Characterization of soy curd residue and full-fat soy flour as protein-based food ingredients

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ABSTRACT

The study investigated the soy curd residue and full-fat soy flour as potential protein-based food ingredients. Standard protocols were used to determine proximate parameters, functional properties, markers of oxidative stability under shelf storage, colour (CIE L* a* b*), and microbial quality of the flours. Commercial *Afayak* soybean varieties were used to prepare soy curd residue flour and two differently treated soy flours, namely full-fat soy flour and cold-water extracted full-fat soy flour. Findings from the study indicate that processing treatment and storage time significantly (p<0.001) affected the parameters measured. Cold-water extraction of full-fat soy flour resulted in a significantly (p<0.001) higher protein content denoting 1.0, and 1.2-fold than full-fat soy flour and soy curd residue, respectively. Full-fat soy flour showed the highest peroxide, acid, and p-anisidine (p < 0.001) under processing and storage conditions. Soy curd residue was the most oxidatively stable among the samples; however, it was noted that cold-water extraction of full-fat soy had better oxidative stability than full-fat Soy flour. After 12 weeks of storage, peroxide and acid values were below the acceptable limit of 10 mEq/Kg and 0.6 mg/KOH/g, respectively. The study supports the hypothesis that the proximate composition, physicochemical properties, and oxidative stability of soy-based flours are affected by the sample processing method and storage time. The study concludes that the samples characterized in this study are oxidatively stable, protein and energy-rich and may be ideal ingredients for food product development with desirable functional properties.

INTRODUCTION

In sub-Saharan Africa (SSA), protein-energy malnutrition, iron, zinc, vitamin A, and iodine deficiency diseases are the most common diet-related problems [1]. The over-dependence on fast-digesting carbohydrate staple foods in Ghana has led to a greater prevalence of stunting in Ghana [2]. Reducing undernutrition among young children has made significant strides. The prevalence of under-five stunting decreased from 28% to 18% between 2008 and 2018 [3].

One possible way to increase the nutritional value of local staples in SSA is to produce low-cost nutritious diets using locally accessible and underutilized cereals, legumes, roots, and tubers [4]. Among the legumes, soybean is an inexpensive and high-quality protein source that could increase the level and quality of protein in cereals and other starch-based foods. Soybean is high in vitamins and minerals and contains approximately 40-

45 % protein and 18-22 % oil [5]. For instance, soy protein provides important functional qualities and complete digestibility in food systems [6].

Ghana produces an average of 50,000 metric tonnes of soybeans annually, yet only 15 metric tons are consumed [7]. Soy curd residue (SCR) is a gluten-free residue of soybean obtained during soybean and tofu processing after extracting aqueous fractions [8]. When 1 kg of soybean grains is processed into tofu, approximately 1.2 kg SCR is produced [9]. This by-product contains a moisture content, making its disposal an environmental problem due to its susceptibility to putrefaction [10].

In Ghana, most companies that produce soymilk and tofu use SCR, popularly known as okara in Japanese, as animal feed or discard it, contributing to food waste [11]. However, SCR is a relatively cheap source of protein known for its good nutritional qualities, including its richness in isoflavones and phenolic compounds, quality protein, and ideal functional properties [12]. The protein efficiency ratio was higher in SCR than in other soy products, for example, 2.71 vs 2.11 in soymilk [13].

Soy protein products such as defatted soy flour, tofu, soymilk, full-fat soy flour (FFSF), and SCR are of interest for food applications to improve the nutritional quality of staple foods in SSA. However, soy products contain higher polyunsaturated fatty acids (PUFA) (indicate the concentration), making them easily susceptible to oxidative rancidity and off-flavours, negatively affecting quality and shelf-life [14].

FFSF is more accessible to obtain, but its high content of PUFAs renders it susceptible to oxidative rancidity [15]. FFSF-based products have a shorter shelf life, especially when subjected to environmental conditions of high temperatures, sunlight, and relative humidity. However, SCR, as reported by [16], is associated with lower PUFAs that could improve the shelf stability of its products compared with FFSF. Therefore, this study investigated the proximate parameters, functional properties, microbial quality, and oxidative stability of soy curd residue flour and full-fat soy flour as potential protein-based food ingredients.

Scientific Hypothesis

The proximate composition, physicochemical properties, and oxidative stability of soy-based flours used in this study will depend on the sample processing method and storage duration. Protein content and oxidative stability are mainly expected to be significantly affected.

MATERIAL AND METHODOLOGY
Samples

Commercial soybean (*Afayak variety grains) was obtained from a commercial farmer in the* Tamale central market in the Northern region of Ghana for the study.

Chemicals

All reagents used in this study were of analytical grades with high purity. They were obtained from Sigma-Aldrich; Merck KGaA, Darmstadt, Germany.

Animals, Plants, and Biological Materials

Animal and biological materials were not used in this research. The plant material used for this study was *Glycine Max (L.) Merr.*

Instruments

Chroma Meter (CR-400 KONICA MINOLTA INC.; JAPAN), Hot-air dryer, electric grinder (F E 05 High-Speed grinder, China), UV-spectrophotometer (Biobase VK-1000), FOSS the Soxtec™ 8000 extraction unit, FOSS Kjeltec™ 9 Analyser.

Laboratory Methods
Proximate analysis of flour samples

Compositional analysis of the samples was conducted in Ghana at the Food and Nutrition Analytical Laboratory, SARI. The methods described in the Official Methods of Analysis of the Association of Official Analytical Chemists (AOAC 2005) International were used to determine moisture content (AOAC 945.39) with slight modification by drying the samples at 105 °C overnight for approximately 12 h instead of 24 h, crude protein (AOAC 945.39), ash (923.03), and crude fat (AOAC 922.06) [17]. Total carbohydrate was computed following the formula (1):

Total carbohydrate = 100 – [moisture + crude protein + total ash + crude fat]. (1)

The energy content was calculated using the Atwater factors [18].

Functional properties

Water absorption capacity (WAC)

Two grams of each sample were measured into a 50 mL centrifuge tube, and 10 mL of distilled water was added. The suspension was allowed to stand for 30 min. The suspension was centrifuged at 3500 x g for 30 min (Hettich Zentrifugen model, Rotofix 32 A). The supernatant was discarded, and droplets were cleaned with cotton wool. The weight change was reported as WAC based on the original sample weight, formula (2).

$$\text{WAC (\%)} = \frac{\text{Weight of water absorbed}}{\text{Weight of dry sample used}} \times 100\ \% \tag{2}$$

Oil absorption capacity (OAC)

Two grams of oil were weighed into 50 mL centrifuge tubes, and 10 ml vegetable oil with a specific gravity of 0.99 was added. The mixture was shaken to mix completely, allowed to stand for 30 min, and centrifuged at 3500 x g for 30 min (Hettich Zentrifugen model, Rotofix 32 A). The supernatant was discarded, and droplets were cleaned from the tube. The weight change was computed and reported as OAC, formula (3).

$$\text{OAC (\%)} = \frac{\text{Weight of oil absorbed x specific gravity of oil}}{\text{Weight of dry sample used}} \times 100\ \% \tag{3}$$

Bulk density (BD)

The method described by [19] was adopted. Fifty grams (50) g of flour was measured into a 100 m measuring cylinder and tapped to a constant volume, following formula (4).

$$\text{BD} = \frac{\text{Weight of sample}}{\text{Volume of sample after tapping}}\ \text{(g/mL)} \tag{4}$$

Swelling index (SI)

The method prescribed by [20] was used to determine the swelling capacity. A graduated cylinder (100mL) was filled to the 10 mL mark with 4g of sample. Distilled water was added to make a total volume of 50 ml. By inverting the cylinder, the head of the graded cylinder was tightly covered and mixed. After 2 minutes, the suspension was inverted again and allowed to stand for 8 min. After 8 min, the sample's volume was measured. The swelling index was computed as below, following formula (5).

$$\text{SI \%} = \frac{\text{Volume after swelling} - \text{volume before swelling}}{\text{Volume before swelling}} \times 100 \tag{5}$$

Foaming capacity (FC)

The approach described by [21] was adopted to determine foam capacity (FC). Distilled water (25 mL) was added to 1 g of flour in a falcon tube. The suspension was shaken for 5 min to foam. The volume of foaming after 30 s whipping was calculated using formula (6).

$$\text{FC \%} = \frac{\text{Volume after whipping} - \text{volume before whipping}}{\text{Volume before whipping}} \times 100\% \tag{6}$$

Oxidative stability analysis

Extraction of crude soy Oil from samples and oxidative analysis

The crude oil was extracted from the flours using the method described by [22] with modification in hexane expelling time from 1 hr to 2 hr (Figure 1). Oil from respective flours (10 g) was extracted with 30 mL hexane in a 500 mL conical flask using a shaking incubator at 230 rpm for 1 hr after 1 min-long vortexing. After centrifuging the mixture at 3500 g for 5 mins, the supernatant was poured into a clean and labeled flask. The hexane was evaporated from the supernatant in a water bath at 60 °C for 2 h. The oil was extracted from the fresh samples before storage, and further extractions were carried out bi-weekly from the flour samples on shelved storage for oxidative stability studies.

Oxidative stability of the oils was carried out bi-weekly for 12 weeks. Official methods were used to determine oxidative parameters [23]. AOCS Cd 8b-90 for peroxide value (PV), AOCS Cd 18–90 for *p*-Anisidine (*p* AV), and AOCS Cd 3d-63 for acid value (AV). Total oxidation was computed using the equation below, formula (7) [24].

TOTOX = ((2 x PV) + p AV). $\qquad$ (7)
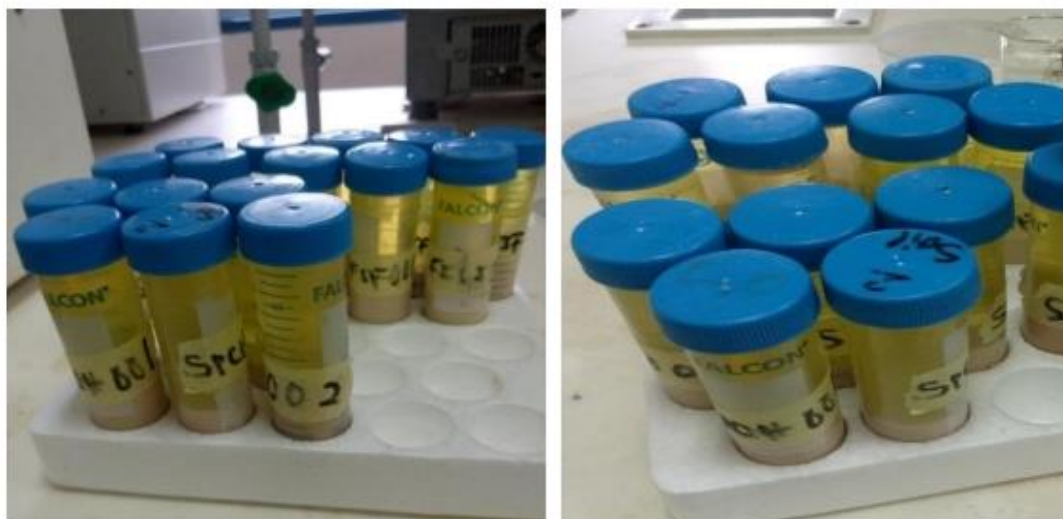
Figure 1 Oil extracted from respective flour samples.

Instrumental colour analysis

Flour samples (30 g each) were measured in a clean petri dish. The color characteristics (L* and chromaticity coordinates) of samples were determined using a Chroma Meter (CR-400 KONICA MINOLTA INC.; JAPAN) as shown in (Figure 2). The browning index was calculated as below using formula (8) **[25]**.

$$BI = 100 \text{ x } \left(\frac{X - 0.31}{0.17}\right)$$ (8)

Where: $X = \frac{(a* + 1.75L)a}{(5.645L + a* - 3.012b*)}$ (9)

a* = redness or greenness
L* = lightness or darkness
b* = yellow or blue
BI = browning index

Total color difference (ΔE) was computed as below using formula (10) provided by **[26]**.

$$\Delta E = \sqrt{(L*t0 - L*t12)^2 + (a*t0 - a*t12)^2 + (b*t0 - b*t12)^2}$$ (10)

Figure 2 Colour determination of samples using Chromameter *(CR-400 KONICA MINOLTA INC.; JAPAN).*

Microbiological analysis

Ten grams of each sample was homogenized in 90 ml sterile diluent (0.1% peptone, 0.8% NaCl, pH 7.2). Tenfold serial dilutions (10^{-1} to 10^{-9}) were made with the same diluent, and 0.1ml was Spread-plated in duplicates on various media to enumerate isolates. Total viable counts and Coliform bacteria were enumerated on Nutrient agar (NA) and Membrane Faecal Coliform (mFC) media [27], respectively, and incubated at 37 °C for 24 h. Yeasts and Molds were enumerated on Potato Dextrose Agar 9(Merck HG00C100) using a spread plate [28]. Plates were incubated for 72 hours at 25 °C. All visible colonies were counted and recorded in cfu/g.

Description of the Experiment
## Sample preparation

Soy curd residue flour (SCRF)

SCRF was produced according to the method described by [29] with modifications in soaking time and amount of water used for soaking. Cleaned and sorted soybean grains (7.5 g) were soaked in water (1:4 parts) for 8 h and wet milled with an electric grinder (F E 05 High-Speed grinder, China). The milk was collected, and the residue was oven-dried at 60°C for 12 h. The dried sample (2.9 Kg) was milled into flour (F

Full-fat soy flour (FFSF)

Sorted soybeans (5 Kg) were soaked in water for 8 h, dehulled, and oven-dried at 60°C for 12h. The dried soybeans (3.25 Kg) were winnowed to remove the hulls and milled into full-fat soy flour (FFSF) with a lab-scale grinding mill. The sample was packaged in an air-tight plastic bag, labeled, and stored at room temperature.

Cold-water extracted full-fat soy flour (CFFSF)

Sorted soybeans (10 Kg) were soaked in water for 8 h, dehulled, dried at 60°C for 12 h in a hot air oven, winnowed, and milled into flour (6.6 Kg). The flour was soaked in 1:5 parts of cold water for 5 h. The supernatants were drained off, and the residue was pressed in a cheesecloth and oven-dried for 12 h at 60 °C. The dried sample was milled and sieved to 355 µm using a laboratory sieve to yield cold-water full-fat soy flour (CFFSF). The flour was packaged in an air-tight plastic bag, labeled, and stored at room temperature.

SCRF   FFSF
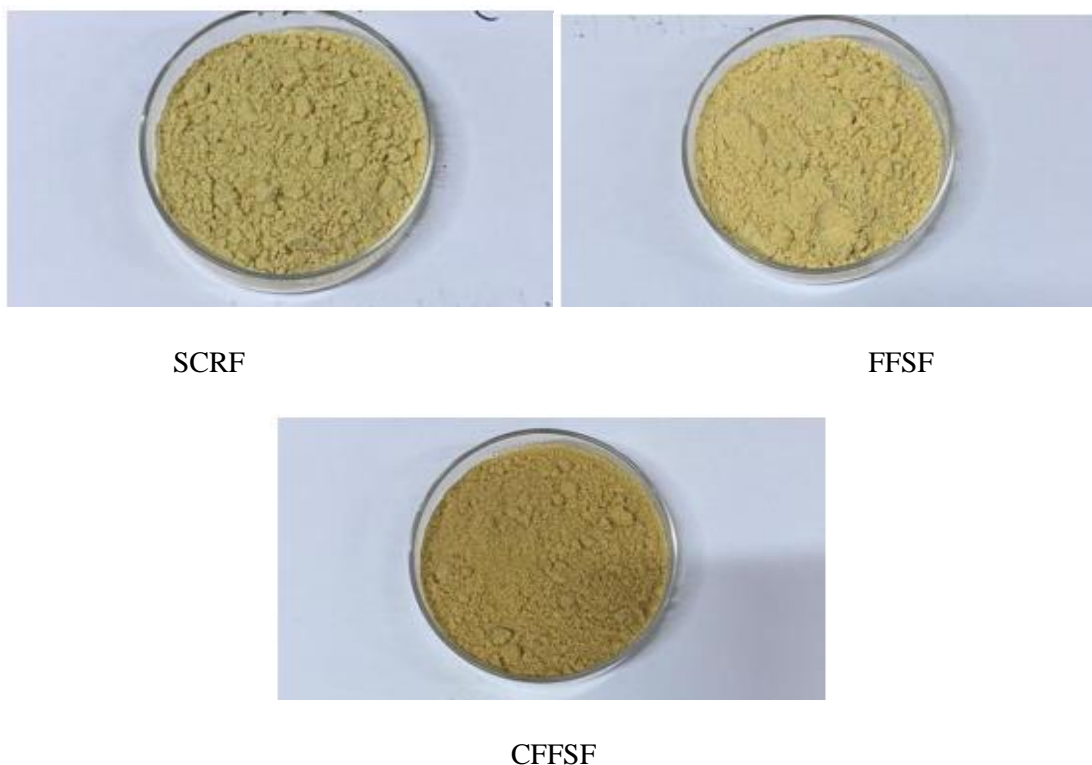
CFFSF

Figure 3 Flour samples.

Note: FFSF = full-fat soy flour, CFFSF = cold-water extracted full-fat soy flour, SCRF = soy curd residue flour.

Number of samples analyzed: 3.

Number of repeated analyses: Except for microbial analysis, which was carried out in duplicate, all other analyses were carried out in triplicate.

Number of experiment replications: 3 reps for each variant.
Design of the experiment:

Soybeans were purchased from the Tamale central market. The soybean was processed into the flour samples described in the sample preparation section. Proximate composition, microbial quality, and functional properties of the samples were determined using standard laboratory protocols. The flour samples were stored on the shelves for 12 weeks. In storage, samples were taken on every second week for colour determination. The flour samples were taken bi-weekly for oil extraction, and oxidative stability analysis was carried out for 12 weeks. The results obtained from the analysis were subjected to statistical analysis, and the validity of our hypothesis was verified.

Statistical Analysis

GenStat Statistical Software Edition 12.0 was used to analyze all the data generated. Data on proximate and functional properties were subjected to a one-way analysis of variance (ANOVA). Oxidative stability and colour data were analyzed using a two-way analysis of variance standardized test was used to separate the means, and a significant difference was determined at $p < 0.05$.

RESULTS AND DISCUSSION
Proximate analysis

Flour samples had moisture contents below 10% (Table 1) and were within levels prescribed by [30]. This may be attributed to low water activity. The result suggests that the samples may be shelf-stable since moisture which is an important medium for microbial growth [31] was very low in the flour samples.
The ash content of FFSF was significantly higher ($p < 0.001$) by 1.33, and 1.13-fold than CFFSF, and SCRF, respectively. It has been reported by [32] that soaking caused a loss of ash content. This might account for the lowest ash content recorded by CFFSF. The higher ash content of the samples suggests that they may be a good source of minerals [31].

Processing treatment also resulted in significantly higher fat content ($p < 0.001$) in CFFSF, which was almost 1.0, and 1.2-fold higher than in FFSF, and SCRF, respectively. The fat content of SCRF aligns with the fat content of 22.3 ± 1.5 g/100 g reported by [33]. Higher fat content may contribute to energy density and act as a flavour enhancer [34], however, the higher fat content of the flour samples could affect product stability as unsaturated fatty acids present in the sample are more liable to oxidative rancidity as reported [35].

The protein content of CFFSF was 1.1, and 1.3 times higher ($p < 0.001$) than that of FFSF, and SCRF, respectively (Table 1). The higher protein content of CFFSF may be attributed to the discarding of soluble carbohydrates after soaking the flour in cold water for 5 h and dehulling, which leads to an increase in protein content and a reduction in fiber content [36]. The low protein content observed for SCRF may be attributed to the soymilk that was extracted from the raw material during its preparation. The high protein contents of the samples suggest their usefulness for improving the protein content of food products and ameliorating protein-energy malnutrition [31].

Total carbohydrate was significantly higher ($p < 0.001$) in SCRF representing 2.1, and 2.7 times than FFSF, and CFFSF respectively. The high carbohydrate content of SCRF may be due to the non-dehulling of the soybeans during sample preparation. This suggests that SCRF could be used in managing protein-energy malnutrition, as there is a substantial quantity of carbohydrates from which energy can be derived to spare the protein for its primary function [34]. In contrast, dehulling and soaking might be the reason for the low total carbohydrate content in FFSF and CFFSF. However, the high carbohydrate content of SCRF derived from the seed hulls might reduce protein digestibility because it contains indigestible fibers that affect the digestibility of protein [36].

CFFSF had the highest total energy, which was 1.0 and 1.1 times higher than FFSF, and SCRF respectively. The energy content of the samples meets the recommended energy values of 360-400 kcal (CODEX), suggesting their suitability as an energy source [37].

Table 1 Proximate composition and energy value.

Flour	Proximate Composition (g/100 g)					
	Total ash	Crude fat	Moisture (%)	Crude protein	Total carbohydrates	Total Energy (kcal/100g)
FFSF	4.98 ± 0.06^c	27.55 ± 0.46^{bc}	7.370 ± 0.19^b	48.39 ± 0.02^b	11.71 ± 0.02^b	488.3 ± 0.12^b
CFFSF	3.74 ± 0.06^a	27.85 ± 0.13^c	6.267 ± 0.15^a	53.33 ± 0.02^c	8.81 ± 0.02^a	499.2 ± 0.09^c
SCRF	4.40 ± 0.42^b	23.22 ± 0.08^a	7.041 ± 0.21^b	41.22 ± 0.02^a	24.12 ± 0.03^c	470.3 ± 0.11^a
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Note: Values are means ± SD; n = 3. All values are on a dry matter basis. Means with different letters (a, b, c) in the same column represent a significant difference (Tukey's LSD; p <0.05). FFSF = full-fat soy flour, CFFSF = cold-water extracted full-fat soy flour, SCRF = soy curd residue flour.

Functional properties

The water absorption capacity of the flours significantly varied (p<0.001) with SCRF having the highest WAC denoting 1.5, and 1.2 times than FFSF and CFFSF respectively (Table 2). The highest WAC of SCRF might be related to its higher total carbohydrate or fiber content, which favours swelling, water holding, and retention capacities [38]. The results show that the flour samples can be useful in the bakery industry, which requires hydration to improve handling qualities.

FFSF had significantly ($p < 0.001$) higher OAC which is 1.1 and 1.2 times than CFFSF and SCRF respectively. High OAC of the samples might improve mouthfeel and flavour retention when the samples are incorporated into food formulations [36].

Generally, the bulk density of the samples was significantly low. FFSF had the lowest bulk density and differed significantly ($p < 0.001$) from CFFSF, and SCRF. Low bulk density is known to promote easy digestibility of food products. The low bulk density of the samples indicates that they may be ideal for complementary food preparations, as reported by [39].

The swelling index differed significantly ($p < 0.001$), with SCRF recording the highest and FFSF the lowest. The lowest swelling index of FFSF may be attributed to dehulling, which reduces water imbibition. The high swelling index recorded for SCRF may be due to its high carbohydrate content. SCRF has been reported to be a good source of dietary fiber, which can increase water-holding capacity [40]. A high swelling index has been reported to be ideal for food products that require swelling [38].

The foaming capacity of the samples varied markedly ($p < 0.001$). CFFSF had the highest foaming capacity, SCRF had the highest, and SCRF had the lowest. Overall, the low foaming capacity (5.63% to 11.20%) may be ascribed to the relatively high-fat contents of the samples, as reported by [38]. Foaming capacity is preferred in baking and as an active constituent in food preparations [41].

Table 2 Functional properties.

| Flour	Functional properties				
	WAC (%)	OAC (%)	BD (g/mL)	SI (mL)	FC (%)
FFSF	141.5 ± 0.46^a	117.4 ± 0.01^c	0.36 ± 0.07^a	1.50 ± 0.05^a	9.43 ± 0.01^b
CFFSF	167.9 ± 0.21^b	106.6 ± 0.02^b	0.40 ± 0.04^b	1.73 ± 0.02^b	11.20 ± 0.18^c
SCRF	201.8 ± 0.03^c	97.5 ± 0.02^a	0.41 ± 0.05^b	1.91 ± 0.02^c	5.63 ± 0.17^a
P-value	<0.001	<0.001	<0.001	<0.001	<0.001

Note: Values are means ± SD; n = 3. Means with different letters (a, b, c) in the same Comparison by column represent a significant difference (Tukey's LSD; P <0.05). FFSF = full-fat soy flour, CFFSF = cold-water extracted full-fat soy flour, SCRF = soy curd residue flour, WAC = water absorption capacity, OAC = oil absorption capacity, BD = bulk density, SI = swelling index, and FC = foaming capacity.

Oxidative stability

A highly notable difference ($p < 0.001$) was observed in the peroxide value (PV) of the samples, time-dependently. An overall increase in PV was generally observed for all samples (Figure 4a). Before storage, the PV of all samples was below 3.60 mEq/Kg. This initial PV recorded might be due to heat generation during

sample milling. The PV declined from week 4 to 6, which was expected due to the decomposition of hydroperoxides. All samples had PV below the limit (10 mEq/Kg) for oil specified in CODEX-STAN 210-1999 at the end of the study **[42]** FFSF had the highest PV (8.677 mEq/Kg), which was 1.07, and 1.55-times higher than CFFSF, and SCRF respectively at the end of week 12. According to O'Brien's categorization of oxidation concerning PV, all samples in this study can be considered moderately oxidized ($5 < PV < 10$) at the end of the analysis **[43]**.

p-anisidine value (p-AV) varied significantly ($p <0.001$) among the samples. A marginal rise in p-AV was observed among the samples from week 0 to week 4. A noticeable and time-dependent increase in p-AV was observed from week 6 to week 12 for all samples except SCRF, which recorded a steady rise (Figure 4b). The general increase in p-AV for all samples was primarily due to hydroperoxide decomposition **[44]**. At the end of week 12, FFSF had the highest p-AV denoting 1.26 and 1.73-fold than CFFSF and SCRF, respectively. The p-AV of all samples corroborates with **[45]**, who reported low oxidized soybean oil to have a p-AV of 4-10. Low p-AV indicates low rancidity, which may be ascribed to soaking that can diminish lipid oxidation as suggested by **[46]**.

a).

b).

c).

d).
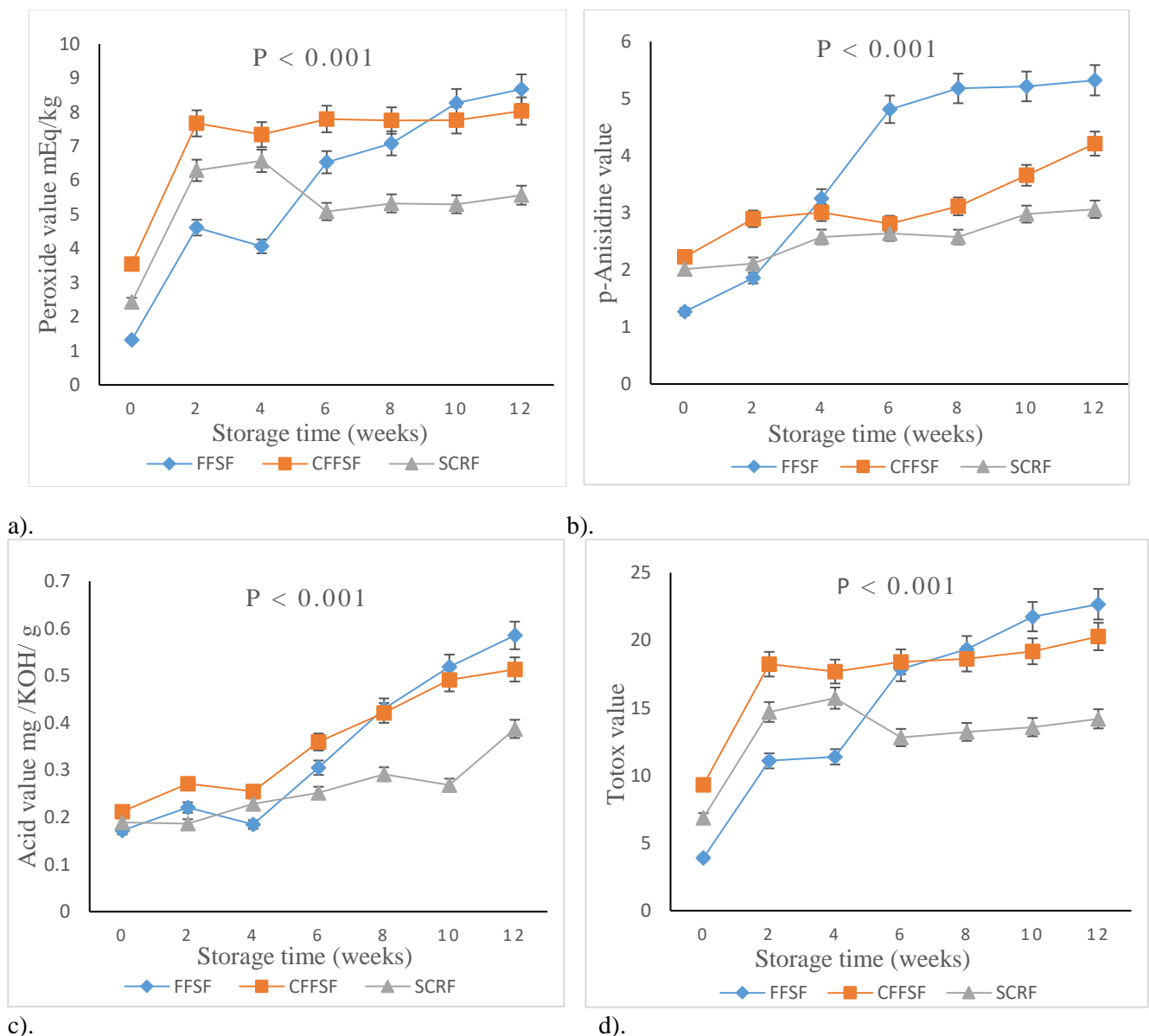
Figure 4 Changes in oxidative stability markers of samples during 12 weeks of storage.

Note: Values are means of triplicate. Error bars represent the standard deviations. A significant difference was observed at $P < 0.05$. FFSF = full-fat soy flour, CFFSF = cold-water extracted full-fat soy flour, SCRF = soy curd residue flour

The acid value (AV) of the samples differed significantly ($p < 0.001$). Initial acid values were below 0.2 mg KOH/g; however, an increased AV was observed with time for all samples, with FFSF recording the highest AV (Figure 4c). At week 12, the AV for all samples was below 0.6 mg/KOH complying with the permissible acid value of 0.6 mg/KOH/g for oil [42]. Given that free fatty acids are typically produced during the breakdown of triglycerides, AV is used as an indicator of oil rancidity, where high numbers indicate the oil or fats deterioration. The results suggest that the samples have acceptable odor intensity after 12 weeks of shelve storage [47].

TOTOX was significantly ($p < 0.001$) affected by processing treatment and storage duration. Based on the PV and AV of oil, the TOTOX value is used to empirically evaluate oxidative degradation.
With time, a general increase was observed in all samples (Figure 4d). From week 6, CFFSF and FFSF observed an accentuated rise in TOTOX. After peaking at week 4, SCRF showed a decline in week 6 and a steady rise until the final week of storage. The highest TOTOX was recorded for FFSF and the lowest by SCRF. The TOTOX ranged from 14.19 to 22.67 at the end of the study. The lower TOTOX indicates a better oil quality [48].

Instrumental colour analysis

Results indicated that storage duration significantly ($p < 0.001$) influenced the colour markers of the samples (Table 3).

Table 3 Colour parameters.

Colour parameter							
Week	Sample	L*	a*	b*	C	h	BI
0	CFFSF	69.92±0.03[a]	7.04±0.11[c]	22.32±0.01[c]	23.41±0.11[b]	72.49±0.09[a]	1299.89±0.07[c]
	FFSF	79.13±0.04[c]	4.76±0.12[b]	22.44±0.08[b]	23.23±0.13[b]	77.95±0.01[c]	822.96±0.11[b]
	SCRF	75.86±0.10[b]	4.54±0.02[a]	21.64±0.06[a]	22.11±0.12[a]	78.17±0.10[b]	761.0±0.09[a]
2	CFFSF	72.11±0.19[a]	6.50±0.06[c]	21.57±0.01[a]	25.86±0.04[c]	73.22±0.08[a]	1185.19±0.08[c]
	FFSF	80.70±0.06[c]	4.92±0.06[b]	23.68±0.13[c]	24.18±0.14[b]	78.12±0.12[b]	870.56±0.12[b]
	SCRF	78.10±0.77[b]	4.28±0.17[a]	22.33±0.14[b]	22.73±0.13[a]	79.16±0.11[c]	716.18±0.09[a]
4	CFFSF	72.11±0.31[c]	6.60±0.16[c]	20.61±0.12[c]	21.63±0.09[c]	72.32±0.66[a]	1406.35±0.11[c]
	FFSF	68.32±0.12[b]	3.47±0.22[b]	14.94±0.09[b]	5.34±0.05[a]	76.90±0.08[b]	1038.93±0.08[b]
	SCRF	58.35±0.15[a]	2.89±0.11[a]	12.79±0.11[a]	13.13±0.05[b]	77.26±0.09[b]	832.68±0.07[a]
6	CFFSF	66.99±0.11[a]	7.87±0.06[c]	27.06±0.11[b]	28.18±0.11[b]	73.78±0.36[a]	1570.67±0.30[c]
	FFSF	68.85±0.14[b]	6.29±0.15[b]	25.94±0.01[a]	26.70±0.15[a]	76.37±0.09[b]	1203.24±0.07[b]
	SCRF	74.88±0.13[c]	5.14±0.02[a]	26.60±0.08[a]	27.09±0.10[a]	79.10±0.09[c]	927.52±0.08[a]
8	CFFSF	65.60±0.04[a]	7.67±0.03[b]	26.27±0.01[a]	27.37±0.29[a]	73.73±0.26[a]	1515.72±0.21[c]
	FFSF	74.76±0.06[b]	5.55±0.06[a]	27.89±0.11[b]	28.65±0.37[b]	76.79±0.33[b]	1270.31±0.20[b]
	SCRF	74.40±0.07[b]	5.17±0.10[a]	26.55±0.06[a]	27.06±0.31[a]	78.97±0.33[c]	945.39±0.31[a]
10	CFFSF	63.88±0.33[a]	7.91±0.30[c]	26.24±0.33[a]	27.40±0.03[a]	73.32±0.05[a]	1517.28±0.05[c]
	FFSF	79.71±0.05[c]	6.81±0.08[b]	27.94±0.66[b]	28.76±0.08[b]	76.30±0.04[b]	1228.19±0.07[b]
	SCRF	72.18±0.13[b]	5.32±0.12[a]	26.59±0.15[a]	27.12±0.08[a]	78.68±0.06[c]	942.43±0.09[a]
12	CFFSF	69.04±0.05[b]	6.86±0.08[b]	27.91±0.08[b]	27.43±0.13[a]	76.29±0.16[b]	1553.60±0.16[c]
	FFSF	63.58±0.04[a]	7.83±0.06[c]	26.58±0.04[a]	28.77±0.16[b]	73.39±0.09[a]	1274.11±0.13[b]
	SCRF	70.84±0.11[b]	5.30±0.08[a]	26.97±0.11[a]	27.34±0.14[a]	78.88±0.09[c]	950.29±0.16[a]
p-value		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Note: Values are means ± SD; n = 3. Means with different letters (a, b, c) in the same comparing column represent a significant difference (Tukey's LSD; P <0.05). FFSF = full-fat soy flour, CFFSF = cold-water extracted full-fat soy flour, SCRF = soy curd residue flour, L* = lightness or darkness, a*= redness or greenness, b* = yellow or blue, C =chroma, h = hue angle, and BI=browning index.

Generally, the sample experienced slight darkening with time. The reduction in lightness may be attributed to pigment degradation, Maillard reaction, caramelization, or oxidation of polyphenols, as suggested by **[49]**. This is consistent with reports by **[16]**, who reported a time-dependent darkening of full-fat soy under storage. The overall colour change was more pronounced in FFSF (Figure 5). The browning index increased sharply in all the samples; however, it was more noticeable in CFFSF. Overall, the increasing browning index of the sample may be attributed to the degradation of pigments, caramelization, or oxidation of polyphenols **[49]**. L* value is anticipated to decrease as browning is observed **[50]**. Total color change denotes a value that represents the change of color over time. The highest colour change was evident in FFSF, followed by SCRF and CFFSF.
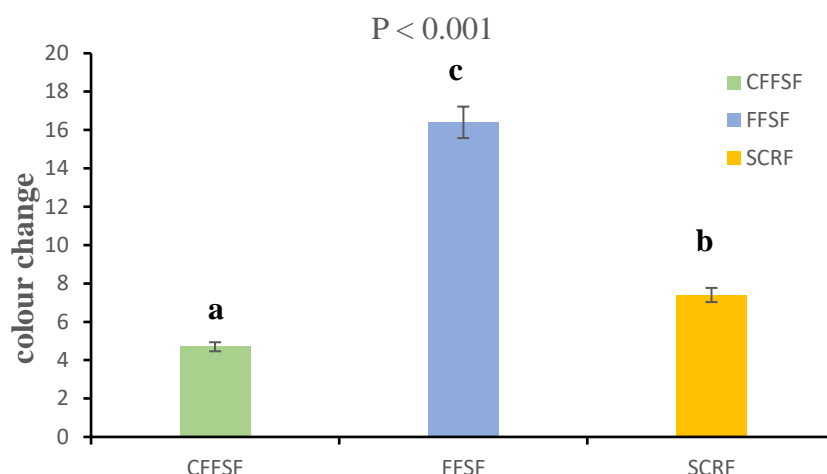
Figure 5 Total colour change in flour samples.

Note: Values are means ± SD; n = 3. Means with different letters (a, b, c) represent a significant difference (Tukey's LSD; P <0.05). FFSF = full-fat soy flour, CFFSF = cold-water extracted full-fat soy flour, SCRF = soy curd residue

Microbiological analysis

All samples observed no mold and yeast growth, except CFFSF (Table 4), which recorded 1.12 x 104 cfu/g, which is below the recommended limit of 10^5 cfu/g for flours according to **[51]**. The molds and yeast growth in CFFSF (Table 4) may be ascribed to post-production contamination from sample handling. There was no growth regarding the total plate count and total coliforms in any of the samples (Table 4). This could be due to the cleanliness of sample preparation and low water activity, which might have inhibited microbial growth. The results indicate that the samples are safe for use as food ingredients.

Table 4 Microbial growth analysis.

Flour	Microbial load (CFU/ g)		
	Total viable counts	Total coliforms	Yeast and molds
FFSF	<10 cfu/g	<10 cfu/g	<10 cfu/g
CFFSF	<10 cfu/g	<10 cfu/g	1.12E+04
SCRF	<10 cfu/g	<10 cfu/g	<10 cfu/g

Note: Values are means (n = 3). FFSF = full-fat soy flour, CFFSF = cold-water extracted full-fat soy flour, SCRF = soy curd residue flour.

CONCLUSION

The study demonstrated that processing treatment and storage time significantly impact the quality metrics under investigation. SCRF was the most oxidatively stable among the samples. However, it was notable that CFFSF was more stable than FFSF. At the end of the oxidative stability study, all samples recorded peroxide and acid values below the acceptable limit of 10 mEq/Kg and 0.6 mg/KOH/g, respectively. This work has shown a higher protein (41.22g – 53.33g / 100g) and energy yield, coupled with better storage stability in full-fat soy flour extracted with cold water (CFFSF) and soy curd residue flour (SCRF), respectively. This may offer an opportunity for protein-rich and shelf-stable product development when these ingredients are utilized in food product development. The lower bulk density alongside desirable functional properties of the samples characterized in this study may indicate their suitability for complementary food development. However, it is vital to recognize the limitations of this study. Certain constraints, such as methodological and sample size, might have influenced the results. These limitations may provide potential opportunities for future research to build upon our work and address the remaining gaps. Overall, this study contributes to the current knowledge base by comprehensively analyzing soy curd residue and full-fat soy flour and their suitability as ingredients for food formulations.

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