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The effect of extrusion condition and blend proportion on the physicochemical and sensory attributes of *teff*-soybean composite flour gluten free extrudates

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ABSTRACT

The effects of soybean-to-teff ratio (SB), feed moisture content (FM) and barrel temperature (BT) on physicochemical properties and sensory attributes of extruded product from teff-soybean flour blend was studied. Increase in BT resulted in increase in expansion ratio(ER), water absorption index (WAI), and water solubility index (WSI) whereas the bulk density (BD) and hardness decreased with increase in BT. Increase in the proportion of SB resulted in increased BD, hardness, and reduced water solubility index (WSI) and sensory scores. Three principal components explained 89.1 % of the variations where the first (PC1), the second (PC2) and the third (PC3) principal components explained 62.4, 20.2 and 6.5 % of the variations respectively. BD, WAI and Hardness are strongly and positively associated with each other whereas they are negatively associated with WSI, crispiness, Specific length (L_{sp}) and ER. Graphical optimization gave best results for BT between 128 and 137 °C and SB proportion between 2 and 7.3 % where the FM is fixed at 10 %. Besides, BT of 135 °C to137 °C, FM of 10–12 % when the SB proportion is fixed at 7.5 % gave optimal product quality. The numerical optimization resulted in optimal extrusion conditions for optimal product quality were BT of 135 °C, FM of 10 % and SB proportion of 5 % with a desirability value of 0.875. The results revealed that SB can be incorporated up to 7.5 % to obtain an acceptable product. Therefore it is possible to produce gluten-free extruded snack by blending teff and soybean flour.

1. Introduction

Celiac disease is an immune-mediated disorder which is associated with the ingestion of foods containing gluten. The only treatment for celiac disease is a lifelong gluten-free (GF) diet [1]. Developing wide variety of GF cereal-based product has been the way to address the challenge and meet the demand of the population segment affected by this disorder. Several cereals like rice, sorghum millet etc. have been used to develop cereal-based GF products. However, the demand for GF products is still increasing and there is also a need to diversify the GF products using new and underutilized materials. Studies have shown that celiac patients have nutritional deficiencies like protein, dietary fiber, minerals and vitamins [2]. Blending raw materials rich in protein like soybean, and rich in fiber and minerals like *Teff* could be an attractive alternative to develop a GF product that addresses the deficiencies [3,4].

Teff (*Eragrostis teff [Zucc.] Trotter*) is indigenous to Ethiopia but currently being produced in other countries including India, South Africa, USA and Canada and it is gaining popularity globally [5,6]. Of the attributes that made *teff* popular is its GF nature making it an important alternative for developing GF products due to its higher nutritional value compared to other GF flours like rice [4]. *Teff* is a good source of nutrients where the protein content has been reported to range from 10 to 13.3 % [3,6-9]. The overall amino acid profile of *teff* is regarded as well-balanced which made it an important material to develop nutritious products [3,10]. It is also a good source of minerals and healthy lipids where the majority of *teff* lipids were found to be unsaturated fatty acids [11]. The total dietary fiber content goes up to 4.54 % (dry basis) which is higher than what was reported for common cereals like wheat (3.4 %), rice (0.43 %), oat (4.05 %), buckwheat (2.18 %), sorghum

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(4.51 %) and maize (2.62 %) [4,6].

The health benefits of *teff* has been reviewed and reported recently [6]. *Teff* is rich in a variety of bioactives like phenolic compounds and saponins and minerals including iron, calcium, copper, zinc, [6,12] . Studies indicated that *Teff* constituents have antioxidant, anti-inflammatory and other health-promoting properties including prevention of anemia [6,12]. In view of the relatively higher crude fiber content and lower glycaemic index (GI) compared to other common grains, *teff*-based foods have the potential to the prevention and amelioration of diabetes [6,13]. *Teff*, as nutrient-rich GF grain is being frequently promoted as the best choice for celiac disease patients [6]. The utilization of *teff* in the past had been limited some Ethiopian traditional foods viz pan-cake like local bread called *injera,* porridge, unleavened bread and beverages. Due to its nutritional and health benefit, however, several other products including *teff*-based extruded products [8,9,14,15], cookies and biscuits [16,17], bread [3,7,13], pasta [18] and others products [3] have been produced.

Soybeans contain 35–40 % protein, about 20 % lipids, and 8.5 % moisture based on the dry weight of mature raw seeds [19]. Soybean is a good source of peptides that have a range of health benefits as anti-diabetes, antihypertensive, anti-cancer, anti-oxidant and others [20]. Despite their numerous benefits, *teff*-based GF foods normally exhibit medium to high GI and low content of resistant starch. The use of natural GF legume flours like soybean might be good alternatives in order to improve nutritional properties of *teff*-based GF foods, since legumes normally exhibit slow-digestible starches [13,18]. Combining *teff* and soybean flour will potentially result in a nutritious GF health benefiting product. Extrusion cooking is a versatile high temperature and short time process for the production of cereal-based snacks and ready-to-eat cereals. During extrusion the food is exposed to high temperature, pressure and shear stress as a result of which it is cooked and texturized [21]. Several studies have shown that the quality of the extruded products including the BD, WAI, WSI and sensory attributes are influenced by the extrusion temperature, the feed moisture content and the composition of the feed [15,22-25]. This study was aimed at investigating the influence of BT, FM and *teff*-to-soybean ratio on the physico-chemical and sensory attributes of *teff*-soybean blend extrudates and optimize the extrusion conditions and *teff*-soybean blend proportion for optimized product quality using response surface methodology.

2. Materials and methods

2.1. Experimental materials

Brown *teff* grain, DZ-01-99 variety, [Eragrostis *teff* (Zucc.) Trotter] and Soybean, AFGAT variety, (Glycine max) were sourced from Debre Zeit Agricultural Research Center (DZARC) and Awassa Agricultural Research Center (AARC), Ethiopia, respectively. Brown *teff* variety was selected due to its relatively lower price in the country and soybean due to its high protein content and functional property. The chemicals and reagents were procured from local suppliers.

2.2. Raw material preparation

Teff grain was cleaned and milled using commercial mill and the flour was sieved using 710 µm test sieve and sealed in plastic bags till it is used for extrusion [8]. The soybean was cleaned to remove physical impurities and blanched in water bath at 95°C for 30 min [26]. The blanched beans were oven dried at 60°C to a moisture content of 8 % [26, 27]. The dried soybeans were dehulled (AB, Alvan Blanch Decorticator, England), winnowed and milled using a commercial mill. The flour was sieved using 710 µm test sieve.

2.3. Determination of proximate composition

Moisture, crude fiber and ash content were determined according to AOAC [28]. Crude protein was determined by Kejeldahl method whereas crude fat was determined by soxhlet extraction method [28]. Total carbohydrate was determined as the difference between 100 and the sum of the percentages of all the other components.

Table 1
Coded and real values of the factors (BT = barrel temperature, FM = feed moisture content, SB = percentage of soy).

Factor/Variable	Levels				
	−α (−1.525)	−1	0	+1	+ α (−1.525)
BT (°C)	122.4	125	130	135	137.6
FM (%)	9.5	10	11	12	12.5
Soy (g/100 g) (SB%)	2.4	5	10	15	17.6

2.4. Extrusion process

Extrusion was done in a co-rotating twin-screw food extruder (Clextral, BC-21 N° 124, Firminy, France) using barrel temperature of 122.4, 125, 130, 135 and 137.6 °C, feed moisture content of 9.5, 10, 11, 12 and 12.5 % and proportion of soy flour 2.4, 5, 10, 15 and 17.6 g/100 g (Table 1). The screw speed and the feed rate were set at 130 rpm and 9 kg/hr, respectively [8]. As the extrudates emerge from the extruder, they were cut to a length of 5 cm, cooled for 30 min at ambient temperature, sealed and stored at room temperature for further evaluation [22]

2.5. Determination of product properties

2.5.1. Specific length (L_{sp})

The L_{sp} was determined by dividing length to the weight of the extrudate [9] . A digital Vernier caliper (СДЕЛAНО, cccp, Russia) with 0.05 mm accuracy and a balance (ADAM, AFP1200, South Africa) with 0.01 g sensitivity were used to measure the length and weight of the extrudates, respectively.

2.5.2. Degree of expansion (ER) and bulk density (BD)

The ER was calculated as the ratio of the diameter of extrudate to the diameter of the die hole [29]. The BD of the extrudates was calculated using the following relationship (Eq. (1)) [30].

$$\rho = \frac{4m}{\pi D_e^2 L_e} \quad (1)$$

Where ρ = bulk density (g/cm^3), D_e = diameter of extrudate (cm), L_e= length of extrudate (cm) and w = mass of extrudate (g)

2.5.3. Texture/Hardness

Hardness was measured using TA-XT2 plus texture analyzer (Ametek, Lloyd, 33,773 Instruments, UK) with a load cell of 1 KN using a 25 mm diameter flat probe. Extruded samples were individually and horizontally placed on the sample platform of the texture analyzer. The samples were compressed at a loading rate of 50 mm/min until the samples break. The force in Newton (N) required to break the samples was recorded and was used as a measure of hardness. Ten measurements were made from each treatment to compute the average.

2.5.4. Water absorption index (WAI) and water solubility index (WSI)

About 1.25 g flour sample was suspended in 15 ml distilled water and incubated in shaking water bath set at 25 °C for 30 min and centrifuged at 3000×*g* for 5 min. The clear supernatant was decanted after centrifugation and the weight of the sediment measured. The difference between the weight of the sediment and the initial ample weight was the weight of water adsorbed. The WAI was computed as grams of adsorbed water per gram of dry sample mass (Eq. (2)). The clear supernatant was evaporated for the estimation of the WSI (Eq. (3)) [31].

Table 2
RSM model coefficients and *p*-values.

Parameters	β_0	β_1	β_2	β_3	β_{12}	β_{13}	β_{23}	β_{11}	β_{22}	β_{33}
L_{sp}	1.249	0.118	−0.036	−0.074	−0.005	−0.058	0.028	0.044	−0.093	0.085
p-values		0.003	0.261	0.032	0.897	0.157	0.481	0.199	0.016	0.025
ER	1.820	0.058	0.032	−0.207	0.024	−0.006	−0.009	0.048	−0.092	0.046
p-values		0.191	0.462	0.001	0.658	0.907	0.870	0.306	0.068	0.327
BD	0.412	−0.015	−0.002	0.088	0.006	−0.001	−0.029	−0.049	0.034	−0.037
p-values		0.560	0.951	0.005	0.843	0.968	0.371	0.091	0.221	0.197
WAI	9.547	−0.216	0.071	0.758	0.139	0.016	0.024	−0.359	0.172	−0.574
p-values		0.503	0.823	0.035	0.730	0.968	0.953	0.312	0.620	0.119
WSI	9.849	0.243	−0.027	−1.072	0.019	−0.266	0.169	0.303	0.013	−0.002
p-values		0.194	0.879	0.000	0.934	0.252	0.459	0.139	0.946	0.992
Hard	231.121	−13.13	0.687	24.984	4.910	3.318	−8.763	−12.90	5.057	−27.930
p-values		0.202	0.945	0.027	0.693	0.790	0.485	0.243	0.638	0.023
Color	5.689	0.613	0.921	−0.518	−0.758	0.313	0.935			
p-values		0.099	0.025	0.153	0.104	0.467	0.055			
Flavor	4.966	0.308	0.722	−0.350	−0.605	0.285	0.535	0.608	−0.106	0.926
p-values		0.415	0.101	0.361	0.229	0.541	0.278	0.580	0.922	0.411
Crispiness	−2.748	0.290	0.091	−0.640	0.121	−0.056	0.066	2.198	1.982	2.447
p-values		0.315	0.737	0.064	0.722	0.868	0.845	0.043	0.058	0.031
OAC	6.324	0.452	0.957	−0.701	−0.534					
p-values		0.209	0.019	0.065	0.236					

$\beta_0 = intercept;\ \beta_1 = coefficient\ of\ BT; \beta_2 = coefficient\ of\ FM;\ \beta_3 = coefficient\ of\ SB;.$
$\beta_{12}, \beta_{13}, \beta_{23} = coefficients\ of\ the\ interactions; \beta_{11}, \beta_{22}, \beta_{33} = coefficients\ of\ the\ square\ terms.$

$$WAI = \frac{W_s - W_0}{W_0} \tag{2}$$

where: W_s - weight of sediment (g) and W_o -weight of sample (g)

$$WSI = \frac{W_r}{W_0} \tag{3}$$

where: W_r -is the weight (g) of residual supernatant after evaporation, W_o -weight of sample (g)

2.6. Sensory evaluation

A 50-member panel (30 males and 20 females) in the age range of 23 to 35 were used for the sensory assessment of the samples. Participants were screened for critical conditions such as allergies to soybean. The sensory attributes; visual color, flavor and overall acceptability were evaluated using a nine point hedonic scale rated from 1 (*extremely dislike*), 5(*neither like nor dislike*) to 9 (*extremely like*) [32] whereas crispiness was assessed using rating scale 1 (*no crispy*) to 5 (*very crispy*). The samples were coded using three digit numbers and served at room temperature [22].

2.7. Experimental design and data analysis

A central composite design with a total of 20 runs having six center points was used to study the effect of BT, blend ratio indicated by percentage of SB to *teff* flour and FM (Table 1) on physicochemical properties and sensory attributes of the extrudates [33]. The levels of the factors were set based on preliminary study. Design Expert version 13 (Stat-Ease Inc, USA) was used to design and analyse the experiment. The response surface model (Eq. (4)) was used to develop relationship between response variables and extrusion conditions. Principal component analysis was used to determine the association between variables using JMP 16 pro (SAS Institute Inc, NC).

$$Y = \beta_0 + \sum_{i=1}^{n} \beta_i X_i + \sum_{i=1}^{n} \beta_{ii} X_i^2 + \sum_{i<j}^{n} \sum_{j=1}^{n} \beta_{ij} X_i X_j + \epsilon \tag{4}$$

2.8. Optimization

An overlay plot was generated by superimposing the contour plots of individual quality attributes for graphical optimization. The optimal region for best product was found based on multiple optimization criteria where sensory attributes were greater or equal to the "*like*" intensity score, minimized BD, minimized Hardness and maximized L_{sp}, ER and crispiness. The desirability function approach was employed to carryout numerical optimization. Individual responses, y_i, were converted into desirability function d_i that varies over the range 0 to 1 [34]. Then, for n responses, the experimental variables are chosen to maximize the overall desirability, D (Eq (5)).

$$D = (d_1 \times d_2 \times d_3 \cdots d_m)^{\frac{1}{n}} \tag{5}$$

3. Results and discussion

3.1. Composition of teff and soybean flour

The results of the proximate composition revealed that *teff* flour had moisture, crude protein, fat, crude fiber, total ash, and total carbohydrate content of 9.35 ± 0.46 %, 11.93 ± 0.21 %, 3.01 ± 1.5 %, 2.10 ± 0.4 %, 1.87 ± 0.39 % and 71.74 ± 0.33 %, respectively. The values obtained in this study are comparable with earlier reported values of 10.21 to 13.3 % protein, 2.48 to 3.6 % fat, 2.0 to 2.6 % ash [3,9,35]. On the other hand soybean flour was found to have 7.97 ± 0.55 % moisture, 43.72 ± 0.38 % protein, 18.32 ± 0.29 % fat, 1.96 ± 0.40 % crude fiber, 4.00 ± 0.18 % total ash and 24.03 ± 0.45 % total carbohydrate. The protein content was higher than 35 %reported by [36] and lower than the 60 % reported by Suksomboon et al. (2011). *Teff* has higher protein content than maize, sorghum, barley, millet and almost equivalent to wheat [3,10,38].

3.2. Effect of extrusion conditions on extrudate quality attributes

3.2.1. Expansion ratio (ER)

The ER was significantly ($p<0.05$) influenced by the extrusion operating conditions (Table 2). The maximum ER was 2.28 for the sample with 5 % SB, 12 % MC and BT of 135 °C whereas the minimum was 1.48 for extrudates with 10 % SB, 12.5 % MC and BT of 130 °C. These values are comparable with *teff*-based and soy-based extruded products [9,37]. The response surface (Fig. 1a and b) showed the effect of extrusion parameters on the ER. In general the ER increased with increase in the BT and decreased with increase in SB proportion. ER

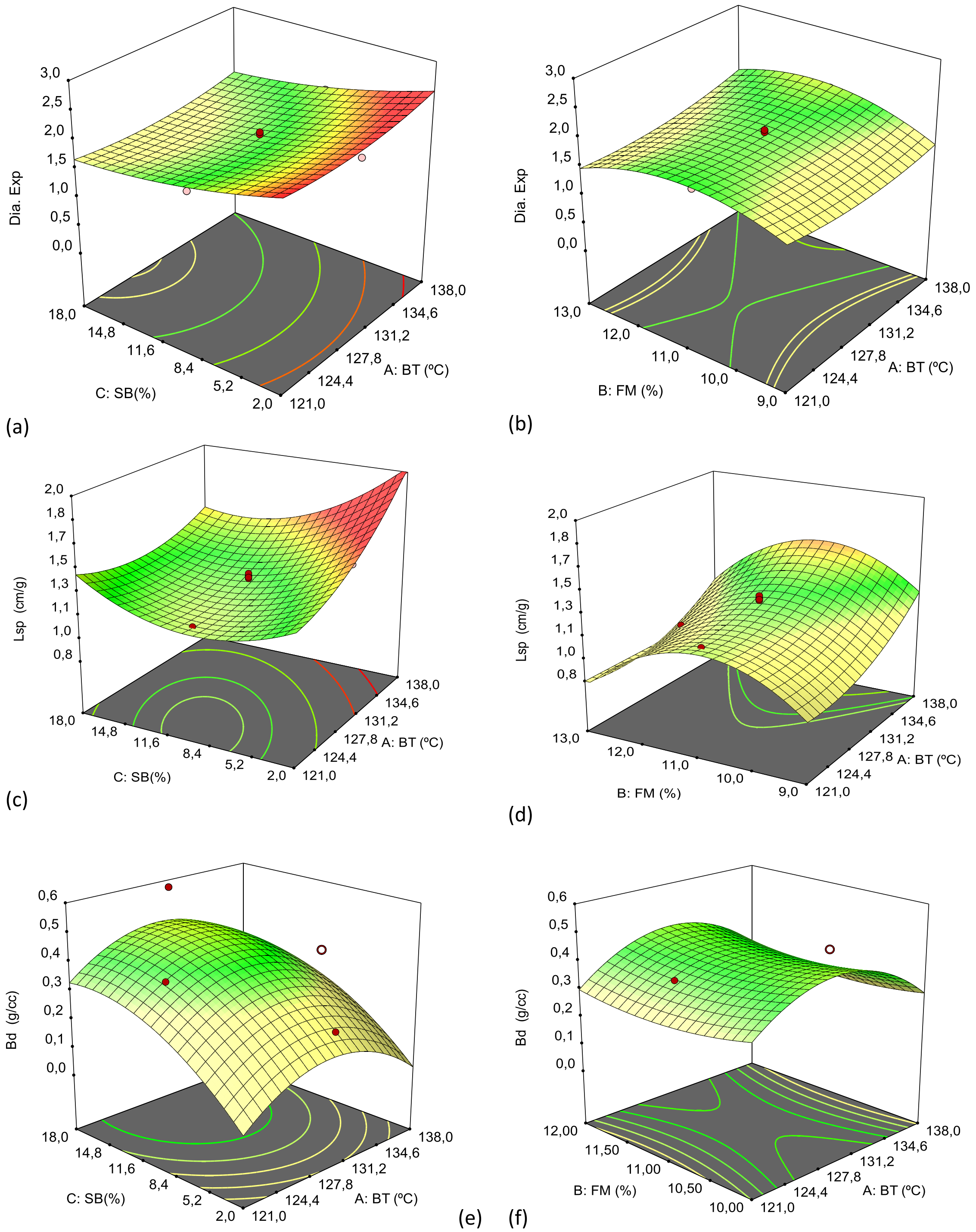

Fig. 1. Response surface for ER (a & b), L_{sp} (b & c), and BD (e and f) as a function of extrusion Barel Temperature (BT), Feed Moisture (FM) and Soy proportion (SB).

indicates the extent of puffing of extruded products. Increase in BT has also been reported to increase the ER of soybean-rice flour extrudates. Moreover increase in the proportion of defatted and texturized soybean flour resulted in decrease in ER [24,25] which could be attributed to the reduction of the starch proportion of the blend which has a significant influence on expansion [35]. Other studies also revealed that increase in barrel temperature increased the ER of *teff*-based extrudates [15,22,23]. The degree of superheating of water in the extruder would increase at higher temperature leading to greater expansion. Increase in soybean proportion was reported to decrease in ER of soybean-rice blend extdrudates where 5 % inclusion of soybean flour exhibited higher expansion compared to 15 % inclusion of soybean flour [37].

3.2.2. Specific length (L_{sp})

The L_{sp} is indicator of the linear expansion of extrudates per unit weight. The L_{sp} was significantly ($p<0.05$) influenced by the BT and SB proportion (Table 2). The maximum L_{sp} was 1.63 cm/g at 5 % SB, 10 % MC and BT of 135 °C whereas the minum was 0.98 cm/g for 10 %SB, 12.5 %MC and 135 °C. The response surface for L_{sp} as a function of the extrusion conditions are presented in Fig. 1c and d. The L_{sp} increased with increase in BT whereas the SL decreased with increase in SB up to 10 % followed by an increase. The L_{sp} increased with increase in FM up

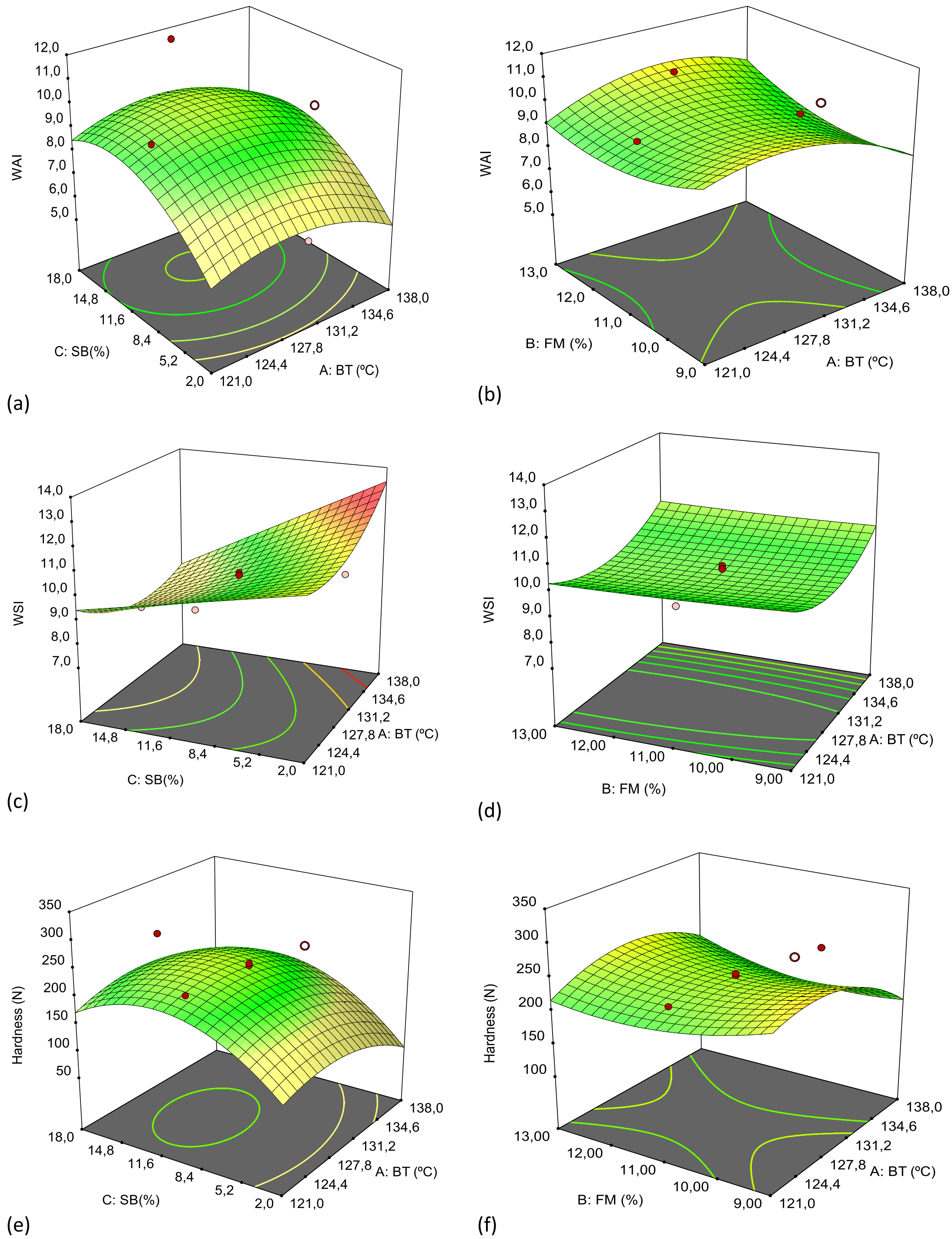

Fig. 2. Response surface for WAI (a & b), WSI (b & c), and Hardness (e and f) as a function of Barel Temperature (BT), Feed Moisture (FM) and Soy proportion (SB).

to 11 % followed by a decrease with further increase in FM. A decrease in L_{sp} with increase in BT from 130 to 140 °C followed by an increase with further increase in temperature to 150 °C has been reported [22]. As the extrudates expand in either the longitudinal and radial direction, their density decrease demonstrating a higher degree of starch gelatinization.

3.2.3. Bulk density (BD)

The BD was significantly ($p<0.05$) influenced by SB proportion whereas BT and FM did not exhibit significant ($p>0.05$) influence on the BD (Table 2). The maximum BD value was 0.59 g/cc for samples with 10 % SB, 12.5 % FM and BT of 130 °C. A comparably high BD of 0.58 g/cc was observed for samples with 17.6 % SB, 11 % FM and BT of 130 °C whereas the minimum was 0.20 g/cc for extrusion conditions of 5 % SB, 10 % FM and BT of 135 °C. The BD values obtained in this study are comparable to *teff*-based and soy-based extrudates (Minweyelet et al., 2021; Sisay et al., 2018; Wondimu & Emire, 2016). The response surface as a function of the extrusion operating conditions is presented in Fig. 1e and f. The BD increased with increase in BT from 122.4 °C to 130 °C followed by a decrease in BD with further increase in BT to 137.6 °C. The BD increased with increase in the proportion SB flour. Increase in BD with increase in proportion of chickpea in *teff*-chickpea blend extrudates was reported [14]. The increase in BD with SB proportion could be attributed to the increase in the protein concentration which is known to

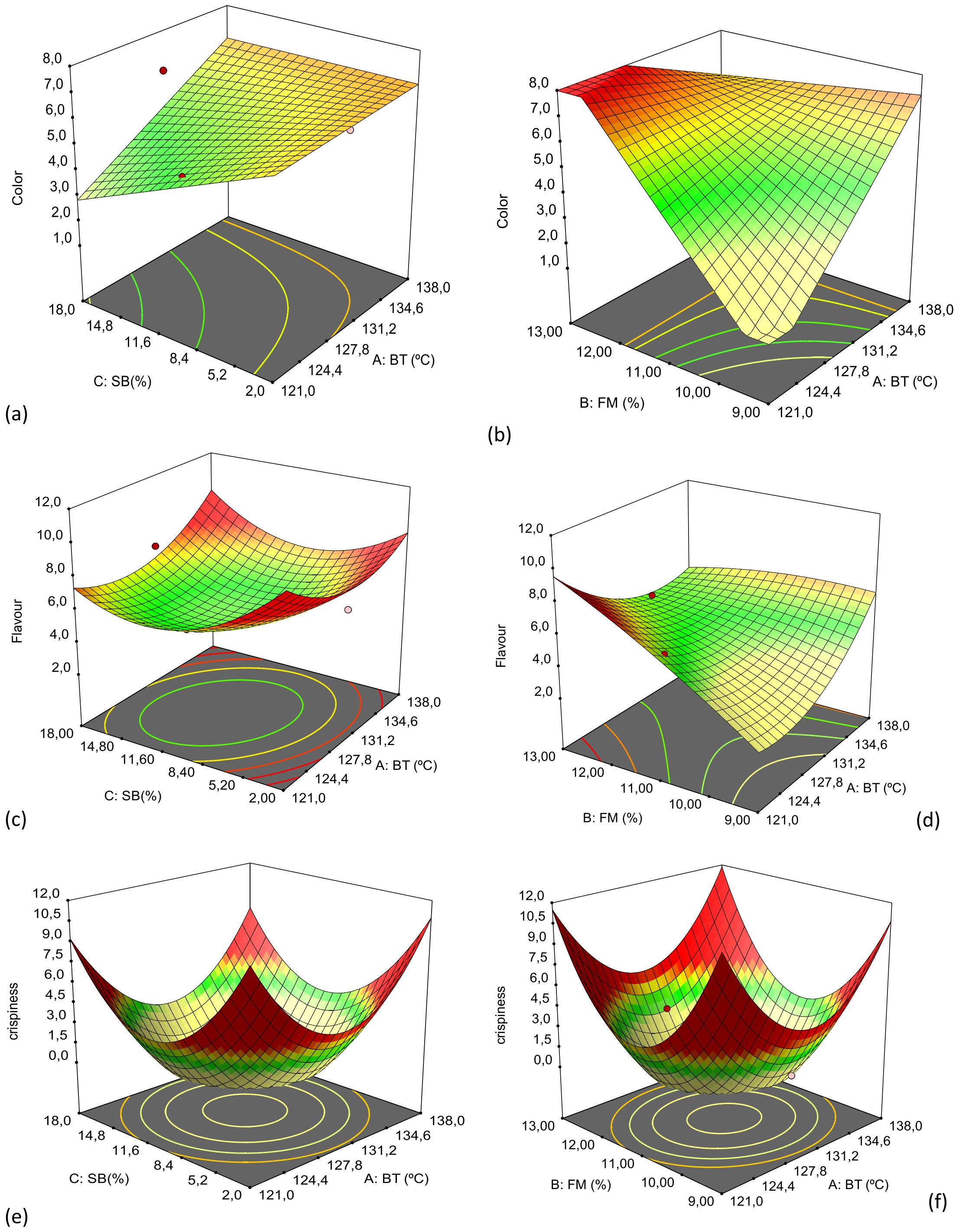

Fig. 3. Response surface for color (a & b), flavour (b & c), and crispiness (e and f) as a function of Barel Temperature (BT), Feed Moisture (FM) and Soy proportion (SB) Response surface for OAC (g & h) as a function of Barel Temperature (BT), Feed Moisture (FM) and Soy proportion (SB).

bind water resulting in a dense product. Moreover high percentage of fat in *SB* may lubricate the melt in the extruder and reduce the degree of transformation [35]. A decrease in BD with increase in extrusion temperature was reported for soybean-rice blend snack [24,37] and other extruded snacks [40].

3.2.4. Water absorption index (WAI)

The proportion SB exhibited a significant (0.05) influence on the WAI (Table 2). A maximum WAI of 11.59 g/g was observed for samples with 17.6 % SB, 11 % FM and 130 °C. Increase in WAI was observed with increase in BT from 122.4 °C to 130 °C followed by a decrease with further increase in temperature to 135 °C (Fig. 2a and b). The minimum WAI was 6.25 g/g for samples with 2.4 % SB, 11 % FM and BT of 130 °C. The WAI values obtained in this study were slightly higher than the values reported for *teff*-based extrudates which ranged from 0.7 to 7.89 g/g [15,22,23,39]. The WAI measures the amount of water absorbed by starch and has been used as an index of gelatinization [40]. Increase in water holding capacity with increase in extrusion temperature of soyprotein-gluten composite has also been reported [41]. The increase in WAI with increase in BT followed by a decrease could be due to

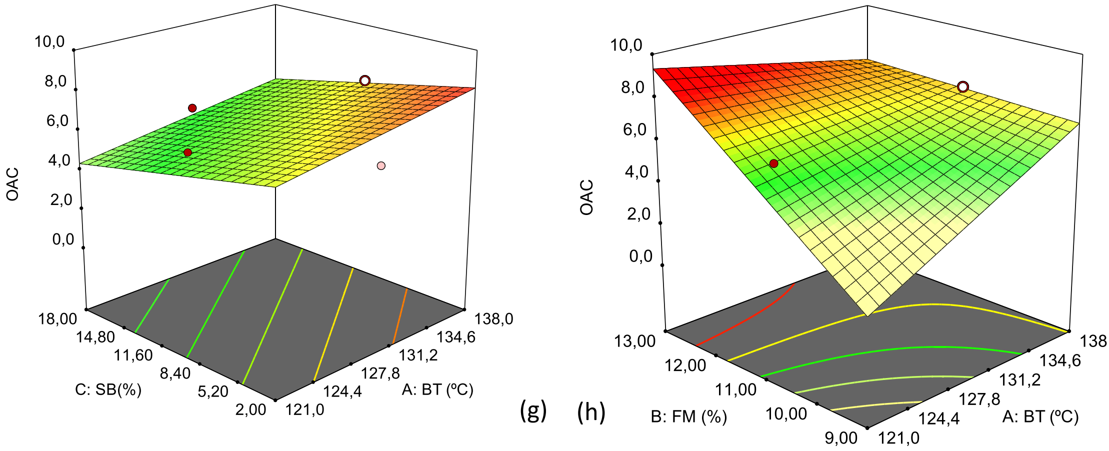

Fig. 3. (*continued*).

increased dextrinization [42]. Moreover, increase in SB proportion resulted in increase in WAI. A general increase in WAI with increase in soybean proportion has been reported in rice-soybean flour blend extrudates [37]

3.2.5. *Water solubility index (WSI)*

A maximum WSI value of 11.95 % was observed for samples with 5 % SB, 12 % FM and BT of 135 °C whereas the lowest value of 7.96 % for samples with 17.6 % SB, 11 % FM and BT of 130 °C. The WSI index was significantly (0.05) influenced by the proportion of SB (Table 2).The response surface for WSI as a function of SB proportion and BT (Fig. 2c and d) showed that WSI increased with increase in BT and decreased with increase in SB. WSI measures the amount of soluble components released from the starch after extrusion [40]. High extrusion temperature resulted in high WSI in soybean-rice extruded snacks which was attributed to increased amount of degraded starch which in turn increased the release of the soluble compound [21,24,37]. Increasing barrel temperature, which resulted in increased product temperature increased WSI [43]. Similar trend of WSI as a function of extrusion temperature was observed for other cereal-based extruded snacks [44]. The decrease in WSI with increase in *SB* proportion could be due to the relatively small amount of starch available for degradation. Comparatively high WSI has been reported for *teff* extrudates and the differences observed in WSI cereal products is a function of a number of factors which may include contents of starch and lipid, starch crystalline structure and particle size[35].

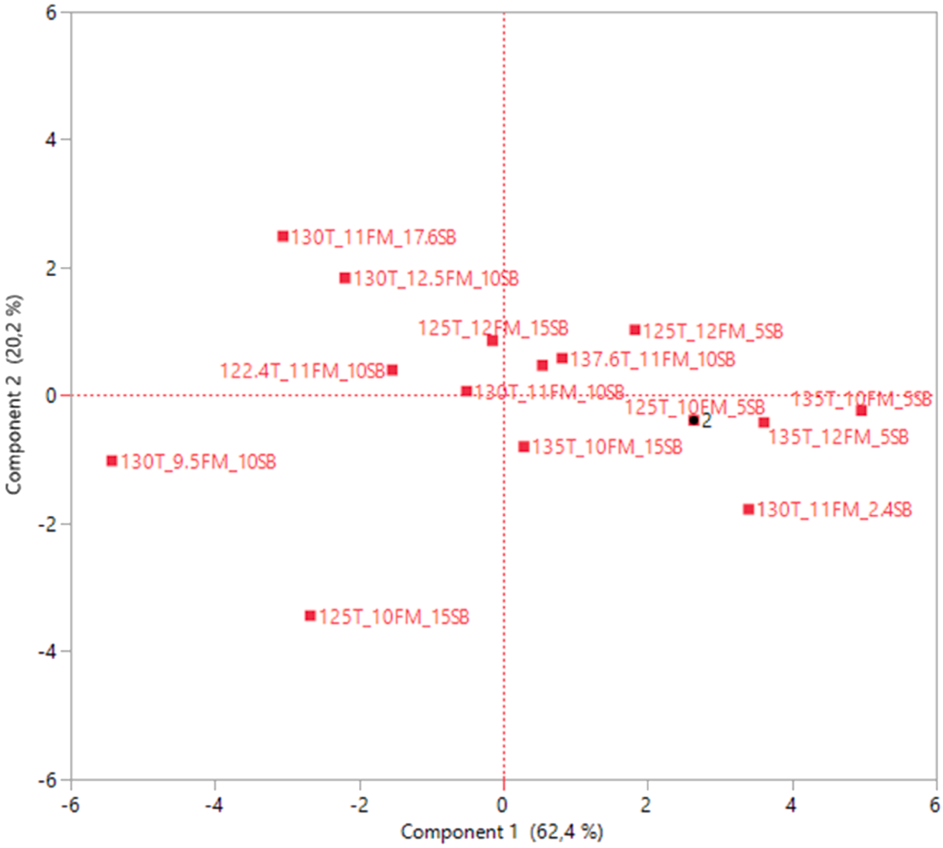

Fig. 4. Score plot of the first and second principal components showing the variability pattern of the samples.

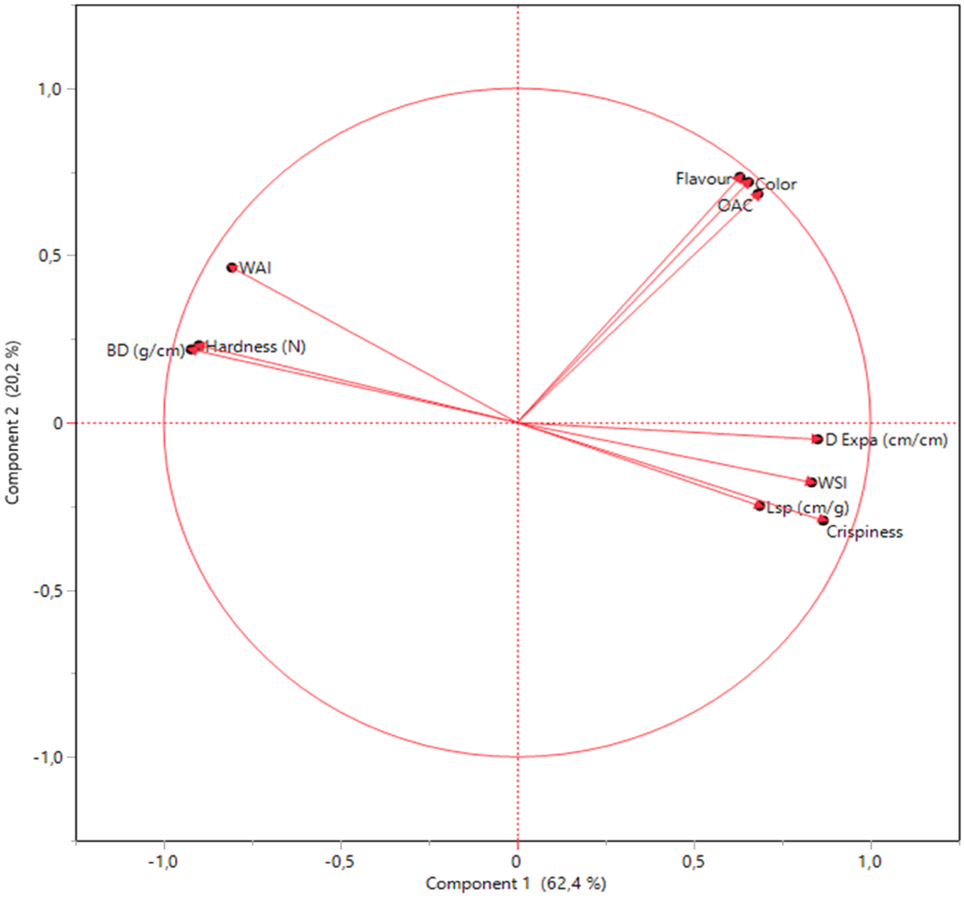

Fig. 5. Loading plot of the first and second principal components showing association between of variables.

3.2.6. *Texture/Hardness*

The SB proportion significantly ($p<0.05$) influenced the hardness value (Table 2). The minimum hardness value was 113.58 N for 5 % SB, 10 % FM and BT of 135 °C whereas the maximum was 300.2 N for 10 % SB, 9.5 % FM and BT of 130 °C. The hardness increased with increase in the proportion of SB (Fig 2e and f). Hardness which is also associated with crispiness of the extrudates was expressed by the force required to break the sample [35,36]. Increase in hardness was observed with increase in BT from 122.4 °C to 130 °C followed by a decrease with further increase in BT to 135 °C (Fig 2e and f). In a similar study, decrease in the hardness of extrudates with increase in the extrusion temperature was reported for corn-soybean blend [36]. High starch gelatinization occurs at high extrusion temperature resulting in high loss of moisture and formation of more air cells resulting in low BD, crispy or less hard extrudate [21,22,39,45]. The FM had no notable influence on hardness. Increase in SB proportion brought about increased hardness of extrudates. Similar trend has been reported for rice-soybean flour blend extrudates [37]. The increase in hardness with increase SB proportion could be attributed to higher protein in SB which caused reduced expansion, increased density and compact extrudates [15,22,35].

3.3. *Sensory quality*

The response surface for the sensory scores as a function of extrusion conditions are presented in Fig. 3a to h. Color score of 1.24 with hedonic intensity of *"dislike extremely"* was observed for extrudates with 15 % SB, 10 % FM and BT of 125 °C whereas a score of 7.75 with hedonic intensity of *"like very much"* was recorded for extrusion conditions of 5 % SB, 10 % FM and BT of 135 °C. There was a general increase in the color score with increase in BT, FM and decrease in SB proportion (Fig. 3a and b). Very low scores of flavor 2.96 and 3.26 with the hedonic intensity of *"dislike moderately"* were observed for samples with 10 % SB, 9.5 % FM and BT of 130 °C and 15 % SB, 10 % FM and BT of 125 °C, respectively. High flavor scores of 7.76, 7.75 and 7.74 with hedonic intensity of *"like very much"* were observed with extrusion conditions of 5 % SB, 10 % FM and BT of 135 °C, 5 % SB, 12 % FM and BT of 125 °C and 17.6 % SB, 11 % FM and BT of 130 °C, respectively. In general, increase in extrusion temperature and feed moisture content combined with low SB proportion gave high flavor score (Fig. 3c and d).

High score of 4.74 with the intensity of crispiness "*very crispy*" was observed for extrudates with 5 %SB, 10 %FM and BT of 135 °C whereas low score of 1.00 and 1.26 with sensory intensity of "*not crispy*" where observed for extrudates with 10 %SB, 11 %FM and BT of 122.4 °C and 18 %SB, 11 %FM and BT of 130 °C, respectively. Increase in BT and decrease in SB proportion exhibited high crispiness score (Fig. 3e and f). Increase in BT and decrease in SB proportion has resulted in decreased hardness and BD. These combinations produce light and porous extrudates that are crispy [21,22,36,45,46]. The response surface for overall acceptability (OAC) of extrudates as a function of the extrusion conditions are presented in Fig. 3g and h. Increase in BT and FM increased the OAC whereas increase in SB proportion decreased the OAC score. High OAC scores of 8 and 8.26 with hedonic intensity of "*like very much*" was obtained for extrudates with 5 %SB, 10 %FM and BT of 135 °C and 5 % SB, 12 %FM and BT 125 °C, respectively. The lowest OAC score was 2.46 with "*dislike moderately*" hedonic intensity was observed for extrudates with 15 %SB, 10 %FM and BT 125 °C . The low OAC score at higher SB proportion could be attributed to beany flavor from soybean flour. High BT has resulted in extrudates with low BD and crispy texture which might have contributed to high OAC of products extruded at 135 °C.

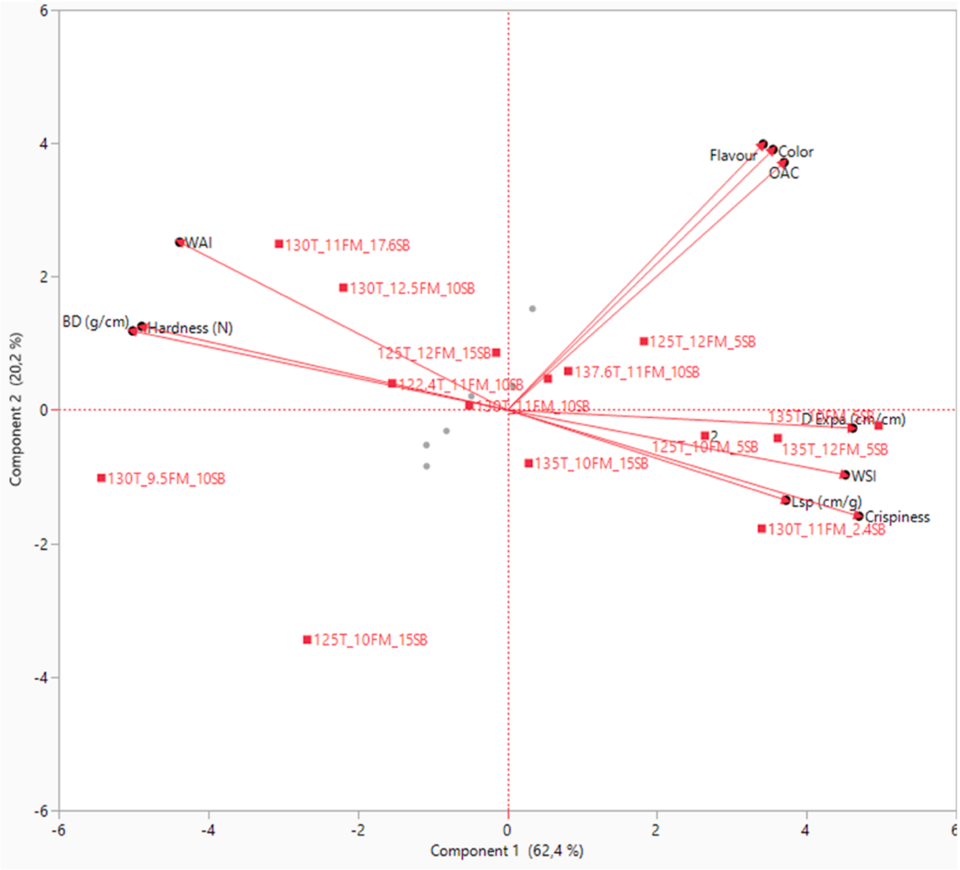

Fig. 6. Bi-plot of the first and second principal components showing association between samples and quality attributes of extrudates.

3.4. *Principal component analysis*

Principal component analysis was carried out to study the association between variables. Three principal components explained 89.1 % of the variations where the first (PC1), the second (PC2) and the third (PC3) principal components explained 62.4, 20.2 and 6.5 % of the variations respectively. The score plot (Fig. 4) showed the pattern of the variability among the samples. The proportion of SB contributed more on PC1. Low SB proportion and high BT samples are on the far right side of the score plot whereas the relatively high proportion SB with low to medium BT are on the left side of the score plot. The loading plot (Fig. 5) showed the correlation between the physical properties and the sensory

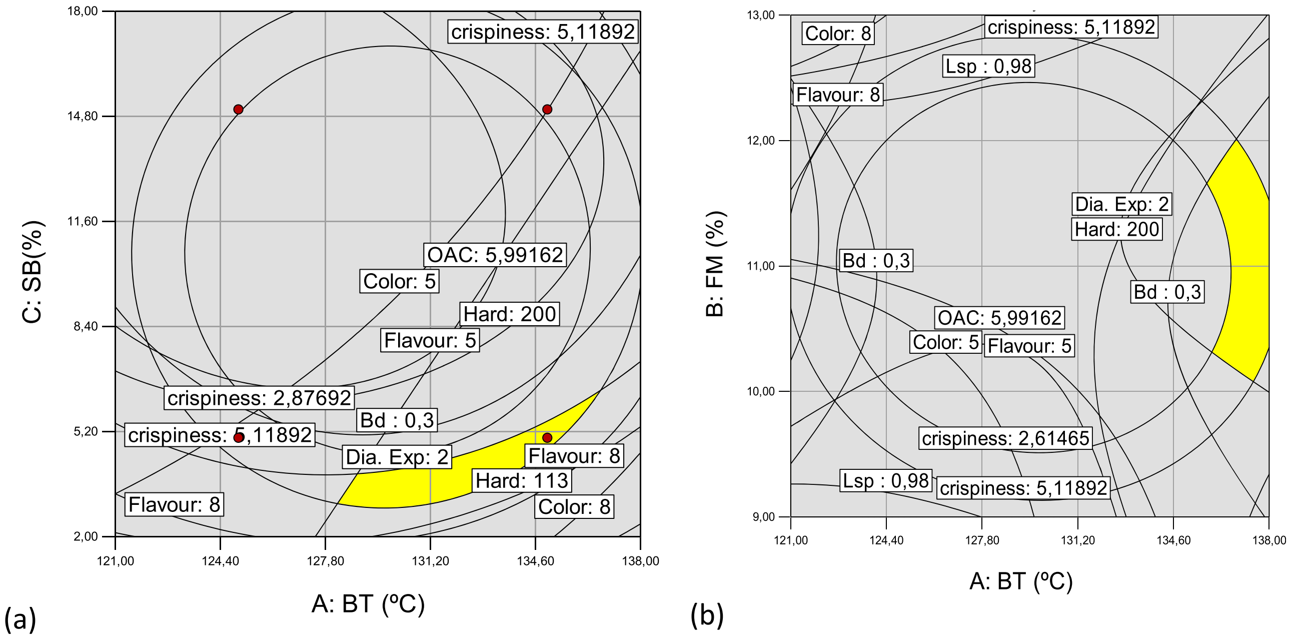

Fig 7. Overlay plot of the physical and sensory properties showing the optimal regions for optimal extrudate quality as a function of BT and SB (a); BT and FM (b).

attributes of extrudates. BD, WAI and Hardness are strongly and positively associated whereas they are negatively associated with WSI, crispiness, L_{sp} and ER. High BD and high WAI are linked to high proportion of SB which resulted in compact and hard extrudates. More expanded products are porous with more air cells and crispy texture [21,22,45,46]. The flavor color and OAC are highly correlated. The bi-plot (Fig. 6) show the association between the extrusion conditions and the measured variable of the extrudates. High SB proportion and relatively low BT are associated with high BD, WAI and hardness whereas low proportion of SB and high BT are associated with ER, L_{sp}, crispiness and OAC. On the contrary high BT and low proportion of SB are positively associated with $L_{sp}$and ER, crispiness and WSI. Similar trends have been reported with soybean-based, *teff*-based and other cereal-based extrudates [15,22,24,37,40,43].

3.5. Optimization

The optimum combination of BT, FM and SB proportion that gives optimal product quality was obtained by superimposing the response surfaces of the individual quality attributes. The optimum region is indicated in the yellow shaded area of Fig. 7a and b. Multiple optimization criteria were used with sensory attributes greater or equal to the "*like*" intensity score, minimized BD and Hardness and maximized L_{sp}, ER and crispiness. Based on graphical optimization the optimal product quality were found BT between 128 and 137 °C and SB proportion between 2 and 7.3 % where the FM is fixed at 10 % (Fig. 7a). Also BT of 135 °C to 137 °C, FM of 10 to12 % when the SB proportion is fixed at 7.5 % (Fig. 7b) gave optimal product quality. For numerical optimization all the sensory attributes, L_{sp} and ER were maximized and Hardness and BD were minimized. The numerical optimization resulted in optimal extrusion conditions for best product to be BT of 135 °C, FM of 10 % and SB proportion of 5 % with a desirability value of 0.875

4. Conclusion

Extrusion conditions and blend proportion significantly influenced the physicochemical properties of extrudates made from *teff*-soybean flour blend. Increase in BT increased the ER, and L_{sp} and reduced BD whereas increase in SB proportion decreased the ER. The WAI increased with increase in extrusion temperature and SB proportion. High BT and low SB proportion resulted in increased WSI. There were significant differences in the sensory attributes due to extrusion conditions. Graphical optimization gave best results for BT from 128 to 137 °C and SB proportion from 2 to 7.3 % where the FM is fixed at 10 %. Moreover, BT of 135 °C to137 °C, FM of 10 to 12 % when the SB proportion is fixed at 7.5 % also gave optimal product quality. The numerical optimization resulted in optimal extrusion conditions for optimal product quality were BT of 135 °C, FM of 10 % and SB proportion of 5 % with a desirability value of 0.875

Declaration of Competing Interest

None.

References

[1] I. Comino, M. De Lourdes Moreno, A. Real, A. Rodríguez-Herrera, F. Barro, C. Sousa, The gluten-free diet: testing alternative cereals tolerated by celiac patients, Nutrients 5 (2013) 4250–4268, https://doi.org/10.3390/nu5104250.

[2] L. Saturni, G. Ferretti, T. Bacchetti, The gluten-free diet: safety and nutritional quality, Nutrients 2 (2010) 16–34, https://doi.org/10.3390/nu2010016.

[3] F. Zhu, Chemical composition and food uses of teff (Eragrostis tef), Food Chem. 239 (2018) 402–415, https://doi.org/10.1016/j.foodchem.2017.06.101.

[4] A.-S. Hager, A. Wolter, F. Jacob, E. Zannini, E.K. Arendt, Nutritional properties and ultra-structure of commercial gluten free flours from different botanical sources compared to wheat flours, J. Cereal Sci. 56 (2012) 239–247, https://doi.org/10.1016/j.jcs.2012.06.005.

[5] S.T. Alemneh, S.A. Emire, B. Hitzmann, V. Zettel, Comparative study of chemical composition, pasting, thermal and functional properties of teff (Eragrostis tef) flours grown in Ethiopia and South Africa, Int. J. Food Prop. 25 (2022) 144–158, https://doi.org/10.1080/10942912.2022.2027441.

[6] Y.A. Gebru, D.B. Sbhatu, K.-P. Kim, Nutritional composition and health benefits of teff (*Eragrostis tef* (Zucc.) trotter), J. Food Qual. 2020 (2020) 1–6, https://doi.org/10.1155/2020/9595086.

[7] A.-S. Hager, E.K. Arendt, Influence of hydroxypropylmethylcellulose (HPMC), xanthan gum and their combination on loaf specific volume, crumb hardness and crumb grain characteristics of gluten-free breads based on rice, maize, teff and buckwheat, Food Hydrocoll. 32 (2013) 195–203, https://doi.org/10.1016/j.foodhyd.2012.12.021.

[8] L. Kebede, S.W. Kidane, G. Bultosa, S. Yetneberk, Effect of extrusion operating conditions on the physical and sensory properties of teff (Eragrostis teff [Zucc.] Trotter) flour extrudates, Ethiopian J. Appl. Sci. Technol. 1 (2010) 27–38.

[9] M. Minweyelet, W.K. Solomon, G. Bultosa, Effects of extrusion operating conditions and blend proportion on the physicochemical and sensory properties of teff-rice blend extruded products, Food Res. 5 (2021) 173–183, https://doi.org/10.26656/fr.2017.5(2).467.

[10] M.M. Gebremariam, M. Zarnkow, T. Becker, Teff (Eragrostis tef) as a raw material for malting, brewing and manufacturing of gluten-free foods and beverages: a review, J. Food Sci. Technol. 51 (2014) 2881–2895, https://doi.org/10.1007/s13197-012-0745-5.

[11] A.-S. Hager, M. Czerny, J. Bez, E. Zannini, E.K. Arendt, Starch properties, in vitro digestibility and sensory evaluation of fresh egg pasta produced from oat, teff and wheat flour, J. Cereal Sci. 58 (2013) 156–163, https://doi.org/10.1016/j.jcs.2013.03.004.

[12] H. Shumoy, K. Raes, Antioxidant potentials and phenolic composition of tef varieties: an indigenous Ethiopian cereal, Cereal Chem. J. 93 (2016) 465–470, https://doi.org/10.1094/CCHEM-10-15-0210-R.

[13] A. Wolter, A.-S. Hager, E. Zannini, E.K. Arendt, In vitro starch digestibility and predicted glycaemic indexes of buckwheat, oat, quinoa, sorghum, teff and commercial gluten-free bread, J. Cereal Sci. 58 (2013) 431–436, https://doi.org/10.1016/j.jcs.2013.09.003.

[14] J. Sadik, Effect of chick pea level and feed moisture content on physical properties of teff flour extrudates, Int. Food Res. J. 22 (2015) 539–545.

[15] A. Wondimu, S. Emire, Process parameters optimization for the manufacture of extruded teff-based gluten free snacks, AJFST 11 (2016) 299–307, https://doi.org/10.19026/ajfst.11.2414.

[16] J. Coleman, A.O. Abaye, W. Barbeau, W. Thomason, The suitability of teff flour in bread, layer cakes, cookies and biscuits, Int. J. Food Sci. Nutr. 64 (2013) 877–881, https://doi.org/10.3109/09637486.2013.800845.

[17] C.M. Mancebo, J. Picón, M. Gómez, Effect of flour properties on the quality characteristics of gluten free sugar-snap cookies, LWT - Food Sci. Technol. 64 (2015) 264–269, https://doi.org/10.1016/j.lwt.2015.05.057.

[18] G. Giuberti, A. Gallo, L. Fiorentini, P. Fortunati, F. Masoero, In vitro starch digestibility and quality attributes of gluten free 'tagliatelle' prepared with teff flour and increasing levels of a new developed bean cultivar: bean flour for gluten free teff pasta, Starch - Stärke 68 (2016) 374–378, https://doi.org/10.1002/star.201500007.

[19] P. Qin, T. Wang, Y. Luo, A review on plant-based proteins from soybean: health benefits and soy product development, J. Agric. Food Res. 7 (2022), 100265, https://doi.org/10.1016/j.jafr.2021.100265.

[20] C. Chatterjee, S. Gleddie, C.-W. Xiao, Soybean bioactive peptides and their functional properties, Nutrients 10 (2018) 1211, https://doi.org/10.3390/nu10091211.

[21] J.P. Singh, A. Kaur, K. Shevkani, N. Singh, B. Singh, Physicochemical characterisation of corn extrudates prepared with varying levels of beetroot (*Beta vulgaris*) at different extrusion temperatures, Int. J. Food Sci. Technol. 51 (2016) 911–919, https://doi.org/10.1111/ijfs.13051.

[22] M. Minweyelet, W.K. Solomon, G. Bultosa, Effects of extrusion operating conditions and blend proportion on the physicochemical and sensory properties of teff-rice blend extruded products, Food Res. 5 (2021) 173–183, https://doi.org/10.26656/fr.2017.5(2).467.

[23] R. Gopirajah, K. Muthukumarappan, Effect of extrusion process conditions on the physical properties of tef-oat healthy snack extrudates, J. Food Process. Preserv. 42 (2018) e13559, https://doi.org/10.1111/jfpp.13559.

[24] M.S. Alam, S. Pathania, A. Sharma, Optimization of the extrusion process for development of high fibre soybean-rice ready-to-eat snacks using carrot pomace and cauliflower trimmings, LWT 74 (2016) 135–144, https://doi.org/10.1016/j.lwt.2016.07.031.

[25] A. Rodríguez-Vidal, H.E. Martínez-Flores, E. González Jasso, G. Velázquez De La Cruz, A.K. Ramírez-Jiménez, E. Morales-Sánchez, Extruded snacks from whole wheat supplemented with textured soy flour: effect on instrumental and sensory textural characteristics: RODRÍGUEZ-VIDAL et al, J. Texture Stud. 48 (2017) 249–257, https://doi.org/10.1111/jtxs.12234.

[26] J.A.V. Famurewa, A.O. Raji, Parameters affecting milling qualities of undefatted soybeans (Glycine max, l. Merill) (1): selected thermal treatment, Int. J. Food Eng. 1 (2005), https://doi.org/10.2202/1556-3758.1026.

[27] D.O. Edem, J.O.I. Ayatse, E.H. Itam, Effect of soy protein supplementation on the nutritive value of 'gari' (farina) from Manihot esculenta, Food Chem. 75 (2001) 57–62, https://doi.org/10.1016/S0308-8146(01)00183-2.

[28] AOAC, Official Methods of Analysis, Wilson, 2000.

[29] D. Seth, G. Rajamanickam, Development of extruded snacks using soy, sorghum, millet and rice blend - a response surface methodology approach: millet based extruded snack, Int. J. Food Sci. Technol. 47 (2012) 1526–1531, https://doi.org/10.1111/j.1365-2621.2012.03001.x.

[30] S.A. Wani, P. Kumar, Characterization of extrudates enriched with health promoting ingredients, Food Measure. 9 (2015) 592–598, https://doi.org/10.1007/s11694-015-9268-x.

[31] R.A. Anderson, H.F. Conway, A.J. Peplinski, Gelatinization of corn grits by roll cooking, extrusion cooking and steaming, Starch/Stärke 22 (1970) 130–135, https://doi.org/10.1002/star.19700220408.

[32] N.T. Manyatsi, W.K. Solomon, J.S. Shelembe, Optimization of blending ratios of wheat-maize-sprouted mungbean (*Vigna radiata* L.) composite flour bread using D-optimal mixture design, Cogent Food Agric. 6 (2020), 1824304, https://doi.org/10.1080/23311932.2020.1824304.

[33] S.W. Kidane, Application of response surface methodology in food process modeling and optimization, in: P. Kayaroganam (Ed.), Response Surface Methodology in Engineering Science, IntechOpen, 2021, https://doi.org/10.5772/intechopen.100113.

[34] D. Montgomery, Design and Analysis of Experiments, 8th ed., John Wiley & Sons, Inc, 2013.

[35] F. Robin, C. Théoduloz, S. Srichuwong, Properties of extruded whole grain cereals and pseudocereals flours, Int. J. Food Sci. Technol. 50 (2015) 2152–2159, https://doi.org/10.1111/ijfs.12893.

[36] A.A. Pérez, S.R. Drago, C.R. Carrara, D.M. De Greef, R.L. Torres, R.J. González, Extrusion cooking of a maize/soybean mixture: factors affecting expanded product characteristics and flour dispersion viscosity, J. Food Eng. 87 (2008) 333–340, https://doi.org/10.1016/j.jfoodeng.2007.12.008.

[37] A. Suksomboon, K. Limroongreungrat, A. Sangnark, K. Thititumjariya, A. Noomhorm, Effect of extrusion conditions on the physicochemical properties of a snack made from purple rice (Hom Nil) and soybean flour blend: extruded snack based on purple rice and soybean flour blend, Int. J. Food Sci. Technol. 46 (2011) 201–208, https://doi.org/10.1111/j.1365-2621.2010.02471.x.

[38] G. Bultosa, J.R.N. Taylor, TEFF. Encyclopedia of Grain Science, Elsevier, 2004, pp. 281–290, https://doi.org/10.1016/B0-12-765490-9/00172-5.

[39] M.T. Sisay, S.A. Emire, H.S. Ramaswamy, T.S. Workneh, Effect of feed components on quality parameters of wheat–tef–sesame–tomato based extruded products, J. Food Sci. Technol. 55 (2018) 2649–2660, https://doi.org/10.1007/s13197-018-3187-x.

[40] Q.-B. Ding, P. Ainsworth, A. Plunkett, G. Tucker, H. Marson, The effect of extrusion conditions on the functional and physical properties of wheat-based expanded snacks, J. Food Eng. 73 (2006) 142–148, https://doi.org/10.1016/j.jfoodeng.2005.01.013.

[41] M. Wu, Y. Sun, C. Bi, F. Ji, B. Li, J. Xing, Effects of extrusion conditions on the physicochemical properties of soy protein/gluten composite, Int. J. Agric. Biol. Eng. 11 (2018) 205–210, https://doi.org/10.25165/j.ijabe.20181104.4162.

[42] G. Sacchetti, G.G. Pinnavaia, E. Guidolin, M.D. Rosa, Effects of extrusion temperature and feed composition on the functional, physical and sensory properties of chestnut and rice flour-based snack-like products, Food Res. Int. 37 (2004) 527–534, https://doi.org/10.1016/j.foodres.2003.11.009.

[43] H. Lei, R.G. Fulcher, R. Ruan, B. Van Lengerich, SME-arrhenius model for WSI of rice flour in a twin-screw extruder, Cereal Chem. J. 82 (2005) 574–581, https://doi.org/10.1094/CC-82-0574.

[44] Q.-B. Ding, P. Ainsworth, G. Tucker, H. Marson, The effect of extrusion conditions on the physicochemical properties and sensory characteristics of rice-based expanded snacks, J. Food Eng. 66 (2005) 283–289, https://doi.org/10.1016/j.jfoodeng.2004.03.019.

[45] H. Köksel, G.-H. Ryu, A. Basman, H. Demiralp, P.K.W. Ng, Effects of extrusion variables on the properties of waxy hulless barley extrudates, Nahrung 48 (2004) 19–24, https://doi.org/10.1002/food.200300324.

[46] M.T. Sisay, S.A. Emire, H.S. Ramaswamy, T.S. Workneh, Effect of feed components on quality parameters of wheat–tef–sesame–tomato based extruded products, J. Food. Sci. Technol. 55 (2018) 2649–2660, https://doi.org/10.1007/s13197-018-3187-x.