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PRODUCTION OF DEEP-FRIED WHEAT CHIPS USING PURPLE WHEAT FLOUR: PHYSICOCHEMICAL, TEXTURAL, SENSORY PROPERTIES AND OPTIMIZATION

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ABSTRACT
The aim of this study was to develop alternative and healthy deep-fried chips by fortifying wheat chips with purple wheat flour (PWF). The effect of process variables (PWF content: 0-100%, frying temp. and time: 170-190 °C and 40-60 s) on the physicochemical, textural, instrumental color, sensorial properties, and optimization of the chips were investigated using response surface methodology. The levels of PWF in the chips receipt dramatically reduced oil uptake (by 23%), whereas the protein content of chips increased of the end products. The instrumental hardness of the enriched chips increased while sensory firmness decreased with increasing PWF. Generally, the chips enriched with PWF received the highest overall acceptability score by the panelists. Higher desirability (optimization results) and the process variables were determined as a 0.73 and 92.72 g/100g PWF, 170 °C, 40 s, respectively. These findings show that PWF can be easily incorporated into products that involve deep-fried chips.

1.Introduction

Currently, snack foods are becoming an important component of many diets. Many age groups, particularly children, consume with them for enjoyment. (Kayacier et al. 2014). There are many various kinds of snack foods, such as chips, cookies, crackers, and granola-type bars. Snack foods comprise of many different types including chips, cookies, and crackers. While they are primarily consumed in between meals, there has been a significant increase in their consumption during main meals. Snack foods are generally known as unhealthy due to their high energy density (Hartmann et al. 2012; Durmaz and Yuksel, 2021). According to statistics, the global chips market is expected to expand at a compound annual growth rate (CAGR) of 3.92% between 2020 and 2028, reaching US$ 43.8 billion by that time (Potato Chips Market, 2024). Excessive energy consumption is related to obesity, which is acknowledged as a risk factor for numerous illnesses, including cancer, diabetes, and heart disease (Romieu et al. 2017). Consumers demand healthy foods. Therefore, the snack industry has studied on the development of healthy snack foods to meet consumer's demand. Recently, most research has been conducted on the addition of functional food components to snack foods, particularly chips. For example, Rababah et al. (2012) studied the fortification of corn chips with broad bean flour, chickpea flour, or isolated soy protein. Yüksel et al. (2015) studied the fortification of wheat chips with barley flour.

Rogalski & Szterk (2015) researched enrichment corn chips with linseed oil. Germinated soybeans were used to create a healthy snack chip by Maetens et al. 2017.

Purple wheat is a hybrid of ancient Abyssinian wheat (*Triticum aethiopicum*) and spelt (*Triticum dicoccum*). Purple wheat has recently become very popular due to its important nutritional properties. In general, flour and bakery products are the top consumption areas (Gamel et al. 2019a). Some of the nutritional and physical properties of purple wheat flour are as follows; 3.0% fat, 13.77% protein, 8.4% dietary fiber, 73.10% hectoliter, 21% gluten, 46 glycemic index, 339 TEAC/100 g total antioxidants, 169.61-177.47 mg GAE/100 g total phenolics (Yu & Beta 2015). One of the most effective qualities of purple wheat is the purple color pigments and anthocyanins in the grain structure. The total anthocyanin content of purple wheat can vary from 96 μg/g (Abdel-Aal et al. 2006) to 230 μg/g (Liu et al. 2010). Purple wheat has already taken its place in the food industry in terms of its content, nutritional efficiency, and bioactive components; and it is thought to be used in the production of products with richer content (Ficco et al. 2016).

In the literature, there is no available study on the fortification of chips with purple wheat flour. The aim of this study was to enrich wheat chips with purple wheat flour to present a new healthy snack for the snack industry. Response surface methodology was applied to evaluate the effect of process variables (purple wheat flour content, frying time, and frying temperature) on the physicochemical properties, textural, instrumental color, and sensorial properties of the enriched wheat chips.

2. Materials and methods

2.1. Materials

Wheat flour, purple wheat flour, frying oil (corn oil), and salt were obtained from a local market (Gumushane, Turkey). Wheat flour comprised 12.9 g $100g^{-1}$ moisture, 11.1 g $100g^{-1}$ of protein, 2.5 g $100g^{-1}$ of dietary fibre, 2.9 g $100g^{-1}$ of fat, and 0.55 g $100g^{-1}$ of ash. Purple wheat flour comprised 13.0 g $100g^{-1}$ moisture, 60.8 g $100g^{-1}$ carbohydrate, 15.0 g $100g^{-1}$ of protein, 8.5 g $100g^{-1}$ of dietary fibre, 2.0 g $100g^{-1}$ of fat, and 0.2 g $100g^{-1}$ of salt.

2.2. Preparation of the chips

Table 1. The coded and uncoded values of design

	Coded Values				**Uncoded Values**	
Samples	A: Frying temperature (°C)	B:Frying time (s)	C: PWF (g/100g)	A: Frying temperature (°C)	B:Frying time (s)	C: PWF (g/100g)
1	0.00	0.00	0.00	180.00	50.00	50.00
2	1.00	0.00	1.00	190.00	50.00	100.00
3	0.00	0.00	0.00	180.00	50.00	50.00
4	0.00	-1.00	-1.00	180.00	40.00	0.00
5	-1.00	0.00	-1.00	170.00	50.00	0.00
6	-1.00	0.00	1.00	170.00	50.00	100.00
7	0.00	0.00	0.00	180.00	50.00	50.00
8	1.00	-1.00	0.00	190.00	40.00	50.00
9	0.00	1.00	1.00	180.00	60.00	100.00
10	-1.00	1.00	0.00	170.00	60.00	50.00
11	-1.00	-1.00	0.00	170.00	40.00	50.00
12	1.00	0.00	-1.00	190.00	50.00	0.00
13	0.00	1.00	-1.00	180.00	60.00	0.00
14	0.00	-1.00	1.00	180.00	40.00	100.00
15	1.00	1.00	0.00	190.00	60.00	50.00

*WF/PWF= 100/100 (w/w). The salt was added as a 1 g/100g for every design point.

Table 1 shows the experimental design. In accordance with the experimental design, mixtures containing WF and PWF in various ratios were prepared, and homogenized for 5 min. After the addition of water (50 mL), the dough was kneaded using a dough mixer for 10 min (Kitchen Aid Professional 600, MI, USA). The resultant dough was rested for 30 min in a plastic wrap. The thickness of the dough was adjusted to 1 mm (Rondo, Doge SS0635, Switzerland), and the chips shape was obtained using a special mold. The prepared chips were fried in an oil bath with a temperature (temp.) controller (Mikrotest, Turkey). The prepared chips are shown in Fig 1. After deep-frying, the chips were cooled on a paper towel.

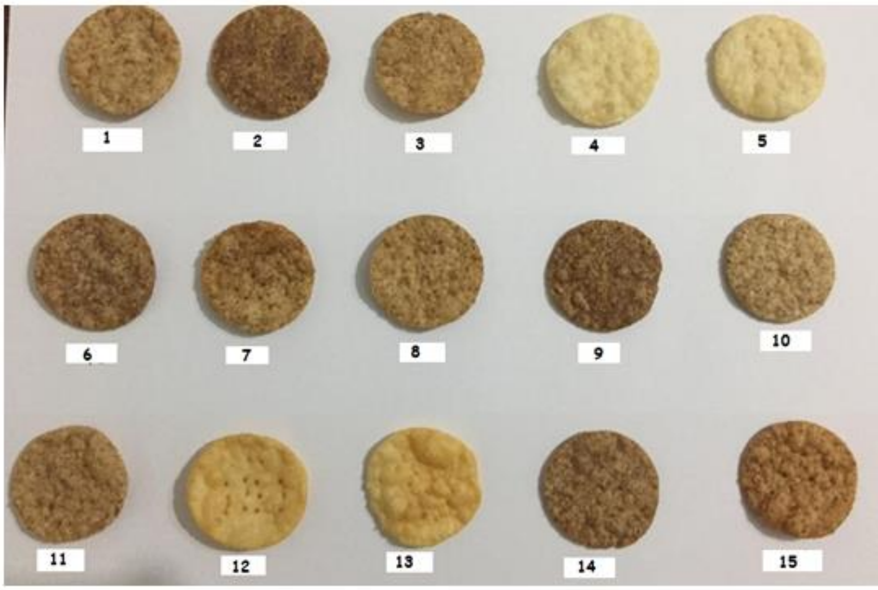


Figure 1. The produced chips according to the design.

2.3. Physicochemical properties

The dry matter contents of the chips sample were determined by the oven drying method using an oven (Nuve FN 120 Turkey). With the use of a furnace (Protherm PLF115M, Turkey) and the dry burning method, the ash content of the chips was determined. To determine the fat content of the sample, a Soxhlet extractor was used (Buchi B-811, Switzerland). The water activity (a_w) was measured using a a_w measurer (Decagon, USA). The protein content of the chips samples was designated by the Kjeldahl method (AOAC 2000).

2.4. Textural properties

The texture analyzer equipped with a Kramer shear cell attachment (HDP/KS 5) (TA.XT Plus, England) was used to determine the hardness of the samples. 3 g chips were inserted into the cell, and the blade was set to 5 cm/min. The highest force necessary to break the chips sample was established from the deformation curve. Ten replications were carried out.

2.5. Color properties

A Lovibond colorimeter (Lovibond, England). was used to determine the instrumental color properties (L*, a*, and b*).

2.6. Sensory properties

Twenty semi-trained panelists used a 9-point scale to evaluate the chips samples (1: undesired and 9: desired). These panelists were selected from students and lecturers of the Food Engineering Department. The color, crispness, taste/odor and overall acceptability of the samples were evaluated. The samples were randomly coded with 3-digit numbers before being served to the panelists. Drink water was given to the panelists to clean their lips between sampling.

2.7. Statistical analysis and modeling

For modeling the processing variables (PWF, frying temp. and time) in the current investigation, a 3-factor-3 level Box Behnken experimental design (Box & Behnken, 1960) with three replicates at the center point was selected, and predictive regression models were built (Table 1). The second-order polynomial equation of function Xi as stated below, was fitted for each response analyzed:

$$Y = b_0 + \sum_{i=1}^{3} b_i X_i + \sum_{i=1}^{3} b_{ii} X_{ii}^{\,2} + \sum_{\substack{i=1 \\ i<j}}^{3} \sum_{j=1}^{3} b_{ij} X_i X_j \quad (1)$$

where Y is the estimated response; b0, bi, bii, bij are constants. Xi, Xii and Xj are processing variables. All analyses were conducted using uncoded values, and as Table 1 illustrates, the maximum number of tests that could be run was 15. As shown in Table 1, the experimental combination was applied in triplicate at the model's center point on the first, third, and seventh runs. Design Expert Statistical Package Software (Version 7.0.0.a Stat Ease Inc. Hennepin, MN, USA) was used for the computational work, including 3D surface plots, in order to conduct the response surface analysis. The Design Expert was used to determine the optimization of the original design based on sensory evaluations.

3.Results and discussions

Response surface methodology was used to examine the impact of the process factors (PWF concentration, frying time, and frying temperature) on the physicochemical, instrumental color, and sensory qualities of the PWF-enriched wheat chips. In addition, the optimization of results was applied. To investigate the main and interaction effects of the variables on the analyzed parameters, a three-factor and three-level Box-Behnken design (Table 1) was used.

3.1 Physicochemical and color properties

The content and variance analysis (F values) of dry matter, ash, a_w, oil, protein, hardness of wheat chips enriched with PWF are tabulated in the Tables 2 and 3, respectively. The maximum and minimum dry matter contents of the chips samples were 99.91 and 96.94 g/100g, respectively. The highest dry matter content was determined as a 99.91 g/100g with a PWF level of 100 g/100g at 180 °C frying temperature for 60 s. Only the frying temperature showed a significant effect on the dry matter content. The dry matter content was significantly and positively impacted by the linear term of the frying temperature ($p<0.05$). This regression model effectively predicts the dry matter content of the chips sample dependent on the PWF, frying temperature, and frying duration due to its maximum coefficient of determination (R2 = 0.87, Table 4). Moisture reduction in deep-fried products is generally expected. This is because the moisture in the samples evaporates away from the product with high heat during frying (Kayacier et al. 2014). Similar findings were reported by Durmaz & Yuksel (2021) and Ayustaningwarno et al. (2020), who observed an increase in the dry matter content of chips.

The higher ash content of the wheat chips enriched with PWF could be explained by the higher dietary fiber content of the PWF. The PWF (8.5 g $100g^{-1}$) had approximately 4 times dietary fiber content than the WF (2.5 g $100g^{-1}$) and so the ash content of the sample was affected by the dietary fiber content of flours. Only PWF showed significant effect on the ash content. The PWF linear term has a significant suitable impact on the ash content. ($p<0.05$, Table 3.). For the evaluation of ash content, the coefficient of determination was determined to be suitable (R2 = 0.66, Table 4). Similar findings were reported by Gamel et al. (2019a), who observed an increase in the ash content of the bars and crackers fortified with the PWF. It can also be said that the salt content used in the production of chips increases the ash content of the samples.

Table 2. Physicochemical, textural, and instrumental color contents of the samples.

Samples	Dry matter (g/100g)	Ash (g/100g)	Water activity (a_w)	Oil (g/100g)	Protein (g/100g)	Hardness (kg)	L*	a*	b*
1	99.26±0.03	1.62±0.09	0.08±0.00	31.94±2.17	8.14±0.08	18.45±2.49	49.73±2.12	7.36±0.46	23.72±1.38
2	99.20±0.25	1.67±0.03	0.07±0.00	35.86±2.01	9.39±0.61	22.48±3.80	44.73±0.85	9.37±0.37	23.38±0.67
3	99.74±0.31	1.00±0.00	0.07±0.02	33.30±3.77	8.06±0.40	19.41±2.63	49.84±2.48	7.75±0.55	24.83±0.72
4	97.08±0.12	1.05±0.07	0.20±0.01	39.05±3.06	7.34±0.08	17.20±2.59	67.95±1.72	1.27±0.36	24.90±1.10
5	96.94±0.95	1.36±0.31	0.17±0.02	37.62±2.33	7.66±0.80	18.39±1.81	66.21±1.67	0.97±0.32	23.69±0.93
6	97.85±0.07	1.86±0.01	0.14±0.00	34.88±2.46	8.46±0.80	26.14±3.67	43.30±1.87	7.57±0.53	19.69±1.08
7	99.29±0.04	1.05±0.01	0.06±0.01	30.58±0.79	7.18±0.16	24.85±2.88	46.40±1.36	7.96±0.17	23.69±0.59
8	99.81±0.01	1.55±0.23	0.07±0.00	36.65±0.08	8.14±0.24	24.57±3.07	48.54±1.32	8.81±0.54	25.81±1.23
9	99.91±0.09	1.67±0.12	0.06±0.00	35.71±1.70	7.34±0.16	38.96±4.51	37.19±2.88	8.63±0.45	21.28±1.69
10	98.99±0.04	1.21±0.21	0.07±0.02	37.56±1.41	5.29±0.40	20.15±2.61	53.17±1.62	5.99±0.49	22.45±1.41
11	98.32±0.15	1.02±0.00	0.13±0.00	29.48±1.74	8.46±0.40	39.61±3.56	51.12±1.68	6.68±0.85	21.66±1.30
12	99.44±0.10	1.09±0.05	0.07±0.00	37.15±0.16	8.06±0.20	20.00±2.69	56.50±2.67	6.41±0.95	29.26±1.98
13	99.35±0.01	1.10±0.09	0.07±0.00	40.73±3.68	5.64±0.24	26.63±2.45	58.67±1.60	6.01±0.56	33.42±1.56
14	98.93±0.07	2.08±0.11	0.09±0.00	32.55±2.68	9.26±0.40	26.27±1.78	46.86±1.04	7.64±0.65	20.19±1.42
15	99.81±0.08	1.67±0.10	0.06±0.00	36.93±2.96	8.62±0.16	32.39±3.41	45.03±1.10	9.47±0.21	27.19±0.68

Table 3. Variance analysis (F values) results of the effect of process variables on changes in the physicochemical, textural, and instrumental color properties of samples

Source	Dry matter (g/100g)	Ash (g/100g)	Water activity (a_w)	Oil (g/100g)	Protein (g/100g)	Hardness (kg)	L*	a*	b*
A	14.36*	0.30	9.67*	1.85	9.03*	0.081	4.15	21.87**	14.86*
B	5.81	3.313E-003	9.07*	6.47	19.09**	0.38	4.80	4.29	6.24
C	3.61	7.50*	4.15	8.97*	15.85*	3.44	68.63**	45.60**	32.18**
AB	0.35	0.010	0.72	4.52	12.76*	5.12	0.71	0.48	0.032
AC	1.00	0.014	0.33	0.16	0.27	0.19	2.86	3.49	0.32
BC	1.25	0.43	3.37	0.16	0.043	0.074	3.454E-003	3.71	4.97
A^2	1.22	0.20	0.68	1.82	2.45	0.19	0.058	0.057	0.19
B^2	0.19	0.12	8.554E-003	4.06	4.80	4.82	0.053	0.020	0.44
C^2	6.16	1.17	5.70	10.86*	0.47	0.029	4.44	11.73*	0.12
Model	3.76	1.07	3.72	4.12	7.27*	1.59	9.51*	10.16**	6.60*
Lack of fit	0.13	0.54	0.06	0.31	0.57	0.19	0.20	0.06	0.09

A: Frying temperature, B: Frying time, C: PWF. *p<0.05, **p<0.01

The water activity of the wheat chips ranged from 0.06 a_w to 0.20 a_w (Table 2). The highest a_w content was determined as a 0.20 a_w with a PWF level of 0.0 g/100g at 180 °C frying temperature for 40 s while the lowest a_w content was determined as a 0.06 a_w with a PWF level of 100.0 g/100g at 180 °C frying temperature for 60 s. The frying temperature and time had a significant effect on the a_w content. The linear term of the frying temperature and time had a significant positive effect on the a_w content ($p<0.05$, Table 3.). This regression model effectively predicts the a_w content of the wheat chips sample dependent on the PWF, frying temperature, and time due to its high coefficient of determination (R2 = 0.87, Table 4). The most important effect on the results of a_w in deep-fried products is said to be moisture content contained in the end product (Yuksel et al. 2020). In this context, considering that the moisture content of the samples is between 3.09 g/100g and 0.09 g/100g, it is seen that the main reason why the a_w results of the samples are found to be quite low.

The PWF showed a significant effect on both oil contents. The highest oil content was determined as a 40.73 g/100g with a PWF level of 0.0 g/100g at 180 °C frying temperature for 60 s while the lowest oil content was determined as a 29.48 g/100g with a PWF level of 50.0 g/100g at 170 °C frying temperature for 40 s. The linear and quadratic term of the PWF content had a significant effect on the oil content of the samples ($p<0.05$). This regression model effectively predicts the oil content of the wheat chips sample based on the PWF, frying temperature, and time due to its high coefficient of determination (R2 = 0.88, Table 4). In deep-frying, mass and heat transmission occur simultaneously. As water from the food evaporates as water vapor, heat is transported from the frying oil to the food's surface, and some of the evaporated water is replaced by the oil as the food absorbs it (Kaplan, et al. 2021). In this study, the oil level in the final chips sample decreased considerably (~ 23%). The major reason for the decreased oil level with the increase of PWF in the recipe of samples might be that PWF behaves as a coating material, which occasioned the formation of lesser pores, and thus less oils were taken up during the frying process. Similar findings were reported by Durmaz & Yuksel (2021) and Mayo-Mayo et al. (2020), who observed a decrease in the oil content of chips and tortillas fortified with potato peel powder, roselle, and mango peel powder.

The maximum protein content was determined as a 9.39 g/100g with a PWF level of 100.0 g/100g at 190 °C frying temperature for 50 s, whereas the minimum protein content was observed to be 5.29 g/100g with a PWF level of 50.0 g/100g at 170 °C frying temperature for 60 s. The linear term of the PWF, frying temperature, and frying time content had a significant effect on the protein content of the samples ($p<0.01$, $p<0.05$ Table 3). In addition, the interaction term of the frying temperature and time content had a significant effect on the protein content of the samples ($p<0.05$ Table 3). This regression model effectively predicts the protein content of the samples based on the PWF, frying temperature, and time due to its high coefficient of determination (R2 = 0.92, Table 4). In this study, the amount of protein in the final chips sample increased considerably. The main reason for the increased protein amount with the increasing of PWF in the recipe of samples is that PWF (15.0 g/100g) has a higher protein content than WF (11.1 g/100g). In the literature, the protein contents of PWF were found to be; 10.3 g/100g protein (Gamel et al. 2019a), 10.3 g/100g protein (Saini et al. 2020), and 11.5 g/100g protein (Abdel-Aal et al. 2018). Gamel et al. (2019b) reported that the protein content of functional foods enriched with purple wheat flour was in the range of 7.3–18.8 g/100 g and that the protein content of bar, crackers, breads, pancakes and, porridge samples was affected by the purple wheat flour content.

The hardness of the wheat chips enriched with PWF ranged from 17.20 kg to 39.61 kg (Table 2). The process factors had no obvious impact on the hardness content ($p>0.05$). The highest hardness value was obtained with a flour level of 50 g/100g at 170 °C for 50 s, whereas the lowest hardness content was observed with 0.0 g/100g with a PWF level of 50.0 g/100g at 180 °C frying temperature for 40 s. The response model's R2 score was 0.74, indicating that it explained 74% of the variability in hardness. Texture is one of the most important attributes that determine, the consumer acceptance of deep-fried foods such as chips. The hardness properties of samples are key parameters that describe the texture of fried foods. In the literature, the instrumental hardness contents of corn chips, wheat chips and wheat chips samples were found as follows; 7.8-17.9 kg (Rababah et al. 2012), 13.48-27.27 kg (Yuksel et al. 2015) and 7.54-35.37 kg (Cevik et al. 2022), respectively. These results in the literature are similar to the instrumental hardness results in our study.

Table 4. Results of model equality and determination coefficients.

Analyze	*Model*	R^2
Dry matter	$Y=-43.90+1.38A+0.25B+0.17C-0.002AB-0.0006AC-0.0006BC-0.003A^2+0.001B^2-0.0003C^2$	0.87
Ash	$Y=25.43-0.27A-0.02B+0.003C-0.0002AB+0.00004AC-0.002BC+0.0008A^2+0.0006B^2-0.00008C^2$	0.66
a_w	$Y=6.04-0.05A-0.03B+0.007C-0.0001AB+0.00001AC-0.00005BC+0.0001A^2+0.00001B^2-0.00001C^2$	0.87
Oil	$Y=311.44-3.61A+1.71B-0.33C-0.02AB+0.0007AC+0.0007BC+0.01A^2+0.02B^2+1.26C^2$	0.88
Protein	$Y=205.68-1.91A-1.13B-0.03C+0.009AB+0.0003AC-0.0001BC+0.004A^2-0.006B^2+0.00007C^2$	0.92
Hardness	$Y=1235.03-8.31A-19.12B+0.5C+0.1AB-0.002AC+0.001BC+0.014A^2+0.1B^2-0.0002C^2$	0.74
*L**	$Y=185.63-1.30A+1.86B-1.33C-0.01AB+0.005AC-0.0002BC+0.004A^2-0.0004B^2+0.001C^2$	0.94
*a**	$Y=17.81-0.35A-0.37B+0.53C+0.003AB-0.001AC-0.001BC+0.001A^2-0.001B^2-0.001C^2$	0.95
*b**	$Y=-131.39+1.54A-0.51B+0.27C+0.001AB-0.001AC-0.003BC-0.003A^2-0.006B^2-0.0001C^2$	0.92
Color	$Y=52.30-0.25A-0.73B-0.12C+0.005AB+0.001AC-0.0002BC-0.0002A^2-0.002B^2+0.00008C^2$	0.64
Hardness	$Y=166.45-1.34A-1.40B-0.12C+0.008AB+0.0007AC-0.00006BC+0.002A^2-0.001B^2+0.00007C^2$	0.77
Taste/Odor	$Y=112.01-0.89A-0.78B-0.1C+0.005AB+0.0006AC-0.0002BC+0.00015A^2-0.002B^2+0.00004C^2$	0.86
Oiliness	$Y=-34.90+0.73A-0.77B-0.17C+0.005AB+0.0009AC-0.00056BC-0.0028A^2-0.0014B^2-0.00012C^2$	0.56
Overall acceptability	$Y=30.26-0.0078A-0.74B-0.11C+0.006AB+0.00067AC-0.000017BC-0.00096A^2-0.0034B^2-0.000095C^2$	0.73

* A: Frying temperature, B: Frying time, C: PWF.

The mean values of the instrumental color properties of wheat chips samples are shown in Table 2. The PWF content and frying temperature showed significant effect on the color properties. The PWF content had a significant effect on the L*, a* and b* values, whereas the frying temperature had a significant effect on a* and b* value ($p<0.01$, $p<0.05$, Table 3). The maximum L* content was determined as a 67.95 with a PWF level of 0.0 g/100g at 180 °C frying temperature for 40 s, whereas the minimum L* content was observed to be 37.19 with a PWF level of 100.0 g/100g at 180 °C frying temperature for 60 s. The linear term of the PWF content negatively impacted the L* value ($p<0.05$). The response model's R2 value was 0.94, indicating that it explained 94% of the variability in L*. The a* value varied from 0.97 to 9.47 (Table 2). The linear term of the PWF and frying temperature positively affected the a* value ($p<0.01$). Also, the quadratic term of the PWF positively affected the a* value ($p<0.05$). The highest a* content was determined as a 9.47 g/100g with a PWF level of 50.0 g/100g at 190 °C frying temperature for 60 s while the lowest a* content was observed to be 0.97 with a PWF level of 0.0 g/100g at 170 °C frying temperature for 50 s. This regression model effectively predicts the a* content of the samples based on the PWF, frying temperature, and time due to its high coefficient of determination (R2 = 0.95, Table 4). The highest b* content was determined as a 33.42 with a PWF level of 0.0 g/100g at 180 °C frying temperature for 60 s while the lowest b* content was observed to be 19.69 with a PWF level of 100.0 g/100g at 170 °C frying temperature for 50 s. The linear term of the PWF and frying temperature negatively impacted the b* value ($p<0.01$, $p<0.05$). This regression model effectively predicts the b* content of the samples based on the PWF, frying temperature, and time due to its high coefficient of determination (R2 = 0.92, Table 4).

PWF negatively impacted the L* and b* values of the wheat chips. The purple color of the PWF could reduce the L* and b* values of the wheat chips. The frying temperature positively impacted the redness and yellowness of the wheat chips enriched with PWF. Caramelization and Maillard reactions could be connected to these findings. This non-enzymatic browning reaction (Caramelization and Maillard) leads to the formation of brown-colored complexes in foods, including carbohydrates. In addition, higher temperatures accelerate the caramelization reaction (Kaplan et al. 2021). Similar findings were reported for potato chips (Lee and Pangloli et al. 2014) and corn tortilla (Rojas-Molina et al. 2020).

3.2. Sensorial Properties

The color, firmness, and taste/odor, oiliness and overall acceptability of the wheat chips enriched with PWF were evaluated by the panelists. The process variables had no apparent impact on the color or oiliness. The linear term of the frying temperature and time negatively affected the taste/odor content ($p<0.05$, Table 5). Also, the interaction term of frying temperature and time significantly affected the firmness, taste/odor, and overall acceptability ($p<0.05$, Table 5). Otherwise, the PWF content showed no significant effect on the sensory properties ($p>0.05$, Table 5). The color score ranged from 5.60 to 7.40 and the maximum color value was determined as a 7.40 with a PWF level of 50 g/100g at 180 °C for 50 s, whereas the minimum color score was observed to be 5.60 with a PWF level of 50 g/100g at 170 °C for 60 s (Fig.2). The firmness score decreased with increasing process variables and, the hardness content of wheat chips samples varied from 5.20 to 7.67 (Fig.2). The highest firmness score of the sample was obtained with PWF 50 g/100g at 170 °C for 40 s. The taste/odor score ranged from 4.67 to 7.00 and the maximum taste/odor score was determined as a 7.00 with a PWF level of 50 g/100g at 170 °C for 40 s while the minimum taste/odor score was observed to be 4.67 with a PWF level of 50 g/100g at 180 °C for 50 s (Fig.2). The oiliness score varied from 4.47 to 6.87 and the lowest oiliness score was determined 4.47 with a PWF level of 50 g/100g at 170 °C for 60 s. The overall acceptability score varied from 5.07 to 7.20. The highest score

(7.20) was obtained using a PWF level of 50 g/100g at 170 °C for 40 s. The response models' R2 values ranged from 0.56 to 0.86, indicating that the models explained 56-86% of the variability in the sensory qualities.

Generally, the most common color of the chips product is golden yellow (Ozcan et al. 2021). In chips prepared with PWF, this color cannot be observed due to the color pigments from the PWF. However, this situation did not cause any negative situation in the panelists, and the colors of the chip samples prepared with PWF were liked. Similar findings were reported by Kumari et al. (2020) and Pasqualone et al. (2015), who observed an increase in the color score of chapatti and biscuits fortified with PWF. Crispness is a desirable sensory parameter in chips products (Durmaz & Yuksel 2021). The sensory hardness values showed that the increasing amount of PWF in the formulation did not negatively affect the friability of the final product. For this reason, it has been observed that chips products produced with PWF can be easily consumed by consumers. No spices other than salt were used in this study. The taste and odor of the chips products originated from PWF and WF. The frying conditions also affected the taste and odor. It was understood that the use of PWF in the production of chips did not cause a negative situation for the panelists and that it could easily be used in the production of chips. Similar findings have been reported for breads (Janeckova et al. 2014) and chapatti (Kumari et al. 2020).

Table 5. Variance analysis (F values) results of the effect of process variables on the changes in the sensory properties of the chips samples

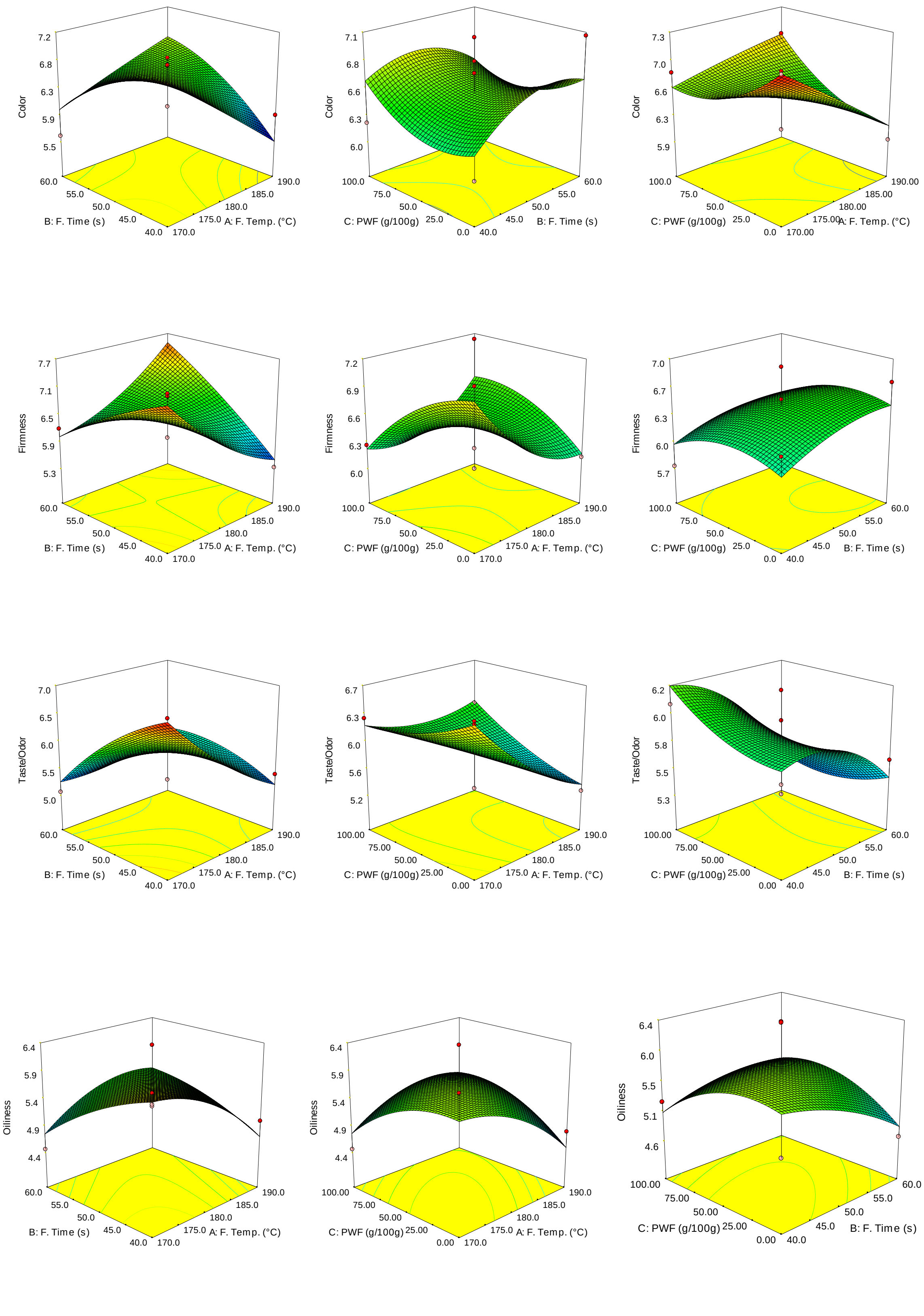
Source	Color	Firmness	Taste/Odor	Oiliness	Overall acceptability
A	1.10	0.45	7.69*	0.43	1.29
B	0.12	0.66	6.61*	0.31	0.017
C	0.089	0.28	0.38	0.012	7.746E-004
AB	4.26	11.95*	9.84*	2.02	6.92*
AC	1.83	2.03	3.11	1.62	2.14
BC	0.17	0.018	0.48	0.68	1.549E-003
A^2	4.798E-003	0.90	0.78	0.66	0.16
B^2	0.61	0.17	1.21	0.16	2.03
C^2	0.59	0.46	0.35	0.67	1.00
Model	0.99	1.89	3.41	0.71	1.47
Lack of fit	2.06	1.27	0.27	1.31	0.70

A: Frying temperature, B: Frying time, C: PWF. *p<0.05, **p<0.01

Table 6. Results of optimization.

Samples	Frying temperature (°C)	Frying time (s)	PWF (g/100g)	**Desirability**
1	170.00	40.00	92.72	**0.730**
2	170.00	40.00	91.30	0.730
3	170.12	40.00	92.20	0.726
4	170.04	40.00	99.94	0.726
5	170.20	40.00	91.23	0.724
6	170.00	40.00	67.54	0.704

* Values of 0.70 and above were taken for desirability.


Color
B: F. Time (s)
A: F. Temp. (°C)
Color
C: PWF (g/100g)
B: F. Time (s)
Color
C: PWF (g/100g)
A: F. Temp. (°C)
Firmness
B: F. Time (s)
A: F. Temp. (°C)
Firmness
C: PWF (g/100g)
A: F. Temp. (°C)
Firmness
C: PWF (g/100g)
B: F. Time (s)
Taste/Odor
B: F. Time (s)
A: F. Temp. (°C)
Taste/Odor
C: PWF (g/100g)
A: F. Temp. (°C)
Taste/Odor
C: PWF (g/100g)
B: F. Time (s)
Oiliness
B: F. Time (s)
A: F. Temp. (°C)
Oiliness
C: PWF (g/100g)
A: F. Temp. (°C)
Oiliness
C: PWF (g/100g)
B: F. Time (s)

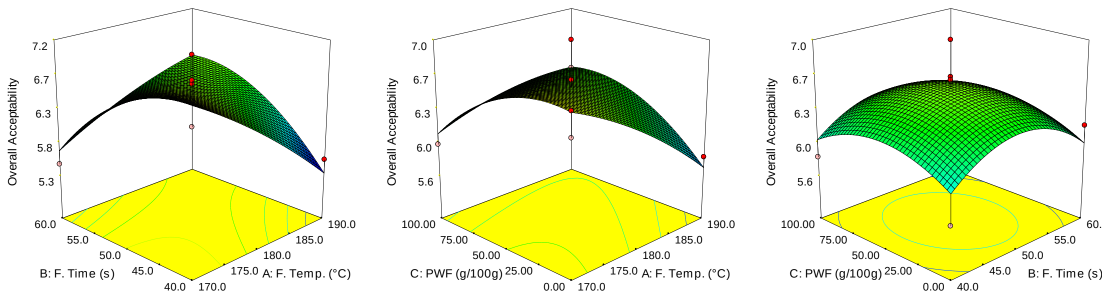


Figure 2. Three-dimensional representation of the sensory properties of chips samples

3.3. Optimization

The optimization results for wheat chips enriched with PWF are shown in Table 6. In addition, the change in the level of desirability according to the formulation variables for chips production conditions and the optimization data for the chips sample with the highest desirability are given in Table 6. The highest desirability value obtained because of the optimization made by considering the most liked points by the panelists was determined as 0.73. The flour formulation and production conditions to be used in the production of chips with the highest desirability are as follows: 92.72 g/100g PWF, 170 °C and 40 s. In addition, all other production conditions with desirability values of 0.70 and above are shown in Table 6. According to the optimization results, it was determined that the level of desirability increased as the content of PWF increased in the chips formulation, whereas the level of desirability decreased as the frying temperature and time increased.

4. Conclusions

PWF was added to the wheat chips to provide a nutritious snack. The addition of PWF into the chips sample formulation reduced the oil absorption of the resultant product. In addition, the protein content of chips samples increased with the addition of PWF. Higher and lower sensory scores were given for the enriched wheat chips by the panelists at the following process variables: 92.72 g/100g PWF, 170 °C, 40 s and 67.54 g/100g PWF, 170 °C, 40 s, respectively. Wheat chips enriched with PWF may find an opportunity to be commercialized as a healthy snack and alternative.

5.References

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