Physicochemical and sensory characterization of okara obtained by two different processes and the study of its use as breaded food

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Abstract

Soybean residue, known as okara, is a byproduct of soymilk production with varying compositions based on the production process. This study explored the characteristics of fresh and dried, disc-milled, and all-metal hammer-milled okara derived from soy crops in Uruguay through different techniques, including physicochemical, microbiological, and sensory analyses. Specifically, dried disc-milled okara was used in making breaded tofu steak, and the sensory traits and oil absorption of the fried product were examined when bread crumbs were substituted with okara in proportions of 0, 25, 50, 75, and 100%. The production process affected moisture, protein, fiber, and oxidative rancidity. Dried samples showed differences in smell, crispness, and particle size, while the drying process reduced microbial load and total polyphenols but enhanced lightness, redness, and yellowness. All samples exhibited a similar fatty acid profile, mainly C18:2. Increasing okara content in breading enhanced the color and smell of fried steaks. Interestingly, there was no significant difference in fat content between the 0 and 100% okara substitutions. This study concludes that dried okara, rich in fiber, protein, and essential fatty acids, presents potential as a functional food for human consumption. It also serves as a sustainable and nutritious breading substitute, offering an alternative to conventional ingredients.

Keywords: soybean; byproduct; okara; fiber; breading.

Practical Application: This manuscript holds significance for the food industry, particularly in the development of sustainable and nutritious food products, as it presents a comprehensive analysis of the potential uses of okara, a soybean residue generated during soymilk production. The study explores the physicochemical and sensory characteristics of okara obtained by two different processes and investigates its potential as a breading food. By utilizing this underexploited byproduct, the food industry can develop innovative and eco-friendly products that align with the increasing demand for nutritious and sustainable food options. Moreover, the incorporation of okara into various food matrixes provides an opportunity for the industry to efficiently manage waste, reduce environmental impact, and foster food security by offering a valuable source of fibers, proteins, and essential fatty acids.

1 INTRODUCTION

Soy is a crop of oleaginous seed that has been sown for more than 3000 years in China and other Asian countries and is of massive consumption in Asia and other continents (Nishinari et al., 2014). Nowadays, soy is the most cultivated plant worldwide, with a production of 121.5 million hectares and 362 million tons of soybeans per year (Bragagnolo et al., 2021; Terzic et al., 2018), and the market value is expected to reach about US$162 billion by 2027 (Singh & Krishnaswamy, 2022).

Uruguay occupies the 12th position as a world soy producer (2.5 million projected tons). However, if considered the regions, Paraguay, Argentina, Uruguay, and Brazil lead the world in soybean production per capita (USDA, 2023).

Of all the products obtained from this grain, soymilk has a very high economic value because the grain is not only commercialized but is also used as a base for the preparation of a great variety of food products, including tofu (bean curd), soymilk whey, soy yogurt, and soy-based cheese (Voss et al., 2018).

The residue obtained when grinding soybeans after extracting the soluble fraction in water to produce soymilk is called okara. For each kilogram of processed soybeans for soymilk preparation, approximately 1.2 kg of fresh okara are obtained (Singh & Krishnaswamy, 2022).

Soymilk extraction implies separating the liquid phase by mechanical methods. The remaining okara is obtained with different degrees of moisture, depending on the efficiency with which the liquid phase was removed in the previous stage. This efficiency depends on the method used for grinding and the separation of grains such as an all-metal hammer-milled, disintegrator, pin mill, or large stainless-steel blender, followed by centrifugation or manual separation with filters (Shurtleff & Aoyagi, 2000). Therefore, the chemical composition of okara will depend on the amount of aqueous phase that is extracted from

the ground soybean as well as whether additional water was used during the process to extract the remaining components (Kamble & Rani, 2020).

As okara is a byproduct, the method of obtaining it will be defined based on the parameters that allow obtaining soymilk with a high percentage of soluble solids (especially proteins) (Shurtleff & Aoyagi, 2000). Other factors that influence its composition will be the zone where the soybean was harvested and the production method (Li et al., 2012).

Okara usually decomposes very quickly due to the high water activity (Noguchi, 1987). The most common method to preserve okara is to dry the product immediately after it is obtained (O'Toole, 1999).

Okara is usually used as animal feed, burned to obtain energy, and discarded as residue, which in the volumes of the industry implies a potential environmental problem due to its combination of high humidity, proteins, and microbial load that makes it susceptible to putrefaction processes (O'Toole, 1999; Redondo-Cuenca et al., 2008). Currently, there has been an increase in research exploring the use of okara for the production of probiotics, bio-okara, health supplements, fertilizers, composites, and various other industrial products, including snack bars, biscuits, and others, as discussed by Nishinari et al. (2018) and Singh and Krishnaswamy (2022).

In this context, the objectives of this study were to characterize from the physicochemical, microbiological, and sensory points of view the fresh and dried okara obtained by two production methods (disc-milled and all-metal hammer-milled) from cultivated soybean in Uruguay and study the feasibility of using dried okara as a breaded food.

2 MATERIALS AND METHODS

2.1 Obtention of okara

The 2022 harvest of soybeans (*Glycine max* (L.) SJC 13621) was provided by a local company called NAVEMAS S.A. The grains were rinsed and moistened in water at room temperature for 8 h.

- Okara's obtention by disc-milling (DO): The hydrated grains were ground with a disc-mill, which consists of two horizontal flat circular stone discs that rotate in opposite directions with adjustable spacing, as a way to crush the soybeans in between, with water at room temperature in a water/soybean proportion of 1.1 L/kg (Shurtleff & Aoyagi, 2000);

- Okara's obtention by all-metal hammer-milling (HO): The hydrated grains were ground with an all-metal hammer mill using continuous circulating boiling water until grinding was complete, with a water/soybean proportion of 7 L/kg (Shurtleff & Aoyagi, 2000);

- Once the samples were obtained, they were immediately frozen in a cooling chamber at -28°C until their analysis and drying;

- The samples of the dried hammer-milled okara (dHO) and dried disc-milled okara (dDO) were obtained by drying the HO and DO samples, respectively, previously defrosted in a refrigerator at 4°C, in a convection heater at 105°C until reaching a humidity lower than 8%, which is the maximum value according to the Uruguayan national regulation for soybean flour (Uruguay, 1994). The dried samples were kept in airtight glass jars at room temperature and out of the sunlight until their use.

2.2 Composition analysis of okara

The proximate composition analysis of DO, HO (previously defrosted at 4°C for 12 h), dDO, and dHO samples was done following the methodologies listed below (Thangaraj, 2016):

- Moisture by direct gravimetric in a convection heater at 105°C until obtaining a constant mass (Gardner, 1986);

- Proteins by Kjeldahl method – AOAC 970.02 (International & Latimer, 2012);

- Total dietetic fiber by Prosky method – AOAC 985.29 (International & Latimer, 2012);

- Total fat by extraction using a mix of hexanol/isopropanol solvents (3/2 v/v) (Hara & Radin, 1978);

- Total ashes by the AOAC 930.05 official method (International & Latimer, 2012);

- Digestible carbohydrates by the difference between the total mass on dried-based and the values of proteins, total dietetic fibers, total fat, and total ashes expressed on dried-based.

All the characterization assays were carried out in triplicate.

2.3 Profile of fatty acids

The determination of the composition in fatty acids of the oil obtained from different okara samples was carried out by previous derivatization of the oils according to the IUPAC 2.301 procedure (Dieffenbacher & Pocklington, 1992) and their qualitative analysis according to AOCS Ce 1c-89 and AOCS Ce 1f-96 (AOCS, 2017), using a Shimadzu model 2014 equipped with an FID detector and provided with a Supelco SP-2560 capillary column of 100 m in length. For the identification of the peaks, the standard Supelco 189-19 was used with the fatty acid methyl esters of interest for the analysis.

2.4 Instrumental color

The color was measured using a Minolta CR-300 colorimeter (Konica Minolta Business Technologies Inc., Tokyo, Japan). The sample color was measured in the CIELAB space with standard illuminant D65, observer angle 10°, and zero and white calibration.

L* (lightness), a* (redness), and b* (yellowness) were measured in the different samples of okara placed on Petri plates. Color readings were taken arbitrary on 10 non-overlapping points on the surface of each sample.

2.5 Total polyphenols

The total polyphenol concentration was followed by the method suggested by Slinkard and Singleton (1977), which consists of a reduction/oxidation (REDOX) reaction among the polyphenols (gallic acid, pattern) present in a sample and the Folin-Ciocalteu reactive. The extracts for the analysis were obtained at a concentration of 10% (mass/volume) using a mix of methanol:water (80:20) as a solvent. The extraction was performed in falcon tubes with magnetic agitation at room temperature for 1 h. The extracts were centrifuged at 4,500 rpm per 15 min and the supernatant was filtered using a membrane of polyvinylidene fluoride (PVDF) of 0.45 μM. The REDOX reaction was measured by UV-Vis spectrophotometry at 750 in quintuplicate.

2.6 Oxidative rancidity

Oxidative rancidity is one of the most frequent causes of food deterioration in matrices that are rich in polyunsaturated fatty acids (Velasco et al., 2010). To study the oxidation of okara lipids, a TBARS assay derived from Kohn and Liversedge (1944) was used. The sample was homogenized and suspended in buffer KCl 0.15M + EDTA 57 mg/mL, sample/buffer ratio 57 mg/mL, and stabilized with 175 μL BHT/g sample (BHT 66 mg/mL concentration). It was centrifuged and separated by 1 mL from the supernatant. It was mixed with 1 mL of a TBA 1%–TCA 20% mix and placed to boiling for 30 min. Then, they were placed on ice for 5 min to stop the reaction. They were left there for 40 min at room temperature. A volume of 3 mL of butanol was placed in each tube, with subsequent centrifugation at 3,000 g. The absorbance was measured at 535 nm for whites and samples. For the calculation of mg MDA/kg equivalents of okara, a molar coefficient of extinction of 157,000 (cm*mol)$^{-1}$ (Du & Bramlage, 1992) was used.

2.7 Microbiological analysis

Due to the lack of national specifications to define the microbiological quality of the okara samples, the CE 2,073/2005 and 1,441/2007 regulations in execution of the European Union for flours and semolina were taken as references because they are considered foods of relative similarity. The total aerobic mesophilic count (ISO 4833-2013), total fungi (VAM cap. 4), yeasts and total coliforms (Salfinger & Tortorello, 2015), *Salmonella spp* (ISO 6579:2017), and *Listeria monocytogens* (ISO 11290-1:2017) were analyzed.

2.8 Sensory characterization

Due to the microbiological results of the wet okara samples, only the sensory characterization of dried okara was performed.

The sensory panel of assessors was integrated by eight people between 25 and 61 years old with previous experience (minimum 250 h) in discriminative tests and the evaluation of various foods through descriptive analysis. To generate the descriptors, dried hammer-milled okara (dHO) as well as dried disc-milled okara (dDO) samples were presented to each assessor. The assessor wrote the descriptors that differentiated the samples, and through an open discussion with the panel leader, the terms to use were agreed upon. The following attributes were selected to describe dried okara samples: intensity of color, overall intensity of smell, crispness, dryness, overall intensity of flavor, soy flavor, bitter taste, and persistence of overall flavor.

For the evaluation, 30 g of each sample (dHO and dDO) were served to the eight assessors in duplicate in white ceramic dishes following a completely random design. The intensity of the chosen attributes was measured with a non-structured scale of 10 cm with the "Little" and "Much" ends, except for the color, where the "Light" and "Dark" ends were used. Still water and crackers without salt were used as drafts. All essays were held at the Sensory Laboratory of the School of Chemistry at the Universidad de la República, Uruguay, designed according to ISO 8589:1988.

2.9 Use of dehydrated okara as breaded food

2.9.1 Preparation of breaded tofu steaks

Within the framework of the circular economy of the company NAVEMAS S.A., which manufactures soymilk and tofu by obtaining okara as a byproduct, we decided to study the possibility of using okara as a total or partial substitute for bread crumbs in the breaded tofu steaks that this company produces.

The commercialized product by this company consists of a tofu steak with an average 10×6.5 cm^2 surface, 1 cm height, and a 75 g mass. For its preparation, the steak is first submerged in a starch suspension formulated with 400 g of manioc starch, 35 g of chickpea flour, and 35 g of salt per liter of water. Then, it comes into close contact with a dried mix composed of 89% bread crumbs, 8% linen, and sesame seeds in equal proportions, and the other 3% of garlic powder, oregano, and thyme in equal proportions. The steaks have an average mass of 100 g after being breaded and are packed and frozen in a freezing tunnel at -30°C. After that, they are kept at -18°C for the market.

For the assays performed, the same procedure performed by the company NAVEMAS S.A. for the production of frozen breaded tofu steaks was used by substituting totally or partially the bread crumbs with okara.

All okara assays were performed using dried disc-milled okara, not only due to its higher performance yield (55%) in tofu production (1.4 g of tofu per gram of disc-milled soybean versus 0.9 g of tofu per gram of hammer disc-milled soybean), but also because of its distinct sensory characteristics and cost effectiveness. Disc-milled okara has a darker color and a stronger overall smell compared to hammer-milled okara, but shows no significant statistical difference in terms of overall flavor intensity or soy oil flavor, among other factors. While the sensory properties and physicochemical characteristics of disc-milled okara (dDO) might initially suggest it as a "worst case scenario" for its application as a breadcrumbs substitute, we intentionally selected this type as it represents a limit condition. This choice, conceived as a benchmark, significantly influenced our selection criteria in the studies concerning the replacement of breadcrumbs with okara.

The dried disc-milled okara was ground and sieved with a 117 μm mesh size, which is equivalent to the size of bread crumbs used by the company.

The experimental design for obtaining breaded steak consisted of a factor (the amount of substitution of bread crumbs with okara) with five levels (0, 25, 50, 75, and 100%). The steaks obtained were unitary and randomly fried submerging them in 2 L of sunflower oil at 180 ± 10°C for 2.5 min each.

2.9.2 Sensory characterization

The panel of sensory assessors was formed by eight assessors who had previously characterized the dried okara. As indicated in the paragraph mentioned earlier, each assessor received samples of the steaks with different percentages of bread crumbs substituted for okara previously cooked, thus generating the appropriate descriptors to carry out the descriptive analysis.

The assessors wrote the descriptors that differentiated the samples, and through an open discussion with the leader of the panel, the terms to be used were agreed upon. The following attributes were chosen to describe the breaded tofu steak: color, intensity of smell, crispness, firmness, moisture, intensity of overall flavor, greasy sensation in the mouth, and acid taste.

For the evaluation, a quarter of each steak of 0, 25, 50, 75, and 100% of approximately 25 g of the samples was served to the eight assessors in duplicate on white ceramic dishes following a completely random design. The intensity of the chosen attributes was measured with a non-structured scale of 10 cm with the ends "Little" and "Much," except for the color, where the ends "Light" and "Dark" were used. Still water was used as a draft. All tests were held in a sensory laboratory designed according to ISO 8589:1988.

2.9.3 Physicochemical characterization

The oil absorption was determined by comparing the total fat of the steak before and after frying in levels 0 and 100% of substitution with okara with the same extraction technique reported in Section 2.2., using the mixture of hexane/isopropanol solvents (3/2 v/v) (Hara & Radin, 1978).

2.10 Statistical analysis

The physicochemical data for okara, dried okara, breading, and oil absorption were analyzed by the analysis of variance (ANOVA), using "sample" as a fixed source of variation. An ANOVA on sensory descriptive analysis data was carried out, considering the sample as the fixed source and the assessor and repetition as random sources of variation. The Tukey's post-hoc test was used to compare the means and determine significant differences ($p \leq 0.05$) on all assays. All statistical analyses were performed using R, version 4.2.2 (The R Foundation for Statistical Computing).

3 RESULTS

3.1 Proximate composition analysis

As observed in Table 1, the HO sample was wetter than the DO sample. The HO and DO samples present a differentiated nutritional profile, with the HO sample being the richest in proteins and fibers. The same trends were kept between the dHO and dDO samples, respectively. Expressed in dry base, there were no significant changes in the physicochemical composition of the pairs (HO,dHO) and (DO,dDO).

Total carbohydrates were found by difference. Results are expressed as the mean ± standard deviation, $n = 3$. Means with a common letter designation in the same column were not statistically different by Tukey's test ($p > 0.05$).

3.2 Profile of fatty acids

There are no qualitative differences in the fatty acid profiles of the HO, DO, dHO, and dDO samples (Figure 1). Linoleic acid (C18:2) is the main fatty acid found in the different okara with a percentage over 50%, followed by oleic acid (C18:1) and palmitic acid (C16:0).

The values are indicated as mean ± standard deviation of three independent experiments. Means with a common letter designation were not statistically different by Tukey's test ($p > 0.05$).

3.3 Other physicochemical parameters

Table 2 shows that the drying of the sample improves the brightness and markedly takes their colors toward yellow (b* parameter) and slightly to red (a* parameter). In general, a notorious browning is produced (sensory confirmation).

In either the HO or DO sample, the concentration of total polyphenols per gram of dried-based sample decreased by
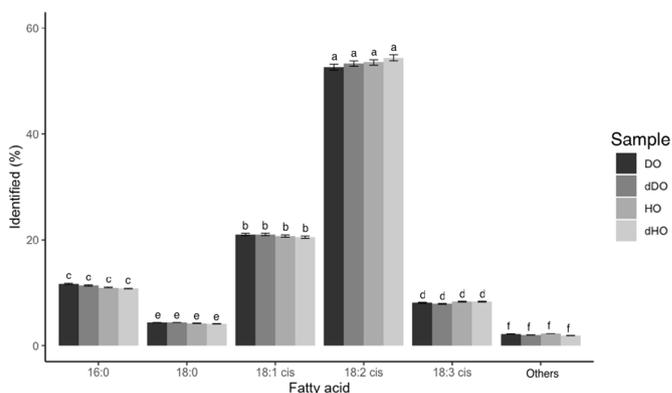

Figure 1. Fatty acid composition in okara samples.

Table 1. Proximate composition analysis results.

Sample	Moisture (%)	Protein (%db)	Total fat (%db)	Fiber (%db)	Ashes (%db)	Total carbohydrates (%db)
HO	(81.81 ± 0.32)a	(34.85 ± 0.57)a	(15.99 ± 0.96)b	(40.21 ± 0.61)a	(4.26 ± 0.02)a	44.90
DO	(67.77 ± 0.65)b	(29.65 ± 1.06)b	(17.99 ± 0.55)a	(34.29 ± 0.63)b	(3.85 ± 0.04)b	48.51
dHO	(7.26 ± 0.57)c	(33.55 ± 0.29)a	(16.14 ± 0.54)ab	(40.19 ± 1.02)a	(4.27 ± 0.01)a	46.04
dDO	(5.75 ± 0.54)d	(31.22 ± 0.06)b	(17.36 ± 0.89)ab	(33.93 ± 0.96)b	(3.83 ± 0.01)b	47.59

approximately half when samples were dried. The HO sample (0.59 mg GAE/g) has a slightly higher amount of total polyphenols ($p < 0.05$) than the DO sample (0.52 mg GAE/g).

The DO sample shows a higher oxidative rancidity, although it does not worsen with drying (dDO), and it is superior to the HO and dHO samples.

3.4 Microbiological analysis

The dHO and dDO samples have considerably lower microbiologic values than their fresh pairs (Table 3), which allows us to perform their sensory characterization.

3.5 Sensory characterization

A significant difference was found in the intensity of smell, crispness, and particle size of both samples ($p \leq 0.05$). The disc-milled sample had a more intense smell than the hammer-milled one, though this was not reflected in their flavor. No significant difference was found in the rest of the attributes assessed (Table 4). The samples were characterized by medium to low intensities of all the sensory attributes evaluated.

3.6 Utilization of dehydrated okara as breaded food

3.6.1 Preparation of breaded tofu steaks

The manual elaboration of the 16 breaded steaks consisted of cutting rectangular tofu steaks $(7.5 \pm 0.2) \times (8.5 \pm 0.2)$ cm²

on each side with a depth of (0.8 ± 0.1) cm. No-breaded steaks had an average mass of 58.9 ± 6.2 g, and after breading, they reached an average mass of 72.5 ± 6.5 g. There was no significant difference ($p > 0.05$) in the adsorbed amount of mass during breading between the samples with different amounts of okara. The breaded tofu stakes were fried as declared in Section 2.9.1, and the results are shown in Figure 2.

Photography of the results from the frying process, sorted (left to right) in crescent order of okara percentage in the breading mixture (0, 25, 50, 75, and 100%). All samples were fried at $180 \pm 10°C$ per 2.5 min each.

3.6.2 Sensory characterization of the steaks

The amount of okara in the breading significantly affected the color and intensity of the smell of the fried steaks ($p < 0.05$). Both attitudes increase when the amount of okara in the breading increases. No significant differences were found ($p > 0.05$) among the other attributes evaluated. All samples were characterized by medium and low intensities of all the evaluated sensory attributes. The results are shown in Table 5.

3.6.3 Fat absorption

No significant difference ($p > 0.05$) was found in the amount of fat among the steaks after frying them with 0 and 100% of okara (Figure 3).

Table 2. Results of assays of instrumental color (L, a, and b), determination of total polyphenols (milligrams of gallic acid equivalents per gram of dried sample), and oxidative rancidness (milligrams of malondialdehyde per kilogram of the dried sample)#.

Sample	L*	a*	b*	mgGalAc*(g dry sample)⁻¹	mgMDA*(kg dry sample)⁻¹
HO	(68.32 ± 1.06)c	(0.65 ± 0.16)d	(13.21 ± 0.64)c	(0.59 ± 0.03)a	(3.68 ± 0.25)b
DO	(67.20 ± 1.45)c	(1.55 ± 0.33)c	(14.60 ± 0.58)b	(0.52 ± 0.02)b	(6.76 ± 1.05)a
dHO	(77.92 ± 0.20)a	(4.33 ± 0.28)b	(20.97 ± 0.26)a	(0.25 ± 0.01)c	(4.67 ± 0.34)b
dDO	(71.78 ± 0.38)b	(7.05 ± 0.20)a	(20.87 ± 0.24)a	(0.23 ± 0.01)c	(6.90 ± 0.47)a

#Results are expressed as the mean ± standard deviation (n = 10 for instrumental color and n = 3 for the other assays). Means with a common letter designation in the same column were not statistically different by Tukey's test ($p > 0.05$).

Table 3. Results of microbiological analysis.

Sample	Mesophilic aerobics (UFC/g)	Fungi (UFC/g)	Yeasts (UFC/g)	Total coliforms (UFC/g)	Listeria monocytogens (UFC/25g)	Salmonella spp. (UFC/25g)
HO	1.50E+07	<100	6.00E+02	1.30E+05	Absence	Absence
DO	7.50E+08	3.50E+03	1.20E+04	1.90E+05	Absence	Absence
dHO	< 1.0E3	<100	100	<100	Absence	Absence
dDO	1.80E+03	<100	<100	<100	Absence	Absence

Table 4. Sensory analysis results of dried samples*.

Sample	Intensity of color	Overall intensity of smell	Crispness	Particle size	Dryness	Overall intensity of flavor	Flavor of soybean oil	Bitter	Overall flavor persistence
dHO	(2.64 ± 1.37)a	(2.26 ± 1.02)b	(3.24 ± 1.01)b	(5.55 ± 1.13)a	(3.97 ± 1.05)a	(3.19 ± 1.32)a	(2.69 ± 1.46)a	(2.27 ± 1.39)a	(2.46 ± 1.28)a
dDO	(3.58 ± 1.25)a	(3.46 ± 1.13)a	(4.25 ± 1.14)a	(1.90 ± 0.84)b	(4.71 ± 1.21)a	(4.11 ± 1.31)a	(3.47 ± 1.37)a	(2.96 ± 1.49)a	(3.20 ± 1.46)a

*Results are expressed as the mean ± standard deviation ($n = 16$). Means with a common letter designation in the same column were not statistically different by Tukey's test ($p > 0.05$).
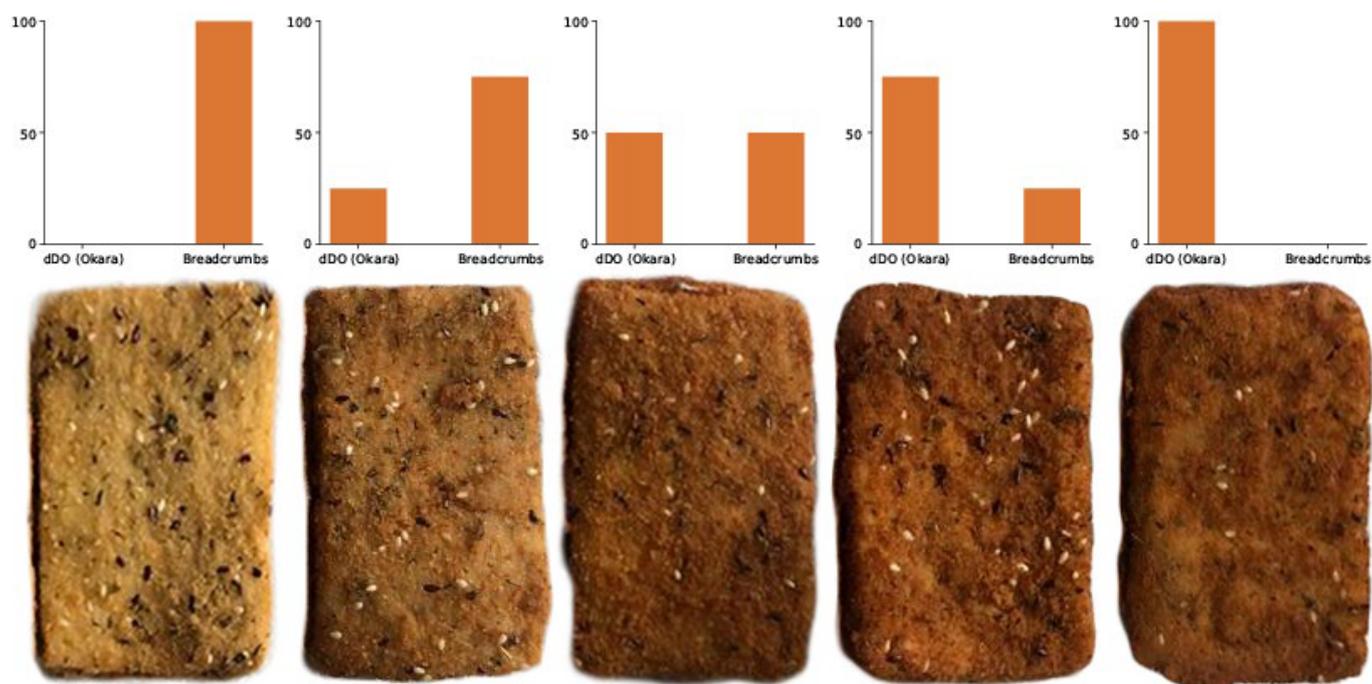
Figure 2. Fried breaded tofu stakes results.

Table 5. Sensory analysis results of steak breaded with breadcrumbs and okara*.

Sample	Intensity of color	Overall intensity of smell	Crispness	Firmness	Moisture	Overall intensity of the flavor	Greasy sensation in the mouth	Acid taste
0%	(1.27 ± 1.06)a	(2.77 ± 1.59)a	(3.58 ± 1.44)a	(4.40 ± 1.64)a	(4.28 ± 1.53)a	(3.31 ± 1.69)a	(3.11 ± 1.21)a	(1.71 ± 1.46)a
25%	(3.65 ± 1.03)b	(3.53 ± 1.48)a,b	(3.13 ± 1.27)a	(3.22 ± 1.39)a	(4.37 ± 1,59)a	(3.85 ± 1.39)a	(3.28 ± 1.41)a	(1.54 ± 1.41)a
50%	(4.83 ± 1.43)b	(4.31 ± 1.76)a,b	(2.97 ± 1.56)a	(4.12 ± 1.41)a	(4.05 ± 1.66)a	(4.30 ± 1.48)a	(3.06 ± 1.37)a	(1.30 ± 1.34)a
75%	(6.63 ± 1.48)c	(4.01 ± 1.67)a,b	(3.07 ± 1.58)a	(4.46 ± 1.61)a	(4.13 ± 1,48)a	(3.67 ± 1,29)a	(2.61 ± 1,24)a	(1.47 ± 1.42)a
100%	(7.07 ± 1.13)c	(4.43 ± 1.54)b	(2.35 ± 1.61)a	(3.52 ± 1.39)a	(3.93 ± 1.53)a	(4.70 ± 1.65)a	(3.06 ± 1.37)a	(1.30 ± 1.16)a

*Results are expressed as the mean ± standard deviation (n = 16). Means with a common letter designation in the same column were not statistically different by Tukey's test ($p > 0.05$).
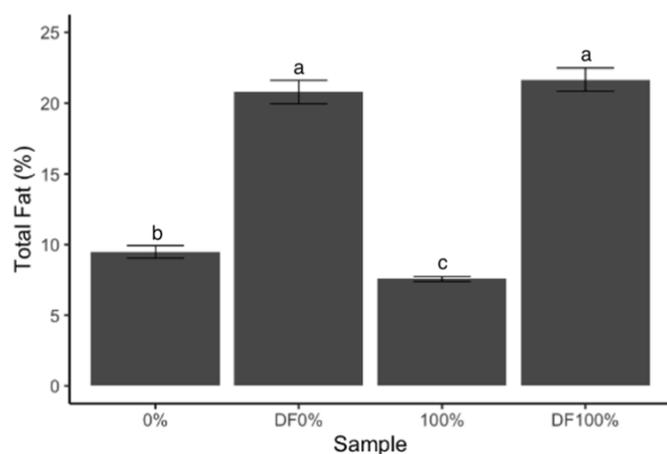
*The values are indicated as mean ± standard deviation of three independent experiments. Means with a common letter designation were not statistically different by Tukey's test ($p > 0.05$).

Figure 3. Total fat in deep-fried (DF) breaded tofu slices*.

4 DISCUSSION

In the Uruguayan okara (Table 1), a higher amount of proteins (29–34%) was found than that reported by countries such as China (24–27%), Philippines (27%), India (25%), and Portugal (28%) (O'Toole, 1999; Sengupta et al., 2012; Voss et al., 2018). Taking the same authors as a reference, the Uruguayan okara has a higher content of fatty mass of 16–18% versus a 9–15% reported in those countries mentioned above. However, the fiber concentration appears to be quite variable in the different references: 34–40% for Uruguay, 14–53% for China, 20% in India, 34% in Portugal, and up to 57% in the Philippines (O'Toole, 1999; Sengupta et al., 2012; Voss et al., 2018). These results are coherent with Grieshop and Fahey (2001) study, where the nutritional profile of the soybean in Brazil is compared with that of China. Despite a slightly higher amount of proteins reported for China's soybean, this soybean also has a higher solubility, and therefore, a lower amount will be found in the okara byproduct.

In another aspect, the profile of fatty acids (Figure 1) is similar to the one reported by other authors, in which linoleic acid (C18:2 n-6) is predominant and its presence is 50% in all cases, followed by oleic acid (C18:1 n-6) with values between 20 and 30% in all cases (Li et al., 2012; Sengupta et al., 2012). Moreover, linoleic acid (C18:3 n-3) must reach values of 8% as well as a lower proportion of saturated fatty acids (between 16 and 17%). Therefore, according to the composition of fatty acids, it can be said that okara is a source of essential fatty acids, mainly of omega 6 and a lower percentage of omega 3.

Regarding the total polyphenols (Table 2), the drying of the samples significantly decreases the content expressed per gram of dried-based as well as the absolute amount of total polyphenols compared with the fresh samples. This observation is in line with the review by Arfaoui (2021), which underscores that heating processes can negatively impact levels of phenolic acids. The values obtained correspond with okara's studies of different regions worldwide: 0.25–0.59 mgGalAc*(g dry sample)$^{-1}$ for Uruguayan okara and 0.27–1.00 mgGalAc*(g dry sample)$^{-1}$ for countries such as Nigeria and Portugal (Ibidapo et al., 2019; Voss et al., 2018).

The levels of TBARS's assay (Table 2) obtained are within the expected range; thus, the HO sample is under a process of membrane breakdown that is less intense and therefore does not completely release okara's oils to the environment and therefore prevents their oxidation. Also, all the enzymatic contribution of oxidation is halted by the thermal process to which the HO sample is subjected. In the case of the DO sample, the sample breakdown is greater, and this is supposed to have closer contact between vegetable oils and water. Moreover, this process is performed at room temperature, so it does not inactivate the natural enzymes that promote the oxidation processes (Velasco et al., 2010).

The drying of the samples increases the oxidative rancidity even more due to their thermal treatment. The results shown in Table 2 are comparable to those reported by Voss et al. (2018), where the drying under similar characteristics increases the okara from 0.86–5.10 mgMDA*(kg dry sample)$^{-1}$, and also comparable with the mean increase from 4.18 to 6.83 mgMDA*(kg dry sample)$^{-1}$ obtained in this study (Table 2).

From a microbiological point of view (Table 3), the samples obtained after the drying process are safe for consumption according to the regulations in execution CE 2,073/2005 and 1,441/2007 of the European Union for flours and semolina, considering them similar in shape and macrocomposition (Moragas et al., 2019).

Despite the reports by Jayasingh and Cornforth (2004) that values higher than 1 mg MDA/kg of the sample are associated with flavors and/or rancid smells by the sensory panelists, in our study, there was no detection of smell and/or rancid flavor, although the MDA values presented were high. In the dDO sample, a significantly higher intensity of smell was perceived than in the dHO sample, even though this was not reflected in the intensity of the flavor.

The color difference in the samples can be due to enzymatic browning (more developed in the DO sample that had no thermal treatment).

The use of okara in the breaded mix did not increase its absorption by the steak and did not present important sensory differences with the control sample. The amount of okara in the breading influenced only the final color of the steak (Figure 2) and its overall intensity of smell (Table 5). Once the amount of okara increased in the breading, the intensity of smell changed from 2.8 (without okara) to 4.4 (100% okara), which is justified by the intensity of smell detected in dried okara.

There were no significant differences in the total content of fat between the steak without okara and with 100% okara in the breading (Figure 3). The complete difference between the steaks post-cooking and the ones previously cooked was 2.8 g fat/100 g of food. This proves that the absorption of the fat while frying by submergence is not a determinant parameter regarding the quantity of bread crumbs that can be substituted by okara in the breading. To determine the economic benefits of including dDO in the production chain of breaded tofu stakes, it is essential to compare the costs of obtaining this byproduct from tofu production with those of drying it. It would be convenient in future studies to explore the acceptability by the consumers of breaded products with okara as well as their perception regarding the use of a byproduct of the soy industry as breaded.

5 LIMITATIONS OF THE STUDY

Our study does have some potential limitations that represent opportunities for further work. For instance, all trials were conducted using the same batch of soy, so variability across different batches was not explored. This could limit how our findings apply to different soy sources. Regarding the frying process, only one type of oil was examined. The effect of different oils on the nutritional composition and overall quality, including oil absorption, of the breaded tofu steaks might vary, and such potential differences were not investigated in this study. Finally, comparing other cooking methods such as baking versus frying tofu steaks could have also given us more insights into the differences in nutrition and texture. These limitations point to future research opportunities to better understand how these variables could affect the quality of okara and its applications.

6 CONCLUSION

Our research shows that the method of soymilk production significantly impacts the physicochemical and sensory characteristics of wet and dried okara. Dried okara is a potential functional food that can be incorporated into the market for human consumption due to its nutritional profile, which is rich in fibers, proteins, and essential fatty acids. Despite being darker and having an overall intensity of smell more intense than dried hammer-milled okara (dHO), dried disc-milled okara (dDO) is apparently adequate for breading tofu steaks. Dried okara has also been found to be safe from a microbiological standpoint. Looking forward, studies focusing on consumer acceptance and the potential for incorporating okara into various foods are needed. The cost of obtaining this byproduct that arises from the process of obtaining tofu must be contrasted with the cost of drying it to determine any economic revenue.

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