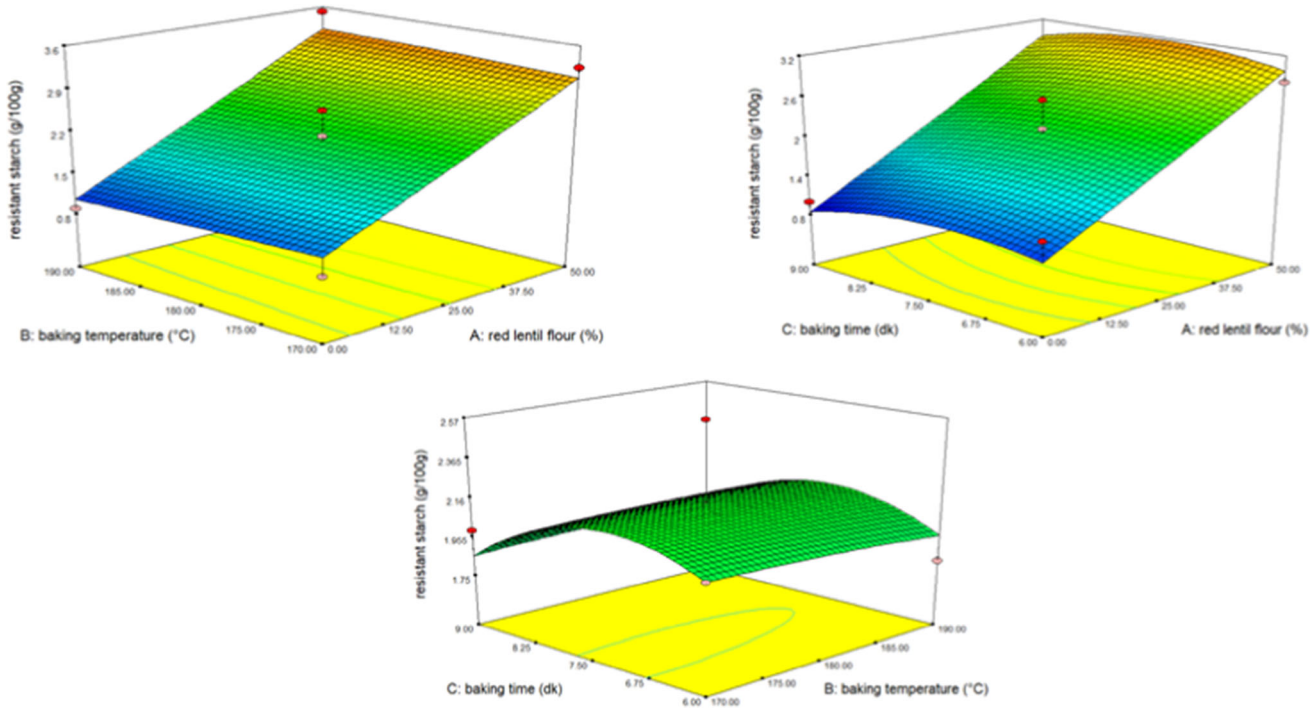

Fig. 2 3D plots of the resistant starch content of the samples

prepared without the addition of red lentil flour and baked at 170 °C for 7.5 min (F1). White bread was selected as a reference material, and its in vitro GI value was taken as 100. As can be seen from Table 2, all the chips samples had lower GI value than white bread (100 GI). Pulses are low glycemic index foods and in a study of Chung et al. (2008), red lentil showed the lowest glycemic index value among the other pulses. Significance analysis of coefficients of each factor showed that red lentil ratio (coded as A) was the only factor effecting the RS content and in vitro glycemic index of the chips samples ($p = 0.0009$ and $p = -0.0018$, respectively, Table 3). The positive regression coefficient between the red lentil ratio and RS indicates that, the increase in the red lentil ratio caused increase in the RS content. The negative regression coefficient between the red lentil ratio and in vitro GI indicates that, in vitro GI decreases with the increase in red lentil ratio. Both results confirm that the addition of legume flour decreased the digestibility of the chips samples.

Texture and sensory analysis

Hardness is an important property for crispy products, and used inter-changeably to describe the crack and crumble of the product (Kayacier and Singh 2003; Jiang et al. 2019). Hardness value of the chips samples varied between 5.95 kg and 35.37 kg (Table 2). The highest hardness value was achieved with the sample prepared with the addition of 25% of red lentil flour and baked at 170 °C for 6 min (F11) and the lowest hardness value was achieved with the sample prepared with the addition of 25% of red lentil flour and baked at 170 °C for 9 min (F10). Regression analysis also indicated that only baking time (coded as C) had significant influence on the hardness value of the chips samples ($p = -0.0244$). The negative coefficient (Table 3) indicated that the hardness value gradually decreased with the increase of baking time. Similar relation between baking time and hardness was also reported in the literature. Jiang et al. (2019) investigated that the hardness of corn chips baked for 6 min was 377 g, whereas the hardness value increased to 2105 g when the chips were baked for 12 min. In another study the hardness value (1328 g) of the tortilla chips baked for 4 min decreased to 945 g when the chips were baked for 5 min (Kayacier and Singh 2003). Jiang et al. (2019) reported that the quick vaporization and diffusion of moisture to form larger sponge-like air cells resulted in less hard chips.

The sensory analysis score (in terms of taste, odor, and crispness and gereral acceptance) are shown in Fig. 3. The samples prepared without addition of lentil flour are F1, F3, F5 and F14 had the highest total score. On the other hand, the samples prepared with the highest lentil flour addition (50%, F6, F12, F13) had comparable sensory scores with the ones prepared without lentil flour addition (F1, F3, F5 and F14). The correlation coefficients between the sensory and some of the quality parameters of the chips were also calculated and the results were shown in Table 4. There was not any significant correlation between the sensory

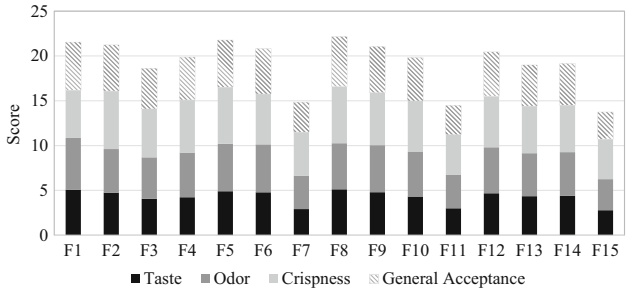

Fig. 3 Sensory scores of the samples

Table 4 Correlation coefficients between sensory properties and some quality parameters of chips samples

Sensory properties	L^*	a^*	AC	HMF
Taste	0.584^{ii}	-0.480^{i}	-0.590^{ii}	ns
Odor	0.569^{ii}	-0.444^{i}	-0.547^{ii}	ns
Crispness	0.542^{ii}	-0.457^{i}	ns	-0.445^{i}
General Acceptance	0.596^{ii}	-0.484^{i}	-0.5870^{ii}	ns

AC, Antioxidant capacity (% inhibition); *HMF*, Hydroxymethyl furfural (mg/kg)

^{i,ii}: Correlations are significant at $p < 0.1$ and $p < 0.05$, respectively

ns: not significant

parameters and the ash, protein, b^*, TPC, RS, in vitro GI, hardness, therefore these properties are not indicated in the table. There was significant correlation between the odor, taste and general acceptance and L^*, a^* and antioxidant capacity (AC) of the samples. However, these sensory parameters were not correlated with the HMF content of the samples. Crispness was the only parameter that had significant correlation with HMF content ($p < 0.1$).

Verification experiments of optimization

The regression equations (see Supplementary File) were solved using Design Expert Software, and the optimal values of the independent variables to obtain the highest total phenolic, antioxidant capacity and resistant starch content with a low HMF content were estimated as follows: A (red lentil flour ratio) = 50%, B (baking temperature) = 170 °C and C (baking time) = 7.5 min. The theoretical values of ash, total phenolic content, antioxidant capacity, colour (L^*, a^* and b^*), and hardness values were 3.49%, 83.37 mg GAE/100 g, 38.24%, 73.07, 6.14, 29.47, and 7.72 kg, respectively.

In order to verify this prediction, a confirmation production of chips sample was conducted to compare the experimental results with the prediction under the optimal conditions. The ash, and total phenolic content, antioxidant

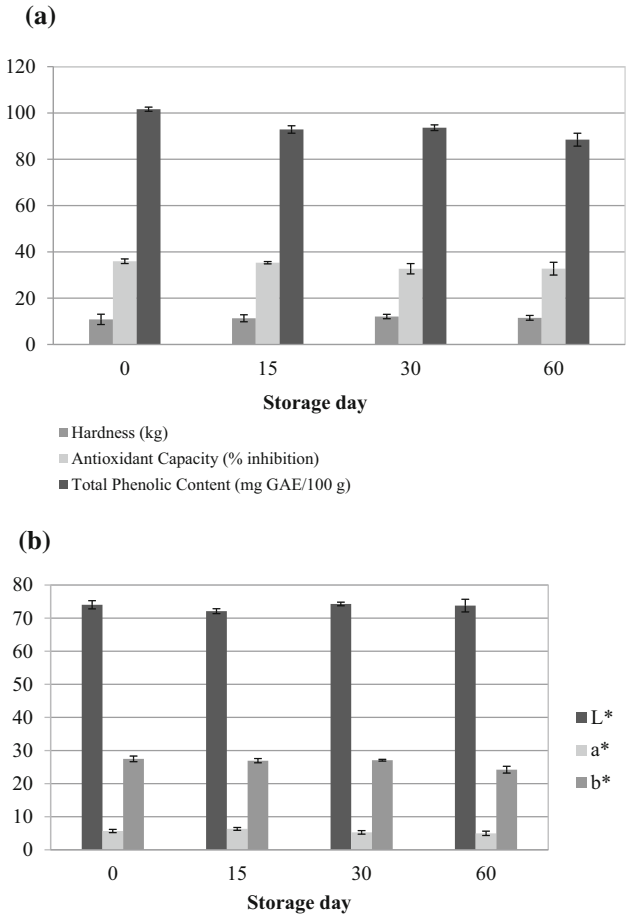

Fig. 4 Effect of storage on **a** hardness, total phenolic content and antioxidant capacity and **b** colour properties of the chips prepared with the addition of 50% of red lentil flour and baked at 170 °C for 7.5 min

capacity, colour (L^*, a^* and b^*) and hardness values of the chips sample produced with the addition of 50% red lentil flour and baked at 170 °C for 7.5 min (F6) were 3.57 ± 0.03%, 101.63 ± 0.91 mg GAE/100 g, 35.94 ± 0.98%, 74.03 ± 1.24, 5.68 ± 0.49, 27.48 ± 0.86, and 11.01 ± 1.59 (kg), respectively, which are consistent with the predicted values just mentioned. As stated before (Fig. 3), the optimized chips sample (F6) had a comparable sensory score with the ones prepared without lentil flour addition (F1, F3, F5, and F14). These results were indicated that enrichment of wheat chips with red lentil flour can be possible without any detrimental sensory properties.

Storage stability of the optimized chips

Storage stability of optimized chips sample at 20 °C was assessed on the basis of changes observed in hardness, total phenolic content, antioxidant capacity and colour (L^*, a^*, b^*). The changes in the hardness, antioxidant capacity and total phenolic content of the chips sample prepared with the

addition of 50% of red lentil flour and baked at 170 °C for 7.5 min are shown in Fig. 4a. As stated in the previous section, hardness value of the chips sample prior to storage was 11.01 ± 1.59 kg. A slight increase was observed in the hardness value of the samples during storage; however, it was not significant. The antioxidant value of the chips sample was 35.94 ± 0.98% prior to storage and it was decreased during storage. However, as it can be seen from the Fig. 4a, the decrease was not significant. As stated in the previous section, total phenolic content of the sample prior to storage was 101.63 ± 0.91 mg GAE/100 g. A significant decrease was observed after 15 days storage, while no considerable difference was observed after more storage. Effect of storage on the colour properties of the chips prepared with the addition of 50% of red lentil flour and baked at 170 °C for 7.5 min is shown in Fig. 4b. No significant difference was observed in the L^*, a^* and b^* values of the chips samples during storage.

Conclusion

Response surface methodology was successfully applied to investigate the effect of red lentil ratio, baking temperature and time on the physicochemical, textural, nutritional, and bioactive properties of the chips. The protein content of the chips samples was increased with an increase in the red lentil ratio. The increase in the baking time and temperature resulted in more darker and reddish chips. Total phenolic content of the samples was not effected from red lentil ratio, whereas the increase in baking time and temperature increased the total phenolic content. The antioxidant capacity was not affected from baking temperature, however increased while the red lentil ratio and baking time increased. HMF content of the chips samples increased with an increase in all of the independent variables (red lentil ratio, baking temperature and baking time). Red lentil ratio was the only factor effecting the RS content and in vitro glycemic index of the chips samples. The relationship between red lentil ratio and RS content was proportional, while red lentil ratio was inversely proportional with the in vitro glycemic index value. The hardness value of the chips samples was affected from only baking time among the process parameters. The storage stability test results showed that the hardness, total phenolic content, antioxidant capacity and colour properties did not change during storage considerably. Overall results of this study proved that red lentil can be used as a source for the enrichment of oven-baked wheat chips as a novel healthy and nutritional snack food without any detrimental sensory properties.

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Declarations

Conflicts of interest The authors have no conflict of interest regarding the content of this paper.

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