International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(Research Article)

Evaluation of Olive Cake from Different Oil Extraction Methods: Chemical Composition and *In Vitro* Digestibility for Ruminant Nutrition

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International Journal of Science and Research Archive, 2025, 17(03), 1227-1235

Publication history: Received on 24 November 2025; revised on 31 December 2025; accepted on 02 January 2026

Article DOI: https://doi.org/10.30574/ijsra.2025.17.3.3380

Abstract

This study carried out on four varieties of olive fruit: Zaity, Sorani, Kaesi and Geltty. Chemical analysis was done on fruit ingredients (mesocarp, endocarp and kernel) for every variety. Digestibility index of dry matter and organic matter were determined *In Vitro* method. The same procedures were applied also on olive cake produced from traditional pistons, new centrifuge, and extraction by organic solvents methods. The results showed that the chemical compositions of Olive cake differ according to the difference methods of Olive constricting's. Fibers percentage was generally high in Olive cakes. The digestibility of dry matter and organic matter was low. However, there is a significant difference ($P < 0.05$) among kinds of Olive cakes. The chemical composition of Olive fruit had clear differences. The nutritional ingredients after extraction were existed in Olive cakes. The high percentage of fibers had negative effect on digestibility of dry matter and organic matter and correlation coefficient between them was negative with high significant ($P < 0.01$). The oil was concentrated in Mesocarp. Digestibility of dry matter and organic matter were better after constriction in when compared with other fruit ingredients. The chemical composition of Endocarp showed its useable in wood manufactures.

Keywords: Olive types; Olive cakes; Chemical composition; *In Vitro* dry matter digestibility (IVDMD)

1. Introduction

Olive oil production generates large quantities of by-products, which can represent up to 50% of the total weight of pressed olives. The management and valorization of these residues have received increasing attention due to their environmental impact and potential use as alternative feed resources. Among these by-products, olive cake, a solid residue composed mainly of the olive pulp, skin, and stone fragments, has been explored as a feed ingredient for ruminants [1-7]

Several studies have demonstrated that olive cake can partially replace conventional roughages without adversely affecting animal performance. For example, García-Rodríguez et al. [8] reported that substituting portions of corn silage and barley straw with olive cake in the diet of lactating ewes did not impair rumen fermentation parameters. The utilization of olive cake is particularly advantageous during periods of forage scarcity, when feed availability and costs pose major challenges to livestock production [9, 10]. Considerable variation has also been reported in the chemical composition and nutritional value of olive cake, depending on the degree of stone removal and processing conditions [11- 17].

Given these inconsistencies, optimizing the utilization of olive cake in ruminant diets requires a better understanding of the effects of fruit composition and processing methods on its nutritional value and digestibility. Therefore, the

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present study aims to determine the optimum processing approach for producing olive-milling by-products suitable for ruminant feeding. Specifically, this work evaluates the chemical composition and *In Vitro* digestibility of different olive cultivars and their processing residues after separating the fleshy mesocarp from the woody endocarp of fresh fruits prior to oil extraction. Additionally, the potential valorization of the woody fraction in wood-based industries is explored as a complementary use strategy.

2. Materials and Methods

2.1. Plant Material and By-Products

Four olive (*Olea europaea L.*) cultivars—Zeitouni, Sourani, Qaisi, and Jlouti—were selected. Olive-milling residues were collected from three extraction systems: traditional press, modern centrifugal processing, and solvent extraction of pomace (périne) using hexane, naphtha, or benzene.

2.2. Sample Preparation

Fruits were analyzed either whole or after separation into major components: mesocarp (flesh), endocarp (stone), and seed. All samples were dried, ground, and subjected to chemical and digestibility analyses.

2.3. Proximate Composition

Dry matter (DM), ash (ASH), and acid-insoluble ash (AIA) were determined. Crude protein (CP) was analyzed by the Kjeldahl method, and crude fat (ether extract, EE) was determined using a Soxhlet apparatus.

2.4. Fiber Fraction Analysis

Neutral detergent fiber (NDF), acid detergent fiber (ADF), and ash-free acid detergent lignin (ADL) were quantified according to the method of Van Soest and Wine [18]. Analyses were performed on both whole fruits and mesocarp tissue after oil extraction.

2.5. *In Vitro* Digestibility

In Vitro dry matter digestibility (DMD) and organic matter digestibility (DOMD) were assessed using sheep rumen fluid according to Tilly and Terry [19]. Tests were conducted on whole fruits, separated components, and the different milling residues.

2.6. Laboratory Facilities

All chemical and digestibility analyses were conducted at the International Center for Agricultural Research in the Dry Areas (ICARDA).

2.7. Statistical Analysis

Data were analyzed using SPSS software. Means were calculated, and significance was tested at the 1% and 5% probability levels using the F-test. Differences among means were evaluated using Duncan's multiple range test. Comparisons included (i) cultivar effects, (ii) whole fruit vs. components, and (iii) residue type by extraction method.

3. Results and Discussion

3.1. Chemical Composition of Olive Residues According to Extraction Methods

The chemical composition of olive residues obtained from different extraction methods is presented in Table 1. Significant variations were observed among residues depending on the extraction process.

Dry matter (DM) content was highest ($P < 0.01$) in residues produced by the organic solvent extraction method, likely due to the secondary thermal treatment and solvent processing steps involved [20]. In contrast, residues from the modern centrifugal extraction method exhibited lower DM values, attributed to the addition of water during oil separation [21- 22]. A similar trend was observed for crude ash (ASH) and acid-insoluble ash (AIA).

Crude protein (CP) and acid detergent lignin (ADL) did not differ significantly ($P > 0.05$) among extraction methods. However, crude fat (EE) content was significantly higher ($P < 0.01$) in residues from the traditional press method compared with those from the modern centrifugal system. This reflects the higher oil retention typical of traditional extraction [23]. Conversely, EE content declined markedly in residues from solvent extraction due to repeated oil removal, where the extracted oil is primarily used for industrial purposes such as soap production [24].

The neutral detergent fiber (NDF) content reached 85.23% in residues obtained by solvent extraction (Table 1), a highly significant increase ($P < 0.01$) relative to other extraction methods. A similar pattern was noted for acid detergent fiber (ADF) and lignin fractions.

Table 1 Chemical composition and digestibility coefficients of residues resulting from different olive fruit extraction methods (component values expressed on a dry matter basis).

Parameter	Solvent Extraction	Modern Centrifugation	Traditional Pressing
DM%	86.78 a	43.94 c	65.31 b
ASH%	5.26 a	3.39 b	2.80 b
AIA%	0.89 a	0.11 b	0.13 b
OM%	94.99 b	96.55 ab	97.01 a
CP%	5.74 NS	4.62	4.83
EE%	2.67 c	12.53 b	18.25 a
NDF%	85.23 a	68.53 b	68.70 b
ADF%	64.04 a	59.09 b	58.13 b
ADL%	36.65 NS	37.28	38.65
DMD%	17.06 b	19.56 a	16.56 b
DOMD%	12.72 a		b

Data are meabs of three replicates. NS = differences between types of residues obtained by different olive oil extraction methods were not significant at the 5% probability level. a, b, c = means within the same row followed by the same superscript letter are not significantly different at the 5% probability level.

3.2. Chemical Composition and Digestibility Coefficients of Whole Olive Fruits

Marked differences in the chemical composition of whole olive fruits were observed among cultivars (Table 2). Oil-type varieties (Zaiti and Sourani) exhibited significantly higher crude fat (EE) content ($P < 0.05$) compared to table-type varieties (Qaisi and Jlati), likely reflecting genetic variation. Crude ash content was greater in table-type varieties before oil extraction but shifted toward higher values in oil-type varieties after extraction ($P < 0.05$).

Crude protein content showed no significant variation ($P > 0.05$) among varieties before extraction; however, highly significant differences ($P < 0.01$) appeared afterward, reflecting differences in residual oil and dry matter concentration. Fiber fractions (NDF, ADF, ADL) did not vary significantly ($P > 0.05$) among varieties.

Digestibility coefficients of dry matter (DMD) and organic matter (DOMD) differed significantly ($P < 0.01$) between oil- and table-type varieties.

Table 2 Chemical composition and digestibility coefficients of olive fruit varieties as whole fruits (values expressed on a dry matter basis).

Parameter	Zaiti	Sourani	Qaisi	Jlati
Before oil extraction				
DM%	51.33 b	57.97 a	52.48 b	47.18 c
ASH%	2.23 ab	2.05 b	3.04 a	3.05 a
AIA%	0.18	0.07	0.26	0.34 NS
OM%	97.77 ab	97.95 a	96.96 b	96.95 b

CP%	3.54	3.36	3.21	4.27 NS
EE%	52.28 a	48.74 ab	45.24 b	51.17 ab
After oil extraction				
ASH%	4.17 b	3.75 b	5.61 a	5.52 a
OM%	95.82 a	96.25 a	94.39 b	94.48 b
CP%	5.36 b	4.23 c	4.85 bc	6.94 a
NDF%	54.72	69.55	52.57	47.66 NS
ADF%	35.75	47.66	42.00	36.06 NS
ADL%	18.66	23.85	26.22	18.14 NS
DMD%	37.07 b	23.86 c	43.23 a	43.24 a
DOMD%	33.55 b	21.40 c		

NS = differences between olive fruit varieties were not significant at the 5% probability level. a, b, c, d = means within the same row followed by the same superscript letter are not significantly different at the 5% probability level.

3.3. Chemical Composition and Digestibility of the Pulp (Fleshy Layer)

The composition of the pulp layer separated from the fruit is summarized in Table 3. Prior to extraction, crude ash content was significantly higher (P < 0.01) in table varieties (Baladi and Jlati) than in oil varieties (Zaiti and Sourani). After extraction, the trend reversed, as the oil content in the pulp of oil varieties increased.

No significant differences (P > 0.05) were observed among varieties in crude protein or acid-insoluble ash before extraction, but post-extraction the table varieties exhibited significantly higher (P < 0.05) crude protein content. Crude fat (EE) content varied significantly (P < 0.05) among cultivars, being highest in the Sourani variety.

Fiber fractions (NDF, ADF, ADL) fluctuated between significant and non-significant levels but were generally elevated in the oil-type cultivars. The digestibility of the pulp differed markedly (P < 0.01) among cultivars, with table varieties (Jlati and Baladi) showing higher DMD and DOMD values. These differences are attributed to higher crude protein and lower fiber content after extraction.

Table 3 Chemical composition and digestibility of the pulp (fleshy layer) in olive fruit varieties (Values expressed as % of dry matter)

Component	Jlati	Qaisi	Sourani	Zaiti
Before extraction				
DM	41.73 b	49.64 a	50.92 a	43.59 b
Ash	3.30 a	2.72 b	2.19 d	2.46 c
AIA	0.28 NS	0.11	0.22	0.21
OM	96.70 d	97.27 c	97.81 a	97.53 b
CP	3.88 NS	3.82	3.87	3.32
EE	59.76 b	60.94 b	68.84 a	56.96 b
After extraction				
Ash	9.27 a	8.08 b	7.66 c	6.76 d
OM	90.72 d	91.92 c	92.35 b	93.23 a
CP	10.51 a	8.04 b	6.83 b	7.81 b
NDF	16.65 NS	28.0	30.99	19.23
ADF	14.72 b	15.17 b	30.56 a	16.94 b

ADL	7.64 NS	7.21	18.87	8.56
DMD	64.9 a	58.38 b	47.44 c	58.89 b
DOMD	56.8 a	53.42 b	41.29 c	53.46 b

NS = Differences between olive varieties are not significant at P > 0.05. a,b,c,d = Similar letters in the same row indicate no significant difference among olive varieties at P ≤ 0.05.

3.4. Chemical Composition and Digestibility of the Woody Layer

As shown in Table 4, no significant differences (P > 0.05) were detected among vari]eties in the woody layer for DM, crude protein, insoluble ash, or fiber fractions. However, fiber fractions were generally high, while protein content was low, leading to low digestibility values for both DMD and DOMD.

These findings indicate that the woody portion (endocarp) contributes little to the nutritional value of olive residues and should be removed prior to using the pomace as feed [25].

Table 4 Chemical composition and digestibility of the woody layer in olive fruit varieties (Values expressed as % of dry matter)

Component	Jlati	Qaisi	Sourani	Zaiti
DM	71.32 NS	74.89	75.66	73.86
Ash	1.37 a	1.22 ab	1.20 ab	1.11 b
AIA	0.15 NS	0.016	0.078	0.039
OM	98.63 b	98.78 ab	98.80 ab	98.88 a
CP	1.63 NS	1.84	1.79	1.52
EE	2.75 b	3.02 b	3.61 ab	4.47 a
NDF	86.81 NS	89.11	88.93	89.12
ADF	63.81 NS	67.50	66.40	64.47
ADL	29.34 NS	33.40	33.01	31.09
DMD	8.27 NS	7.29	9.20	8.34
DOMD	1.94 b	0.25 c	1.0 bc	

NS = Differences between olive varieties are not significant at P > 0.05. a,b,c = Similar letters in the same row indicate no significant difference among olive varieties at P ≤ 0.05.

3.5. Dry Matter and Crude Fat Content of Seeds

Given that olive seeds represent less than 1.5% of the total fruit weight (Abu Arqoub, 1998), only the crude fat content was analyzed (Table 5). The Sourani variety exhibited the highest crude fat value (34.3%), followed by the Zaiti variety, while the Qaisi variety recorded the lowest (17.4%). These results correspond with the oil-rich characteristics of the Sourani cultivar.

Table 5 Dry matter and crude fat content of olive fruit seeds (Crude fat expressed as % of dry matter)

Component	Jlati	Qaisi	Sourani	Zaiti
DM	66.67 b	64.23 c	75.3 a	60.54 d
EE	23.32 ab	17.42 b	34.3 a	25.52 ab

a,b = Similar letters in the same row indicate no significant difference among olive varieties at P ≤ 0.05.

3.6. Chemical Composition and Digestibility of Olive Fruit Components

Table 6 summarizes the chemical composition and digestibility parameters across all fruit components, independent of variety. The woody layer exhibited the highest (P < 0.01) dry matter and ash contents due to its high lignocellulosic content [26]. The pulp layer contained the highest (P < 0.01) crude fat, confirming it as the main oil storage tissue, while crude protein was most concentrated in the seed [27- 28]. Fiber fractions (NDF, ADF, ADL) were primarily concentrated in the woody layer (P < 0.01), reducing overall digestibility. The current results also align with findings by Tzamaloukas et al. [29], who demonstrated that feeding olive by-products can enhance the fatty acid profile of ruminant products

Digestibility was markedly affected by fiber content. DMD values in residues ranged from 16.56% to 19.56% (Table 1), while in the woody layer they ranged from 7.29% to 9.20% (Table 4). The high fiber content in the woody layer (8.08% DMD, 1.75% DOMD) contrasts with the pulp layer (57.41% DMD, 51.24% DOMD), confirming the negative impact of lignin on digestibility. These results agree with the fact that high lignin content reduces cellulose digestibility due to the formation of lignin–cellulose complexes [30-33].

Table 6 Chemical composition and digestibility of olive fruit components, overall (Values expressed as % of dry matter)

Component	Seed	Woody layer	Pulp layer	Whole fruit
Before extraction				
DM	66.51 b	73.96 a	46.47 d	52.24 c
Ash	2.15 b	1.15 c	2.67 a	2.59 a
AIA	0.1 NS	0.066	0.21	0.21
OM	97.84 b	98.79 a	97.33 c	97.41 c
CP	19.07 a	1.69 c	3.72 b	3.6 b
EE	24.64 c	3.25 d	61.63 a	49.36 b
After extraction				
Ash	2.15 c	1.15 d	7.94 a	4.76 b
OM	97.84 b	98.79 a	92.05 d	95.24 c
CP	19.07 a	1.69 d	8.3 b	5.35 c
NDF	88.87 a	23.72 c	56.13 b	-
ADF	65.78 a	19.35 c	40.37 b	-
ADL	31.82 a	10.57 c	21.72 b	-
DMD	44.72 b	8.08 d	57.41 a	36.86 c
DOMD	40.35 b	1.75 d	51.24 a	

NS = No significant differences among varieties at P > 0.05. a,b,c,d = Similar letters in the same row indicate no significant difference among olive varieties at P ≤ 0.05.

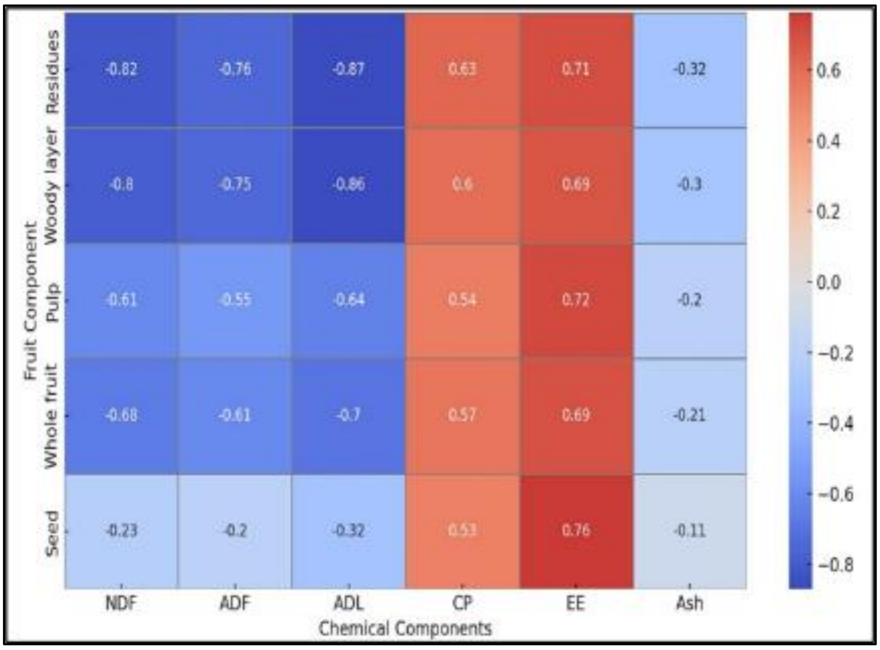

Figure 1 Heatmap visualizing the correlations between chemical composition and digestibility for individual olive fruit components. The colors indicate the strength and direction of correlation, with blue representing negative correlations and red representing positive correlations

A highly significant negative correlation ($P < 0.01$) was found between fiber fractions (NDF, ADF, ADL) and digestibility parameters (DMD, DOMD), with correlation coefficients for ADL versus DMD/DOMD reaching $r = -0.867$ (Figure 1). These results are in accordance with the need to partially remove the olive kernel before feeding ruminants to improve the nutritional quality of olive pomace [6].

Overall, the results emphasize that partial or complete removal of the woody fraction before oil extraction can significantly improve the nutritional value and digestibility of olive by-products used in ruminant feeding systems.

Conclusion:
The present study demonstrated that the chemical composition and digestibility of olive residues and fruit components vary considerably depending on the extraction method and olive variety. Residues obtained from solvent extraction exhibited the highest fiber fractions (NDF, ADF, and ADL) and the lowest digestibility coefficients, indicating limited nutritional value for ruminant feeding. Conversely, press residues retained higher crude fat content, reflecting the influence of traditional extraction methods on feed quality. Among olive varieties, the table types (Jlati and Baladi) showed higher dry matter and organic matter digestibility than the oil varieties (Sourani and Zaiti), mainly due to lower fiber and higher protein contents. The pulp layer, which contains most of the oil, exhibited higher crude fat and digestibility values compared to the woody layer, which was characterized by high fiber and low protein levels, resulting in poor digestibility. The strong negative correlation between fiber fractions and digestibility parameters confirms that lignin and other structural fibers are the main limiting factors in the utilization of olive residues by ruminants. Overall, the findings suggest that removing or reducing the woody fraction (seed and pit) from olive residues before use in animal feed can substantially improve their nutritive value. The woody layer (seed), after separation, is suitable for use in wood-related industries. Moreover, partial inclusion of properly processed olive residues, particularly from press extraction, may serve as a sustainable alternative feed resource, contributing to waste valorization and environmental protection in olive-producing regions.

Compliance with ethical standards

Disclosure of conflict of interest

We declare that we have no competing interests.

Availability of data and material

All data generated or analyzed during this study are included in this published article and supplementary file

Funding

This research was self-funded.

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