Foods and Raw Materials. 2026;14(1)
ISSN 2308-4057 (Print)
ISSN 2310-9599 (Online)
Short Communication
Open Access
Available online at http://jfrm.ru/en
https://doi.org/10.21603/2308-4057-2026-1-662
https://elibrary.ru/USAXXS

Sunflower press-cake and its protein extract for food applications: Effects of sonication on functional properties

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Received 07.02.2025; Revised 27.02.2025; Accepted 04.03.2025; Published online 27.03.2025

Abstract:
Oilseed press-cakes, a by-product of the oil industry, are currently utilized primarily as animal feed. However, their high protein content and nutritional value make them a promising and sustainable alternative protein source for human nutrition. Their utilization aligns with the principles of circular economy and resource upcycling, promoting a more efficient use of agro-industrial by-products in the food sector.
This research featured industrial dehulled sunflower press-cake with the protein content of 44.4% and the total phenolic content of 33.8 mg GAE/g total solids. The functional properties of the micronized press-cake and its protein extract were investigated, with a focus on the impact of ultrasound treatment.
Sonication notably enhanced the water-holding capacity by 25% and the oil-holding capacity by 48% in the micronized press-cake improving its suitability for applications that require moisture and lipid retention, such as baked goods and snacks. In the extracted protein fraction (72.6% protein), the ultrasound treatment improved the emulsifying capacity by 8.5% and the emulsifying stability by 17%, reinforcing its potential for protein-fortified beverages, sauces, and other emulsified foods.
In this research, sonication emerged as a promising processing step worthy of further optimization, given its ability to enhance key functional properties of sunflower materials. Targeted micronization, protein extraction, and sonication made it possible to upcycle sunflower press-cake as a nutritionally valuable and sustainable ingredient in the food industry, either in its micronized form or as a concentrated protein extract.

Keywords: Oilseed cake, protein-rich ingredients, alternative protein sources, upcycling, ultrasound treatment, sonication

Funding: The project was supported under the National Recovery and Resilience Plan (NRRP) (Mission 4, Component 2, Investment 1.3; Call for tender no. 341, March 15, 2022) of Italian Ministry of University and Research and funded by the European Union – NextGenerationEU (Project code PE00000003, Concession Decree no. 1550, October 11, 2022; adopted by the Italian Ministry of University and Research, CUP D93C22000890001, Project title: ON Foods – Research and Innovation Network on Food and Nutrition Sustainability, Safety, and Security – Working ON Foods).

Please cite this article in press as: Girotto F. Sunflower press-cake and its protein extract for food applications: Effects of sonication on functional properties. Foods and Raw Materials. 2026;14(1):117–122. https://doi.org/10.21603/2308-4057-2026-1-662

INTRODUCTION

With the rapid growth of the global population and the rising consumer awareness of sustainability and environmental concerns, the search for alternative and sustainable protein sources has become increasingly crucial. The food industry is under pressure to reduce its reliance on conventional animal-based proteins, shifting toward more sustainable, plant-based alternatives. Oilseed cake, a by-product of oil extraction, is currently predominantly used in the animal feed sector [1] and, to a lesser extent, as a natural fertilizer. Yet, its high protein content, typically ranging from 27 to 53% [2], positions it as a promising ingredient for human nutrition. Valorizing this by-product aligns with the principles of circular economy and resource upcycling, promoting a more sustainable use of agricultural materials.

Among oilseed cakes, sunflower press-cake stands out due to its substantial global trade volumes, which indicates its economic significance. According to the World Integrated Trade Solution (WITS) software, the leading exporters of sunflower press-cake are Ukraine ($761.8 million, 3.28 billion kg), the European Union

($361.3 million, 1.01 billion kg), Bulgaria ($323.7 million, 906.5 million kg), Hungary ($182.7 million, 526.4 million kg), and Argentina ($150.4 million, 590.5 million kg). The primary importers include China ($956.6 million, 2.33 billion kg), the European Union ($859.5 million, 2.76 billion kg), France ($234.2 million, 641.9 million kg), Italy ($232.9 million, 722.2 million kg), and Turkey ($221.8 million, 682 million kg).

Although scientific literature extensively discusses the use of sunflower seeds in the food industry and the potential of press-cakes as a protein source [3], publications that focus on the direct application of whole sunflower press-cake in food formulations remain scarce. This is likely due to its high content of insoluble fibers, which can impact texture, processing properties, and digestibility. However, this limitation can be addressed through a preliminary dehulling step before oil extraction [4, 5]. Dehulling has increasingly gained attention as a key processing strategy [6, 7], and the Italian oil industry is actively working to optimize the method of mechanical oil extraction following the achene removal, based on the varying characteristics of seeds.

This study explored the valorization of industrial dehulled sunflower press-cake as a protein-rich ingredient for food applications, both in its raw form and after protein extraction. Micronization was applied with a dual purpose: breaking down plant cell walls to improve access to intracellular proteins for extraction [8] and potentially enhancing dispersibility, thus contributing to a smoother, creamier texture while reducing the perception of grittiness or roughness in formulations [9].

The functional properties of sunflower press-cake are critical physicochemical parameters that determine its behavior in food matrices. Such key properties as water-holding capacity, oil-holding capacity, foaming capacity, and emulsifying capacity shape the texture, stability, and sensory attributes of food products. These properties arise from the intricate interactions between structural and molecular components; they affect the formulation, processing, and final product quality [10].

To further assess the functional potential of sunflower press-cake, we also examined the impact of ultrasound treatment as a means of optimizing the technological and functional properties needed for food applications. Sonication is known to modify protein structures and solubility, which improves the functional properties of the material, rendering ultrasound treatment a promising technique for food ingredient development [11]. By demonstrating the feasibility of sunflower press-cake as a functional and sustainable ingredient, this study contributes to the development of novel plant-based protein alternatives, supporting a more circular and resource-efficient food system.

STUDY OBJECTS AND METHODS

Dehulled sunflower press-cake was provided by Savi Italo Srl (Fiorenzuola d'Arda, Italy). It was obtained after cold pressing oil from dehulled seeds using a single helix screw press and stored under vacuum at room temperature. All chemicals were purchased from Sigma-Aldrich (USA) and Merck KGaA (Germany).

Micronization and protein extraction. The micronization of the dehulled sunflower press-cake involved a KMX-500 ultra-fine mill (Separ Microsystem, Italy) operating at a frequency of 70 Hz. This process produced a micronized flour with particle sizes below 700 μm. Sunflower proteins were chemically extracted at their isoelectric point (pH 4) [12], neutralized to pH 7 with 1N NaOH, and freeze-dried for 72 h using a LIO-5PDGT lyophilizer (5pascal S.r.l., Italy), then stored under vacuum at room temperature.

Chemical and physicochemical analyses. The total solids, ash, and protein contents in the micronized dehulled sunflower press-cake and its protein extract were determined according to the specific methods outlined by the Association of Official Analytical Chemists [13]. The protein quantification involved the Kjeldahl method with a nitrogen-to-protein conversion factor of 5.6 [14]. The total phenolic content was measured using the Folin-Ciocalteu assay as described by Dewanto *et al.* [15], with few modifications.

The color profile was defined with a tristimulus colorimeter (Chroma Meter II Reflectance, Konica-Minolta, Japan), calibrated with a Konica Minolta ceramic white pad (99%), and expressed using the CIE $L^*a^*b^*$ space [12].

Functional properties. The functional properties of the micronized dehulled sunflower press-cake and its protein concentrate included water-holding capacity, oil-holding capacity, foaming capacity, emulsifying capacity, and emulsifying stability. The analyses relied on the methodologies adapted from Girotto *et al.* [5] for water- and oil-holding capacity, Siddiq *et al.* [16] for emulsifying capacity and stability, and Waghmare *et al.* [17] for foaming capacity. The analyses were conducted on both the micronized dehulled sunflower press-cake and its protein extract, with and without ultrasound treatment.

Ultrasound treatment. The ultrasound treatment involved a sonicator (Fisherbrand, FB505EUK-220, USA) equipped with a three-millimeter diameter probe. The sonicator operated at an ultrasonic frequency of 20 kHz and an amplitude of 45% (~100 μm) for 5 min (20 s on, 10 s off). The samples remained in an ice bath to prevent any temperature variation exceeding 2°C.

Statistical analysis. The data represented the mean of three replicates ± their standard deviation. The JMP 5.0 software (SAS Institute Cary NC, USA) provided a one-way analysis of variance (ANOVA) with Tukey-Kramer honestly significant difference $p < 0.05$.

RESULTS AND DISCUSSION

Through isoelectric point precipitation, the sunflower proteins obtained from the micronized dehulled sunflower press-cake were concentrated into an extract (72.6 g protein per 100 g), representing an approximate 64% increase compared to the protein content in the raw press-cake (44.4 g protein per 100 g) (Table 1).

The total solids concentration was significantly higher in the protein extract (99.58 ± 0.17%) due to the

Table 1 Physicochemical analysis of micronized dehulled sunflower press-cake and its protein extract

Chemical component	Micronized dehulled sunflower press-cake	Protein extract
Total solids, %	92.84 ± 0.16[a]	99.58 ± 0.17[b]
Ash, %	7.00 ± 0.02[a]	3.85 ± 0.09[b]
Proteins, %	44.35 ± 0.50[a]	72.61 ± 0.66[b]
Total phenolics, mg GAE/g total solids	33.75 ± 0.33[a]	35.20 ± 1.11[a]

Values within a row with different superscripts are significantly different ($p < 0.05$)

Table 2 Color characteristics of micronized dehulled sunflower press-cake and its protein extract

Color	Micronized dehulled sunflower press-cake	Protein extract
*L**	65.4 ± 0.4[a]	47.2 ± 0.6[b]
*a**	0.8 ± 0.2[a]	–18.9 ± 0.4[b]
*b**	13.5 ± 0.5[a]	–1.6 ± 0.5[b]

Values within a row with different superscripts are significantly different ($p < 0.05$)

Table 3 Functional properties of micronized dehulled sunflower press-cake and its protein extract

Functional properties	Micronized dehulled sunflower press-cake	Protein extract
Water-holding capacity, g H_2O/g total solids	1.12 ± 0.17[a]	0.92 ± 0.01[a]
Oil-holding capacity, g oil/g total solids	1.20 ± 0.02[a]	1.57 ± 0.01[b]
Foaming capacity, %	21.0 ± 1.1[a]	77.0 ± 4.9[b]
Emulsifying capacity, %	54.2 ± 7.2[a]	58.8 ± 1.8[a]
Emulsifying stability, %	26.7 ± 2.9[a]	37.0 ± 0.6[b]

Values within a row with different superscripts are significantly different ($p < 0.05$)

optimal lyophilization performance, compared to the press-cake (92.84 ± 0.16%). However, the ash content, which represented the mineral component, was higher in the dehulled sunflower press-cake (7.00 ± 0.02%). The high total phenolic content was observed both in the dehulled sunflower press-cake (33.75 ± 0.33 mg GAE/g total solids) and in the sunflower protein concentrate (35.20 ± 1.11 mg GAE/g total solids). According to our previous study, chlorogenic acid was detected as the main phenolic compound sunflower press-cake [5]. The significant presence of phenolic compounds in sunflower kernels and shells, previously reported by Weisz *et al.* [18], offers a valuable opportunity to improve the nutritional profile and health-promoting properties of food formulations.

The dehulled sunflower press-cake and its protein extract differed in color (Table 2).

The protein concentrate exhibited a strong green component (*a** = –18.9 ± 0.4) and a slight blue component (*b** = –1.6 ± 0.5), whereas the press-cake had a pronounced yellowness (*b** = 13.5 ± 0.5). The green coloration resulted from the interactions between chlorogenic acid and proteins [19], which presents a unique opportunity for industrial formulators. The distinct natural hue of the extracted sunflower proteins could be particularly appealing to consumers looking for innovative and eco-friendly beverage options [20].

Table 3 presents the functional properties of micronized dehulled sunflower press-cake and its protein concentrate, which are essential for predicting their suitability as protein-rich ingredients for the food industry. A better understanding water-holding, oil-holding, foaming, and emulsifying capacities enables manufacturers to predict how these ingredients will behave in various processing conditions and food applications.

Significant differences were highlighted. Despite the similar water-holding capacity, the protein extract showed a significantly higher oil-holding capacity (1.57 ± 0.01 g oil/g total solids) than the micronized press-cake (1.20 ± 0.02 g oil/g total solids). This result could be attributed to the greater affinity of concentrated proteins for lipids, facilitated by their purer and more specific molecular structure. The reduced amount of fiber and complex carbohydrates in the extract, compared to the press-cake, allowed proteins to interact with lipids more effectively, thus enhancing the oil absorption capacity. Indeed, non-polar side chains of amino acids are known to form hydrophobic interactions with the hydrocarbon chains of lipids [21].

The foaming capacity is another parameter that showed a significant difference, with the protein extract reaching a much higher value (77 ± 4.9%) compared to the press-cake (21 ± 1.1%). The higher solubility and structural flexibility of the concentrated proteins probably allowed them to stabilize entrapped air more effectively than the less refined proteins present in the press-cake, which was rich in polysaccharides, e.g., dietary fibers.

Despite the similar emulsifying capacity, the emulsifying stability was significantly higher in the protein extract (37 ± 0.6%) than in the press-cake (26.7 ± 2.9%). The greater homogeneity and purity of the protein extract, free from coarse components, allowed for a better emulsion stability and reduced the phase separation.

Overall, the protein extract emerged as a more suitable matrix for applications requiring high performance in terms of protein ingredient purity, lipid interaction capacity, and emulsifying properties. These characteristics suggest the potential application of the protein extract in protein beverages, sauces, dressings, creams, and glazes.

The potential of sunflower press-cake becomes evident when comparing its functional properties with those of other plant-based protein-rich ingredients popular in the food sector. For instance, lentil flour exhibits a water-holding capacity of 1.33 ± 0.02 g H_2O/g total solids, while chickpea flour reaches 1.19 ± 0.01 g H_2O/g total solids [22], both of which are comparable to the values observed in this research for the dehulled sunflower press-cake. In terms of emulsifying capacity, lentil and chickpea flours achieve 65.75 ± 0.11 and 61.1 4 ± 0.61%, respectively, which are nearly matched by those calculated for sunflower protein concentrate in this research.

Effect of sonication on functional properties. Sonication is a physical treatment that uses high-frequency sound waves to induce physical and chemical phenomena within food matrices. Ultrasound waves with frequencies ≥20 kHz generate high-intensity vibrations that cause cavitation phenomena, leading to the formation of vapor microbubbles that undergo alternating compression and expansion phases, growing until they implode. This implosion releases shock energy that impacts the surface under treatment. The collapse of the bubbles causes a shock that generates intense mechanical forces and localized temperatures. They alter the physical structure, e.g., cell wall rupture, and chemical composition of the matrices, thus modifying their functional properties [23]. In protein matrices, ultrasound primarily alters the three-dimensional structure of proteins, causing denaturation, solubilization, and fragmentation [24].

In this study, the ultrasound treatment had a serious impact on the functional properties of both the micronized sunflower press-cake and its protein extract, inducing relevant structural modifications in both matrices and producing significant functional variations (Table 4). As for the water-holding capacity, the ultrasound treatment increased the value for the press-cake from 1.12 ± 0.17 to 1.40 ± 0.02 g H_2O/g total solids. This effect seems attributable to the formation of micro-channels within the press-cake structure generated by the ultrasound action. These micro-channels facilitate water penetration and retention [25]. Conversely, the water-holding capacity of the protein extract decreased from 0.92 ± 0.01 to 0.78 ± 0.09 g H_2O/g total solids. It happened as a result of increased protein solubility, which reduced the ability to absorb and retain water within the modified protein matrix.

The ultrasound treatment significantly improved the oil-holding capacity of the press-cake, which grew from 1.20 ± 0.02 to 1.78 ± 0.04 g oil/g total solids. This increase could again be due to the greater porosity of the press-cake structure, which facilitated the interaction and oil retention. For the protein extract, the oil-holding capacity decreased from 1.57 ± 0.01 to 1.35 ± 0.04 g oil/g total solids. Apparently, the ultrasound treatment reduced the lipid affinity of the matrix, possibly due to the changes in protein conformation, which altered its fat-binding efficiency.

The foaming capacity went down in both matrices, dropping from 21.0 ± 1.1 to 13.0 ± 0.1% in the dehulled sunflower press-cake and from 77.0 ± 4.9 to 48.0 ± 2.9% in the protein extract. This reduction could be attributed to protein denaturation, which impairs the ability of the matrix to form and stabilize air bubbles, thus reducing the foaming capacity and, consequently, foaming stability.

The sonication had a differentiated effect on the emulsifying capacity. In the press-cake, the emulsifying capacity dropped down from 54.2 ± 7.2 to 38.3 ± 1.4%. Conversely, in the protein extract, the emulsifying capacity increased from 58.8 ± 1.8 to 63.8 ± 1.8%, suggesting that ultrasound-modified proteins had a stronger stabilizing effect on the emulsions. This improvement was likely due to the increased conformational flexibility and reduced particle size, both of which enhanced molecular interactions at the oil-water interface.

While the emulsifying stability remained unchanged in the dehulled sunflower press-cake, it increased from 37.0 ± 0.6 to 43.4 ± 0.7% in the protein extract. The result could be attributed to the improved adsorption of smaller protein aggregates onto the interface, which reinforced the emulsion stability [26].

In summary, the ultrasound treatment had different effects on the functional properties of the sunflower press-cake and its protein extract, making them more suitable for specific applications. The sonicated sunflower press-cake with its good water- and oil-holding capacities could be used in bakery products that benefit from moisture retention and a soft texture (e.g., cakes and muffins) and in formulations requiring sufficient fat-holding ability (e.g., sweet and savory snacks). On the other hand, the sonicated protein extract with its enhanced emulsifying capacity and stability demonstrated good prospects for formulations that require stable emulsions (e.g., salad dressings or mayonnaise-like sauces). However, the low foaming capacity in both matrices may limit their use in aerated products, e.g., whipped or leavened ones.

Ultrasound treatment offers significant advantages over traditional physical treatment methods, particularly by avoiding thermal damage. This study provided important insights into the functional properties of the sonicated micronized dehulled sunflower press-cake and its protein concentrate. However, the research had some limitations that could affect the interpretation and generalization of the results. Since the effectiveness of sonication hinges on the precise regulation of key parameters, such as exposure time and intensity, different treatment conditions should be further investigated to understand the outcomes and optimize the setting parameters according to specific formulation objectives. Additionally, it would be useful to examine other functional characte-

Table 4 Functional properties of sonicated micronized dehulled sunflower press-cake and its protein extract

Functional properties after sonication	Micronized dehulled sunflower press-cake	Protein extract
Water-holding capacity, g H_2O/g total solids	1.40 ± 0.02^a	0.78 ± 0.09^b
Oil-holding capacity, g oil/g total solids	1.78 ± 0.04^a	1.35 ± 0.04^b
Foaming capacity, %	13.0 ± 0.1^a	48.0 ± 2.9^b
Emulsifying capacity, %	38.3 ± 1.4^a	63.8 ± 1.8^b
Emulsifying stability, %	20.0 ± 4.3^a	43.4 ± 0.7^b

Means within a row with different superscripts are significantly different ($p < 0.05$)

ristics, such as protein solubility, gelling capacity, or dispersion viscosity, which may be affected by ultrasound treatment and could impact food applications.

CONCLUSION

This study explored the potential of micronized dehulled sunflower press-cake as an alternative protein source in the food industry, emphasizing the importance of upcycled by-products in the agro-industrial sector. It revealed the functional properties of micronized sunflower press-cake and its protein extract with and without ultrasound treatment. The micronized dehulled sunflower press-cake demonstrated good water and oil absorption capacities (1.12 g H_2O/g total solids; 1.20 g oil/g total solids), both of which could be enhanced through sonication (1.40 g H_2O/g total solids; 1.78 g oil/g total solids). As a result, the press-cake showed a strong potential for applications in baked goods, as well as in sweet and savory snacks. Meanwhile, the protein extract (72.6% protein) had superior emulsifying capacity (58.8%) and stability (37%), particularly when sonicated (63.8 and 43.4%, respectively). It proved to be an ideal ingredient for formulations that require effective fat integration and prolonged stability of both oil and aqueous phases. Its applications are promising for sauces, dressings, protein beverages, and creams. However, neither the press-cake nor its protein concentrate could be used in formulations that need a strong foaming capacity.

This study represents a significant step toward the integration of sunflower press-cake and its protein concentrate in the food industry. Sonication proved to be an important technological step that enhances their functional properties and expands application prospects. Additional research is needed to optimize the ultrasound treatment conditions and explore other types of oilseed meals, fostering the development of more sustainable and innovative plant-based protein-rich food alternatives.

CONFLICT OF INTEREST

The author declared no conflict of interests regarding the publication of this article.

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