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Optimization of Processing Conditions for *Shiro* Flour Production from Chickpea (*Cicer arietinum* L.) via Response Surface Methodology

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Abstract

Chickpea *shiro* flour is widely used across both rural and urban areas of Ethiopia to prepare *shiro-wot*, a traditional stew typically consumed with *injera*. While the core processing steps, soaking and roasting, are consistently applied in traditional practice, key parameters such as soaking duration, roasting temperature, and roasting time have not been systematically optimized. Variations in these factors can lead to substantial differences in nutritional composition, ultimately affecting the marketability and consumer acceptance of the final product. This study aimed to optimize processing parameters (soaking time, roasting temperature, and roasting duration) for the production of high-quality chickpea *shiro* flour via response surface methodology. The effects of soaking time (25–112 minutes), roasting temperature (165.9–334.1 °C), and roasting duration (1.59–18.41 minutes) were evaluated with respect to dehulling efficiency, functional attributes, proximate composition, color, and consumer acceptability. Statistical modeling and ANOVA demonstrated that all three parameters significantly ($p < 0.05$) influenced critical quality traits. The optimal conditions of 90 minutes of soaking, 300 °C roasting, and 5 minutes of roasting resulted in the highest overall acceptability score (4.98), efficient dehulling, desirable color, and balanced functional properties. These findings emphasize the value of moderate roasting temperatures combined with shorter roasting times to achieve a balance between flavor development, nutrient preservation, and structural integrity. The optimized protocol provides a practical framework for industrial-scale flour production, enhancing product quality, nutritional value, and consumer appeal.

Keywords: chickpea, shiro, nutritional value, soaking time, roasting temperature

Introduction

Legumes are recognized as powerhouses of nutrients. While their nutritional value may vary slightly among species, all pulses are nutrient-dense, offering rich sources of fiber, protein, minerals, and vitamins. Chickpea (*Cicer arietinum* L.) is a particularly important grain legume that provides an excellent balance of protein, carbohydrates, lipids, fiber, key micronutrients, and vitamins, making it highly relevant for meeting the world's growing food and nutritional demands. The chickpea protein features a well-balanced amino acid profile with high bioavailability. Owing to this balanced nutrient composition, chickpea serves as an effective alternative to animal protein and a valuable resource for addressing hidden hunger and malnutrition, especially in low-income countries (Jha et al., 2024). In addition, chickpea species are rich in bioactive compounds, particularly flavonoids and polyphenols, which act as potent antioxidants and are especially concentrated in darker-seeded desi genotypes. They also provide significant amounts of tocopherol, folic acid, and water-soluble vitamins such as riboflavin, pyridoxine, and pantothenic acid—often at higher concentrations than those found in other pulses (Gupta et al., 2017).

Ethiopia is the largest producer of chickpea in Africa, accounting for approximately 46% of the continent's production from 1994--2006. It is also the fifth largest producer worldwide and contributes approximately 3.2% of the total global chickpea production (FAOSTAT, 2014). Chickpea, locally known as *shimbira*, is one of the major pulse crops (including faba bean, field pea, haricot bean, lentil and grass pea) in Ethiopia, and in terms of production, it is the second most important legume crop after beans. It contributed approximately 17.6% of the total pulse production in 2014, and Ethiopia is a major producer and consumer of chickpea-based products, with approximately 0.5 million tons produced during the main cropping season of 2020–2021 (CSA, 2021). In Ethiopia, chickpea grain is widely used in different forms in traditional food product development, such as green vegetables, *Kollo*, *nifro*, *dabo*, *genfo* (porridge), *kita*, *shembera asa*, *bokelet*, *kik*, *mitad shiro* and *shiro*, which are used to prepare the so-called *wot* (sauces) eaten with Ethiopian injera.

Chickpeas, prior to their incorporation into various food products, typically undergo primary processing steps such as soaking, roasting, and dehulling. During the drying of moistened grains, the cotyledons shrink unevenly, causing distortion and contact only at the edges. This facilitates

loosening of the hull, which can subsequently be removed by the shearing action of dehulling machines. Roasting plays a key role in enhancing chickpea flour quality by developing desirable flavors, improving color and texture, increasing overall acceptability, and extending shelf-life, largely through the formation of carbonyl compounds during heating (Subuola et al., 2012). The roasting parameters, specifically time and temperature, are adjusted according to the chickpea type and intended product application. Careful control of the degree of roasting is essential to ensure that sufficient chemical reactions occur without burning the grains and compromising the sensory quality of the *Shiro* flour (Mendes et al., 2001).

Shiro is a traditional Ethiopian dish widely consumed in both rural and urban areas. It is a quick-cooking stew (*shiro-wot*) prepared by blending roasted chickpea flour with minced onion, garlic, ginger, or chopped tomatoes and peppers combined with boiling water and edible oil. The dish is typically served with *injera* (a leavened flatbread made mainly from tef) or bread and is valued for its rich flavor, which is also highly appreciated by tourists. In Ethiopia, roasted chickpea flour is commonly used for *shiro* preparation, although other legumes may also be substituted. The production of *Shiro* flour involves soaking raw chickpea seeds, drying them in sunlight, roasting them, splitting them into single cotyledons, and finally, milling them. The resulting flour, obtained from roasted, dehulled, and spiced chickpeas, is used as a thickening agent for the stew, which is similar to the desired consistency.

Prior research has mostly concentrated on the creation or improvement of spice blends used to make *shiro* flour, paying little to no attention to pre-processing variables like soaking time, roasting temperature, and roasting time that have a significant impact on product quality. Yet, no published study has methodically investigated or improved these essential factors to provide uniform processing standards to produce *shiro* flour. The development of uniform *shiro* flour quality across domestic and commercial manufacturing systems has been hampered by this information gap. Determining quality standards, guaranteeing product homogeneity, and enhancing customer satisfaction are further hampered by the lack of thorough data on the physical, chemical, and functional characteristics of chickpea-based *shiro* flour under various processing settings. The novelty of the present study lies in its integrated and data-driven approach to optimizing the key pre-processing parameters specifically soaking time, roasting temperature, and roasting duration for chickpea *shiro* flour production. By systematically evaluating the impact of these parameters on the physicochemical, functional and consumer characteristics of the product, this research provides the first scientific basis for process optimization in *shiro* flour preparation. Additionally, by bridging the gap between scientific food engineering and indigenous knowledge, the findings directly aid in the modernization and standardization of traditional food processing techniques. The study's findings support increased production efficiency, better product quality, and increased market competitiveness for *shiro* products made from chickpeas, which have practical implications for both small-scale producers and large-scale industrial processors.

Materials and methods

Sample preparation

Desi-type chickpeas (cv. Natoli), which were selected for their representativeness of other desi genotypes in terms of seed shape, size, and key attributes, were obtained from the DZARC chickpea and lentil national research program. The seeds were manually cleaned and sorted to remove foreign materials. The spice mixture applied in all the treatments consisted primarily of red pepper powder (berbere) and tomato, with additional spices included uniformly across the treatments in standardized quantity and quality. Preliminary experiments were conducted to determine the minimum and maximum levels of the independent variables: soaking time, roasting temperature, and roasting duration.

Experimental design

Response surface methodology (RSM) with a central composite rotatable design (CCD) was employed to optimize the independent variables and evaluate the effects of soaking time, roasting temperature, and roasting duration on the chemical composition and sensory characteristics of chickpea *shiro* flour. A three-factor, five-level full factorial CCD was generated via Design-Expert software (version 13) to determine the optimal level of each variable. The five levels of each variable were coded as $-\alpha$, -1 , 0 , $+1$, and $+\alpha$. A total of 20 experimental runs, including three replicates at the center point, were conducted in random order.

In accordance with Peng et al. (2015), polynomial functions with quadratic terms (Equation (1)) were applied to fit the experimental data, allowing the identification of critical points (maximum, minimum, or saddle) and the assessment of the effects of the independent variables on the response parameters.

$$1) \quad Y = \beta_0 + \sum_{i=1}^k \beta_i X_i + \sum_{i=1}^k \beta_{ii} X_i^2 + \sum_{i=1}^k \sum_{j=i+1}^k \beta_{ij} X_i X_j$$

where:

Y- predicted response

X_i , X_j and X_{ij} - independent variables (soaking time, roasting temperature, and roasting time)

β_0 - intercept (constant term)

β_i - linear regression coefficients

β_{ii} - quadratic regression coefficients

β_{ij} - interaction regression coefficients

i, j - indices representing the independent variables

Shiro flour preparation

To ensure uniform heating, cleaned desi-type chickpea species were manually sorted by size. Approximately 300 g of grains were soaked in water at a 2:1 (water: grain) ratio at room

temperature and subsequently dried in an oven at 65 °C overnight (Fig. 1). The pretreated chickpea species were then subjected to dry heat in a roasting pan under different combinations of temperatures and times. Following roasting, the samples were cooled to room temperature and dehulled via a manual decorticator and traditional stone sheller, and the hulls were separated by winnowing. The dehulled chickpea samples were then milled into flour, which was stored in sealed plastic bags at refrigeration (4 °C) until further analysis.

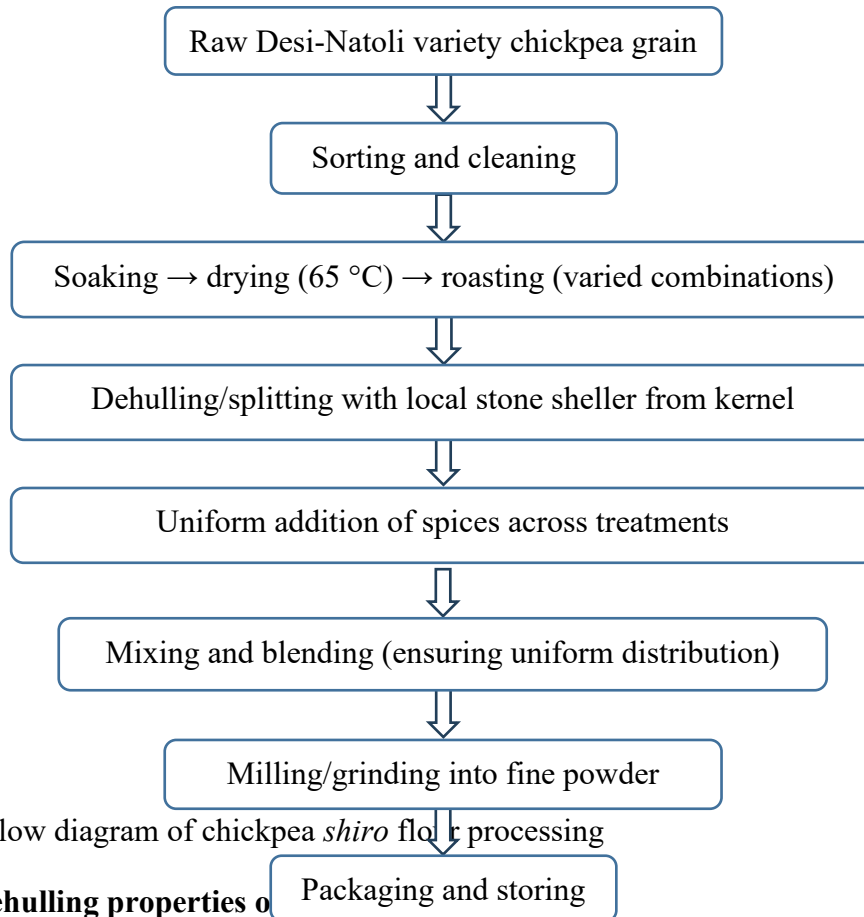


Figure 1: Flow diagram of chickpea *shiro* flour processing

Physical dehulling properties of

Dehulling efficiency

Dehulling efficiency (DE), also termed the degree of dehulling or dehulling index, is the yield of an edible, dehulled product (the sum of dehulled whole seeds and dhal) expressed as a percentage of the original seed mass (Equation 2).

$$2) \quad DE (\%) = \frac{DWS + D}{Wt} \times 100$$

where:

165 DWS = mass of dehulled whole seeds (g)

166 D = mass of dhal (split cotyledons) (g)

167 Wt = original mass of whole seeds prior to dehulling (g)

168 **Dehulling index**

169 The maximum response level (+1) corresponds to complete dehulling (100% of the seeds dehulled,
170 with no fine or unde-hulled grains), whereas the minimum response level (-1) represents complete
171 failure (all seeds remaining unde-hulled or broken into fines). The dehulling index (n) was
172 calculated as (Equation 3):

173 3)
$$n = \frac{(Mc + Mh) - (Muh + Mf)}{Mg}$$

174 where:

175 Marrow mass of cotyledons and broken cotyledons

176 Mh- mass of removed hulls

177 Muh- mass of kernels that remained unde-hulled

178 Mf- mass of fines in the final product

179 The total mass removed is the ratio of the mass of hull removed during dehulling to the initial mass
180 of the sample used for the dehulling process.

181 **Split yield (SY)**

182 The split yield (SY), also referred to as the dhal yield, represents the proportion of dehulled and
183 split material (dhal) relative to the original seed weight, expressed as a percentage:

184 4)
$$SY (\%) = \frac{D * 100}{Wt}$$

185 D- mass of dehulled splits

186 Wt- original seed weight

188 This calculation can also be adapted to determine the percentage of other milled products, such as
189 dehulled whole seeds.

190 **Percentage kibble or broken**

191 The percentage of kibble or broken yield represents the proportion of broken product material
192 obtained after dehulling, expressed as a percentage of the original seed weight:

193
194 5) Broken (%) = $\frac{K*100}{W_t}$
195

196 where:

197 K- mass of kibble or broken (kibble or broken are defined as cotyledon fragments retained on a
198 0.80 mm sieve)

199 W_t- original weight

200 **Functional properties of chickpea flour**

201 The water and oil absorption capacities of the chickpea flours were evaluated according to the
202 methods of Aremu et al. (2007) and Segev et al. (2011). The results are expressed as grams of
203 water or oil absorbed per gram of sample on a dry-weight basis.

204 Foaming properties were assessed following the procedure of Oladele and Aina (2007).
205 Approximately one gram of flour was dispersed in 50 mL of distilled water in a capped test tube
206 and shaken vigorously for 5 minutes. The mixture was then immediately transferred into a 250 mL
207 graduated cylinder, and the foam volume was recorded to determine the foaming capacity (mL/100
208 mL). Foam stability was evaluated after 60 minutes and expressed as the percentage of the initial
209 foam volume retained.

210 **Proximate composition analysis of *Shiro* flour**

211 The proximate composition of *the Shiro* flour, namely, moisture, crude protein, crude fat, crude
212 fiber, and total ash, was determined according to the official methods of the Association of Official
213 Analytical Chemists (AOAC, 2000; Methods 925.10, 920.87, 920.39, 962.09, and 923.03,
214 respectively). The utilizable carbohydrate content was estimated following the procedures outlined
215 by FAO (1998). Gross energy was calculated via Atwater's conversion factors: 4 kcal/g for protein,
216 9 kcal/g for fat, and 4 kcal/g for carbohydrates (FAO, 2002).

217 **Consumer acceptability**

218 Sensory evaluation of chickpea *shiro-wot* was carried out with 25 trained panelists via a seven-
219 point hedonic scale to assess the acceptability of the selected attributes. Samples from different
220 treatment combinations were prepared via a standardized recipe and presented in randomized,
221 coded order. Each panelist evaluated the samples individually with a spoon and rinsed their mouths
222 with bottled water between tastings to minimize carryover effects.

Statistical analysis

All measurements were performed in triplicate on a dry weight basis and expressed as the mean values $\pm$ standard deviations (SD), rounded to two decimal places. The data were analyzed via response surface methodology (RSM) with Design-Expert software (version 13). Stationary points (maximum, minimum, or saddle) were visualized via three-dimensional surface plots. In addition, statistical analyses were conducted with SPSS software, applying two-way ANOVA at a significance level of $p < 0.05$.

Results

Statistical analysis and mathematical model fitting

The experimental results for the dehulling properties, functional properties, proximate composition, and consumer acceptability are summarized in Tables 3-7. The model equation was found to be adequate, showing no significant lack of fit and yielding high R^2 values across all the responses. Table 1 presents the ANOVA results for the effects of soaking time, roasting temperature, and roasting duration on these parameters. Most of the evaluated attributes were significantly ($p < 0.05$) influenced by the processing conditions.

ANOVA revealed the effects of soaking time, roasting temperature, and roasting duration on multiple response variables, including dehulling efficiency, degree of dehulling, split yield, percentage of broken grains, bulk density (BD), foaming capacity (FC), oil absorption capacity (OAC), and water absorption capacity (WAC). The model was statistically significant across all the responses, with strong effects ($p < 0.001$) observed for the percentage of broken grains, FC, OAC, and WAC and moderate effects for dehulling efficiency, degree of dehulling, and BD. The roasting temperature had the most pronounced influence, significantly affecting the percentage of broken grains, FC, OAC, and WAC, whereas the roasting duration strongly impacted the percentage of broken grains, FC, and WAC. In contrast, soaking time had little effect, except for BD. High R^2 values for the percentage of broken grains, FC, OAC, and WAC indicate that these responses were well explained by the tested factors.

This ANOVA assessed the effects of different factors on both proximate composition and sensory attributes, including moisture, ash, fat, fiber, protein, aroma, color, taste, and overall acceptability. Significant differences ($p < 0.05$, $p < 0.01$, $**p < 0.001$) were observed for several parameters. Fat,

protein, aroma, color, taste, and overall acceptability were highly significant, indicating their strong contribution to sensory acceptance. Moisture, ash, fat, fiber, and protein also had notable effects, with protein and fat exerting the most consistent influence across the tested factors. In contrast, attributes such as moisture, fiber, aroma, and color presented only moderate or no significant variation. The high R^2 values for aroma, color, and taste suggest that the model provided a strong explanatory fit for these sensory attributes.

The regression coefficients (Table 2) of the second-order polynomial model emphasize the influence of soaking time, roasting temperature, and roasting time, together with their interaction and quadratic terms, on a range of response parameters. Significant coefficients (indicated by *) reflect strong effects. For the dehulling efficiency, the quadratic terms of the roasting temperature and roasting time were particularly important, whereas the interaction between the soaking time and roasting time had a moderate negative effect. For the degree of dehulling and split yield, the roasting temperature was the dominant factor, with dehulling also showing sensitivity to the quadratic effect of soaking time.

For the percentage of broken samples, the roasting temperature and roasting time were key, with strong positive linear effects and quadratic contributions from both factors. The foaming capacity and oil absorption capacity were significantly and negatively affected by the roasting temperature and roasting time, with moderate interaction terms also influencing the foaming capacity. The moisture content decreased with increasing roasting temperature and roasting time, whereas the fat content responded positively to all the main effects, with a significant contribution from the quadratic effect of soaking time. With respect to sensory attributes such as aroma, color, and overall acceptability, roasting time clearly had a negative effect, particularly in quadratic terms, suggesting reduced acceptability at higher roasting times.

Overall, these results underscore the importance of optimizing chickpea *and* flour processing conditions, as specific factors and their interactions distinctly influence each quality attribute. The large number of significant interactions and quadratic terms further highlights the complexity of the relationships between processing parameters and product qualities.

280 **Table 1:** Analysis of variance (ANOVA) for physical dehulling properties, functional properties, proximate composition and consumer
281 acceptability of *Shiro* flour

Source	Degree of freedom	Sum of square							
		Dehulling Efficiency	Degree of dehulling	Split yield	% Broken	BD	FC	OAC	WAC
Model	9	3005.95**	53.36*	368.8*	113.65***	0.012*	88.46***	1.37***	1.18***
A (ST)	1	206.27ns	2.39ns	184.25	0.18	0.525**	0.459ns	0.0044ns	0.0028ns
B (RT)	1	81.15ns	12.85*	11.86	18.91***	0.667**	25.76***	0.9195***	0.8676***
C (Rt)	1	241.5ns	3.90ns	0.33	53.91***	0.3489*	43.58***	0.2695**	0.3081***
Lack of fit	5	576.95ns	12.02ns	1127.24ns	4.25ns	0.0047ns	4.68ns	0.0853ns	0.0815ns
Pure error	5	32.61	4.85	65.23	0.2349	0.0065	0.3973	0.0485	0.02
Cor total	19	3615.52	72.24	1555.27	118.13	0.0231	93.53	1.5	1.28
R ²		0.8314	0.778	0.633	0.9621	0.7189	0.95	0.9108	0.9229
Continued									
Moisture	Ash	Fat	Fiber	Protein	Aroma	Color	Test	Overall acceptability	
16.78*	0.9612*	9.94***	33.68*	19.96***	22.76**	24.49**	28.13**	32.22**	
0.2015ns	0.4618*	7.07***	19.08*	0.3061ns	0.0483ns	0.0437ns	0.0026ns	0.022ns	
8.06*	0.0666ns	1.34***	0.9595ns	0.9867**	1.05ns	1.11ns	0.6991ns	0.7505ns	
5.72*	0.0439ns	0.357***	3.52ns	18.67***	2.50*	2.51*	2.03ns	1.86ns	
11.48ns	0.5206ns	0.185ns	14.99ns	1.08ns	4.28ns	4.23ns	6.05ns	6.39ns	
1.71	0.1497	0.13	14.65	0.5871	0.069	0.0388	0.01	0.1238	
29.96	1.63	10.26	63.32	21.64	27.11	28.75	34.2	38.74	
0.56	0.5892	0.969	0.5319	0.9229	0.84	0.8516	0.82	0.8318	

283 Note: ST-soaking time, RT-roasting temperature, Rt-roasting time, ns-nonsignificant, BD-bulk density, FC-foaming capacity, OAC-oil absorption capacity and
284 WAC-water absorption capacity

285

286

287 **Table 2:** Regression coefficients of the second-order polynomials for the response of different *shiro* flour parameters

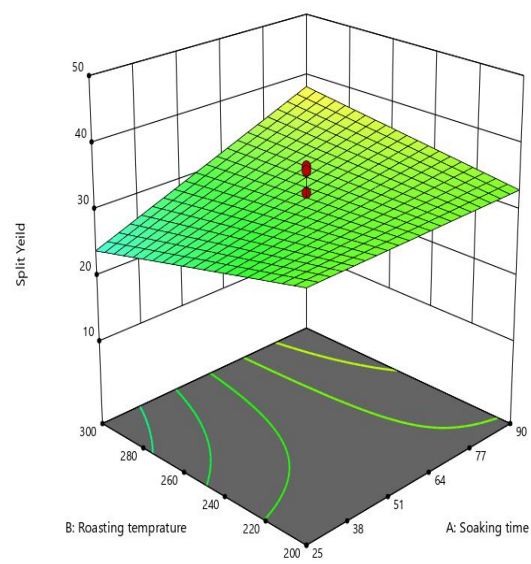
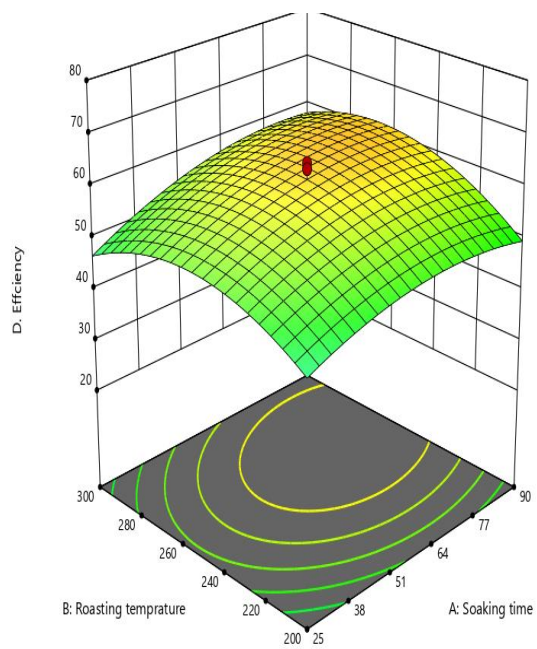
	Intercept	A	B	C	AB	AC	BC	A ²	B ²	C ²
Dehulling Efficiency	61.36	3.89	2.44	-4.21	1.85	-1.36	-8.52*	-3.98	-7.41*	-8.91*
Degree of dehulling	8.86	0.4188	0.9701*	0.5344	-0.33	-0.52	-0.06	1.38*	-0.0084	-0.4715
Split yield	32	3.67	-0.9317	-0.1564	3.43	1.87	2.35			
%Broken	3	0.1134	1.18*	1.99*	-0.1438	0.0462	1.03*	-0.3329	0.8515*	1.18*
BD	1	-0.0059	-0.004	-0.0089	-0.0213	-0.0023	-0.0023	0.0037	0.0154	-0.0126
FC	10	0.1833	-1.37*	-1.79*	-0.6704*	1.34*	-0.2363	-0.0596	-0.0956	0.037
OAC	1	0.018	0.2595*	0.1405*	0.02	0.0725	0.01	-0.0088	0.0549	0.0778*
WAC	2	0.0142	0.2521*	0.1502*						
Moisture	5	-0.1215	-0.7683*	-0.6474*	-0.072	0.577	-0.1017			
Ash	2.82	-0.1839*	-0.0699	-0.0567	0.0629	0.0454	-0.0768	-0.132	-0.0073	-0.0661
Fat	3	0.7196*	0.3136*	0.1617*	-0.2263*	-0.0563	0.1012	0.0901	0.1078*	0.1820*
Fiber	5	-1.18*	0.2651	-0.5077	-0.0609	0.0386	-0.571	0.4705	-0.3217	0.4096
Protein	21	0.1497	0.2688*	-1.17*						
Aroma	4.15	0.0595	0.2771	-0.4274*	-0.1013	0.0813	-0.6924*	-0.0052	-0.6575*	-0.84*
Color	4.06	0.0566	0.2845	-0.4291*	-0.045	0.0225	-0.7417*	0.042	-0.6704*	-0.87*
Test	4.19	0.0138	0.2263	-0.386	-0.0439	-0.021	-0.7206*	0.1129	-0.8346*	-0.92*
OAA	4.46	0.0402	0.2344	-0.3689	0.0037	-0.044	-0.751*	0.0414	-0.9292*	-1.00*

288 Note: OAA-overall acceptability

Effects of soaking time, roasting time and temperature on the physical dehulling properties of chickpea

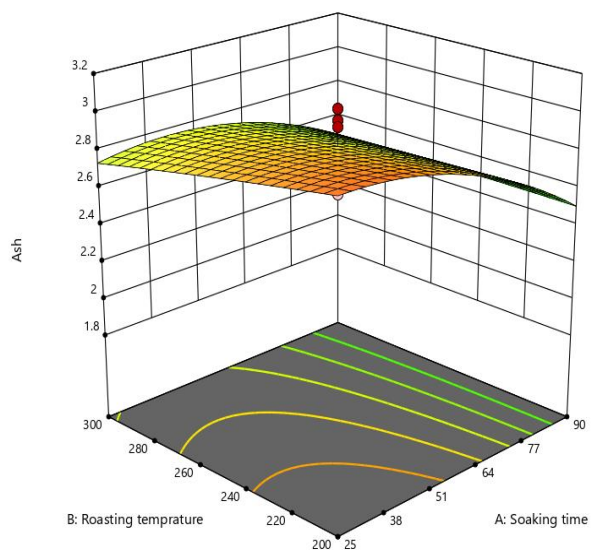
The experimental data analyzed demonstrated that pretreatment and roasting conditions (soaking time, roasting temperature, and roasting duration) significantly influence the milling quality of chickpeas (Table 3). To maximize the dehulling efficiency and yield while minimizing seed damage, both soaking and roasting require careful optimization. The moisture content, seed size, and hull thickness are critical factors: excessive moisture promotes hull adhesion, whereas insufficient moisture increases breakage.

The split yield was negatively correlated with extreme thermal or mechanical stress (Fig. 2B). Moderate roasting (5-10 minute) balanced yield and seed integrity, whereas insufficient roasting (25 minutes soaking, 200 °C, 5 minutes roasting) led to a moderate yield (40.87%) but increased breakage (8.98%). Prolonged or high-temperature roasting (57.5 minutes soaking, 250 °C, 18.41 minutes roasting; 90 minutes soaking, 300 °C, 5 minutes roasting) resulted in very poor split yields (<20%) and high breakage, which was consistent with seed embrittlement from excessive dehydration and protein denaturation.

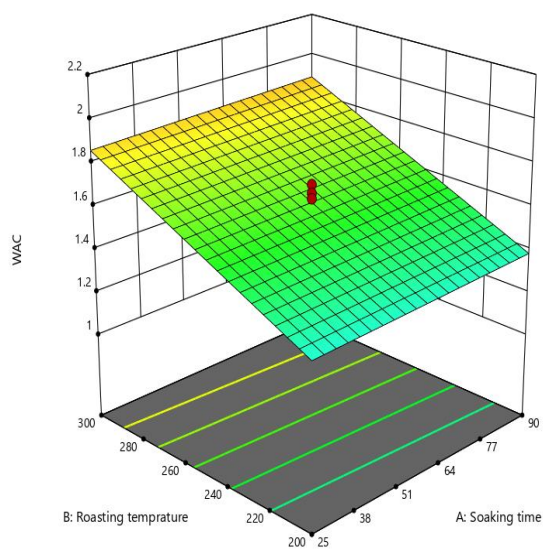


306 **A**

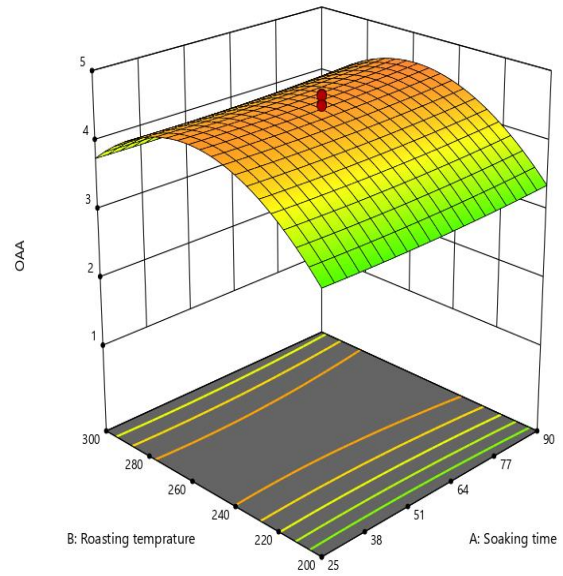
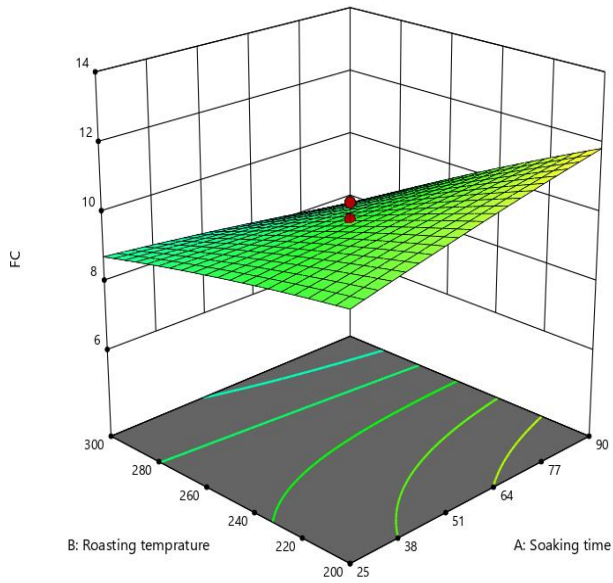
B



307 **C**



D



308 **E**

F

309 Figure 2: Response surface for (A) dehulling efficiency, (B) split yield, (C) ash content, (D) water
 310 absorption capacity, (E) foaming capacity and (F) overall consumer acceptability of chickpea *shiro*
 311 flour as a function of soaking time and roasting temperature.

312 Table 3: Effects of processing conditions on the dehulling properties of roasted chickpea *grains produced from Shiro* flour

Soaking time	Roasting temperature	Roasting time	Dehulling efficiency (%)	Degree of dehulling (%)	Split yield (%)	Percentage broken (%)
57.5	250	10	63.09±0.29 ^d	9.93±0.09 ^{de}	31.83±0.19 ⁱ	2.86±0.12 ⁱ
2.8417	250	10	58.6±0.44 ^e	7.78±0.41 ⁱ	29.64±0.10 ^j	2.9±0.03h ⁱ
90	200	5	59.66±0.51 ^e	9.11±0.28 ^{gh}	36.89±0.15 ^g	3.14±0.23 ^{gh}
57.5	250	10	35.15±0.49 ^l	6.36±0.02 ^m	41.74±0.20 ^b	2.5±0.03 ^j
57.5	165.9	10	31.83±0.19 ⁿ	7.05±0.22 ^l	22.79±0.49 ^l	2.73±0.08 ^{ij}
57.5	250	10	70.5±0.36 ^a	10.11±0.41 ^d	45.91±0.75 ^a	2.4±0.33 ^k
57.5	334.1	10	67.35±0.27 ^b	9.43±0.1f ^s	40.3±0.21 ^d	2.8±0.15 ⁱ
25	200	15	57.15±0.24 ^f	14.23±0.03 ^a	31.55±0.35 ⁱ	2.04±0.10 ^l
57.5	250	10	64.3±0.12 ^c	9.98±0.15 ^{de}	27.79±0.16 ^k	3.37±0.12 ^g
25	300	5	36.57±0.33 ^k	13.49±0.22 ^b	14.68±0.39 ^q	2.05±0.23 ^l
25	200	5	36.52±0.06 ^k	10.26±0.07 ^d	40.87±0.16 ^c	8.98±0.05 ^b
57.5	250	1.591	33.47±0.43 ^m	12±0.08 ^c	16.77±0.38 ^o	9.04±0.04 ^b
57.5	250	18.41	40.02±0.41 ⁱ	7.74±0.15 ^{ij}	19.56±0.34 ⁿ	2.5±0.17j ^k
112.16	250	10	29.91±0.08 ^o	7.43±0.09 ^{jk}	21.81±0.16 ^m	8.25±0.05 ^c
57.5	250	10	40.76±0.09 ^h	8.91±0.07 ^h	38.39±0.62 ^e	4.77±0.06 ^e
90	300	15	39.77±0.29 ⁱ	9.65±0.07 ^{ef}	39.91±0.23 ^d	3.76±0.09 ^f
90	300	5	33.9±0.42 ^m	10.09±0.21 ^d	38.86±0.35 ^e	10.04±0.14 ^a
57.5	250	10	37.88±0.18 ^j	8.9±0.15 ^h	37.63±0.06 ^f	5.03±0.05 ^d
90	200	15	60.07±0.1 ^{de}	8.82±0.11 ^h	32.94±0.31 ^h	3.13±0.08 ^{gh}
25	300	15	63.8±0.28 ^c	7.4±0.28 ^k	36.42±0.11 ^g	2.85±0.22 ⁱ

313 All the data are expressed as the means ± SDs, and the means of three replicates within the same line are significantly different (p < 0.05).

314 **Effects of soaking time, roasting time and temperature on the functional properties of *Shiro***
315 **flour**

316 The functional properties of chickpea shiro flour include bulk density, water absorption capacity,
317 foaming capacity, and oil absorption capacity (Table 4). Bulk density (BD) reflects the compaction
318 and porosity of flour, influencing its handling and suitability for use in Ethiopian *shiro-wot*. The
319 foaming capacity (FC) decreased significantly with roasting (Table 4). FC is influenced by factors
320 such as protein type, temperature, and processing method. The WAC is a measure of flour's ability
321 to retain water, which affects the texture and moisture of final food products. The WAC values
322 ranged from 0.59 to 2.21 (g/g), with the maximum recorded at 334.1 °C for 10 minutes (Fig. 2D).

323 **Table 4:** Effects of processing conditions on the functional properties of chickpea *Shiro* flour

ST	RT	Rt	BD (g/mL)	FC (%)	OAC (g/g)	WAC (g/g)
57.5	250	10	0.77±0.02 ^{fgh}	9.60±0.07 ^h	1.35±0.01 ^{de}	1.61±0.06 ^e
2.8417	250	10	0.76±0.02 ^{gh}	9.35±0.23 ⁱ	1.22±0.05 ^{fgh}	1.62±0.06 ^e
90	200	5	0.89±0.03 ^a	11.68±0.35 ^d	1.73±0.12 ^b	1.32±0.16 ^f
57.5	250	10	0.86±0.05 ^{abc}	9.76±0.1 ^{gh}	1.18±0.07 ^{gh}	1.67±0.05 ^e
57.5	165.9	10	0.86±0.05 ^{a-d}	12.93±0.1 ^b	0.80±0.02 ⁱ	0.59±0.47 ^g
57.5	250	10	0.79±0.01 ^{d-h}	9.90±0.05 ^g	1.16±0.05 ^{gh}	1.63±0.06 ^e
57.5	334.1	10	0.88±0.03 ^{ab}	6.53±0.12 ^m	1.93±0.03 ^a	2.21±0.13 ^a
25	200	15	0.86±0.01 ^{abc}	7.38±0.07 ^l	1.27±0.06 ^{efgh}	1.73±0.1 ^{cde}
57.5	250	10	0.87±0.03 ^{abc}	9.76±0.09 ^{gh}	1.25±0.06 ^{efgh}	1.83±0.12 ^{bcd}
25	300	5	0.85±0.04 ^{a-e}	12.47±0.12 ^c	1.59±0.1 ^c	1.79±0.1 ^{bcd}
25	200	5	0.78±0.04 ^{e-h}	12.48±0.09 ^c	1.15±0.09 ^h	1.27±0.07 ^f
57.5	250	1.591	0.81±0.02 ^{c-g}	13.76±0.08 ^a	1.23±0.11 ^{efgh}	1.59±0.11 ^e
57.5	250	18.41	0.78±0.03 ^{e-h}	6.53±0.2 ^m	1.77±0.08 ^b	1.94±0.05 ^{bcd}
112.16	250	10	0.81±0.06 ^{b-g}	10.43±0.1 ^f	1.21±0.06 ^{gh}	1.70±0.06 ^{de}
57.5	250	10	0.76±0.06 ^{gh}	10.38±0.05 ^f	1.33±0.05 ^{def}	1.71±0.04 ^{de}
90	300	15	0.73±0.05 ^h	7.71±0.04 ^k	1.91±0.05 ^a	1.97±0.02 ^{bc}
90	300	5	0.78±0.03 ^{e-h}	8.43±0.1 ^j	1.42±0.04 ^d	1.79±0.02 ^{bcd}
57.5	250	10	0.85±0.03 ^{a-e}	9.62±0.06 ^h	1.28±0.04 ^{efg}	1.97±0.03 ^{bc}

90	200	15	0.84±0.06 ^{a-e}	11.45±0.12 ^e	1.35±0.04 ^{de}	1.75±0.1 ^{cde}
25	300	15	0.84±0.05 ^{a-f}	6.16±0.1 ⁿ	1.6±0.07 ^c	2.01±0.5 ^{ab}

In each row, the presence of identical letters indicates a non-significant difference, whereas distinct letters denote a significant difference at $p < 0.05$. The data are presented as mean values $\pm$ standard error for each group

Effects of processing methods on the color of chickpea *shiro* flour

Table 5 shows that the color parameters (L^* , a^* , and b^*) of roasted chickpea *Shiro* flour were significantly influenced by soaking time, roasting temperature, and roasting duration, reflecting the physicochemical changes that occur during processing (Fig. 3). The soaking time also affected color, although to a lesser extent than roasting did. At 250 °C for 10 minutes, the soaking time had a nonlinear effect: very short or very long soaking slightly darkened the flour and increased redness (a^*), whereas intermediate soaking (57.5 minute) produced a lighter, less red flour.

Table 5: Color of the *Shiro* flour

ST	RT	Rt	L^*	a^*	b^*
57.5	250	10	72.73±0.02 ^k	4.60±0.01 ^h	27.58±1.09 ^a
2.84	250	10	71.27±0.12 ^l	5.03±0.01 ^f	26.66±0.22 ^b
90	200	5	87.44±0.02 ^a	1.98±0.01 ^o	25.04±0.16 ^{cd}
57.5	250	10	73.42±0.09 ^j	4.43±0.17 ⁱ	27.6±0.01 ^a
57.5	165.91	10	86.34±0.23 ^c	1.64±0.03 ^m	24.71±0.03 ^{de}
57.5	250	10	73.96±0.27 ⁱ	4.39±0.04 ⁱ	27.62±0.08 ^a
57.5	334.09	10	57.62±0.15 ^o	7.64±0.01 ^d	24.36±0.12 ^{de}
25	200	15	81.52±0.08 ^e	0.89±0.01 ^l	24.56±0.01 ^{de}
57.5	250	10	76.47±0.07 ^g	3.13±0.02 ^j	27.63±0.02 ^a
25	300	5	76.57±0.25 ^g	3.10±0.08 ^j	27.17±1.02 ^{ab}
25	200	5	86.93±0.08 ^b	1.83±0.06 ⁿ	24.43±0.1 ^{de}
57.5	250	1.59	86.87±0.05 ^b	1.57±0.01 ^m	23.67±0.05 ^f
57.5	250	18.41	60.37±0.02 ⁿ	8.21±0.03 ^c	27.4±0.03 ^a
112.16	250	10	70.61±0.26 ^m	5.44±0.02 ^c	27.03±0.01 ^{ab}
57.5	250	10	72.64±0.08 ^k	4.78±0.20 ^g	27.66±0.14 ^a
90	300	15	51.46±0.07 ^r	9.36±0.01 ^a	24.12±0.05 ^{ef}
90	300	5	78.78±0.06 ^f	1.71±0.01 ^k	27.24±0.17 ^{ab}

57.5	250	10	76.11±0.14 ^h	3.20±0.01 ^j	27.64±0.03 ^a
90	200	15	81.80±0.04 ^d	0.97±0.02 ^l	24.86±0.01 ^{cd}
25	300	15	54.27±0.12 ^p	8.81±0.02 ^b	25.45±0.36 ^c

All the data are expressed as the mean ± standard deviation (SD) of three replicates. Values within the same row followed by different letters are significantly different ($p < 0.05$).



Figure 2: Color of different chickpea cultivars produced under different processing conditions

Effects of soaking time, roasting time and temperature on the proximate composition of *Shiro* flour

Proximate composition analysis is critical for food manufacturers to ensure compliance with safety and regulatory standards, as it evaluates the primary components of food, moisture, ash, crude protein, crude fat, crude fiber, and carbohydrates, expressed as percentages of total weight. The proximate composition of processed chickpea *shiro* flour, presented on a dry weight basis, included protein, ash, fat, fiber, and carbohydrate contents (Table 6). Processing conditions such as roasting temperature, roasting time, and soaking time significantly affected these parameters. The ash content, an indicator of mineral content, remained relatively stable across treatments, ranging from 2.55% to 3.16%. The maximum ash level (3.16%) was recorded after 58 minutes of soaking, roasting at 250 °C, and a short roasting time (1.59 minute), whereas the lowest value (2.55%) occurred after 90 minutes of soaking, 200 °C roasting, and 5 minutes of roasting (Fig. 2C).

356 **Table 6:** Effects of different processing conditions on the proximate composition of chickpea *Shiro* flour

Soaking time (minutes)	Roasting temperature	Roasting time	Ash (%)	Protein (%)	Fat (%)	Fiber (%)	Carbohydrate (%)	Energy (kcal/100 g)
57.5	250	10	2.71±0.17 ^b	20.07±0.62 ^{fg}	3.63±0.22 ^{cd}	4.02±0.13 ^{fgh}	65.99±0.53 ^{bc}	376.96±1.57 ^b
2.84	250	10	2.78±0.25 ^b	20.38±0.25 ^{efg}	2.89±0.06 ^{fg}	6.70±0.04 ^{ab}	59.76±0.48 ⁱ	346.53±1.45 ^j
90	200	5	2.55±0.18 ^b	21.75±0.18 ^{bc}	4.28±0.07 ^a	2.82±0.15 ^k	65.02±0.51 ^{cde}	385.57±1.95 ^a
57.5	250	10	2.75±0.55 ^b	20.63±0.45 ^{def}	3.59±0.38 ^{cd}	4.03±0.19 ^{fgh}	65.45±0.23 ^{bcd}	376.66±2.14 ^b
57.5	166	10	2.84±0.10 ^b	20.32±0.45 ^{efg}	3.86±0.01 ^{bc}	4.73±0.13 ^e	64.40±0.13 ^{de}	373.61±1.39 ^{bcd}
57.5	250	10	2.80±0.04 ^b	20.51±0.63 ^{efg}	3.64±0.38 ^{cd}	4.07±0.56 ^{fgh}	65.44±1.12 ^{bcd}	376.54±0.84 ^b
57.5	334	10	2.76±0.04 ^b	20.47±0.48 ^{efg}	3.18±0.07 ^{ef}	6.33±0.12 ^{bc}	61.80±0.16 ^{gh}	357.71±1.93 ^{ik}
25	200	15	2.90±0.10 ^b	19.01±0.26 ^h	2.88±0.03 ^{fg}	3.76±0.03 ^{gh}	66.88±0.36 ^{ab}	369.48±0.12 ^{def}
57.5	250	10	2.77±0.52 ^b	20.62±0.36 ^{def}	3.59±0.47 ^{cd}	4.02±0.24 ^{fgh}	65.51±0.64 ^{bcd}	376.85±3.04 ^b
25	300	5	2.82±0.18 ^a	22.35±0.52 ^{ab}	3.97±0.05 ^{abc}	3.70±0.02 ^{gh}	60.59±2.43 ^{hi}	367.50±3.24 ^{efg}
25	200	5	2.84±0.31 ^b	21.23±0.41 ^{cd}	3.32±0.20 ^{de}	3.14±0.10 ^{ik}	62.63±0.22 ^{fg}	365.32±0.72 ^{fg}
57.5	250	1.59	3.16±0.08 ^b	22.51±0.33 ^a	2.59±0.05 ^{gh}	3.67±0.05 ^{gh}	61.26±0.16 ^{gh}	358.36±1.17 ^{hi}
57.5	250	18.41	2.73±0.22 ^b	18.94±0.19 ^h	4.06±0.04 ^{ab}	4.44±0.07 ^{ef}	67.54±0.26 ^a	382.42±0.89 ^a
112.16	250	10	2.77±0.02 ^b	20.89±0.16 ^{de}	2.28±0.09 ^h	6.61±0.12 ^b	62.15±0.33 ^g	352.69±1.48 ^k
57.5	250	10	2.74±0.15 ^b	20.85±0.26 ^{de}	3.59±0.15 ^{cd}	4.15±0.13 ^{fg}	65.08±0.14 ^{cde}	376.04±1.84 ^b
90	300	15	3.02±0.03 ^b	20.05±0.30 ^{fg}	2.73±0.09 ^g	6.05±0.19 ^c	64.54±0.94 ^{cde}	362.90±3.56 ^{gh}
90	300	5	3.09±0.04 ^b	22.50±0.41 ^a	2.62±0.16 ^{gh}	3.58±0.04 ^{hi}	63.65±0.86 ^{ef}	368.15±0.31 ^{ef}
57.5	250	10	2.81±0.11 ^b	20.75±0.12 ^{def}	3.63±0.05 ^{cd}	4.07±0.30 ^{fgh}	63.79±0.51 ^{ef}	370.79±1.56 ^{cde}
90	200	15	3.04±0.20 ^b	19.84±0.12 ^g	3.31±0.07 ^{de}	6.77±0.10 ^a	61.95±0.37 ^{gh}	356.94±1.62 ^{ik}
25	300	15	2.92±0.03 ^b	20.29±0.26 ^{efg}	4.24±0.26 ^a	5.46±0.18 ^d	64.07±0.67 ^{bc}	375.53±1.38 ^d

357 All the data are presented as the mean ± standard deviation (SD) of three replicates. Values within the same row followed by different
 358 letters are significantly different ($p < 0.05$).

Effects of soaking time, roasting time and temperature on consumer acceptability of chickpea *shiro-wot*

Customer acceptance is a significant motivator in food product development and reformulation, with sensory qualities acting as key indicators of quality and purchase intent. Foods have various sensory properties, such as flavor, aroma, texture, appearance, and mouthfeel, which are influenced mainly by processing factors, formulation composition, and storage conditions. The sensory attributes of chickpea *shiro-wot* are significantly influenced by soaking time, roasting temperature, and roasting time, as demonstrated by consumer acceptability scores (Table 7). Overall consumer acceptability exhibited significant variation across the processing conditions, and maximum acceptability was consistently associated with optimum processing conditions, yielding a synergistically favorable sensory profile across key sensory attributes. Conversely, acceptability was minimized under extreme processing conditions; these conditions induced cumulative negative sensory characteristics, including degradation-derived off-notes, undesirable textural changes, and excessive color development, collectively rendering the product sensorially unacceptable. In general, chickpea *shiro* flour roasted at high temperatures for shorter durations generally scored highest in overall sensory acceptability (Fig. 2F).

Table 7: Effects of processing conditions on the consumer acceptability of chickpea *shiro-wot*

ST	RT	Rt	Aroma	Texture	Color	Test	OAA
57.5	250	10	4.05±0.04 ^e	4.02±0.04 ^e	4.13±0.04 ^d	4.30±0.02 ^c	4.71±0.06 ^c
2.842	250	10	3.68±0.04 ^f	3.58±0.04 ^f	3.61±0.03 ^g	4.01±0.04 ^f	3.92±0.03 ^h
90	200	5	2.23±0.05 ⁱ	2.38±0.02 ^j	2.24±0.03 ^j	2.51±0.05 ⁱ	2.42±0.04 ^j
57.5	250	10	4.07±0.06 ^e	4.02±0.03 ^e	3.94±0.03 ^f	4.17±0.03 ^e	4.54±0.03 ^d
57.5	165.9	10	2.26±0.02 ⁱ	1.78±0.02 ^o	1.93±0.02 ^l	1.54±0.02 ^m	1.45±0.03 ^m
57.5	250	10	4.15±0.03 ^d	4.03±0.03 ^e	4.14±0.03 ^{cd}	4.25±0.03 ^d	4.36±0.02 ^e
57.5	334.1	10	1.13±0.01 ⁿ	2.55±0.02 ^h	1.23±0.01 ⁿ	1.01±0.01 ^o	1.01±0.01 ⁿ
25	200	15	2.05±0.04 ^k	2.30±0.02 ^k	2.29±0.02 ⁱ	2.55±0.01 ^h	2.66±0.02 ⁱ
57.5	250	10	4.3±0.01 ^c	4.13±0.02 ^c	4.17±0.02 ^c	4.27±0.02 ^{cd}	4.69±0.02 ^c
25	300	5	4.95±0.01 ^a	4.46±0.03 ^a	4.88±0.02 ^a	4.89±0.01 ^a	4.78±0.02 ^b
25	200	5	2.34±0.03 ^h	2.44±0.02 ⁱ	2.23±0.02 ^j	2.24±0.02 ^j	2.36±0.02 ^k

57.5	250	1.591	1.55±0.02 ^l	1.87±0.02 ⁿ	1.33±0.02 ^m	1.07±0.02 ⁿ	1.05±0.02 ⁿ
57.5	250	18.41	1.42±0.02 ^m	1.73±0.02 ^p	1.10±0.02 ^o	1.03±0.02 ^o	1.01±0.01 ⁿ
112.2	250	10	4.03±0.02 ^e	4.24±0.03 ^b	3.99±0.01 ^e	3.93±0.02 ^g	4.04±0.02 ^g
57.5	250	10	4.34±0.03 ^c	4.04±0.03 ^e	4.15±0.03 ^{cd}	4.26±0.01 ^e	4.30±0.02 ^f
90	300	15	2.01±0.01 ^k	1.99±0.01 ^m	1.97±0.02 ^k	2.14±0.02 ^k	2.13±0.02 ^l
90	300	5	4.77±0.03 ^b	4.46±0.02 ^a	4.78±0.01 ^b	4.78±0.01 ^b	4.98±0.01 ^a
57.5	250	10	4.19±0.01 ^d	4.08±0.02 ^d	4.15±0.03 ^{cd}	4.20±0.01 ^l	4.55±0.02 ^d
90	200	15	2.57±0.03 ^g	2.65±0.02 ^g	2.46±0.02 ^h	2.55±0.03 ^h	2.69±0.02 ⁱ
25	300	15	2.13±0.02 ^j	2.07±0.02 ^l	1.99±0.01 ^k	2.05±0.01 ^l	2.16±0.01 ^l

Note: All the data are expressed as the mean ± standard deviation (SD) of three replicates. Values within the same row followed by different letters are significantly different ($p < 0.05$).

Discussion

The dehulling efficiency was particularly sensitive to the roasting temperature and duration. The highest efficiency (70.5%) occurred under central-point conditions (57.5 minutes soaking, 250 °C roasting, and 10 minutes roasting), indicating near-optimal processing. Both very low (165.9 °C) and high (334.1 °C) roasting temperatures, as well as very short (1.59 minute) or extended (18.41 minute) roasting times, produced significantly lower efficiencies, reflecting an inverted U-shaped response (Fig. 2A). Hydration facilitates hull removal by weakening the pectin-rich middle lamella between the Testa and cotyledon (Wood & Grusak, 2007), whereas excessive soaking softens seeds excessively, increasing breakage and lowering split yield (Ghavidel & Prakash, 2006). Similarly, inadequate thermal input fails to loosen seed coats, whereas excessive heat induces case hardening or hull combustion, both of which hinder clean dehulling.

Interestingly, the highest degree of dehulling (14.23%) was achieved under different conditions (25 minutes soaking, 200 °C, 15 minutes roasting). This highlights a disconnect between efficiency (number of seeds dehulled) and completeness of hull removal per seed. In addition, cooler roasts promoted more thorough hull separation per seed, whereas high temperature/short-term treatments (25 minutes soaking, 300 °C, and 5 minutes roasting) also produced high degrees of dehulling but at the expense of split yield, suggesting violent hull removal that damaged cotyledons.

The breakage percentage proved to be the most reliable indicator of process-induced damage. Balanced moisture and thermal conditions minimized breakage (2-3%), whereas over roasting (≥ 300 °C) or extended soaking (>110 minute) markedly increased fracture rates (8-10%), which is consistent with previous reports of structural weakening under prolonged thermal stress (Morteza & Jamuna, 2020; Offia & Madubuike, 2015). Overall, these findings emphasize that optimal chickpea dehulling requires coordinated control of soaking, roasting temperature, and roasting duration. Soaking loosens the seed coat, whereas roasting controls moisture release and structural weakening. Excessive roasting induces brittleness and breakage, whereas insufficient roasting fails to adequately release hulls. Therefore, moderate soaking and controlled roasting conditions maximize dehulling efficiency, yield, and whole splits, offering practical strategies to improve *Shiro* flour processing, reduce postharvest losses, and increase economic returns.

In this study, the BD values ranged from 0.73 to 0.89 g/mL, with the highest value obtained at 200 °C and a short roasting time of 5 minutes. Previous findings indicate that lower roasting temperatures promote higher BD due to greater moisture retention and reduced structural modifications (Ferawati et al., 2019). In contrast, higher roasting temperatures decrease BD by increasing porosity through moisture loss (Mukhopadhyay et al., 2015).

Heat treatment reduces protein solubility, lowering the foaming potential of roasted legumes (Okache et al., 2020). Moderate temperatures may promote partial protein denaturation, exposing hydrophobic groups that enhance foam stabilization (Byarugaba et al., 2023). Similar trends have been reported for roasted African yam bean, mung bean, and chickpea (Obatolu et al., 2007; Nwosu et al., 2011; Offia-Olua & Madubuike, 2015; Jogihalli et al., 2017a), although the results differ for roasted lima beans (Ogechukwu & Ikechukwu, 2021). The reduced FC in heat-treated samples is generally attributed to protein denaturation, which diminishes solubility and flexibility (Keskin et al., 2022; Offia-Olua & Madubuike, 2015). Protein solubility in water remains the primary determinant of foaming ability and foam stability.

Oil absorption capacity (OAC) is critical for food applications where flavor retention and mouthfeel are important. In this study, the OAC values ranged from 0.80 to 1.93 (g/g), highlighting the influence of roasting temperature and duration. A higher OAC is generally associated with greater roasting intensity, as heat-induced protein denaturation exposes hydrophobic sites that

enhance fat binding (Ozolina et al., 2024; Keskin et al., 2022). Roasting modifies protein structure, redistributing polar and nonpolar binding sites, thereby improving oil absorption (Dhua et al., 2021).

Increasing roasting temperatures enhance WAC by disrupting cellular structures and increasing hydration capacity (Kaur & Prasad, 2022). Similar observations have been reported for roasted African yam beans and chickpeas (Obatolu et al., 2007; Jogihalli et al., 2017b; Kumar et al., 2020). This improvement is likely due to protein unfolding, which exposes additional hydration sites (Xu et al., 2016; Gulzar et al., 2024), and starch gelatinization, which increases water binding (Oghbaei & Prakash, 2016). However, excessively high temperatures may over dry flour, damaging the starch-protein matrix and reducing the WAC (Zilic et al., 2006). Overall, these results suggest that moderate roasting conditions optimize functional properties by balancing structural modifications with moisture retention. This aligns with the literature showing that processing conditions can be fine-tuned to customize legume functionality for specific food applications.

Color is a critical determinant of consumer acceptance, making these processing variables important indicators of flour quality. The roasting temperature and time were the dominant factors affecting color. Yellowness (b^*) tended to increase at moderate roasting temperatures before decreasing at higher roasting temperatures. This trend corresponds to Maillard reactions and caramelization, which intensify with increasing temperature and result in darker flour (Martins et al., 2000). Prolonged roasting at 250 °C following 57.5 minutes of soaking produced notably darker flour, which is consistent with the findings of Xu et al. (2019), who reported darker and more intense browning in bean flour after extended roasting.

This nonlinear behavior may be explained by moisture differences prior to roasting. As noted by Kaur et al. (2005), soaking modifies the moisture content, which affects heat transfer and the rate of browning reactions. Prolonged soaking may initially slow the increase in temperature but ultimately accelerate Maillard reactions during high-temperature roasting. After 90 minutes of soaking combined with extended roasting at high temperature, the flour presented the darkest color and the greatest redness, indicative of substantial browning. Conversely, at the same soaking time but with milder roasting (200 °C for 5 minutes), the flour was pale and lighter in appearance. In summary, the color of roasted chickpea *shiro* flour is strongly dependent on processing conditions.

Browning is governed primarily by roasting temperature and duration, with soaking time exerting additional effects through its influence on moisture content.

Variations may result from mineral leaching during extended soaking or from concentration effects from high-temperature roasting. Similar findings were reported by Kumar et al. (2022), who reported reduced ash in legumes after prolonged thermal processing. Conversely, other studies suggest minimal changes, with only extreme roasting conditions resulting in slight mineral losses (Xu & Chang, 2007).

The crude protein content ranged from 18.94% to 22.51%. The highest protein content was obtained after 58 minutes of soaking, 250 °C roasting, and 1.59 minute of roasting, whereas the lowest protein content occurred after 18.41 minutes of roasting. These results indicate that both the roasting temperature and time are critical. Shorter roasting times at moderate temperatures help preserve or concentrate protein levels, whereas longer durations promote denaturation and Maillard reactions that reduce amino acid availability. Previous studies confirmed that prolonged heating reduces protein quality and quantity in legumes by inducing aggregation and degradation (Muzquiz et al., 2012; Alonso et al., 2009). Nonetheless, roasting can increase protein digestibility and solubility by inactivating antinutritional factors (Aviles-Gaxiola et al., 2018).

The fat content varied between 2.28% and 4.28%. The highest value was found with 90 minutes of soaking, roasting at 200 °C, and 5 minutes of roasting, whereas the lowest value was observed after 112 minutes of soaking and 10 minutes of roasting at 250 °C. The lower fat contents after prolonged soaking may be linked to the leaching of soluble lipids, whereas prolonged high-temperature roasting can induce lipid oxidation. Similar patterns have been reported in chickpeas and other legumes, where overheating reduces fat content or alters lipid quality (Tekgul et al., 2023; Zou et al., 2011). Moderate roasting conditions are therefore preferred to preserve fat quality.

The crude fiber content ranged from 2.82% to 6.77%. The maximum was observed at 90 minutes of soaking, 200°C, and 15 minutes of roasting, whereas the minimum was recorded at 90 minutes of soaking, 200°C, and 5 minutes of roasting. Longer roasting tends to increase insoluble fibers by modifying cellulose and hemicellulose. Alajaji & El-Adawy (2006) reported increased dietary fiber after roasting, which was linked to lignin and resistant starch formation. However, some studies suggest reductions under extreme roasting conditions (Xu & Chang, 2007). Chickpea

studies further indicate that roasting may decrease soluble fiber but increase insoluble fractions, potentially enhancing digestive benefits (Simsek et al., 2016).

The carbohydrate content, calculated by difference, ranged from 59.76% to 67.54%. The highest value (67.54%) was obtained after 58 minutes of soaking and roasting at 250 °C for 18.41 minutes, whereas the lowest value (59.76%) was recorded after only 3 minutes of soaking and 10 minutes of roasting at 250 °C. Increases with longer roasting times are likely due to concentration effects from moisture loss, as also observed in roasted nuts (Wang et al., 2009). Similar findings in legumes attributed increased caloric density to both concentration and slight sugar caramelization (Zhan et al., 2019).

The energy content ranged from 346.53 to 385.57 kcal/100 g. The maximum value (385.57 kcal/100g) corresponded to high fat (4.28%) and moderate protein (21.75%) levels after 90 minutes of soaking, roasting at 200 °C, and 5 minutes of roasting. The lowest yield (346.53 kcal) was associated with reduced fat (2.89%) following 3 minutes of soaking, 250 °C roasting, and 10 minutes of roasting. Since fat contributes 9 kcal/g, its level is a primary determinant of energy density. These findings align with those of Olatidoye et al. (2017), who noted that heating conditions preserving fat retention increase the caloric content of legume flours. In summary, processing conditions strongly influence the proximate composition of chickpea *shiro* flour. Moderate roasting and soaking treatments optimize nutrient retention, balancing protein, fat, and carbohydrate preservation while maintaining desirable energy levels.

The aroma intensity scores significantly changed, with the highest values corresponding to the optimum high-temperature and short-duration treatments. This improvement is related to thermally induced reactions that promote the production of favorable volatile molecules. In contrast, at high roasting temperatures and times, the breakdown of essential aromatic compounds and the creation of undesirable sensory notes occur. Similarly, texture acceptability was produced via specific processing combinations that favored controlled thermal exposure, whereas considerably lower scores were related to conditions involving prolonged thermal treatment. Moderate roasting temperatures and short durations most likely improved protein denaturation and starch gelatinization, resulting in a crisp yet delicate texture. On the other hand, extended roasting caused severe moisture loss and structural collapse, resulting in the product being harder. Kaur et

al. (2005) reported that extended bean roasting increased hardness and reduced cohesiveness, which they attributed to protein aggregation.

The minimal scores of colors were associated with extended roasting treatment, which resulted in significant darkening due to advanced browning reactions and carbonization. The flavor scores showed a wide range, with maximum acceptance reached under settings that promoted the production of the desired savory flavor compounds via thermally driven reaction pathways. In contrast, supra-optimal thermal input resulted in minimal scores, which were correlated with the development of degradation products, resulting in pronounced negative sensory properties.

The central combination of a soaking time of 57.5 minutes, a roasting temperature of 2500 °C, and a roasting time of 10 minutes demonstrated consistent, relatively high acceptability across all attributes, indicating that it represents stable and reliable baseline processing conditions. However, minor deviations from this central point within the experimental design generally led to noticeable decreases in one or more sensory scores. Overall, the data underscores that consumer acceptability is optimized within a specific processing parameters, with significant declines occurring when parameters fall outside this optimal range, particularly for roasting time and roasting temperature.

Optimization of processing conditions for chickpea *shiro* flour production

The physical dehulling properties, proximate composition, functional properties and sensory acceptability of chickpea *shiro* flour were used to determine its quality characteristics. The response surface plot shows how the combined influence of soaking time and roasting temperature affects the attractiveness of chickpea *shiro* flour. Overall, the desirability values vary from moderate 0.6 to high 0.9, with the highest values obtained with longer soaking times and higher roasting temperatures. Increasing the soaking duration from 25 to 90 minutes resulted in a consistent improvement in desirability, most likely to improve hydration, softening, and more uniform roasting of the chickpea seeds. Similarly, increasing the roasting temperature from approximately 200 °C to 300 °C increases attractiveness, possibly through better flavor development via Maillard reactions and good color creation. The plot also shows a substantial impact between the two factors: when the soaking time is short, higher roasting temperatures generate only moderate improvements, but for longer soaking times, high roasting

temperatures produce the most desirable results. A significant decrease in desirability is observed when short soaking times (approximately 25-30 minutes) are combined with low-to-mid roasting temperatures (220-240 °C), indicating that processing conditions negatively affect product quality, possibly due to incomplete cooking or undesirable flavor profiles.

In the case of numerical optimization, an attempt was made to maximize the response dehulling efficiency, degree of dehulling, split yield, water absorption capacity, crude protein, ash, CHO, energy, and sensory acceptability. The responses broken percentage, foaming capacity, oil absorption capacity, crude fat content and moisture content were minimized, and the responses bulk density were adjusted to develop a predicted optimum soaking time, roasting temperature and roasting time. The optimal soaking time, roasting temperature and roasting time for the response were 90 minutes, 292.906 °C and 6.84 minutes, respectively, with a desirability of 74.4% (Fig. 3). However, desirability is sufficient and indicative of optimum combinations in such food studies. This finding was greater than that of the case study by Park et al. (2011), who reported that the desirability of coffee roasting operations was 69.4% when all the sensory attributes were maximized. Food processing industries are usually interested in the optimization of multiple responses simultaneously. There is not a single choice to make decisions about selecting optimum conditions, and the most desirable is predicted given that other practical considerations are feasible.

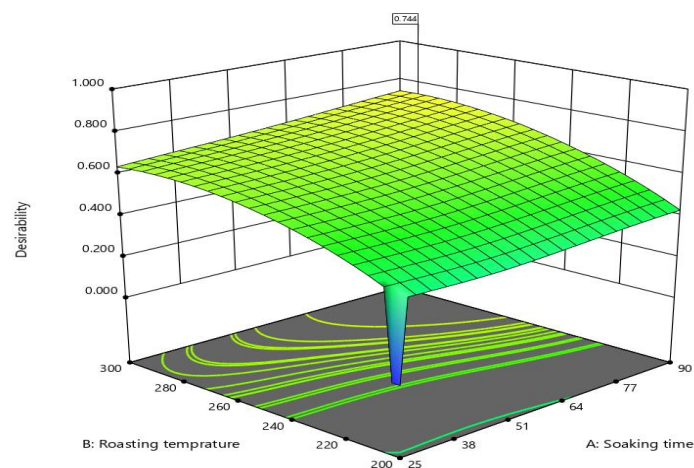


Figure 3: Response surface for the desirability of chickpea *shiro* flour as a function of soaking time and roasting temperature

Conclusions

The study findings indicated that changes in soaking time, roasting temperature and roasting time influenced the physical dehulling properties, proximate composition, functional properties, and consumer acceptability of chickpea *shiro* flour; these effects were largely explained by quadratic models. Among the three factors listed above, the roasting temperature and time were the most critical factors, directly affecting the dehulling efficiency, split yield, foaming capacity, water and oil absorption capacities, color, and overall acceptability. Our model equation accurately predicts the link between factors and responses for dehulling physical, functional, proximal, and sensory aspects; most parameters did not show a significant lack of fit ($p < 0.05$). An evaluation of the coefficient of determination (R^2), adjusted R^2 , and F statistic indicates that most developed models provide statistically significant descriptions of the relationships between the experimental factors and observed responses in chickpea *shiro-wot*. The ideal soaking duration, roasting temperature, and roasting time for the replies were 90 minutes, 292.906°C, and 6.84 minutes, respectively, with a desirability of 74.4%, high consumer acceptance, desirable functionality, and good nutritional retention. These findings provide a scientifically validated framework for industrial-scale chickpea flour production, ensuring consistent quality and consumer satisfaction. For large-scale production, adopting the optimized conditions identified in this study to achieve both high product quality and process efficiency is recommended.

Further research directions

This study provides useful insights into the processing optimization of desi-type chickpea for *shiro* flour manufacturing; nevertheless, it only looks at one chickpea variety. Given the genetic diversity and vast adaptation of chickpea varieties evolved across the country, future studies should include a broader range of genotypes, such as desi and kabuli kinds. A detailed comparative examination of these varieties will help in determining which have the best physicochemical, functional, and sensory features for *shiro* flour processing. The post-processing factors which affect the quality of *shiro* flour, like storage time, temperature, humidity, and packing materials, also need to be further investigated. To guarantee product safety, shelf life, and consumer acceptance, it will be crucial to comprehend the effects of lipid oxidation, microbiological activity,

and storage stability under various environmental and packaging circumstances. Furthermore, investigating cutting-edge roasting and processing techniques like controlled-atmosphere roasting and fluidized bed roasting may improve the product's overall functioning, color, flavor, and nutritional value. These methods may also improve sustainability and process efficiency, which would increase the adaptability of *shiro* flour production for large-scale manufacturing. Future studies may also integrate breeding and food science disciplines to identify or develop chickpea genotypes that are specifically tailored for *shiro* flour production. Collaborative efforts among plant breeders, food technologists, and microbiologists could facilitate the selection of genotypes with desirable compositional traits and improved processing characteristics. This interdisciplinary approach would contribute not only to enhancing *shiro* flour quality but also to strengthening the value chain of chickpea-based food products, promoting nutritional security and market diversification.

List of abbreviations

RSM-response surface methodology
CCD-central composite rotatable design
DWS-mass of dehulled whole seeds
D-mass of dhal (split cotyledons)
Wt-original mass of whole seeds prior to dehulling
Mc- mass of cotyledons and broken cotyledons
Mh- mass of removed hulls
Muh- mass of kernels that remained un-dehulled
Mf- mass of fines in the final product
D- mass of dehulled splits
K- mass of kibble or broken
ST-soaking time,
RT-roasting temperature
Rt-roasting time, ns-nonsignificant
BD-bulk density
FC-foaming capacity

620 OAC-oil absorption capacity

621 WAC-water absorption capacity

622 OAA = overall acceptability

623 **Declarations**

624 **Ethics approval and consent to participate**

625 Not applicable

626 **Consent for publication**

627 Not applicable

628 **Availability of data and materials**

629 The datasets used and/or analyzed during the current study are available from the corresponding
630 author on reasonable request

631 **Competing interests**

632 The authors declare that they have no competing interests

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635 **Authors' contributions**

636 Lamesgen Yegrem: Proposed the main research point and carried out the statistical evaluation.

637 Write the main manuscript draft. Workineh Abebe, Tamerat Kore, Deribe Mengestu and Muhaba

638 Seyfu: Designing the laboratory experimental design. Oli legesse, Semhal Mersha and Shashitu

639 Alelgn: doing laboratory analysis for different parameters which are included in the manuscript.

640 Dagnachew Bekele, Assefa Funga: designing the field experiment and growing the chickpea grain

641 in the field. Ronit Yaa'ri: executively rewrite and review the manuscript. All authors contributed

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