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Rheo logical properties of dough and bread quality characteristics as influenced by the proportion of wheat flour substitution with orange-fleshed sweet potato flour and baking conditions

Solomon Kofi Chikpah [a,b,*], Joseph Kudadam Korese [c], Oliver Hensel [a], Barbara Sturm [a,d,e], Elke Pawelzik [f]

[a] Department of Agricultural and Biosystems Engineering, Faculty of Organic Agricultural Sciences, University of Kassel, Nordbahnhoftsrasse 1a, 37213, Witzenhausen, Germany
[b] Department of Food Science and Technology, Faculty of Agriculture, Food and Consumer Sciences, University for Development Studies, Post Office Box TL 1882, Nyankpala Campus, Tamale, Ghana
[c] Department of Agricultural Mechanization and Irrigation Technology, Faculty of Agriculture, Food and Consumer Sciences, University for Development Studies, Post Office Box TL 1882, Nyankpala Campus, Tamale, Ghana
[d] Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB), Max-Eyth-Allee 100, 14469 Potsdam, Germany
[e] Humboldt-Universität zu Berlin, Albrecht Daniel Thaer-Institute of Agricultural and Horticultural Sciences, Hinter der Reinhardtsstrasse 6–8, 10115 Berlin, Germany
[f] Division Quality of Plant Products, Department of Crop Science, Faculty of Agricultural Sciences, Georg-August-Universität Göttingen, Carl-Sprengel-Weg 1, 37075, Göttingen, Germany

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ABSTRACT

This study investigated the influence of wheat flour substitution with 10–60% of peeled or unpeeled orange-fleshed sweet potato (OFSP) flour on dough rheological properties as well as the effects of the flour mixture, baking temperature (150–200 °C) and time (15–25 min) on the physical and textural properties of the composite bread. I-optimal (combined) design of the Design-Expert software was used for the experimental design whereas the flour mixture and baking conditions for wheat-OFSP composite bread formulation were optimized using the response surface methodology. Significant models were developed where lack-of-fit was insignificant ($p > 0.05$), coefficient of determination, R^2 and adjusted R^2 were greater than 0.90 for all response variables of the dough and bread. Farinograph optimum water absorption decreased whereas dough development time increased with increased OFSP flour addition. Moreover, increasing OFSP flour, baking temperature and time significantly ($p < 0.05$) decreased loaf volume, specific volume, crumb water activity, crust and crumb lightness, crumb springiness, cohesiveness and resilience whereas crust and crumb redness, hardness and chewiness increased. The substitution of wheat flour with 29.4 or 28.0% of peeled or unpeeled OFSP flour, respectively and baking at 180 °C for 15 min produced optimum dough and bread quality characteristics.

1. Introduction

Bread is consumed globally as a staple food (Azeem, Mu, & Zhang, 2020; Hager et al., 2012) and plays a crucial role in food and nutrition security. Wheat flour is the major raw material for breadmaking due to its gluten-forming proteins which provide unique quality properties for dough and bread (Azeem, Mu, & Zhang, 2020; Sahin, Wiertz, & Arendt, 2020). Studies have demonstrated that gluten forms a network structure that is responsible for the visco-elastic property and carbon dioxide gas retention ability of dough during fermentation and the early phase of baking (Barak, Mudgil, & Khatkar, 2013; Cappelli, Oliva, & Cini, 2020). According to Sahin et al. (2020), high-quality bread cannot be produced without gluten.

Despite the outstanding qualities of wheat flour for breadmaking, wheat flour is low in health-promoting bioactive compounds like vitamins, beta-carotene, polyphenols and flavonoids as well as dietary fibre (Liu, Zhao, Wang, & Liu, 2020). Additionally, wheat flour contains high amounts of digestible starch with a high glycemic index, which makes

* Corresponding author. Department of Agricultural and Biosystems Engineering, Faculty of Organic Agricultural Sciences, University of Kassel, Nordbahnhoftsrasse 1a, 37213 Witzenhausen, Germany.
E-mail address: schikpah@uds.edu.gh (S.K. Chikpah).

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wheat bread unsuitable for consumption by people with diabetic, hypertensive and other related cardiovascular disease conditions (Riccardi, Rivellese, & Giacco, 2008). Moreover, the cost of wheat flour in Sub-Saharan Africa (SSA) is high due to its importation. Therefore, to enhance the nutritional and health benefits of wheat bread as well as to minimise wheat flour importation in SSA, several studies were performed to explore the potentials of gluten-free flours for bread making. For example, flour or porridge from rice, maize and sorghum (Hager et al., 2012; Thiranusornkij, Thamnarathip, Chandrachai, Kuakpetoon, & Adisakwattana, 2019; Tsai et al., 2012), cassava, sweet potato and sorghum mixed (Monthe et al., 2019), potato and sweet potato (Zhao, Mu, & Sun, 2019; Carballo Pérez, Mu, Zhang, & Ji, 2017; Trejo-González, Loyo-González, & Mungui'a-Mazariegos, 2014) were used to produce bread.

Orange-fleshed sweet potato (OFSP), a biofortified cultivar of sweet potato is rich in beta carotene, a vitamin A precursor and other health-promoting bioactive compounds like polyphenols, flavonoid, and vitamin C as well as dietary fibre and minerals (Azeem, Mu, & Zhang, 2020; Chikpah, Korese, Hensel, & Sturm, 2020). High-quality OFSP flour has many potentials in the bakery industry such as to replace wheat flour, improve the eating quality, nutritional and health benefits of baked products (Korese, Chikpah, Hensel, Pawelzik, & Sturm, 2021). Azeem, Mu, & Zhang, 2020; Awuni, Alhassan, and Amagloh (2018); Edun, Olatunde, Shittu, and Adeogun (2018); Nzamwita, Duodu, and Minnaar (2017) studied the effect of incorporating OFSP flour or puree in wheat flour on bread quality. According to Edun et al. (2018), the substitution of wheat flour with peeled OFSP flour (10–30%) decreased specific volume and oven spring but increased crumb moisture and total carotenoids content. Also, Awuni et al. (2018) indicated that wheat-OFSP bread had higher dietary vitamin A content and consumer preference scores than the conventional bread samples.

Studies have shown that replacing wheat flour with gluten-free flour would dilute gluten and influence the dough and bread quality properties (Barros, Telis, Taboga, & Franco, 2018). Similarly, bread quality properties that are of interest to manufacturers and consumers are not only affected by the formulation ingredients such as flour but also the baking conditions used for breadmaking (Bredariol, Spatti, & Vanin, 2019). However, according to Azeem, Mu, & Zhang, 2020, a lot of the researchers focused on the effect of substituting wheat flour with 5–30% peeled OFSP flour on dough and bread quality properties. There is limited information on the influence of substituting wheat flour with different proportions of peeled and unpeeled OFSP flour on the rheological properties of bread dough as well as the effect of the flour proportions and baking conditions on the quality properties of wheat-OFSP composite bread.

This study, therefore, investigated the effects of wheat flour substitution with peeled or unpeeled OFSP flours on the rheological properties of dough as well as the effects of the flour mixture, baking temperature and time on the physical properties, textural profile and staling of the composite bread. Additionally, the study aimed at optimizing the wheat-OFSP flour mixture and baking conditions using the response surface methodology.

2. Materials and methods

2.1. Source and preparation of materials

Mature and non-damaged orange–fleshed sweet potato (OFSP) roots (*Ipomoea batatas* L.cv.CRI-Apomuden) harvested 100 days after planting were obtained from a commercial farm at Dambai, Krachi East Municipality of the Oti Region of Ghana. The roots (500 kg) were transported to the laboratory, stored under room condition (23 ± 1 °C) and processed within five days after the roots were harvested following the procedure described by Chikpah et al. (2020). The roots were manually washed, sorted and trimmed. Peeled and unpeeled OFSP roots were cut into smaller slices (3 mm thick) with the aid of an electric slicing machine (Ritter E16, Ritterwerk GmbH, Gröbenzell, Germany) followed by 5 min pretreatment in a sodium metabisulfite solution (5 g/L). The pretreated slices were spread out on perforated trays in a thin layer and dried in a "Hohenheim HT mini" cabinet dryer (Innotech-Ingenieursgesellschaft mbH, Altdorf Germany) at 60 °C air temperature for 4 h. The dried peeled and unpeeled OFSP slices were milled separately and sieved with a 250 μm aperture size mesh (Model: Setaccio Di Prova, Laboratory test sieve, Milano, Italy). The flour was packaged into well-labelled double high-density polyethylene (HDPE) bags, transported from Ghana to the University of Kassel, Witzenhausen, Germany where the flour was stored at 4 ± 1 °C for further use. Wheat flour, type 550 (protein of 11% on dry basis) and all other ingredients used for the bread preparation were purchased from Aldi-Nord supermarket, Goettingen, Germany.

2.2. Experimental design

The response surface methodology was used to investigate the effect of wheat flour substitution with either peeled or unpeeled OFSP flour on bread dough properties as well as the impact of the flour proportions and baking conditions on bread quality characteristics. A total of 17 experimental runs were created using the I-optimal (combined) design of the Design-Expert software version 11 (Stat-Ease Inc., Minneapolis, United States). The low and high limits of the flour mixture and processing factors were 40–90% for wheat flour (A), 10–60% for OFSP flour (B) whereas the baking temperature (C) and time (D) ranged between 150–200 °C, and 15–25 min, respectively. The response variables measured were dough farinograph parameters, unfermented dough pH, baking loss, loaf volume, specific volume, CIE-LAB colour of bread crust and crumb, crumb moisture content, water activity, textural properties, and staling rate.

2.3. Bread making procedure

The bread was prepared following the ICC standard No. 131 with slight modification based on Kieffer, Belitz, Zweier, Ipfelkofer, and Fischbeck (1993). The bread formula consists of composite flour (100 g on 14% moisture basis), water (based on farinograph optimal water absorption), baker's yeast (5%), sugar (1%), margarine (1%), and salt (1.5%) on basis of flour weight. The dough was kneaded with a farinograph (Farinograph-E, Brabender, GmbH & Co. KG, Duisburg, Germany) to optimum consistency based on the farinograph dough development time for each experimental run. The dough was fermented for 20 min at 30 °C and 85% relative humidity (RH) in a proofer (model UNOX XLT 133, Cadoneghe, Italy). The fermented dough was portioned into pieces (50 g), rounded by hand and kept for 3 min under room condition (23 ± 1 °C). After relaxation, the dough was rolled once using Delihom pasta making machine and folded to a shape similar to a croissant. This was followed by proofing for 35 min at 30 °C and 85 RH after which the dough pieces were baked in a professional oven with steam injection (Unox XFT133 ARIANNA, Cadoneghe, Italy) at temperature and time specified for each experimental run. Steam (100 mL water) was introduced into the oven during the first 45 s of baking. The baked bread was allowed to cool for 2 h at room temperature (23 ± 1 °C) after which the bread quality parameters were measured. After 2 h of cooling, some of the bread samples were packed in HDPE bags and stored at 25 °C and 50% RH for 24 h in a climatic chamber (VCL 4010, Vötsch Industrietechnik GmbH, Germany) to study crumb staling rate.

2.4. Determination of dough rheological properties and unfermented dough pH

The following farinograph parameters of dough (optimum water absorption, dough development time, stability time, and degree of softening) were measured with a farinograph (Farinograph-E, Brabender, GmbH & Co. KG, Duisburg, Germany) following the Americans

Table 1
Farinograph properties and pH of wheat–peeled and –unpeeled OFSP blended flour dough and ANOVA results.

Trial number	wheat flour (%)	Peeled OFSP flour (%)	OWA (%)	DDT (min)	ST (min)	DOS (BU)	pH
F1	65.12	34.88	58.9 ± 0.1^{e}	5.3 ± 0.1^{f}	6.4 ± 0.3^{gh}	131.5 ± 3.7^{a}	6.05 ± 0.01^{e}
F2	40.00	60.00	52.5 ± 0.3^{j}	9.6 ± 0.1^{a}	9.5 ± 0.1^{a}	60.0 ± 2.9^{i}	5.87 ± 0.01^{i}
F3	68.05	31.95	59.1 ± 0.2^{de}	4.9 ± 0.1^{g}	6.3 ± 0.2^{hi}	134.0 ± 1.3^{a}	6.07 ± 0.03^{de}
F4	40.00	60.00	52.7 ± 0.2^{j}	9.4 ± 0.1^{a}	9.5 ± 0.4^{a}	59.0 ± 2.5^{i}	5.86 ± 0.01^{i}
F5	90.00	10.00	60.1 ± 0.0^{a}	2.7 ± 0.1^{j}	7.4 ± 0.1^{d}	88.5 ± 4.1^{g}	6.23 ± 0.01^{a}
F6	40.00	60.00	52.6 ± 0.1^{j}	9.3 ± 0.1^{a}	9.6 ± 0.4^{a}	63.5 ± 3.3^{i}	5.85 ± 0.01^{i}
F7	40.00	60.00	52.5 ± 0.2^{j}	9.5 ± 0.3^{a}	9.4 ± 0.2^{a}	65.0 ± 1.8^{i}	5.84 ± 0.03^{i}
F8	65.12	34.88	58.3 ± 0.1^{e}	5.4 ± 0.1^{f}	6.5 ± 0.1^{gh}	130.0 ± 2.4^{a}	6.05 ± 0.02^{e}
F9	65.81	34.19	58.7 ± 0.3^{e}	5.1 ± 0.1^{f}	6.4 ± 0.1^{ghi}	133.0 ± 3.0^{a}	6.05 ± 0.01^{e}
F10	54.71	45.29	56.6 ± 0.1^{g}	6.7 ± 0.2^{d}	7.3 ± 0.1^{e}	116.9 ± 6.4^{d}	5.96 ± 0.01^{g}
F11	75.45	24.55	59.5 ± 0.1^{c}	4.0 ± 0.1^{h}	6.2 ± 0.2^{i}	129.5 ± 3.8^{c}	6.12 ± 0.01^{c}
F12	59.51	40.49	57.8 ± 0.2^{f}	6.3 ± 0.1^{e}	6.6 ± 0.3^{f}	125.5 ± 2.1^{b}	6.00 ± 0.01^{f}
F13	49.28	50.72	55.5 ± 0.1^{h}	7.8 ± 0.2^{c}	7.8 ± 0.1^{c}	104.3 ± 5.1^{f}	5.93 ± 0.01^{h}
F14	83.01	16.99	60.0 ± 0.1^{b}	3.3 ± 0.1^{i}	6.9 ± 0.2^{g}	115.6 ± 5.8^{e}	6.17 ± 0.01^{b}
F15	90.00	10.00	60.3 ± 0.0^{a}	2.9 ± 0.1^{j}	7.5 ± 0.4^{d}	90.5 ± 4.7^{g}	6.21 ± 0.03^{a}
F16	42.50	57.50	53.6 ± 0.3^{i}	8.8 ± 0.1^{b}	9.1 ± 0.3^{b}	70.0 ± 1.9^{h}	5.88 ± 0.01^{i}
F17	70.19	29.81	59.1 ± 0.2^{cd}	4.7 ± 0.2^{g}	6.2 ± 0.1^{hi}	133.8 ± 5.6^{a}	6.09 ± 0.01^{d}
Model			Quadratic	Quadratic	Quadratic	Quadratic	Linear
Model (F-value)			2490.58^{***}	3493.42^{***}	2919.73^{***}	1642.90^{***}	4497.73^{***}
Lack of fit (F-value)			1.230^{ns}	0.849^{ns}	0.662^{ns}	0.647^{ns}	0.307^{ns}
R^2			0.9972	0.9980	0.9976	0.9958	0.9967
Adjusted R^2			0.9968	0.9977	0.9973	0.9952	0.9965
Trial number	wheat flour (%)	unpeeled OFSP flour (%)	OWA (%)	DDT (min)	ST (min)	DOS (BU)	pH
F1	65.12	34.88	59.8 ± 0.1^{f}	4.5 ± 0.2^{fg}	5.9 ± 0.1^{g}	138.2 ± 3.3^{cd}	6.07 ± 0.02^{e}
F2	40.00	60.00	55.3 ± 0.1^{k}	8.7 ± 0.1^{a}	8.7 ± 0.1^{a}	73.5 ± 4.6^{k}	5.91 ± 0.02^{hi}
F3	68.05	31.95	60.6 ± 0.3^{e}	4.3 ± 0.3^{gh}	5.8 ± 0.2^{g}	140.1 ± 5.1^{a}	6.09 ± 0.00^{d}
F4	40.00	60.00	55.1 ± 0.2^{k}	8.6 ± 0.1^{a}	8.9 ± 0.3^{a}	71.8 ± 3.9^{k}	5.90 ± 0.01^{i}
F5	90.00	10.00	63.3 ± 0.1^{a}	2.5 ± 0.1^{j}	6.9 ± 0.2^{d}	93.7 ± 6.2^{i}	6.24 ± 0.01^{a}
F6	40.00	60.00	55.4 ± 0.2^{k}	8.5 ± 0.2^{a}	8.7 ± 0.2^{a}	70.5 ± 4.9^{k}	5.91 ± 0.01^{hi}
F7	40.00	60.00	55.5 ± 0.3^{k}	8.6 ± 0.1^{a}	8.8 ± 0.1^{a}	68.6 ± 5.0^{k}	5.91 ± 0.02^{hi}
F8	65.12	34.88	59.7 ± 0.2^{f}	4.8 ± 0.1^{f}	6.0 ± 0.4^{g}	137.0 ± 6.6^{d}	6.06 ± 0.02^{e}
F9	65.81	34.19	60.1 ± 0.1^{f}	4.7 ± 0.3^{f}	5.9 ± 0.2^{g}	139.2 ± 4.4^{b}	6.07 ± 0.03^{de}
F10	54.71	45.29	58.0 ± 0.1^{h}	6.2 ± 0.2^{d}	6.5 ± 0.1^{e}	122.9 ± 1.7^{f}	5.99 ± 0.01^{f}
F11	75.45	24.55	61.6 ± 0.3^{c}	3.6 ± 0.1^{i}	5.9 ± 0.3^{g}	133.1 ± 2.1^{e}	6.14 ± 0.01^{c}
F12	59.51	40.49	58.9 ± 0.4^{g}	5.7 ± 0.1^{e}	6.2 ± 0.2^{f}	134.0 ± 5.7^{e}	6.03 ± 0.01^{f}
F13	49.28	50.72	57.2 ± 0.2^{i}	7.1 ± 0.1^{c}	7.3 ± 0.1^{c}	107.2 ± 3.9^{h}	5.96 ± 0.03^{g}
F14	83.01	16.99	62.4 ± 0.1^{b}	2.9 ± 0.1^{j}	6.4 ± 0.2^{f}	116.8 ± 1.6^{g}	6.19 ± 0.02^{b}
F15	90.00	10.00	63.1 ± 0.3^{a}	2.6 ± 0.1^{j}	7.0 ± 0.2^{d}	92.5 ± 3.2^{i}	6.22 ± 0.01^{a}
F16	42.50	57.50	55.9 ± 0.2^{j}	8.2 ± 0.3^{b}	8.3 ± 0.1^{b}	81.3 ± 6.3^{j}	5.92 ± 0.01^{h}
F17	70.19	29.81	60.8 ± 0.1^{d}	4.1 ± 0.1^{h}	5.8 ± 0.1^{g}	138.7 ± 4.8^{bc}	6.10 ± 0.01^{d}
Model			Quadratic	Quadratic	Quadratic	Quadratic	Linear
Model (F-value)			3727.03^{***}	2277.83^{***}	1474.58^{***}	4117.27^{***}	7089.40^{***}
Lack of fit (F-value)			0.506^{ns}	0.817^{ns}	0.379^{ns}	0.457^{ns}	0.106^{ns}
R^2			0.9981	0.9969	0.9953	0.9983	0.9979
Adjusted R^2			0.9979	0.9965	0.9946	0.9981	0.9977

Values represent mean ± standard deviation (n = 3). Values within a column that have no superscript in common are significantly different ($p < 0.05$). OWA = Optimum water absorption; DDT = Dough development time; ST =Stability time; DOS = Degree of softening; ***P < 0.0001 and ns = not significant ($p > 0.05$).

Association of Cereal Chemists methods 54–21 (AACC, 2000). For each analysis, 50 g of flour (14% moisture basis) was used while the equipment chamber temperature and kneading speed were 30 °C, and 63 rpm, respectively. The pH of the dough was analysed using a pH meter (WTW inoLab pH level 1, GmbH & Co. KG, Weilheim, Germany) at 24 °C.

2.5. Assessment of bread quality characteristics

2.5.1. Baking loss, loaf volume and specific volume

The weight (g) of bread before (W_1) and 2 h after baking (W_2) was measured with a precision balance (KERN 572, KERN & SOHN GmbH, Germany) with ±0.001 g accuracy. The percentage of baking loss was calculated using Equation (1) (Ureta, Olivera, & Salvadori, 2014).

$$\text{Baking loss } (\%) = \frac{W1 - W2}{W1} \times 100 \quad (1)$$

The loaf volume (cm^3) was determined using the rapeseed displacement method described in AACC standard method 10–05.01 (AACC, 2000). The specific volume (cm^3/g) was calculated by dividing the loaf volume by its weight (Barros et al., 2018).

2.5.2. Crumb moisture content and water activity

The crumb moisture was measured with an electric oven (Memmert GmbH, Germany) using the oven-drying method (AACC, 2000). The water activity meter (Labswift-aw, Novasina AG, Switzerland) was used to measure the crumb water activity at 23 ± 1 °C.

2.5.3. Crust and crumb colour

The crust and crumb CIE-LAB L*, a*, b* colour parameters were measured at five different locations of the bread with a colorimeter (CR-400 Konica Minolta Inc., Japan). Before measurement, the equipment was calibrated with a standard white plate at D65 illumination (Y = 80.1, x = 0.3219, y = 0.3394). The bread edges (3 mm) were trimmed before taking the crust colour after which the crust was removed followed by measurement of the crumb colour.

2.5.4. Crumb textural profile analysis

The textural profile analysis (TPA) was conducted on bread crumbs

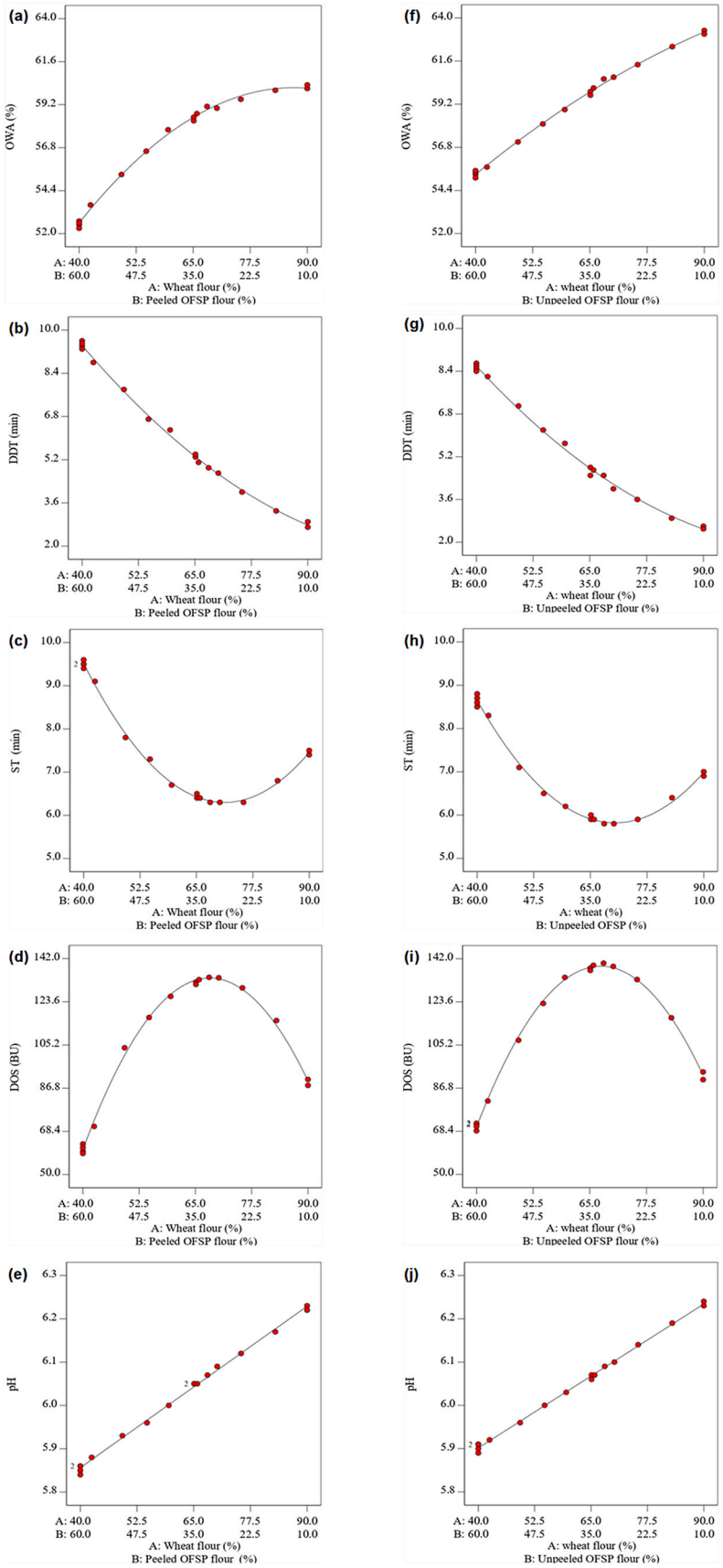

Fig. 1. Response surface graphs showing the effect of blend proportions on the optimum water absorption (OWA), dough development time (DDT), stability time (ST), degree of softening (DOS), and pH of wheat –peeled OFSP composite dough (a, b, c, d and e, respectively) and wheat–unpeeled OFSP composite dough (f, g, h, i and j, respectively).

after 2 h of baking and 24 h of storage using a texture analyzer (model TA.XT plus, Stable Micro Systems Ltd, Godalming, UK) equipped with Texture Exponent 32 software (SMS Ltd) following the procedure described by Hager et al. (2012) with modifications. The bread edges (3 mm) and crust were removed manually using a knife. The crumb was sliced manually with a stainless steel knife to 26 mm × 26 mm dimensions and a thickness of 20 mm. The bread dimensions were measured with a digital vernier caliper with ± 0.02 mm precision. The individual crumb slices were subjected to two consecutive unidirectional compression cycles using a 25-mm-diameter cylinder aluminium probe (SMS/P25), a 50 kg load cell, a trigger force of 0.098 N, a strain of 50% based on a trial experiment; pretest, test and post-test speeds of 1, 2 and 2 mm/s, respectively and holding time of 1 s. The textural parameters determined from the force-time graph of the TPA were: hardness (kg, the peak force of the first compression cycle), springiness (calculated by dividing the distance of the detected height of the second compression cycle by the original compression distance), cohesiveness (i.e. ratio of the positive force area of the second compression and the positive force area of the first compression cycle), resilience (i.e. the upstroke energy of the first compression cycle divided by the down-stroke energy of the first compression) and chewiness (kg, a product of hardness, cohesiveness and springiness). The staling rate of crumbs was determined using Equation (2) (Sahin et al., 2020).

$$\text{Staling rate} = \frac{\textit{Crumb hardness (kg) after 24 h storage} - \textit{Crumb hardness (kg) after 2 h of baking}}{\textit{Crumb hardness (kg) after 2 h of baking}} \quad (2)$$

2.6. Optimization procedure

Optimization of the mixture components and baking conditions in terms of the wheat-OFSP composite dough and bread quality properties was performed using the modified desirability function method (Derringer & Suich, 1980) with the aid of the Design-Expert software version 11.1.2.0 (Stat-Ease Inc., Minneapolis, United States). This optimization technique is frequently used for simultaneous optimization of multi-response variables (Del Castillo, Montgomery, & McCarville, 1996; Derringer & Suich, 1980). The desirability method involved the application of mathematical methods to transform a multivariate problem into a univariate problem (Del Castillo et al., 1996; Derringer & Suich, 1980). The desirability function method converts each measured response variable (Y_i) to an individual desirable index (d_i), whose value range between 0 (unacceptable) and 1 (most acceptable) followed by the calculation of the geometric mean or global desirability of the response variables using Equation (3) (Derringer & Suich, 1980).

$$D = [d_1(Y_1) \times d_2(Y_2) \times d_3(Y_3) \ldots \ldots d_k(Y_k)]^{1/k} \quad (3)$$

Where D = global desirability index, k = number of response variables.

2.7. Statistical analysis

Statistical analyses were performed using the Response Surface Methodology (RSM) of the Design-Expert software version 11.1.2.0 (Stat-Ease Inc., Minneapolis, United States). The best-crossed model for mixture and process factors for each response variable was chosen using the combined model fit summary followed by an assessment of model fitness using the analysis of variance (ANOVA). Model selection focused on the model with the highest order polynomial where additional model terms were significant ($p < 0.05$) and not aliased; lack of fit was insignificant ($p > 0.05$) as well as maximizing the coefficient of determination (R^2) and adjusted R^2. Also, where many insignificant model terms that did not support model hierarchy existed, a model reduction was applied using the p-value criterion (alpha = 0.1) and a backward selection to improve the model. The normal residuals plot and Box-Cox plots for power transforms were used to diagnose the normality of the response data. All the response data were adequately normal and no response transformation was applied. Moreover, a One-way ANOVA followed by Tukey's test ($p < 0.05$) were performed using SPSS software (IMB SPSS Statistics, version 25) to determine the significant differences ($p < 0.05$) between the dough and bread quality characteristics of the various formulations. Additionally, Principal Component Analysis (PCA) was conducted using XLSTAT software (Version 2018.1, Addinsoft, 2018) to establish the relationship between the responses and also to distinguish among the bread samples (Altamirano-Fortoul & Rosell, 2011).

3. Results and discussion

3.1. Dough rheological properties and unfermented dough pH

Table 1 shows the farinograph optimum water absorption (OWA, %), dough development time (DDT, min), stability time (ST, min), degree of softening (DOS, BU) and pH of the wheat-peeled and –unpeeled OFSP flour blended doughs as influenced by the proportions of wheat and OFSP flours. The average OWA, DDT, ST, DOS and pH values ranged between 52.5–60.3%, 2.7–9.6 min, 6.2–9.6 min, 60.0–134.0 BU and 5.84–6.23, respectively for wheat-peeled OFSP composite dough and 55.1–63.3%, 2.5–8.7 min, 5.8–8.9 min, 68.6–140.1 BU and 5.90–6.24 for wheat-unpeeled composite doughs respectively. The results showed a continuous decrease in OWA and pH, and increase DDT as wheat flour substitution with OFSP flour was increased from 10–60% (Fig. 1). Conversely, dough ST reduced whereas DOS increased up to 35% OFSP flour addition, thereafter, further increase in OFSP flour resulted in increased dough ST and decreased DOS (Fig. 1). The results of the current study partially disagreed with the findings of Trejo-Gonzalez, Loyo-González, and Munguía-Mazariegos (2014), who reported a slight increased in OWA with decreased DDT and dough ST when wheat flour was replaced by 10–20% peeled sweet potato flour. This could be attributed to differences in the chemical compositions of the flours. According to Dhaka and Khatkar (2015), increasing the gluten content of wheat flour resulted in an increased water absorption since gluten-forming proteins can absorb a considerable amount of water in their interconnected network and interaction with starch granules. Therefore, the decreased OWA observed among the composite doughs can be attributed to the dilution of gluten by the OFSP flour. According to Kwa, Tock, and Osman (1976), increasing sugar content in wheat flour reduced free water required for the formation of gluten network in the dough and consequently increased DDT. Other studies have demonstrated that increasing the fibre content of flour increased DDT and dough ST while DOS reduced (Gómez, Ronda, Blanco, Caballero, & Apesteguía, 2003). Therefore, the high sugar and fibre content reported in OFSP flour (Chikpah et al., 2020), may be responsible for the increased in DDT of the wheat-OFSP composite as well as the increased in dough ST and decreased DOS as OFSP flour exceeded 35%. Moreover, the decreasing trend for dough pH as OFSP proportion increased can be attributed to the high ascorbic acid content of OFSP flour (Chikpah et al.,

Table 2
Physical characteristics of wheat–peeled and –unpeeled OFSP bread as influenced by blend proportions and baking conditions.

Trial number	Wheat flour (%)	Peeled OFSP flour (%)	Baking tempt. (^{o} C)	Baking time (min)	Baking loss (%)	Loaf volume (cm^3/100 g flour)	Specific volume (cm^3/g)	Crumb moisture (%)	Crumb a_w
F1	65.12	34.88	170	19	25.07 ± 0.12^{g}	290.55 ± 0.71^{e}	2.42 ± 0.09^{e}	32.78 ± 0.11^{e}	0.887 ± 0.001^{e}
F2	40.00	60.00	170	25	26.92 ± 0.16^{e}	183.29 ± 1.41^{m}	1.59 ± 0.15^{l}	27.29 ± 0.07^{m}	0.848 ± 0.001^{l}
F3	68.05	31.95	200	21	31.69 ± 0.28^{b}	241.10 ± 1.39^{i}	2.15 ± 0.08^{h}	25.32 ± 0.09^{n}	0.866 ± 0.003^{k}
F4	40.00	60.00	180	15	19.97 ± 0.05^{i}	202.71 ± 2.83^{l}	1.73 ± 0.02^{k}	30.78 ± 0.15^{h}	0.870 ± 0.002^{ij}
F5	90.00	10.00	150	17	18.91 ± 0.11^{j}	330.09 ± 4.55^{b}	2.61 ± 0.11^{b}	36.30 ± 0.08^{c}	0.927 ± 0.001^{a}
F6	40.00	60.00	200	19	28.55 ± 0.04^{d}	174.36 ± 1.12^{n}	1.60 ± 0.06^{l}	28.83 ± 0.04^{l}	0.844 ± 0.001^{l}
F7	40.00	60.00	150	21	18.42 ± 0.06^{k}	209.52 ± 2.63^{k}	1.71 ± 0.12^{k}	29.18 ± 0.13^{k}	0.873 ± 0.002^{hi}
F8	65.12	34.88	170	19	25.21 ± 0.13^{g}	292.48 ± 3.80^{e}	2.45 ± 0.07^{e}	32.80 ± 0.02^{e}	0.887 ± 0.001^{e}
F9	65.81	34.19	180	23	29.62 ± 0.09^{c}	252.07 ± 2.46^{h}	2.21 ± 0.03^{g}	29.43 ± 0.06^{j}	0.876 ± 0.001^{gh}
F10	54.71	45.29	160	23	26.04 ± 0.17^{f}	261.85 ± 1.93^{g}	2.19 ± 0.05^{gh}	31.12 ± 0.03^{g}	0.882 ± 0.001^{f}
F11	75.45	24.55	180	21	29.82 ± 0.08^{c}	301.25 ± 3.01^{d}	2.57 ± 0.08^{c}	30.05 ± 0.08^{i}	0.890 ± 0.003^{e}
F12	59.51	40.49	180	17	25.46 ± 0.13^{g}	280.56 ± 1.84^{f}	2.35 ± 0.13^{f}	31.50 ± 0.14^{f}	0.879 ± 0.001^{fg}
F13	49.28	50.72	150	15	12.40 ± 0.10^{l}	253.79 ± 1.35^{h}	2.04 ± 0.19^{i}	39.77 ± 0.09^{a}	0.872 ± 0.001^{hi}
F14	83.01	16.99	150	19	23.09 ± 0.31^{h}	357.25 ± 4.08^{a}	2.87 ± 0.22^{a}	39.16 ± 0.06^{b}	0.920 ± 0.001^{b}
F15	90.00	10.00	200	21	33.19 ± 0.19^{a}	291.83 ± 2.15^{e}	2.52 ± 0.03^{d}	20.56 s $\pm$ 0.04°	0.894 ± 0.002^{d}
F16	42.50	57.50	160	19	19.20 ± 0.23^{j}	221.27 ± 1.77^{j}	1.84 ± 0.18^{j}	32.70 ± 0.18^{e}	0.868 ± 0.002^{ik}
F17	70.19	29.81	160	19	23.50 ± 0.18^{h}	313.69 ± 3.25^{c}	2.56 ± 0.05^{cd}	35.28 ± 0.10^{d}	0.898 ± 0.001^{c}
Model (mixture × baking conditions)					Linear × 2Fl	Linear × 2Fl	Linear × 2Fl	Linear × 2Fl	Linear × 2Fl
F-value (model)					9358.35^{***}	9595.86^{***}	4537.18^{***}	47787.38^{***}	2899.74^{***}
F-value (lack of fit)					0.355^{ns}	0.291^{ns}	1.430^{ns}	0.776^{ns}	0.368^{ns}
Adjusted R^2					0.9969	0.9981	0.9964	0.9978	0.9984
Trial number	Wheat flour (%)	Unpeeled OFSP flour (%)	Baking tempt. (^{o} C)	Baking time (min)	Baking loss (%)	Loaf volume (cm^3/100 g flour)	Specific volume (cm3/g)	Crumb moisture (%)	Crumb a_w
F1	65.12	34.88	170	19	27.52 ± 0.05^{g}	240.25 ± 1.80^{e}	2.09 ± 0.17^{g}	33.38 ± 0.04^{e}	0.879 ± 0.003^{e}
F2	40.00	60.00	170	25	29.45 ± 0.07^{e}	167.45 ± 2.24^{k}	1.47 ± 0.03^{m}	27.71 ± 0.12^{l}	0.842 ± 0.001^{k}
F3	68.05	31.95	200	21	34.75 ± 0.24^{b}	218.03 ± 1.89^{h}	2.11 ± 0.06^{f}	25.59 ± 0.03^{m}	0.859 ± 0.001^{j}
F4	40.00	60.00	180	15	21.79 ± 0.11^{i}	201.75 ± 4.02^{j}	1.61 ± 0.20^{j}	31.21 ± 0.06^{h}	0.862 ± 0.002^{ij}
F5	90.00	10.00	150	17	20.78 ± 0.13^{j}	279.90 ± 1.63^{a}	2.30 ± 0.07^{d}	36.83 ± 0.09^{c}	0.920 ± 0.001^{a}
F6	40.00	60.00	200	19	31.16 ± 0.09^{d}	165.53 ± 2.56^{l}	1.53 ± 0.09^{l}	29.29 ± 0.15^{k}	0.837 ± 0.004^{l}
F7	40.00	60.00	150	21	20.14 ± 0.13^{k}	203.15 ± 0.97^{i}	1.56 ± 0.04^{k}	29.64 ± 0.11^{j}	0.865 ± 0.001^{hi}
F8	65.12	34.88	170	19	27.54 ± 0.21^{g}	240.30 ± 1.93^{e}	2.05 ± 0.11^{g}	33.39 ± 0.04^{e}	0.880 ± 0.001^{de}
F9	65.81	34.19	180	23	32.44 ± 0.11^{c}	222.35 ± 3.17^{g}	2.07 ± 0.14^{g}	29.87 ± 0.16^{j}	0.868 ± 0.002^{gh}
F10	54.71	45.29	160	23	28.58 ± 0.27^{f}	222.41 ± 1.38^{g}	1.94 ± 0.09^{i}	31.59 ± 0.10^{g}	0.874 ± 0.001^{f}
F11	75.45	24.55	180	21	32.67 ± 0.19^{c}	251.60 ± 4.11^{d}	2.37 ± 0.05^{c}	30.52 ± 0.02^{i}	0.884 ± 0.001^{d}
F12	59.51	40.49	180	17	27.91 ± 0.10^{g}	231.92 ± 3.71^{f}	2.03 ± 0.10^{h}	31.94 ± 0.05^{f}	0.871 ± 0.001^{fg}
F13	49.28	50.72	150	15	13.58 ± 0.06^{l}	218.85 ± 2.85^{h}	1.57 ± 0.13^{k}	40.42 ± 0.20^{a}	0.866 ± 0.002^{hi}
F14	83.01	16.99	150	19	25.29 ± 0.14^{h}	279.90 ± 1.17^{a}	2.41 ± 0.08^{b}	39.69 ± 0.11^{b}	0.912 ± 0.003^{b}
F15	90.00	10.00	200	21	36.35 ± 0.08^{a}	271.25 ± 1.99^{b}	2.66 ± 0.24^{a}	20.82 ± 0.07^{n}	0.889 ± 0.001^{c}
F16	42.50	57.50	160	19	21.01 ± 0.34^{j}	201.63 ± 3.40^{j}	1.58 ± 0.05^{k}	33.09 ± 0.13^{e}	0.860 ± 0.001^{j}
F17	70.19	29.81	160	19	25.79 ± 0.26^{h}	253.95 ± 2.58^{c}	2.17 ± 0.21^{e}	35.70 ± 0.08^{d}	0.891 ± 0.002^{c}
Model (mixture × baking conditions)					Linear × 2Fl	Linear × 2Fl	Linear × 2Fl	Linear × 2Fl	Linear × 2Fl
F-value (model)					10589.10^{***}	11796.42^{***}	$534.40.74^{***}$	19781.94^{***}	2284.46^{***}
F-value (lack of fit)					0.336^{ns}	0.415^{ns}	0.225^{ns}	0.926^{ns}	0.662^{ns}
Adjusted R^2					0.9980	0.9994	0.9957	0.9962	0.9979

Values represent mean ± standard deviation (n = 3). Values within a column that have no superscript in common are significantly different ($p < 0.05$). tempt. = temperature; a_w = water activity; comp. = components; $^{***}P < 0.0001$ and ns = not significant.

2020). Generally, the wheat–peeled OFSP composite dough had lower OWA and DOS but longer DDT and ST as compared with the wheat–unpeeled OFSP mixed dough.

The quadratic model fitted the dough rheological properties whereas the pH data was best described by a linear model. The model and model terms were highly significant ($p < 0.0001$), lack-of-fit was insignificant, coefficient of determination, R^2 and the adjusted R^2 for all the dough response variables were higher than 0.90 (Table 1). The models developed were highly sufficient since the R^2 was greater than 0.80 (Gan et al., 2007). The actual model equations for OWA and DDT of wheat-peeled and -unpeeled OFSP composite dough as influenced by wheat flour (A) and OFSP flour (B) proportions (%) are shown in Equations (4) and (5), respectively.

$$\text{OWA}_{\text{(wheat-peeled OFSP)}} = 0.5958A + 0.3431B + 0.0034AB \quad (4a)$$

$$\text{OWA}_{\text{(wheat-unpeeled OFSP)}} = 0.6420A + 0.4535B + 0.0010AB \quad (4b)$$

$$\text{DDT}_{\text{(wheat-peeled OFSP)}} = 0.0219A + 0.1923B–0.0012AB \quad (5a)$$

$$\text{DDT}_{\text{(wheat-unpeeled OFSP)}} = 0.0202A + 0.1792B–0.0012AB \quad (5b)$$

3.2. Physical properties of the bread

Mostly, high-quality bread has been characterized by a high specific volume (Sahin et al., 2020; Lapčíková, Burešová, Lapčík, Dabash, & Valenta, 2019). However, a low baking loss and water activity of bread are also desirable. The baking loss, loaf volume, specific volume, crumb moisture and water activity (a_w) of the experimental bread varied between 12.40 and 33.19%, 174.36–357.25 cm^3/100 g flour, 1.59–2.87 cm^3/g, 20.56–39.77% and 0.844 and 0.927, respectively for the wheat-OFSP composite bread whereas the values for wheat-unpeeled OFSP composite bread varied between 13.58 and 36.35%, 165.53–279.90 cm^3/100 g flour, 1.47–2.66 cm^3/g, 20.82–40.41%, and 0.837–0.920, respectively (Table 2). The baking loss, loaf volume, specific volume, crumb moisture content and a_w of the wheat-OFSP bread were significantly ($p < 0.05$) affected by the wheat flour (A, %) and OFSP flour (B, %), baking temperature (C) and time (D). Generally, irrespective of the baking conditions, increasing the proportion of OFSP flour decreased the loaf volume and specific volume of the composite bread (Fig. 2). Similarly, Edun et al. (2018) reported a decrease in bread specific volume when wheat flour was replaced with 10–30% OFSP flour. The formation of a gluten network structure during bread making is responsible for the visco-elastic property of dough and carbon dioxide gas retaining ability during fermentation and early stages of baking (Barak et al., 2013; Cappelli et al., 2020). Starch granules in flour interact with gluten to form starch–starch and starch–gluten interactions during dough mixing which are crucial for dough elasticity (Mohammed, Tarleton, Charalambides, & Williams, 2013). Studies have shown that gelatinization of starch during baking causes an increase in dough viscosity, minimise dough extensibility, and increase pressure in closed gas cells resulting to rupture of gas cell membranes (Gan et al., 1990; Zhang, Lucas, Doursat, Flick, & Wagner, 2007). According to Kusunose, Fujii, and Matsumoto (1999) potato starch flour gelatinizes very early during the baking phase due to its lower gelatinization temperature and reduced dough expansion, an action that resulted in a lower loaf volume, specific volume and oven spring than wheat starch flour bread. Therefore, the substitution of wheat flour with OFSP flour dilutes-gluten as well as lower starch gelatinization temperature and subsequently cause a decline in loaf volume and specific volume of the composite bread. The crumb a_w also decreased with increased OFSP flour proportion. This could be attributed to the fibre and sugars in OFSP flour which can absorb free water and reduce its availability in the final baked product (Korese, Chikpah, Hensel, Pawelzik, & Sturm, 2021).

The loaf volume and specific volume decreased with increasing baking temperature (Fig. 2). This contradicts with findings of Bredariol et al. (2019), who found no significant difference in the specific volume of wheat bread as the baking temperature increased from 160 to 190 °C with steam injection. This variation could be due to the difference in the chemical composition of flours. Generally, the baking loss increased whereas crumb moisture content and a_w declined with increased baking temperature (Fig. 2). The baking process is characterized by the evaporation of moisture from the dough. Therefore, increasing the baking temperature and time result in an increase moisture loss from bread (Bredariol et al., 2019) and hence, decrease crumb moisture and a_w while increase baking loss.

The physical properties of the wheat-OFSP composite bread discussed above were best described by a linear × 2Fl (flour mixture × baking conditions) crossed-model. The model and model terms (A, B, AC, AD, BC, BD, ACD and BCD) were significant ($p < 0.0001$), the lack of fit was insignificant ($p > 0.05$) and the adjusted R^2 values ranged between 0.9943 and 0.9994 (Table 2).

The model equations that described the specific volume of wheat-peeled and –unpeeled OFSP composite bread are shown in Equations (6a) and (6b), respectively.

$$\text{Specific volume } (cm^3/g) = -0.4086113A + 0.3977940B + 0.0025885AC + 0.0229652AD - 0.0022512BC - 0.0198059BD - 0.0001344ACD + 0.0001138BCD \quad (6a)$$

$$\text{Specific volume } (cm^3/g) = -0.1531041A + 0.0553074B + 0.0010238AC + 0.0089042AD - 0.0002406BC - 0.0021264BD - 0.0000499ACD + 0.0000099BCD \quad (6b)$$

Equations (7a) and (7b) indicate the model equations for crumb moisture of the wheat-peeled and -unpeeled OFSP bread respectively.

$$\text{Crumb moisture } (\%) = -2.9464690A + 6.5519180B + 0.0190130AC + 0.2032400AD - 0.0352590BC - 0.3360410BD - 0.0011760ACD + 0.0018950BCD \quad (7a)$$

$$\text{Crumb moisture } (\%) = -2.9882420A + 6.6658390B + 0.0192798AC + 0.2062015AD - 0.0358802BC - 0.3419132BD - 0.0011934ACD + 0.0019282BCD \quad (7b)$$

3.3. Crust and crumb colour

Bread colour is an important quality property that influences consumer acceptability. The colour of bread is dependent on flour and chemical reactions like Maillard reaction that occurs during baking (Barros et al., 2018). The lightness (L*), redness (a*) and yellowness (b*) values of the crust and crumb varied significantly ($p < 0.05$) among the various wheat-OFSP composite bread formulations (Table 3). It was obvious from the contour plots (Fig. 3) that the bread crust and crumb L* values decreased whereas a* and b* increased with the addition of OFSP flour. This can be linked to the high beta-carotene and other pigments in OFSP flours (Chikpah et al., 2020). Also, bread crust L* and b* reduced greatly while a* increased as the baking conditions increased. This can be attributed to the Maillard reaction during baking (Barros et al., 2018), facilitated by the reducing sugar in OFSP flour and increasing heat intensity. The L*, a* and b* colour data of the wheat-OFSP composite bread were described by linear × 2Fl model (flour mixture × baking conditions), adjusted R^2 values ranged from 0.9946 to 0.9995 and the lack of fit was insignificant (Table 3).

3.4. Textural properties and staling of bread crumbs

Mostly, soft and springy crumb are characteristics of high-quality bread (Lapčíková et al., 2019; Sahin et al., 2020). The crumb textural properties (hardness, springiness, cohesiveness, chewiness and resilience) differed significantly ($p < 0.05$) among the wheat-peeled and

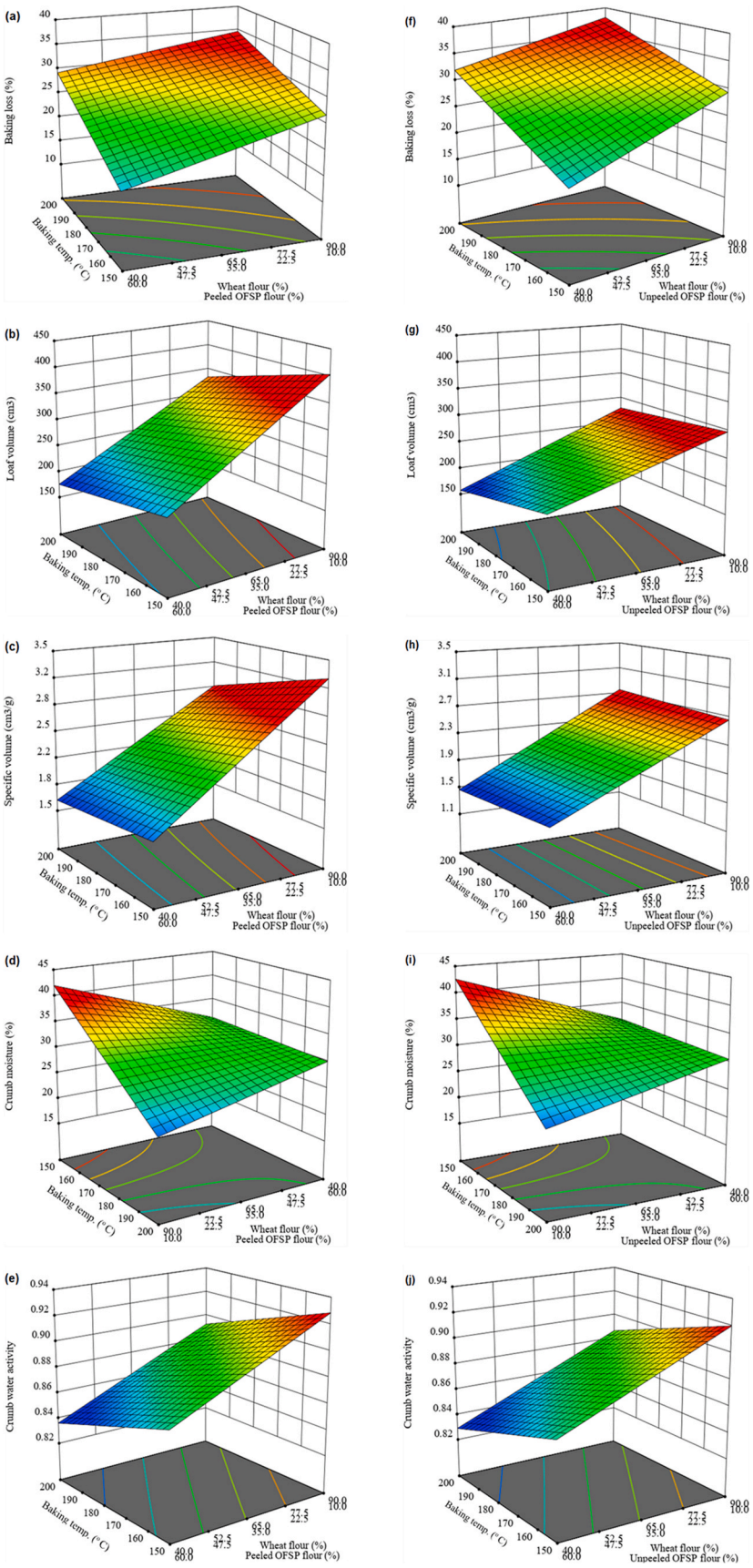

Fig. 2. Response surface plots showing the effect of flour proportion, baking temperature and baking time (20 min) on the baking loss, loaf volume, specific volume, crumb moisture content and water activity of wheat-peeled OFSP blended bread (a, b, c, d and e, respectively) and wheat-unpeeled OFSP blended bread (f, g, h, i and j, respectively).

Table 3
Crust and crumb CIELAB L*, a* b* colour parameters of wheat-peeled OFSP and -unpeeled OFSP composite bread.

Trial number	Wheat flour (%)	Peeled OFSP flour (%)	Baking tempt. (°C)	Baking time (min)	Crust colour			Crumb colour		
					L*	a*	b*	L*	a*	b*
F1	65.12	34.88	170	19	49.82 ± 0.92^{f}	10.01 ± 0.04^{d}	11.84 ± 0.34^{h}	60.42 ± 0.06^{e}	4.12 ± 0.01^{e}	25.68 ± 0.18^{g}
F2	40.00	60.00	170	25	35.48 ± 1.03^{l}	16.59 ± 0.37^{a}	15.91 ± 0.81^{c}	41.07 ± 0.08^{k}	5.22 ± 0.06^{c}	34.64 ± 0.20^{b}
F3	68.05	31.95	200	21	31.22 ± 0.75^{m}	11.67 ± 0.18^{c}	10.43 ± 0.55^{k}	54.06 ± 0.04^{g}	2.44 ± 0.08^{gh}	22.57 ± 0.15^{i}
F4	40.00	60.00	180	15	43.14 ± 0.82^{i}	14.13 ± 0.18^{b}	17.03 ± 0.23^{b}	45.34 ± 0.23^{j}	7.28 ± 0.01^{a}	37.12 ± 0.05^{a}
F5	90.00	10.00	150	17	67.91 ± 1.22^{a}	3.87 ± 0.12^{g}	$6.30 \pm 0.87^{\circ}$	68.70 ± 0.09^{a}	1.47 ± 0.02^{i}	13.60 ± 0.06^{m}
F6	40.00	60.00	200	19	26.12 ± 0.64^{n}	16.55 ± 0.41^{a}	15.61 ± 0.25^{d}	38.20 ± 0.17^{l}	5.35 ± 0.07^{c}	33.81 ± 0.04^{c}
F7	40.00	60.00	150	21	52.59 ± 1.43^{e}	14.29 ± 0.31^{b}	17.44 ± 0.11^{a}	47.89 ± 0.31^{i}	7.36 ± 0.15^{a}	37.59 ± 0.15^{a}
F8	65.12	34.88	170	19	49.49 ± 1.17^{f}	10.03 ± 0.08^{d}	11.82 ± 0.18^{h}	60.41 ± 0.19^{e}	4.05 ± 0.21^{ef}	25.78 ± 0.09^{g}
F9	65.81	34.19	180	23	39.66 ± 0.86^{j}	11.53 ± 0.42^{c}	10.57 ± 0.60^{j}	58.45 ± 0.06^{f}	2.64 ± 0.08^{g}	22.93 ± 0.16^{hi}
F10	54.71	45.29	160	23	48.84 ± 1.15^{g}	13.74 ± 0.07^{b}	14.19 ± 0.09^{e}	55.16 ± 0.25^{g}	4.78 ± 0.03^{d}	30.81 ± 0.06^{d}
F11	75.45	24.55	180	21	45.01 ± 0.36^{h}	10.03 ± 0.11^{d}	9.65 ± 0.12^{l}	63.81 ± 0.81^{d}	2.39 ± 0.04^{gh}	21.05 ± 0.03^{j}
F12	59.51	40.49	180	17	45.11 ± 0.95^{h}	11.50 ± 0.45^{c}	13.52 ± 0.47^{f}	55.13 ± 0.73^{g}	5.01 ± 0.03^{cd}	29.43 ± 0.05^{e}
F13	49.28	50.72	150	15	58.58 ± 1.13^{c}	5.38 ± 0.27^{f}	12.97 ± 0.18^{g}	64.64 ± 0.44^{cd}	6.90 ± 0.02^{b}	28.38 ± 0.21^{f}
F14	83.01	16.99	150	19	64.99 ± 1.26^{b}	5.97 ± 0.34^{f}	8.04 ± 0.58^{m}	67.93 ± 0.23^{b}	2.21 ± 0.02^{h}	17.39 ± 0.10^{k}
F15	90.00	10.00	200	21	38.56 ± 0.51^{k}	9.30 ± 0.08^{de}	7.52 ± 0.71^{n}	63.88 ± 0.69^{cd}	0.83 ± 0.01^{j}	16.20 ± 0.15^{l}
F16	42.50	57.50	160	19	49.03 ± 1.02^{g}	12.27 ± 0.05^{c}	15.83 ± 0.29^{c}	51.83 ± 0.35^{h}	6.86 ± 0.09^{b}	34.51 ± 0.04^{b}
F17	70.19	29.81	160	19	56.27 ± 1.16^{d}	8.58 ± 0.03^{e}	10.72 ± 0.50^{i}	65.16 ± 0.21^{c}	3.69 ± 0.13^{f}	23.41 ± 0.07^{h}
Model (mixture × baking conditions)					Linear × 2Fl	Linear × 2Fl	Linear × 2Fl	Linear × 2Fl	Linear × 2Fl	Linear × 2Fl
F-value (model)					48510.00***	2066.98***	62021.15***	5819.31***	3171.67***	15130.04***
F-value (lack of fit)					0.413^{ns}	0.284^{ns}	0.804^{ns}	0.102^{ns}	0.206^{ns}	0.716^{ns}
Adjusted R^2					0.9946	0.9977	0.9989	0.9992	0.9985	0.9967
Trial number	Wheat flour (%)	Unpeeled OFSP flour (%)	Baking tempt. (°C)	Baking time (min)	Crust colour			Crumb colour		
					L*	a*	b*	L*	a*	b*
F1	65.12	34.88	170	19	47.75 ± 0.59^{f}	8.80 ± 0.17^{e}	9.71 ± 0.04^{f}	53.15 ± 0.16^{fg}	3.86 ± 0.13^{f}	24.95 ± 0.11^{g}
F2	40.00	60.00	170	25	34.57 ± 0.71^{l}	14.93 ± 0.15^{a}	13.07 ± 0.02^{c}	51.13 ± 0.27^{hi}	5.04 ± 0.09^{d}	33.58 ± 0.05^{b}
F3	68.05	31.95	200	21	30.07 ± 1.05^{m}	10.45 ± 0.13^{cd}	8.51 ± 0.05^{g}	57.72 ± 0.13^{d}	2.32 ± 0.04^{g}	21.91 ± 0.08^{i}
F4	40.00	60.00	180	15	41.65 ± 0.09^{i}	12.64 ± 0.10^{b}	13.72 ± 0.23^{b}	48.88 ± 0.30^{j}	6.98 ± 0.06^{ab}	36.02 ± 0.06^{a}
F5	90.00	10.00	150	17	65.38 ± 1.14^{a}	3.41 ± 0.16^{h}	5.13 ± 0.06^{j}	68.59 ± 0.04^{a}	1.35 ± 0.08^{h}	13.22 ± 0.22^{m}
F6	40.00	60.00	200	19	25.24 ± 0.47^{n}	14.61 ± 0.23^{a}	12.71 ± 0.11^{c}	50.04 ± 0.26^{ij}	5.04 ± 0.03^{d}	32.72 ± 0.10^{c}
F7	40.00	60.00	150	21	50.81 ± 1.10^{e}	12.72 ± 0.28^{b}	14.29 ± 0.03^{a}	51.92 ± 0.05^{gh}	7.06 ± 0.07^{a}	36.43 ± 0.09^{a}
F8	65.12	34.88	170	19	47.77 ± 0.93^{f}	8.82 ± 0.06^{e}	9.60 ± 0.15^{f}	53.16 ± 0.06^{fg}	3.90 ± 0.16^{f}	25.01 ± 0.13^{g}
F9	65.81	34.19	180	23	38.32 ± 0.36^{j}	10.19 ± 0.18^{d}	8.75 ± 0.09^{g}	56.31 ± 0.54^{e}	2.46 ± 0.13^{g}	22.24 ± 0.06^{hi}
F10	54.71	45.29	160	23	47.19 ± 0.05^{g}	12.23 ± 0.06^{b}	11.68 ± 0.07^{d}	56.28 ± 0.18^{e}	4.63 ± 0.05^{e}	29.88 ± 0.18^{d}
F11	75.45	24.55	180	21	43.43 ± 0.33^{h}	8.83 ± 0.04^{e}	7.91 ± 0.01^{h}	59.67 ± 0.05^{c}	2.27 ± 0.06^{g}	20.42 ± 0.03^{j}
F12	59.51	40.49	180	17	43.58 ± 0.84^{h}	10.21 ± 0.09^{d}	11.05 ± 0.05^{e}	51.93 ± 0.08^{gh}	4.74 ± 0.11^{de}	28.60 ± 0.12^{e}
F13	49.28	50.72	150	15	56.69 ± 1.22^{c}	4.74 ± 0.14^{g}	10.72 ± 0.09^{e}	27.14 ± 0.06^{l}	6.55 ± 0.08^{c}	27.53 ± 0.13^{f}
F14	83.01	16.99	150	19	62.79 ± 0.90^{b}	5.24 ± 0.03^{g}	6.61 ± 0.02^{i}	59.45 ± 0.04^{c}	2.11 ± 0.03^{g}	16.87 ± 0.07^{k}
F15	90.00	10.00	200	21	36.92 ± 1.15^{k}	8.28 ± 0.05^{ef}	6.17 ± 0.03^{i}	67.89 ± 0.13^{b}	0.78 ± 0.01^{i}	15.71 ± 0.04^{l}
F16	42.50	57.50	160	19	47.32 ± 1.07^{fg}	10.91 ± 0.04^{c}	12.99 ± 0.04^{c}	42.71 ± 0.09^{k}	6.59 ± 0.05^{bc}	33.61 ± 0.12^{b}
F17	70.19	29.81	160	19	54.42 ± 0.06^{d}	7.75 ± 0.11^{f}	8.80 ± 0.10^{g}	54.32 ± 0.07^{f}	3.51 ± 0.09^{f}	22.71 ± 0.07^{h}
Model (mixture × baking conditions)					Linear × 2Fl	Linear × 2Fl	Linear × 2Fl	Linear × 2Fl	Linear × 2Fl	Linear × 2Fl
F-value (model)					43317.25***	1992.15***	3609.21***	5057.98***	2448.63***	9757.34***
F-value (lack of fit)					0.819^{ns}	1.360^{ns}	0.294^{ns}	1.701^{ns}	0.269^{ns}	1.453^{ns}
Adjusted R^2					0.9970	0.9976	0.9987	0.9990	0.9981	0.9995

Values represent mean ± standard deviation (n = 3). Values within a column that have no superscript in common are significantly different ($p < 0.05$). Abbreviation tempt. = temperature; *** $P < 0.0001$ and ns = not significant.

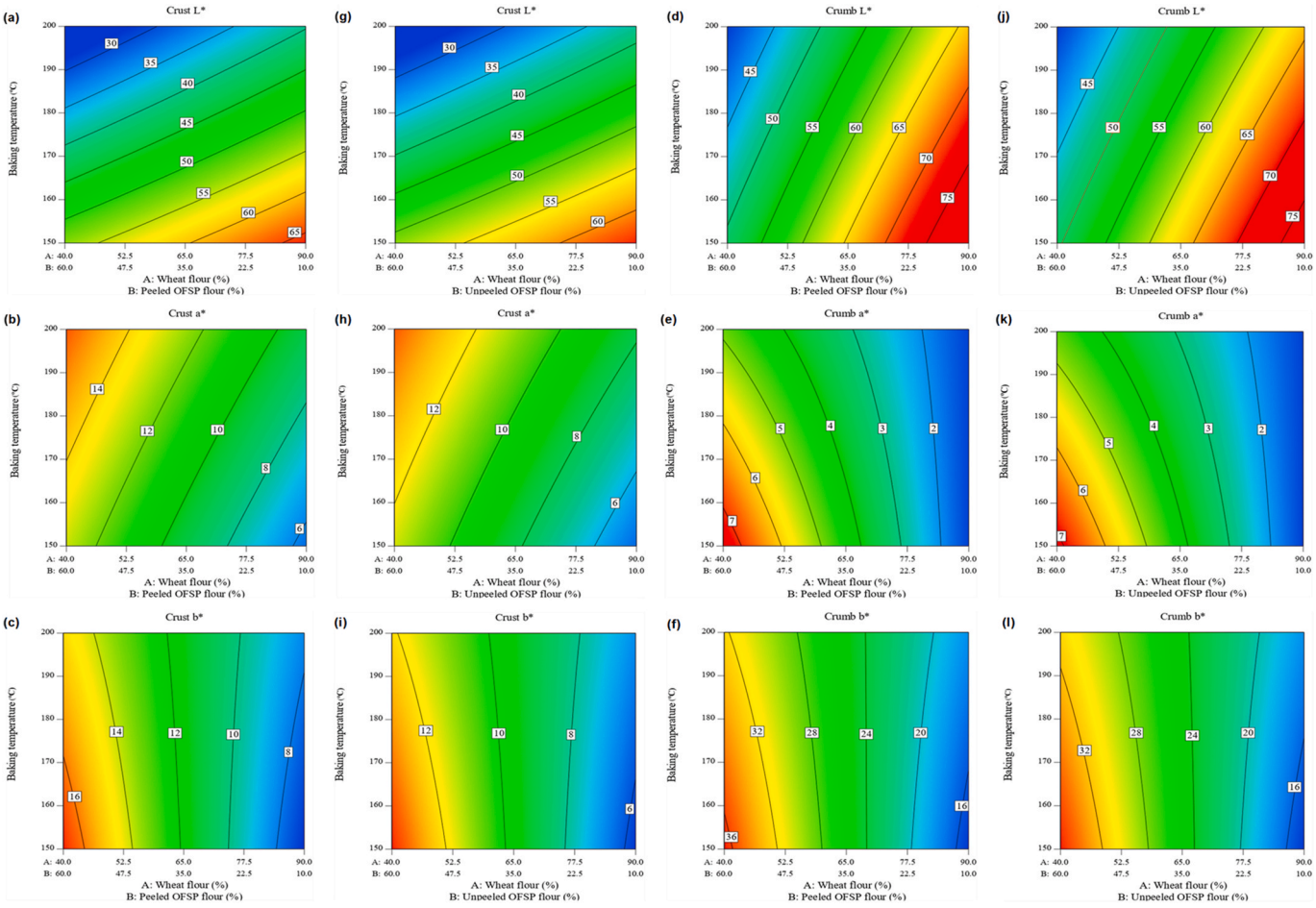

Fig. 3. Contour plots showing the effect of flour proportion, baking temperature and time (20 min) on the CILAB L*, a*, b* values of the crust and crumb of wheat-peeled OFSP blended bread (a, b, c, d, e and f, respectively) and wheat-unpeeled OFSP blended bread (g, h, I, j, k and l, respectively).

-unpeeled OFSP composite bread (Table 4). In the current study, the response surface plots (Fig. 4) revealed that increasing OFSP flour and baking conditions led to a significant ($p < 0.05$) increased in crumb hardness and chewiness values but decreased crumb springiness, cohesiveness and resilience. Similarly, Edun et al. (2018) reported an increased bread firmness when wheat flour was replaced with 10–30% peeled OFSP flour. Also, Bredariol et al. (2019) indicated that at the same baking temperature, hardness increased with increasing baking time.

Bread crumb staling is mainly characterized by crumb firming and has a great influence on consumer acceptability. Staling of bread crumb is largely caused by amylopectin retrogradation, migration of moisture from crumb to crust, and gluten-starch interaction during storage (Barros et al., 2018). The staling rate of wheat-peeled and -unpeeled OFSP bread crumbs after 24 h of storage differed between 0.139-0.409 and 0.131–0.392, respectively (Table 4). The response surface plot (Fig. 4.) showed a decreasing trend for crumb staling rate with increasing substitution of wheat flour with OFSP flour. This can be attributed to the low retrogradation capacity of OFSP flour (Chikpah et al., 2020). It was revealed that the crumb staling rate increased with rising baking conditions (Fig. 4). This can be attributed to decreasing moisture content of crumbs with rising baking conditions.

The crumb hardness, springiness, cohesiveness and resilience were best described by a linear × 2Fl model (mixture × process factors). The model and model terms were significant ($p < 0.0001$), lack of fit was insignificant ($p > 0.05$), and adjusted R^2 values were between 0.9980 and 0.9997. The model equations that described the crumb hardness are shown in Equations (8a) and (8b) whereas springiness was explained by Equations (9a) and (9b)) respectively for the wheat-peeled and unpeeled OFSP composite bread.

$$\text{Hardness (kg)} = -0.5838911A + 1.3931379B + 0.0033950AC + 0.0326718AD - 0.0077801BC - 0.0716707BD - 0.0001884ACD + 0.0004260BCD \quad (8a)$$

$$\text{Hardness (kg)} = -0.2331502A + 0.5567609B + 0.0013560AC + 0.0130474AD - 0.0031095BC - 0.0286430BD - 0.0000752ACD + 0.0001703BCD \quad (8b)$$

$$\text{Springiness} = 0.0382848A - 0.0836339B - 0.0001795AC - 0.0015530AD + 0.0005445BC + 0.0049851BD + 0.0000098ACD - 0.0000302BCD \quad (9a)$$

$$\text{Springiness} = 0.0280881A - 0.0649897B - 0.0001222AC - 0.0010293AD + 0.0004389BC + 0.0040595BD + 0.0000068ACD - 0.0000249BCD \quad (9b)$$

The chewiness values of both wheat-peeled and -unpeeled OFSP composite bread was best described by a reduced quadratic × 2Fl model. The adjusted R^2 value for the peeled and unpeeled OFSP composite bread chewiness was 0.9932 and 0.9965, respectively. The model equations that explained the crumb chewiness in terms of proportions of flours and baking conditions are shown in Equations (10a) and (10b) respectively for wheat-peeled and-unpeeled OFSP composite bread.

$$\text{Chewiness (kg)} = -0.3803462A + 0.3291603B - 0.0013045AB + 0.0021709AC + 0.0222445AD - 0.0017710BC - 0.0142579BD + 0.0000100ABC - 0.0001257ACD + 0.0000838BCD \quad (10a)$$

Table 4
Textural profile and staling rate of wheat–peeled OFSP and –unpeeled OFSP bread crumbs as influenced by blend proportions and baking conditions.

Trial code	Wheat flour (%)	Peeled OFSP flour (%)	Baking tempt. (°C)	Baking time (min)	Hardness (kg)	Springiness	Cohesiveness	Chewiness (kg)	Resilience	Staling rate
F1	65.12	34.88	170	19	3.307 ± 0.005^{j}	0.855 ± 0.004^{f}	0.792 ± 0.003^{e}	2.238 ± 0.008^{g}	0.408 ± 0.001^{f}	0.208 ± 0.003^{e}
F2	40.00	60.00	170	25	5.739 ± 0.002^{a}	0.737 ± 0.002^{j}	0.717 ± 0.003^{i}	3.032 ± 0.002^{a}	0.350 ± 0.001^{i}	0.216 ± 0.001^{e}
F3	68.05	31.95	200	21	3.197 ± 0.002^{k}	0.840 ± 0.001^{g}	0.754 ± 0.002^{g}	2.024 ± 0.011^{i}	0.371 ± 0.001^{g}	0.306 ± 0.002^{b}
F4	40.00	60.00	180	15	4.427 ± 0.005^{f}	0.825 ± 0.004^{h}	0.763 ± 0.005^{f}	2.785 ± 0.021^{d}	0.363 ± 0.001^{h}	0.155 ± 0.004^{j}
F5	90.00	10.00	150	17	0.981 ± 0.003^{o}	0.946 ± 0.004^{b}	0.886 ± 0.001^{a}	0.822 ± 0.006^{l}	0.437 ± 0.002^{b}	0.297 ± 0.003^{c}
F6	40.00	60.00	200	19	5.658 ± 0.002^{b}	0.715 ± 0.001^{k}	0.725 ± 0.004^{i}	2.931 ± 0.001^{b}	0.348 ± 0.002^{i}	0.183 ± 0.003^{h}
F7	40.00	60.00	150	21	4.505 ± 0.006^{e}	0.842 ± 0.004^{g}	0.755 ± 0.003^{fg}	2.863 ± 0.013^{c}	0.366 ± 0.001^{gh}	0.189 ± 0.001^{gh}
F8	65.12	34.88	170	19	3.308 ± 0.004^{j}	0.854 ± 0.005^{f}	0.793 ± 0.008^{e}	2.239 ± 0.009^{g}	0.406 ± 0.001^{f}	0.213 ± 0.002^{e}
F9	65.81	34.19	180	23	3.619 ± 0.003^{h}	0.844 ± 0.001^{g}	0.737 ± 0.002^{h}	2.248 ± 0.010^{g}	0.372 ± 0.001^{g}	0.269 ± 0.003^{d}
F10	54.71	45.29	160	23	4.022 ± 0.003^{g}	0.856 ± 0.001^{f}	0.791 ± 0.006^{e}	2.721 ± 0.014^{e}	0.414 ± 0.004^{e}	0.201 ± 0.001^{f}
F11	75.45	24.55	180	21	2.491 ± 0.002^{m}	0.901 ± 0.001^{d}	0.807 ± 0.001^{d}	1.809 ± 0.005^{j}	0.419 ± 0.001^{d}	0.272 ± 0.004^{d}
F12	59.51	40.49	180	17	3.502 ± 0.007^{i}	0.838 ± 0.002^{g}	0.812 ± 0.003^{d}	2.382 ± 0.010^{f}	0.415 ± 0.002^{e}	0.194 ± 0.002^{fg}
F13	49.28	50.72	150	15	5.143 ± 0.002^{c}	0.744 ± 0.002^{j}	0.584 ± 0.002^{j}	2.231 ± 0.003^{g}	0.263 ± 0.002^{k}	0.139 ± 0.005^{k}
F14	83.01	16.99	150	19	2.093 ± 0.003^{n}	0.916 ± 0.001^{c}	0.845 ± 0.004^{c}	1.619 ± 0.007^{k}	0.450 ± 0.001^{a}	0.218 ± 0.003^{e}
F15	90.00	10.00	200	21	0.316 ± 0.002^{p}	0.997 ± 0.001^{a}	0.861 ± 0.007^{b}	0.271 ± 0.002^{m}	0.427 ± 0.002^{c}	0.409 ± 0.002^{a}
F16	42.50	57.50	160	19	5.011 ± 0.002^{d}	0.786 ± 0.002^{i}	0.694 ± 0.004^{j}	2.730 ± 0.005^{e}	0.332 ± 0.001^{j}	0.165 ± 0.001^{i}
F17	70.19	29.81	160	19	2.941 ± 0.004^{l}	0.875 ± 0.001^{e}	0.803 ± 0.002^{d}	2.065 ± 0.003^{h}	0.416 ± 0.001^{de}	0.211 ± 0.001^{e}
	Model (mixture × baking conditions)				Linear × 2Fl	Linear × 2Fl	Linear × 2Fl	Reduced quadratic ×2Fl	Linear × 2Fl	Linear × 2Fl
	F-value (model)				15299.29***	2463.68***	5610.76***	607.85***	4066.62***	7706.55***
	F-value (lack of fit)				1.590^{ns}	2.340^{ns}	0.368^{ns}	1.320^{ns}	0.153^{ns}	0.197^{ns}
	Adjusted R^2				0.9997	0.9980	0.9992	0.9932	0.9988	0.9950
Trial number	Wheat flour (%)	Unpeeled OFSP flour (%)	Baking tempt. (°C)	Baking time (min)	Hardness (kg)	Springiness	Cohesiveness	Chewiness (kg)	Resilience	Staling rate
F1	65.12	34.88	170	19	1.323 ± 0.002^{j}	0.852 ± 0.004^{f}	0.823 ± 0.001^{d}	0.927 ± 0.011^{g}	0.400 ± 0.001^{d}	0.207 ± 0.003^{e}
F2	40.00	60.00	170	25	2.296 ± 0.001^{a}	0.734 ± 0.001^{l}	0.744 ± 0.003^{g}	1.253 ± 0.004^{a}	0.346 ± 0.002^{g}	0.215 ± 0.001^{d}
F3	68.05	31.95	200	21	1.279 ± 0.001^{k}	0.827 ± 0.005^{hi}	0.748 ± 0.001^{g}	0.790 ± 0.007^{j}	0.364 ± 0.001^{ef}	0.294 ± 0.004^{b}
F4	40.00	60.00	180	15	1.771 ± 0.003^{f}	0.820 ± 0.001^{i}	0.763 ± 0.002^{f}	1.108 ± 0.005^{d}	0.357 ± 0.001^{f}	0.142 ± 0.003^{j}
F5	90.00	10.00	150	17	0.394 ± 0.001^{o}	0.924 ± 0.003^{b}	0.896 ± 0.002^{a}	0.326 ± 0.010^{m}	0.430 ± 0.001^{b}	0.295 ± 0.002^{b}
F6	40.00	60.00	200	19	2.264 ± 0.002^{b}	0.711 ± 0.001^{m}	0.737 ± 0.002^{h}	1.185 ± 0.008^{b}	0.339 ± 0.001^{g}	0.174 ± 0.001^{h}
F7	40.00	60.00	150	21	1.803 ± 0.004^{e}	0.839 ± 0.002^{g}	0.768 ± 0.003^{f}	1.160 ± 0.013^{c}	0.362 ± 0.002^{ef}	0.183 ± 0.003^{g}
F8	65.12	34.88	170	19	1.324 ± 0.001^{j}	0.853 ± 0.001^{f}	0.822 ± 0.001^{d}	0.928 ± 0.001^{g}	0.401 ± 0.001^{d}	0.209 ± 0.002^{e}
F9	65.81	34.19	180	23	1.448 ± 0.001^{h}	0.838 ± 0.003^{g}	0.742 ± 0.004^{gh}	0.900 ± 0.004^{h}	0.365 ± 0.001^{e}	0.262 ± 0.001^{c}
F10	54.71	45.29	160	23	1.609 ± 0.002^{g}	0.854 ± 0.003^{f}	0.813 ± 0.003^{e}	1.117 ± 0.006^{d}	0.411 ± 0.001^{c}	0.198 ± 0.004^{f}
F11	75.45	24.55	180	21	0.996 ± 0.001^{m}	0.889 ± 0.003^{d}	0.813 ± 0.001^{e}	0.721 ± 0.001^{k}	0.414 ± 0.002^{c}	0.264 ± 0.005^{c}
F12	59.51	40.49	180	17	1.402 ± 0.003^{i}	0.833 ± 0.002^{gh}	0.839 ± 0.001^{c}	0.980 ± 0.002^{f}	0.407 ± 0.003^{cd}	0.187 ± 0.002^{g}
F13	49.28	50.72	150	15	2.057 ± 0.003^{c}	0.762 ± 0.001^{k}	0.649 ± 0.002^{j}	1.017 ± 0.006^{e}	0.234 ± 0.002^{i}	0.131 ± 0.004^{k}
F14	83.01	16.99	150	19	0.838 ± 0.002^{n}	0.910 ± 0.002^{c}	0.882 ± 0.001^{b}	0.672 ± 0.011^{l}	0.440 ± 0.001^{a}	0.217 ± 0.002^{d}
F15	90.00	10.00	200	21	0.126 ± 0.001^{p}	0.982 ± 0.001^{a}	0.809 ± 0.001^{e}	0.101 ± 0.004^{n}	0.432 ± 0.001^{b}	0.392 ± 0.004^{a}
F16	42.50	57.50	160	19	2.005 ± 0.004^{d}	0.791 ± 0.001^{j}	0.726 ± 0.001^{i}	1.149 ± 0.007^{c}	0.322 ± 0.002^{h}	0.158 ± 0.003^{i}
F17	70.19	29.81	160	19	1.176 ± 0.001^{l}	0.873 ± 0.001^{e}	0.836 ± 0.003^{c}	0.859 ± 0.005^{i}	0.407 ± 0.003^{cd}	0.207 ± 0.003^{e}
	Model (mixture × baking conditions)				Linear × 2Fl	Linear × 2Fl	Linear × 2Fl	Reduced quadratic × 2Fl	Linear × 2Fl	Linear × 2Fl
	F-value (model)				15006.92***	3620.21***	8011.67***	1182.97***	4065.49***	7896.07***
	F-value (lack of fit)				1.440^{ns}	0.319^{ns}	0.154^{ns}	0.289^{ns}	0.108^{ns}	1.092^{ns}
	Adjusted R^2				0.9996	0.9985	0.9994	0.9965	0.9988	0.9973

Values represent mean ± standard deviation (n=3). Values within a column that have no superscript in common are significantly different ($p < 0.05$). Abbreviation tempt. = temperature; *** $P < 0.0001$ and ns = not significant.

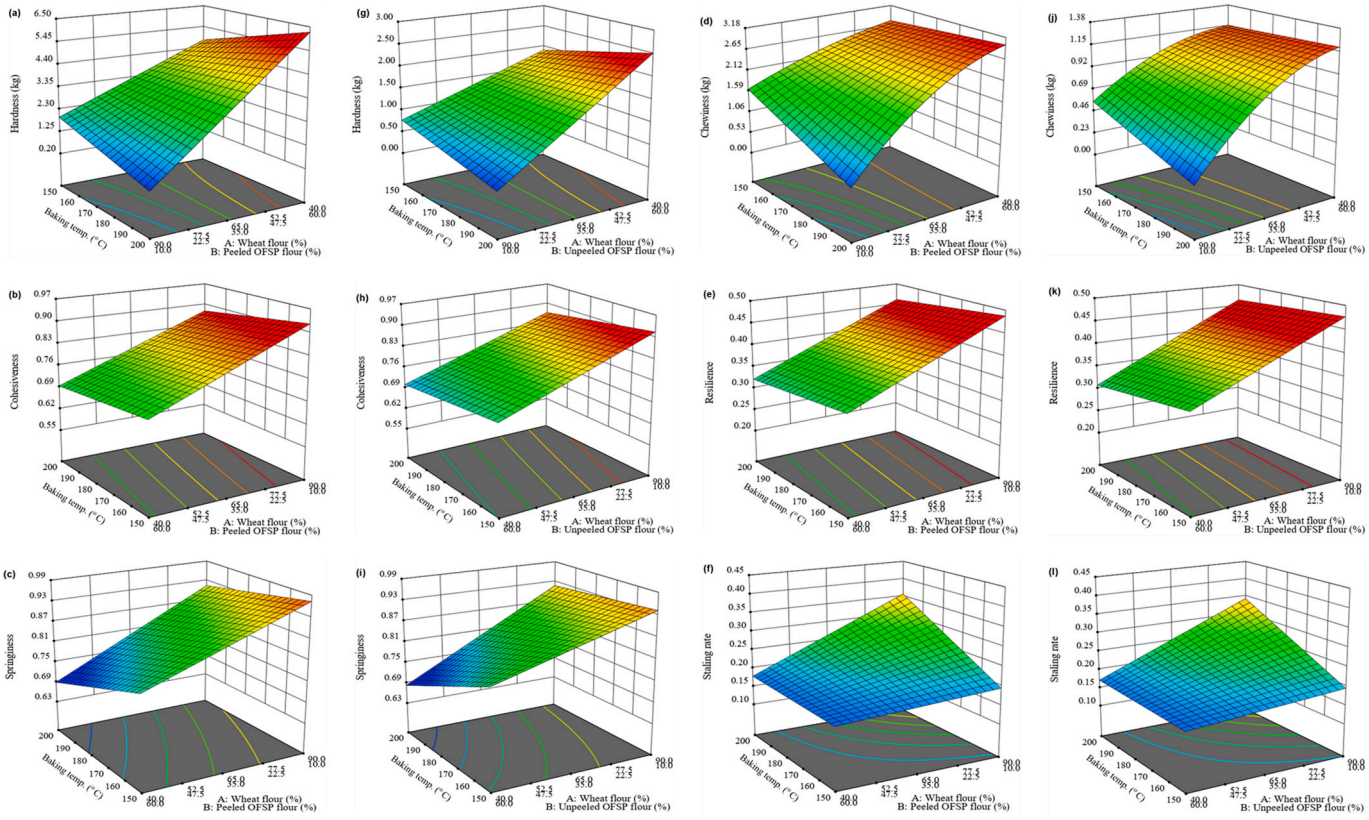

Fig. 4. Response surface plots showing the effect of flour proportion, baking temperature and baking time (20 min) on the hardness, cohesiveness, springiness, chewiness, resilience and staling rate of wheat-peeled OFSP blended bread crumbs (a, b, c, d, e and f, respectively) and wheat-unpeeled OFSP blended bread crumbs (g, h, i, j, k and l, respectively).

$$\text{Chewiness (kg)} = -0.0985719A + 0.0816682B - 0.0000795AB + 0.0005651AC + 0.0058965AD - 0.0004399BC - 0.0037154BD + 0.0000019ABC - 0.0000336ACD + 0.0000224BCD \quad (10b)$$

3.5. Relationship between the dough and bread quality properties

The correlation loading and score plots from the Principal Component Analysis (PCA) of the wheat-OFSP composite dough and bread quality properties are shown in Fig. 5a and 5b, respectively. The PCA results showed that two principal components (PC1, x-axis and PC2, y-axis) explained a total of 91.83% of the variance in the original data. A larger percentage of the variance (74.60%) was defined by the first component, PC1 whereas the second component, PC2 accounted for 17.23% of the variance. PC1 was largely characterized by dough development time (DDT), stability time (ST), crust and crumb redness (a*) and yellowness (b*), crumb hardness and chewiness on the positive axis (Fig. 5a), and these quality properties were prominent in bread formulations F2, F4, F6, F7 and F16 (Fig. 5b). Moreover, on the negative axis, PC1 was described by dough optimum water absorption (OWA), loaf volume, specific volume, crumb lightness (L*), springiness, cohesiveness, resilience, staling rate, and a_w, characteristics that were prevailed in samples F5, F11, F14, and F15 (Fig. 5b). The second component, PC2 on its positive axis was well-defined by crumb moisture and crust L* which were dominant in F5, F13 and F14 whereas the negative axis of PC2 was explained by baking loss, a prime attribute of sample F15. The PCA has revealed the disparities among the wheat-OFSP composite dough and bread products in terms of their quality characteristics as affected by the flour proportions, baking temperature and time. This confirmed the fact that bread specialties can be distinguished using PCA (Altamirano-Fortoul & Rosell, 2011). Additionally, a significant positive correlation was found between OWA, loaf volume, specific volume, crumb springiness, cohesiveness, resilience and staling ($r = 0.696$ to 0.974, $p < 0.001$) but was inversely correlated with DDT, dough ST, crumb hardness and chewiness ($r = -0.765$ to -0.997, $p < 0.001$). This shows that farinograph properties of dough can be applied to predict the physical and textural properties of final baked wheat-OFSP composite bread.

3.6. Optimization of flour mixture and baking conditions

Table 5 shows the optimization criteria and values of the response variables for the optimized flour mixture and baking conditions for wheat-OFSP bread. The optimization goals were maximization of dough OWA, bread volume, specific volume, crumb springiness, cohesiveness and resilience), minimization of DDT, baking loss, a_w, crumb hardness and chewiness as well as to attain target values for crumb moisture, crust and crumb colour. Based on the optimization criteria, the optimized formulations for the wheat-OFSP composite bread was blending of 70.6% of wheat flour with 29.4% peeled OFSP flour or mixing 72.0% wheat flour with 28.0% unpeeled OFSP flour and baking at 180 °C for 15 min. These flour mixture and baking conditions had global desirability values of 0.71 and 0.67, respectively for the wheat-peeled and -unpeeled OFSP composite bread formulations (Table 5).

4. Conclusion

The present study has demonstrated the effect of wheat flour substitution with peeled and unpeeled OFSP flour, and baking conditions on dough and bread quality characteristics. The substitution of wheat flour with OFSP flour decreased optimum water absorption and increased dough development time. The addition of OFSP flour above 35%

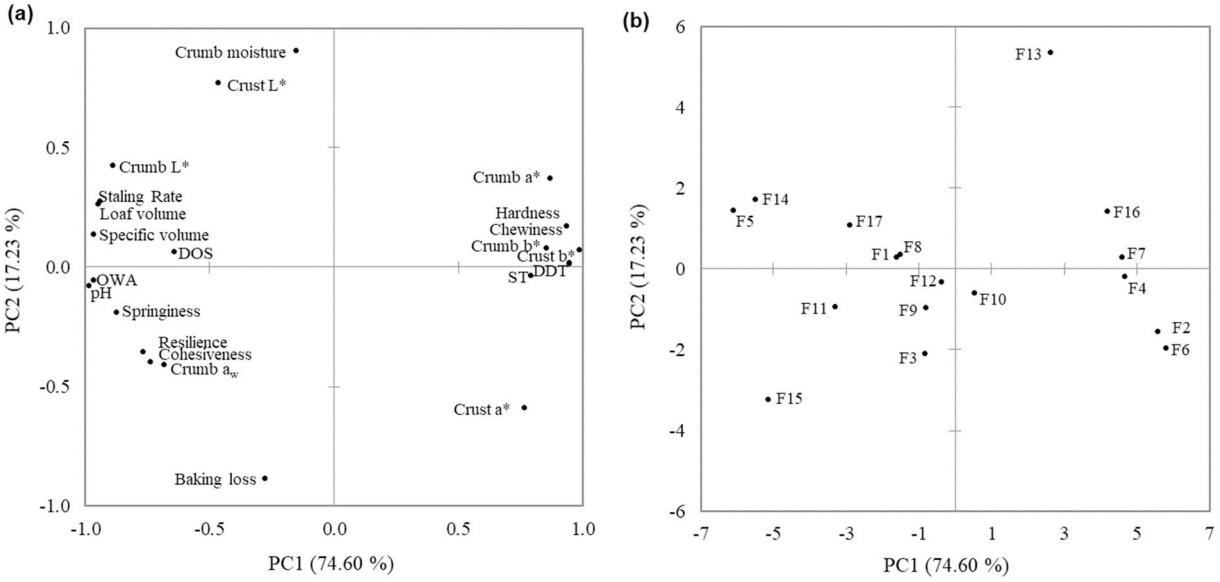

Fig. 5. Correlation loading plots (a), and score plots (b) from the principal component analysis of wheat-OFSP blended dough and bread quality characteristics. OWA = optimum water absorption, DOS = degree of softening, DDT = dough development time, and a_w = water activity whereas F1, F2, F3, ….. F17 represent the various formulations for wheat-OFSP composite bread.

Table 5
Optimization criteria and optimal values of the response variables for wheat-peeled and –unpeeled OFSP composite bread.

Factors & Responses	Optimization goal	Lower limit	Target value	Upper limit	Importance	Desirability index (*dn*)	Optimized values
Factors							
Wheat flour (%)	keep in range	40		90	-	1.0	70.6 (72.0)
OFSP flour (%)	keep in range	10		60	-	1.0	29.4 (28.0)
Baking temp. (°C)	keep in range	150		200	-	1.0	180
Baking time (min)	keep in range	15		25	-	1.0	15
Responses							
OWA (%)	maximise	54.3 (55.1)		60.3 (63.3)	5	0.82 (0.69)	58.96 (60.94)
DDT (min)	minimise	1.7 (2.5)		9.6 (8.7)	5	0.71 (0.74)	4.35 (3.99)
Dough stability (min)	keep in range	4.8 (5.8)		11.6 (8.8)	-	1.0 (1.0)	5.95 (5.83)
Loaf volume (cm^3)	maximise	174.0 (165.5)		358.0 (279.9)	5	0.98 (0.83)	345.48 (264.12)
Specific volume (cm^3/g)	maximise	1.59 (1.47)		2.87 (2.67)	5	0.99 (0.73)	2.81 (2.40)
Baking loss (%)	minimise	12.29 (13.5)		33.24 (36.35)	5	0.33 (0.34)	26.71 (29.25)
Crumb moisture (%)	target	20.53 (20.82)	30.0	39.77 (40.42)	5	0.68 (0.67)	32.76 (33.47)
Crumb a_w	minimise	0.843 (0.837)		0.926 (0.920)	5	0.40 (0.43)	0.889 (0.885)
Crust L*	target	26.06 (25.24)	49.5	68.06 (65.56)	5	0.86 (1)	50.09 (49.03)
Crust a*	target	3.78 (3.47)	9.5	16.87 (14.94)	5	0.87 (0.78)	9.49 (8.12)
Crust b*	target	6.28 (5.13)	11.8	17.35 (14.19)	5	0.99 (0.72)	12.34 (9.93)
Crumb L*	target	37.48 (37.01)	56.0	73.17 (70.82)	5	0.63 (0.76)	60.91 (59.97)
Crumb a*	target	0.81 (0.78)	5.0	7.36 (7.07)	5	0.83 (0.82)	4.53 (4.23)
Crumb b*	target	13.41 (13.22)	25.5	37.69 (36.41)	5	0.98 (0.97)	26.98 (25.91)
Hardness (kg)	minimise	0.314 (0.126)		5.740 (2.296)	5	0.61 (0.58)	2.626 (1.011)
Springiness	maximise	0.714 (0.711)		0.998 (0.982)	5	0.58 (0.55)	0.873 (0.861)
Cohesiveness	maximise	0.582 (0.649)		0.886 (0.896)	5	1.0 (1.0)	0.886 (0.944)
Chewiness	minimise	0.273 (0.100)		3.030 (1.2530	5	0.34 (0.28)	2.167 (0.940)
Resilience	maximise	0.261 (0.234)		0.451 (0.440)	5	1.0 (1.0)	0.470 (0.467)
Staling rate	keep in range	0.139 (0.131)		0.409 (0.392)	5	1.0 (1.0)	0.179 (0.184)
Combined desirability						**0.71 (0.67)**	

Values kept in brackets represent corresponding values for wheat-unpeeled OFSP bread.

improved dough stability and decreased the degree of softening. The study confirmed that specific volume, crumb water activity, springiness, cohesiveness and resilience of crumb decreased while crumb hardness and chewiness increased as the rate of wheat flour substitution with OFSP flour, baking temperature and time increased. The crumb staling rate declined with rising OFSP flour proportion in the composite bread. Generally, the peeled OFSP composite bread had higher specific volume, crumb water activity, springiness, hardness, chewiness and staling but lower crumb moisture content than the corresponding unpeeled OFSP composite bread. The substitution of wheat flour with 29.4% or 28.8% of peeled or unpeeled OFSP flour, respectively and baking at 180 °C for 15 min gave the optimum dough and bread quality properties. This study has provided vital results that have potential applications in the bakery industry.

CRediT authorship contribution statement

Solomon Kofi Chikpah: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft. **Joseph Kudadam Korese:** Conceptualization, Resources, Supervision, Writing – review & editing, Funding acquisition. **Oliver Hensel:** Resources, Supervision, Writing – review & editing, Funding acquisition. **Barbara Sturm:** Supervision, Writing – review & editing, Funding acquisition. **Elke Pawelzik:** Resources, Supervision, Validation, Writing – review &

editing.

Declaration of competing interest

The authors declare that there is no conflict of interest.

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