Scientific Papers. Series B, Horticulture. Vol. LXX, No. 1, 2026
Print ISSN 2285-5653, CD-ROM ISSN 2285-5661, Online ISSN 2286-1580, ISSN-L 2285-5653

ADDING VALUE TO THE AGRI-FOOD SIDE-STREAMS – A REVIEW ON THE ROMANIAN APPROACH TO APPLE POMACE

Ecaterina-Andreea CONSTANTIN[1, 2], Luminita DIMITRIU[2], Florentina MATEI[1, 3], Diana CONSTANTINESCU-ARUXANDEI[2], Florin OANCEA[2, 1]

[1]University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Mărăști Blvd, District 1, Bucharest, Romania
[2]National Institute for Research & Development in Chemistry and Petrochemistry - ICECHIM, 202 A Splaiul Independenței, District 6, 060021, Bucharest, Romania
[3]Transilvania University of Brașov, 148 Castelului Street, 500014, Brașov, Romania

Corresponding author email: florin.aoncea@icechim.ro

Abstract

Due to the industrialization of both fruits and vegetables, significant quantities of plant waste are generated annually, accounting for over 40% of the total processed plant products. An important by-product of this industrial process is apple pomace, which results from the processing of apples into products such as juice and fruit preserves, which are obtained through pressing, boiling, and fermentation processes. Although often perceived as a seemingly valueless by-product, apple pomace holds significant potential as a source of valuable compounds. Recent research on its use as a substrate in microbial processes has influenced the production of low-alcohol beverages that are richer in organic acids or single-cell proteins. Recent trends indicate a growing interest in using residues from apple processing as by-products in the food industry to extract value-added products, including dietary fibers, proteins, natural antioxidants, biopolymers, pigments, and compounds with unique properties. In this study, we focused on methods of valorization of apple pomace from different varieties grown in Romania.

Key words*: bioeconomy side streams, apple pomace, organic acids, valorization, Romania.*

INTRODUCTION

Romania has a rich history of apple growing due to favorable climatic conditions. However, apple production has steadily declined, ranking fourth out of five European apple-producing countries, according to a 2022 study (I. M. Vlad et al., 2022). The country's orchards are dominated by apple varieties of the genus *Malus* sp., family *Rosaceae*, including *Starkrimson*, *Jonathan*, *Red Delicious*, *Idared*, *Golden Delicious*, *Florina*, *Jonagold, Romus 3 and 4*, *Generos de Voinești*, *Topaz*, *Frumos de Voinești*, *Granny Smith, Domnesc, Crețesc, Poinic, Pătul, Ardelean, Ciprian, Poinic, Sovari Nobil* and *Gala* (Popescu, 2012; I. M. Vlad et al., 2022).

One of the prominent agro-industrial wastes in Romania includes apple peel/pomace, along with red and white grape pomace, as well as red beet pomace/skin. Industrial processing of apples generates significant volumes of vegetable waste each year, from juice extraction or fermentation processes to produce apple brandy/pălincă (a Romanian-specific alcoholic beverage), vinegar, and cider. If unmanaged, the high moisture of apple waste can pose risks to human health, air quality, soil, and ecosystems (Ghinea et al., 2019; Vodnar et al., 2017). Despite the potential value of apple waste, there remains a significant disposal problem in Romania. In particular, apple peel, a major residue from fruit processing, possesses antioxidant properties and may serve as a cardioprotective and anticarcinogenic agent, containing flavonoids such as quercetin glycosides and anthocyanins that are usually absent in fruit pulp (Vodnar et al., 2017).

The main purpose of this review is to analyze and describe the valorization of apple waste in Romania, to perform this analysis, articles published in 2009 were studied, consulting international databases such as PubMed, Google Scholar, Web of Science, Science-Clarivate, using keywords such as "apple waste in Romania", "industrial waste in Romania", and "Romanian apple varieties".

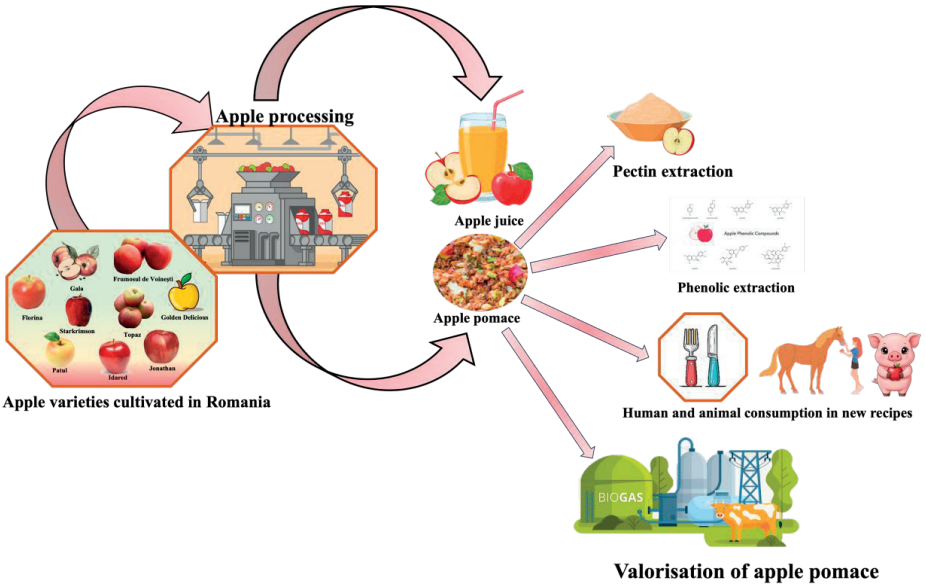

Figure 1. Bioeconomic model for the use of agro-industrial waste from apples

BIOCHEMICAL COMPOSITION OF APPLE POMACE

Apples are highly valued for their rich content of bioactive compounds, such as flavonoids, hydroxycinnamic acids, vitamins, fiber, and minerals, making them a popular choice for consumption as both whole fruit and juice. The nutritional profile of apples, which is high in water (85%), carbohydrates (14%), pectin (0.2%), fat (0.6%), and essential vitamins and minerals, varies according to the climatic zone of cultivation (Campeanu et al., 2009; Popescu, 2012; Velciov et al., 2022).

Apple waste, composed mainly of pulp (54%), seeds (7%) and peel (34%), is fiber-rich and suitable for food/feed enrichment. An emerging trend in the food industry involves the re-use of by-products from fruit processing to enrich food for both humans and animals, providing additional bioactive compounds (Vasiliu et al., 2018).

Polyphenols, abundant in apples, are bioactive secondary metabolites with strong antioxidant, antimicrobial, antidiabetic, and anticarcinogenic properties, making them valuable for pharmaceutical, cosmetic, and food applications (Lang et al., 2024; Szabo et al., 2022; Vasiliu et al., 2018).

Pectin, a complex polysaccharide extracted from apple residues, finds applications in various industries as a thickening agent in foods and as a capsule substitute in the pharmaceutical and medical sectors (Marcon et al., 2005; Vasiliu et al., 2018).

In addition, the high carbohydrate and fiber content of apple residues allows them to be used as a substrate in fermentative processes, which could lead to biogas and contribute to ongoing bioenergy research (Călinoiu et al., 2018; Ciuta et al., 2016; Vasiliu et al., 2018).

Apple waste (AW) is therefore proving to be a versatile resource, with applications ranging from the food industry to pharmaceutical.

PECTIN FROM APPLES

Pectin, an intricate polysaccharide originating from plants, contains linear polymers such as homogalacturonan and rhamnogalacturonan, interspersed with neutral sugars such as L-rhamnose, L-arabinose, and D-galactose (Canteri-Schemin et al., 2005; Gurev et al., 2023; Müller-Maatsch et al., 2016). This adaptable compound finds widespread application in numerous sectors, including food, pharmaceuticals, textiles, and more, owing to its outstanding gelling properties, stability, and ability to thicken substances (Wang et al., 2014; Wikiera et al., 2015).

In addition to its industrial uses, pectin serves significant biological roles. It functions as a

stabilizer and protective agent in various food and beverage products, demonstrates immunomodulatory properties, reduces serum cholesterol levels, and has been observed to induce apoptosis in colon cancer cells. Its diverse array of advantages positions it as a prized ingredient for product enhancement and human health promotion (Girón-Hernández et al., 2023; Marcon et al., 2005; Wang et al., 2014).

The efficiency of pectin extraction, according to studies conducted so far, is influenced by the extraction method (Dranca et al., 2020; Gurev et al., 2023; Camelia C. Vlad et al., 2022). Among the most commonly used methods for extracting pectin AW obtained from Romanian-grown apple fruits (generally *Malus domestica*) are physicochemical methods (ultrasound-assisted extraction, microwave-assisted extraction), enzymatic methods (endo-xylanase and endo-cellulase), alkaline extraction, and classical methods such as citric acid extraction (Dranca et al., 2020).

Ultrasound-assisted extraction (UAE) enhances pectin extraction from AW by using ultrasonic waves and solvents to increase mass transfer efficiency. This method is energy-efficient and requires minimal solvent use (Canteri-Schemin et al., 2005). The improvement in extraction is attributed to ultrasonic cavitation and mechanical mixing, which disrupt cell walls, promote solvent penetration, and facilitate compound diffusion through mild heating (Egüés et al., 2021; Gurev et al., 2023; Wang et al., 2014).

Microwave-assisted extraction (MW) uses microwave energy to rapidly heat the solvent, enhancing its penetration into apple waste matrices and enabling efficient extraction of pectin, cellulose, and hemicellulose (Wang et al., 2007). Studies have demonstrated that MW significantly increases pectin yield while requiring less solvent and shorter extraction time, making it a fast and high-efficiency method (Bagherian et al., 2011; Spinei et al., 2022; Zarei et al., 2017).

Pectin is generally extracted using acids such as H_2SO_4, HNO_3, and HCl, or citric acid, and the extraction process can lead to the corrosion of production line components as well as the generation of large amounts of acidic industrial waste (Wikiera et al., 2021). As a sustainable alternative, enzymatic extraction is preferred due to its selectivity and minimal impact on polymer structure (Wikiera et al., 2015; Wikiera et al., 2015a). In addition, pectin extracted by acid extraction has a high molecular weight and low polygalacturonic acid content. Compared to acid extraction, enzymatic methods using enzymes such as endo-xylanase and endo-cellulase produce different pectin in terms of molecular weight and sugar content, as in terms of the high extraction yield of galacturonic acid (Wikiera et al., 2016). In general, a combination of physicochemical-enzymatic or classical methods is preferred (Wikiera et al., 2015).

Pectin characterization commonly involves titrimetric methods (Gurev et al., 2023), and physicochemical techniques such as FT-IR (Fourier Transform Infrared Spectroscopy) in the wavelength range of 4000-400 cm^{-1}. FT-IR is employed for determining the degree of esterification, which is defined as the number of carboxyl groups esterified, typically assessed at the wavelength of 1730 cm^{-1}. The degree of esterification (DE) can be calculated based on the sum of areas of bands between 1730 and 1600 cm^{-1}, corresponding to the total carboxylic groups. This proportionality aids in understanding the esterification level of the pectin (Dranca et al., 2020).

The characterization of pectin extracted from apple waste (*Malus domestica* Fălticeni) involves two essential parameters - the degree of esterification (DE) and the galacturonic acid content - both of which critically influence its structure and functional behavior. The degree of esterification, determined by infrared spectrophotometry, can be calculated using specific analytical formulas (Dranca et al., 2020; Naqash et al., 2021). This parameter represents the proportion of carboxyl groups (–COOH) in galacturonic acid units that are esterified with methyl radicals ($–OCH_3$), thus determining the physicochemical characteristics and gelation mechanism of pectin. Complementarily, the galacturonic acid content is quantified using methods such as the sulfamate/m-hydroxydiphenyl test (Dranca et al., 2020; Müller-Maatsch et al., 2016), which measures the proportion of D-galacturonic acid in the polysaccharide structure. A high galacturonic acid content, usually above 65%, indicates higher structural purity and is associated with

superior gel-forming capacity, increased viscosity, and improved biological functionality, as free carboxyl groups actively participate in ionic interactions and the gelation process (Cui et al., 2023; Naqash et al., 2021).

Furthermore, the DE value determines the type of gelation and the application potential of pectin. Pectins with high methoxyl content (DE > 50%) form gels in the presence of sugar and under acidic conditions, making them suitable for conventional food products such as jams and jellies. In contrast, pectins with low methoxyl content (DE < 50%) require calcium ions for gelation and can form gels even in low-sugar systems; thus, they widely used in food and pharmaceutical formulations (Löfgren & Hermansson, 2007; Rascón-Chu et al., 2019). DE also affects other functional properties, including solubility, water-binding capacity, and molecular interactions: pectins with high DE values tend to be more hydrophobic and gel more quickly, while those with low DE values have a higher number of free carboxyl groups, conferring greater chemical reactivity and biological activity (Morris et al., 2010).

The interaction between galacturonic acid content and esterification degree defines both the quality and versatility of pectin application. An optimal balance between these two parameters ensures desirable gelling properties and extends its use in several sectors - from the food industry, where it serves as a gelling, thickening, and stabilizing agent, to the pharmaceutical and biomedical fields, where it functions in controlled release systems and as a component of biocompatible materials (Dranca et al., 2018; Huang et al., 2022; Naqash et al., 2023). Further characterization includes monosaccharides by HPLC (High-Performance Liquid Chromatography) (Wikiera et al., 2015a, 2015b), thermal analysis throughcalorimetry, microstructure examination through scanning electron microscopy (SEM), and rheological analysis all of which provide valuable insights into pectin structure and the effects of extraction methods on its functional properties (Dranca et al., 2020).

These characterization methods provide essential information about the composition, structure, and quality of pectin, aiding in its utilization in various industries, including food, pharmaceuticals, and cosmetics (Franchi et al., 2014).

To determine the most efficient method for pectin extraction from AW, various techniques have been evaluated, including citric acid extraction, classical extraction combined with UAE or MW, as well as enzymatic extraction.

Studies (Dranca et al., 2021) conducted using treatment with citric acid, at a ratio of 1:10 (w/v) with *Malus domestica* apple residue from Fălticeni, highlighted that the optimal extraction parameters were a temperature of 85.71°C and a time of 147 minutes, resulting in an extraction yield of 23.26%, a galacturonic acid concentration of 99.25 g/100 g, and an esterification degree of 81.18%

In another study (Dranca et al., 2019) from 2019, combining classical extraction with UAE, followed by thermal treatment, resulted in an extraction yield of 6.8%, a GalA content of 69.694 g/100 g, and an esterification degree of 80.09% ata temperature of 90°C, pH of 1.92, and time of 147 minutes and 43 seconds. Through MW at 560 W, pH of 2.2, and a time of 120 seconds, an extraction yield of 24%, a GalA content of 91.82 g/100 g, and an esterification degree of 88.52% were obtained. Compared to classical extraction with citric acid, this method showed better results in terms of extraction yield, galacturonic acid content, and esterification degree. Regarding enzymatic extraction, a study indicated that the optimum was achieved after 18 hours, at a temperature of 48°C, using 43 µl/g of enzyme, resulting in an extraction yield of 6.8%, a galacturonic acid content of 97.46 g/100 g of pectin, and an esterification degree of 96.02% (Dranca et al., 2019).

Table.1 Synthesis of data regarding the extraction of pectin from Romanian apple waste

Extraction	Yield, %	Gala, g/100 g	DE, %	Reference
CE	23.26	86.5	81.18-84.40 37.68	(Dranca et al., 2021; Dranca et al., 2020; Camelia Cristina Vlad et al., 2022)
MW	23.32	90.6 47.31-73.02	73.80-88.5 38.69-71.37	(Dranca et al., 2021; Dranca et al., 2020; Gurev et al., 2023)
UAE	9.18	92.83 49.16-78.71	81.18-77 36.47-73.78	(Dranca et al., 2021; Dranca et al., 2020; Gurev et al., 2023)
EEC	7.17	78.8	53.5	(Dranca et al., 2020)
EECL	6.76	85.2	44.6	(Dranca et al., 2019; Dranca et al., 2020)
UAE-H	6.86	69.06	80.7	(Dranca et al., 2019; Dranca et al., 2020)
EE-UT	7.95	75	47.6%	(Dranca et al., 2020)

CE – citric acid extraction, MW – microwave extraction,
UAE – ultrasound-assisted extraction, EEC – enzyme-assisted extraction with cellulase, EECL – enzyme-assisted extraction with Celluclast, UAE-H – ultrasound-assisted extraction – heating treatment, EE-UT – enzyme-assisted extraction – ultrasound treatment

In Table 1, it can be observed that the highest extraction yield of pectin from AW derived from *Malus domestica* apples cultivated in Romania is achieved through MW, with a yield of 23.32% (Dranca et al., 2021; Dranca et al., 2020; Gurev et al., 2023). Additionally, the classical extraction method using citric acid also yields high extraction efficiency. On the other hand, the lowest extraction yield is obtained from enzymatic treatments with Celluclast 1.5 L (Dranca et al., 2019). In terms of galacturonic acid content, the highest value, depending on pH, extraction time, and method, is obtained through UAE at 92.83 g/100 g of sample. Moreover, the highest degree of esterification is observed in pectin samples obtained through citric acid treatment followed by UAE (Dranca et al., 2019; Dranca et al., 2020; Gurev et al., 2023).

The pectin extracted through classical and microwave methods was subsequently analyzed using HPLC at a wavelength of 250 nm. (Dranca et al., 2021). In the study conducted by Dranca et al., 2021, it was observed that pectin obtained from the secondary product of apples through citric acid extraction has a galacturonic acid content of 78.2% mol^2, arabinose 7.51% mol, rhamnose 4.81% mol, xylose 1.16% mol, glucose 6.37% mol, and mannose 1.84% mol, with a molecular weight of 2.63×10^{-5}. Meanwhile, through MW, the galacturonic acid content was found to be 86.21 mol^2, arabinose 4.66% mol, rhamnose 3.10% mol, xylose 0.97% mol, glucose 3.71% mol, and mannose 1.48% mol, with a molecular weight of 2.64×10^{-5}. Because of their similar molecular weights, it was reported in previous research that neither method affects the structure of pectin throughout the extraction process (Mao et al., 2019).

Through SEM analysis of pectin, it has been demonstrated that, after testing numerous extraction protocols on apple pomace from Romania that pectin obtained through classical extraction exhibits a homogeneous appearance with a porous surface. Conversely, pectin obtained through microwave- and ultrasound-assisted extraction and heating appears very rough and slightly ruptured. On the other hand, enzymatic extraction imparts a homogeneous and smooth appearance to the pectin, indicating that the extraction method significantly influences the structure of the obtained pectin (Dranca et al., 2020).

POLYPHENOLS FROM APPLE WASTE

Polyphenols are important plant secondary metabolites with various biochemical and biological properties and applications (Bertelli et al., 2021; Sridhar et al., 2021). Polyphenols from AW include phenolic acids, such as hydroxycinnamic acids (caffeic acid, chlorogenic acid, coumaric acid), hydroxybenzoic acids (gallic acid, protocatechuic acid, ellagic acid), anthocyanins (cyanidin-glucoside), dihydrochalcones such as phloridzin, flavonols (rutin, quercitrin, myricetin, epicatechin), flavan-3-ols (theaflavin, catechin, cafestol, procyanidin A1, procyanidin B1), flavanones (kaempferol, hesperidin, apigenin) (Gurev et al., 2023a; Sereti et al., 2024; Camelia C. Vlad et al., 2022; Vodnar et al.; 2017).

Romanian researchers have produced few articles regarding the extraction, analysis, and valorization of polyphenols from AW. Table 2 provides data on the extraction methods, along with details regarding the profile and quantity of the extracted polyphenols from AW.

Table 2. Synthesis of data regarding the extraction of polyphenols from apple pomace

Method and conditions of extraction	Polyphenolic compounds	References
Conventional solvent extraction with 80% methanol solution (v/v) at 25°C and 150 rpm, for 2 h	Gallic acid – 86.42 ± 2.26 mg/100 g DM; Caffeic acid – 3.62 ± 0.80 mg/100 g DM; Theaflavin – 71.73 ± 0.72 mg/100 g DM; Hesperidin – 42.83 ± 0.27 mg/100 g DM; Myricetin – 4.84 ± 0.01 mg/100 g DM	(Camelia C. Vlad et al., 2022)
Acid hydrolysis with 2M HCl at 100°C for 1 h	Caffeic acid – 4978.00 ± 900.00 mg/100 g DM; Protocatechuic acid – 2144.20 ± 37.60 mg/100 g DM; Quercetin 3-β-D-glucoside – 236.60 ± 3.12 mg/100 g; Kaempferol 27.80 ± 1.36 mg/100 g	
Conventional solvent extraction with continuous stirring for 30 min at 45°C, 1:4 ratio between apple pomace and extraction solution composed of 50% MeOH: 0.3 % HCl (v/v)	TPC – 2163.6 ±78.0 mg GAE/100g; 3,4-Dihydroxybenzoic acid – 308.47 ±16.99 µg/g; Gallic acid – 99.76 ±4.52 µg/g; 4-Hydroxybenzoic acid – 169.51 ±12.56 µg/g; Chlorogenic acid – 59.60 ±4.26 µg/g; Catechin – 37.63 ±2.84 µg/g	(Sereti et al., 2024)
UAE, 1:100 (w/v) apple pomace and 50% ethanol solution (v/v) at a frequency of 37 kHz and a temperature of 40 ± 1°C, for 30 min	TPC – 6.03 ± 0.21 mg GAE/g DW TFC – 2.13 ± 0.13 mg QE/g DW TT – 0.61± 0.03 mg TAE/g DW	(Gurev et al., 2023a)
UAE, 1:5 (w/v) apple pomace and methanol at room temperature for 15 min	Chlorogenic acid – 1173.13 ± 0.19 µg/g; Gallic acid-glucoside – 106.62 ± 0.14 µg/g; Epicatechin – 736.21 ± 0.44 µg/g; Isoquercitrin – 358.58 ± 0.07 µg/g; Quercitrin – 164.07 ± 0.09; Phloridzin – 720.39 ± 0.09 µg/g; Total phenolics – 4952.40 ± 0.08 µg/g	(Teleky et al., 2022)
UAE, extraction solution composed of HCl:MeOH:H_2O (1:80:19) at 40°C for 30 min	TPC – 564 ± 39.5 mgGAE/100gDW; Caffeic acid-4-O-glucoside – 2.492 mg/100 g DW; Quercetin 3-O-rutinoside – 4.318 mg/100 g DW; Phloridzin – 5.714 mg/100 g DW; Phloretin 2′-O-glucoside – 1.125 mg/100 g DW	(Vodnar et al., 2017)

[1]DW - dried weight, DM - dried mass

In these articles, polyphenols quantification from AW was performed by colorimetric methods with the Folin-Ciocalteau reagent (TPC) (Gurev et al., 2023a; Sereti et al., 2024) and chromatographic analysis by HPLC coupled with different detectors: a multi-wavelength detector (MWD) (Gurev et al., 2023a; Camelia C. Vlad et al., 2022). photodiode array detector (PDA) (Sereti et al., 2024), diode-array detector and electrospray ionization mass spectrometer (HPLC-DAD-ESI-MS) (Vodnar et al., 2017), variable wavelength detector (VWD) (Teleky et al., 2022). The polyphenolic composition and extraction yield are significantly influenced by apple cultivar, extraction technique, solvent polarity, the physical state of the biomass (fresh, frozen, or dried), and pretreatments applied prior to extraction (Vodnar et al., 2017).

UAE has been widely reported for its efficiency, yielding TP) values between 5.64 ± 0.395 and 6.03 ± 0.21 mg GAE/g DW, depending on the extraction solvent system, such as 50% ethanol (Gurev et al., 2023a) vs. HCl:MeOH:H_2O (1:80:19) (Sereti et al., 2024). These little differences are also attributed to the raw material characteristics. (Gurev et al., 2023a) used apple waste derived from the Golden Delicious variety, wich underwent citric acid pretreatment to prevent oxidation prior to drying at 70°C, whereas (Vodnar et al., 2017) extracted polyphenols directly from fresh apple peel obtained of the Ionatan de Voineşti variety. In another study on Romanian apple cultivars by (Catană et al., 2018), reported TPC values ranging between 17.83 and 38.83 mg GAE/g DW, with Golden Delicious exhibiting the lowest content and Jonathan thehighest. The same study demonstrated that extraction efficiency was significantly influenced by solvent, with 70% acetone showing a superior

extraction yield compared to 50% methanol and 50% ethanol. The effectiveness of the extraction solvent is closely associated with solvent polarity, phenolic solubility, degree of polymerization, and interactions with other matrix components, which can form insoluble complexes and limit extractability (Perussello et al., 2017; Venkatesan et al., 2019).

Polyphenols in apple cell walls are presented in both free and bound forms, with the latter typically esterified with polysaccharides like cellulose and hemicellulose. Extracting bound forms is more challenging due to their association with structural components (Fernandes et al., 2019; Vidot et al., 2020). The common extraction method involves first extracting free polyphenols using an aqueous organic solvent, followed by extracting bound polyphenols using base and/or acid hydrolysis (Li et al., 2020). Camelia C. Vlad et al. (2022) studied this sequential extraction of polyphenols from freeze-dried Idared AW. They found that using a 2M HCl acid solution and a high temperature (100°C) improved the polyphenol profile and content compared with extraction using 80% methanol at 25°C, reducing the extraction time from 2 hours to 1 hour. This method enhanced the content of certain phenolic acids (e.g., caffeic acid content increased from 3.62 ± 0.80 mg/100 g DM to 4978.00 ± 900.00 mg/100 g DM), altered flavonol and flavanone profiles, but reduced flavan-3-ol content in the bound fraction compared with the free fraction extracted with methanol at 25°C for 2 hours, and some compounds were poorly extracted or undetected.

In their study (Vodnar et al., 2017) investigated the impact of thermal pre-treatment (10 minutes at 80°C) on polyphenol extraction from apple peel in comparison to fresh peel. They observed a significant effect of the thermal pre-treatment on TPC and certain polyphenols, such as caffeic acid-4-O-glucoside and 3-caffeoylquinic acid, as determined by HPLC-DAD-ESI-MS. Interestingly, some polyphenol levels, like phloridzin and phloretin 2′-O-glucoside, decreased after the thermal pre-treatment. Their findings indicated both positive and negative impacts of thermal pre-treatment on polyphenol content, depending on the type of polyphenols (hydroxycinnamic acids or dihydrochalcones). These effects are attributed to the characteristics of low-temperature thermal pre-treatments (below 90°C), which promote macromolecule de-flocculation (Wang et al., 2022) while minimally affecting the solubilization of lignocellulosic matter ultimately leading to increased phenolic compound content through polysaccharide hydrolysis (Jain et al., 2015; Rodríguez-Gutiérrez et al., 2019),

Apple Pomace: From Agro-Industrial Waste to a Valuable Component in Food and Bioprocesses

Apple waste is a valuable source of bioactive compounds, such as polysaccharides, fatty acids, and polyphenols, with promising applications in biotechnology and the food industry (Pop et al., 2021). Due to their nutritional composition, these by-products have been used as a fermentation substrate with lactic acid bacteria (*Loigolactobacillus bifermentans, Lactobacillus plantarum, Lactobacillus casei*), fructolactobacilli (*Fructilactobacillus florum*), and yeasts (*Saccharomyces cerevisiae, Saccharomyces boulardi*), to obtain functional foods, such as sourdough bread or soy milk (Camelia Cristina Vlad et al., 2022).

In recent years, research in Romania has focused on exploiting this potential by developing innovative foods enriched with valuable bioactive compounds (Martau et al., 2021; Camelia Cristina Vlad et al., 2022).

A relevant example is provided by studies conducted on Romanian AW from apple varieties, including the Idared (Galați, Romania) and Jonathan (Bistrița-Năsăud, Romania) varieties, which demonstrated prebiotic effects due to their high pectin and polyphenol content. The addition of a small amount of dried pomace to the culture medium significantly increased prebiotic activity compared with the control. Optimization of this process enables the development of functional products rich in nutrients and antioxidants, contributing to improved health outcomes. (Martau et al., 2021; Camelia Cristina Vlad et al., 2022).

Further research Plămadă (2025) confirmed that pomace from Red Delicious and Granny Smith varieties also promotes the growth of beneficial microorganisms such as *L. plantarum*, *L. casei*, *S. boulardii* at low and moderate concentrations, thus supporting its prebiotic potential, although

the prebiotic index remained lower than that of the control (Plamada et al., 2025).

During the fermentation process, the pH of the samples decreases due to the production of lactate and lactic acid, other organic acids, which also leads to changes in secondary metabolites. This effect has been observed in sourdough bread enriched with Jonathan apple pomace, where fermentation enhanced both acidity and bioactive compound content (Magyar et al., 2016; Martău et al., 2021).

Apple pomace has also been used as a fermentation substrate to obtain a nutraceutical product enriched with lipophilic carotenoid pigments through fermentation with *Zygomycetes* (Dulf et al., 2023), such as strains of *Actinomucor* elegans and *Umbelopsis isabellina* - fungal strains having the role of producing significant amounts of enzymes, lipids or pigments (Klempová et al., 2020). The bioactive compounds and antioxidant content of the resulting product were screened during this process (Dulf et al., 2023).

Another application in Romania that has been studied is the incorporation of apple pomace as a functional ingredient in foods such as biscuits, breads, muffins, jelly candies, and fruit protein bars (Ciurlă et al., 2024; Mandache et al., 2025; Mureșan et al., 2024; Pop et al., 2021). Due to its high fiber content, comprising approximately 35-60% dietary fiber (approximately 25% lignin, 10% pectin, 40% cellulose, and 25% hemicellulose), these figures are influenced by the variety of apples from which they originate (Pop et al., 2021; Rațu et al., 2023). The fibers from apple pomace play the role of retaining water and forming gels, increasing viscosity, as demonstrated by their incorporation into biscuits or jelly (Ciurlă et al., 2024; Fărcaș et al., 2022). In addition to the high fiber content, AW inclusion significantly enhanced the phenolic profile and antioxidant capacity of the final food products (Mandache et al., 2025).

Apples, which are rich in bioactive compounds, polysaccharides, carbohydrates, and fibers, as well as a valuable source of pectin, have been used as a stabilizing agent for oil-in-water emulsions, replacing the margarine used in conventional biscuit recipes, resulting in a new product that offers high nutritional value and antioxidant activity (Sereti et al., 2024; Velciov et al., 2022).

Apple pomace, including the Golden Delicious variety, is also used in fruit bars, where pectin extracted from the pomace acts as a gelling agent, forming a protective layer that prevents the physicochemical changes that may occur during storage. These changes include reducing antioxidant activity, pH, and acidity alterations, as well as variations in water activity, which could promote the development of pathogens such as yeasts and molds, thereby compromising the safety of the product for consumption (Gurev et al., 2023).

In the framework of current challenges regarding animal nutrition and restrictions imposed on the use of antibiotics, it has become necessary to identify sustainable and safe alternatives. One such direction is the utilization of agri-food by-products, which, instead of being discarded, can represent valuable sources of antimicrobial compounds, fibers, and essential nutrients. In this regard, Anghel et al. (2024) investigated the antimicrobial activity of apple extract before and after fermentation with *Saccharomyces cerevisiae*, highlighting its potential for use as a natural substitute for antibiotics and zinc oxide in the feed of piglets (Anghel et al., 2024). Complementarily, Filip (2024) (Filip et al., 2024) analyzed the biochemical composition of red and yellow apples before and after the drying process, with the aim of evaluating their applicability as a functional ingredient in animal feed.

In 2022, Telekey and his collaborators adopted an innovative approach to the recovery and reuse of biological materials using apple pomace from the Red Delicious variety to produce biodegradable biopolymers, replacing chemically produced polymers. This initiative addressed two important and topical issues, namely the valorization of raw materials and their integration into the food industry.

This study focused on the formation of films from apple pectin, which was mixed with poly(vinyl alcohol) (PVA) and itaconic acid, obtained from filamentous fungi of the *Aspergillus terreus* species, and with the addition of extracts from apple pomace. The formulation of these films resulted in materials with improved rheological properties because of the combination of pectin, PVA, and itaconic acid with polyphenols extracted from apple residues. In addition, this formulation

significantly improved the physicochemical properties of the films, particularly in terms of antioxidant activity, mechanical resistance, and their ability to resist vapor and dissolve less in water (Dranca et al., 2021; Teleky et al., 2022).

Another study from 2016 focused on the valorization of Romanian agro-industrial residues, primarily focusing on biogas production. This energy source can be naturally generated through organic degradation under anaerobic conditions (Ciuta et al., 2016). Apple pomace, with its high moisture content, provides the perfect environment for this microbial degradation, both in aerobic and anaerobic processes (Dalpaz et al., 2020; Maragkaki et al., 2018). It contains approximately 90% volatile solids and a moisture content of approximately 75-80%.

An essential aspect of the efficiency of anaerobic degradation is the optimal carbon-to-nitrogen ratio, which ranges between 15 and 30 according to previous studies (Ciuta et al., 2016). By analyzing the elements composing the degradation consortium, it can be classified according to the UNI CEN/TS 15359 (Rada et al., 2012) standard into one of the five essential classes, providing valuable information about the compatibility of the co-digestion process. The rapid degradation of apple pomace, occurring in just two days, and its potential to produce biogas in significant quantities, highlighted by a respirometric index of 4888 ± 804 mg $O2 \cdot kgVS^{-1} \cdot h^{-1}$ and anaerobic biogas potential of 60.84 ($Nm^3 \cdot t_tq^{-1}$), represent a promising perspective for the valorization of these residues in energy production (Ciuta et al., 2016).

As well as using apple pomace in making food and functional supplements for people and animals, and in making biopolymers and biogas, there has been a big focus on using it in farming over the last few years. In 2025, Pădureanu et al. all evaluated the potential of apple pomace extract as a biostimulant. Although studies conducted to date have not shown significant effects on stimulating wheat plant growth, researchers have nevertheless suggested its use as a bioherbicide, given the persistent challenges associated with weed control in Romanian agriculture (Padureanu et al., 2025).

Water pollution with heavy metals is a major environmental problem. Recent research has shown that apple pomace can be used as a natural biosorbent, without chemical treatments, to remove lead ions from water. Research has shown high adsorption efficiency and high metal retention capacity, demonstrating its potential as an environmentally friendly and sustainable solution for treating contaminated water, while also making use of an abundant agri-food by-product (Ungureanu et al., 2024).

CONCLUSIONS

Based on studies conducted to date on the utilization of apple pomace, we have concluded that apple waste is a complex and sustainable source of bioactive compounds with multidisciplinary applications. Optimizing extraction processes, detailed characterization of chemical components, and the development of environmentally friendly recovery technologies contribute to transforming this agro-industrial waste into a strategic resource for sustainable development and industrial innovation.

The most important compound extracted from apple pomace is pectin, which has valuable functional properties, mainly determined by the degree of esterification (DE) and galacturonic acid content. These parameters are essential for determining both the quality and the areas of application of pectin. Pectins with a high degree of esterification (DE > 50%) are suitable for classic food products such as jellies and jams, while pectins with a lower degree of esterification (DE < 50%) are frequently used in pharmaceutical and biomedical applications. In addition, modern extraction methods - such as ultrasound-assisted extraction (UAE) or microwave extraction (MW) - have proven to be more efficient than conventional methods, offering higher yields, greater purity, and improved structural properties of pectin.

On the other hand, apple pomace is an important source of phenolic compounds, which have a wide range of biological benefits, such as antioxidant, antimicrobial, and anticarcinogenic activity. Due to these properties, phenolic compounds are recommended as valuable ingredients in the formulation of functional foods, food supplements, and cosmetics. The composition and concentration of these compounds vary depending on the apple variety,

the extraction method and solvent used, and the preliminary treatments applied to the waste.

The application of apple by-products in biotechnology and industry has undergone significant development. They can be used as a substrate in fermentation processes to obtain biogas or fermented products with high functional value, but also in the production of biodegradable materials based on pectin and natural polymers. Furthermore, the use of apple waste as a food additive or natural feed offers nutritional and antimicrobial benefits, and recent research confirms its potential as an environmentally friendly biosorbent for removing heavy metals from contaminated water.

Overall, the recovery of apple waste contributes to reducing pollution, promoting a circular economy, and developing sustainable, innovative, and high-value-added products, demonstrating its strategic importance for the future of the bioeconomy.

ACKNOWLEDGEMENTS

This work was supported by the Romanian Ministry of Agriculture and Rural Development, project Research regarding development of sustainable technologies for obtaining and valorizing innovative ingredients and foods for nutritional equilibration of modern consumers' diets - ADER 17.1.2.

REFERENCES

Anghel, A. C., Tranu I., Ortan A., Babeanu N. (2024). Antimicrobial effects of polyphenols from fermented and non-fermented apple and carrot pomace against Escherichia coli. *Food and Feed Research*, *51*(2), 175-187.

Bagherian, H., Ashtiani, F. Z., Fouladitajar, A., & Mohtashamy, M. (2011). Comparisons between conventional, microwave-and ultrasound-assisted methods for extraction of pectin from grapefruit. *Chemical engineering and processing: Process Intensification*, *50*(11-12), 1237-1243.

Bertelli, A., Biagi, M., Corsini, M., Baini, G., Cappellucci, G., & Miraldi, E. (2021). Polyphenols: From Theory to Practice. *Foods*, *10*(11).

Călinoiu, L., Mitrea, L., Precup, G., Bindea, M., Rusu, B., Szabo, K., Dulf, F., Ştefănescu, B., & Vodnar, D. (2018). Sustainable use of agro-industrial wastes for feeding 10 billion people by 2050. In *Professionals in food chains* (pp. 101-111). Wageningen Academic Publishers.

Campeanu, G., Neata, G., & Darjanschi, G. (2009). Chemical composition of the fruits of several apple cultivars growth as biological crop. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, *37*(2), 161-164.

Canteri-Schemin, M., H., Fertonani, H., C. R., Waszczynskyj, N., & Wosiacki, G. (2005). Extraction of pectin from apple pomace. *Brazilian archives of biology and technology*, *48*, 259-266.

Catană, M., Catană, L., IORGA, E., Lazăr, M.-A., Lazăr, A.-G., Teodorescu, R., I., Asănică, A., C., & Nastasia, B. (2018). Achieving functional ingredients from apple waste resulting from the apple juice industry. *AgroLife Scientific Journal*, *7*(1).

Ciurlă, L., Enache, I.-M., Buțerchi, I., Mihalache, G., Lipșa, F. D., & Patraș, A. (2024). A new approach to recover bioactive compounds from apple pomace: Healthy jelly candies. *Foods*, *14*(1), 39.

Ciuta, S., Antognoni, S., Rada, E., C., Ragazzi, M., Badea, A., & Cioca, L. I. (2016). Respirometric index and biogas potential of different foods and agricultural discarded biomass. *Sustainability*, *8*(12), 1311.

Cui, Y., Chen, J., & Zhang, S. (2023). The effect of degree of esterification of pectin on the interaction between pectin and wheat gluten protein. *Food Hydrocolloids*, *136*, 108272.

Dalpaz, R., Konrad, O., da Silva Cyrne, C., C., Barzotto, H., P., Hasan, C., & Guerini Filho, M. (2020). Using biogas for energy cogeneration: An analysis of electric and Thermal Energy Generation from agro-industrial waste. Sustainable Energy Technologies and Assessments, 40, 100774. In.

Dranca, F., & Oroian, M. (2018). Extraction, purification, and characterization of pectin from alternative sources with potential technological applications. *Food Research International*, *113*, 327-350.

Dranca, F., & Oroian, M. (2019). Optimization of pectin enzymatic extraction from malus domestica 'fălticeni'apple pomace with Celluclast 1.5 L. *Molecules*, *24*(11), 2158.

Dranca, F., Talón, E., Vargas, M., & Oroian, M. (2021). Microwave vs. conventional extraction of pectin from Malus domestica 'Fălticeni'pomace and its potential use in hydrocolloid-based films. *Food Hydrocolloids*, *121*, 107026.

Dranca, F., Vargas, M., & Oroian, M. (2020). Physicochemical properties of pectin from Malus domestica 'Fălticeni'apple pomace as affected by non-conventional extraction techniques. *Food Hydrocolloids*, *100*, 105383.

Dulf, F. V., Vodnar, D., C., & Dulf, E.-H. (2023). Solid-state fermentation with Zygomycetes fungi as a tool for biofortification of apple pomace with γ-linolenic acid, carotenoid pigments, and phenolic antioxidants. *Food Research International*, *173*, 113448.

Egüés, I., Hernandez-Ramos, F., Rivilla, I., & Labidi, J. (2021). Optimization of ultrasound assisted extraction of bioactive compounds from apple pomace. *Molecules*, *26*(13), 3783.

Fărcaș, A. C., Socaci, S. A., Chiș, M. S., Dulf, F. V., Podea, P.; & Tofană, M. (2022). Analysis of fatty acids, amino acids, and volatile profile of apple by-products by gas chromatography-mass spectrometry. *Molecules*, *27*(6), 1987.

Fernandes, P.; A. R., Le Bourvellec, C.; Renard, C.; M. G. C., Nunes, F.; M., Bastos, R.; Coelho, E.; Wessel, D.; F., Coimbra, M.; A., & Cardoso, S. M. (2019). Revisiting the chemistry of apple pomace polyphenols. *Food Chemistry*, *294*, 9-18.

Filip, M., Vlassa, M., Petean, I., Țăranu, I., Marin, D., Perhaiță, I., Prodan, D., Borodi, G., & Dragomir, C. (2024). Structural Characterization and Bioactive Compound Evaluation of Fruit and Vegetable Waste for Potential Animal Feed Applications. *Agriculture*, *14*(11), 2038.

Franchi, M.; L., Marzialetti, M.; B., Pose, G.; N., & Cavalitto, S. F. (2014). Evaluation of enzymatic pectin extraction by a recombinant polygalacturonase (PGI) from apples and pears pomace of argentinean production and characterization of the extracted pectin.

Ghinea, C.; Apostol, L.; C., Prisacaru, A.; E., & Leahu, A. (2019). Development of a model for food waste composting. *Environmental Science and Pollution Research*, *26*, 4056-4069.

Girón-Hernández, J.; Pazmino, M.; Barrios-Rodríguez, Y.; F., Turo, C.; T., Wills, C.; Cucinotta, F.; Benlloch-Tinoco, M.; & Gentile, P. (2023). Exploring the effect of utilising organic acid solutions in ultrasound-assisted extraction of pectin from apple pomace and its potential for biomedical purposes. *Heliyon*, *9*(7).

Gurev, A., Cesko, T., Dragancea, V., Ghendov-Mosanu, A., Pintea, A., & Sturza, R. (2023a). Ultrasound- and Microwave-Assisted Extraction of Pectin from Apple Pomace and Its Effect on the Quality of Fruit Bars. *Foods*, *12*(14), 2773.

Huang, W., Fang, Q., Fan, L., Hong, T., Tan, H., & Nie, S. (2022). Pectin with various degrees of esterification differentially alters gut microbiota and metabolome of healthy adults. *Efood*, *3*(1-2), e5.

Jain, S., Jain, S., Wolf, I. T., Lee, J., & Tong, Y. W. (2015). A comprehensive review of operating parameters and different pretreatment methodologies for anaerobic digestion of municipal solid waste. *Renewable and Sustainable Energy Reviews*, *52*, 142-154.

Klempová, T., Slaný, O., Šišmiš, M., Marcinčák, S., & Čertík, M. (2020). Dual production of polyunsaturated fatty acids and beta-carotene with Mucor wosnessenskii by the process of solid-state fermentation using agro-industrial waste. *Journal of Biotechnology*, *311*, 1-11.

Lang, Y., Gao, N., Zang, Z., Meng, X., Lin, Y., Yang, S., Yang, Y., Jin, Z., & Li, B. (2024). Classification and antioxidant assays of polyphenols: A review. *Journal of Future Foods*, *4*(3), 193-204.

Li, W., Yang, R., Ying, D., Yu, J., Sanguansri, L., & Augustin, M. A. (2020). Analysis of polyphenols in apple pomace: A comparative study of different extraction and hydrolysis procedures. *Industrial Crops and Products*, *147*, 112250.

Löfgren, C., & Hermansson, A.-M. (2007). Synergistic rheological behaviour of mixed HM/LM pectin gels. *Food Hydrocolloids*, *21*(3), 480-486.

Magyar, M., da Costa Sousa, L., Jin, M., Sarks, C., & Balan, V. (2016). Conversion of apple pomace waste to ethanol at industrial relevant conditions. *Applied Microbiology and biotechnology*, *100*, 7349-7358.

Mandache, M. B., Vijan, L. E., & Cosmulescu, S. (2025). Insight into Bioactive Compounds and Antioxidant Activity of Bakery Products Fortified with Fruit Pomace. *Foods*, *14*(5), 806.

Mao, G., Wu, D., Wei, C., Tao, W., Ye, X., Linhardt, R., J., Orfila, C., & Chen, S. (2019). Reconsidering conventional and innovative methods for pectin extraction from fruit and vegetable waste: Targeting rhamnogalacturonan I. *Trends in Food Science & Technology*, *94*, 65-78.

Maragkaki, A., Fountoulakis, M., Kyriakou, A., Lasaridi, K., & Manios, T. (2018). Boosting biogas production from sewage sludge by adding small amount of agro-industrial by-products and food waste residues. *Waste Management*, *71*, 605-611.

Marcon, M., V., Vriesmann, L., C., Wosiacki, G., Beleski-Carneiro, E., & Petkowicz, C. L. (2005). Pectins from apple pomace. *Polímeros*, *15*, 127-129.

Martau, G., Teleky, B., Ranga, F., Pop, I. & Vodnar, D. (2021). Apple pomace as a sustainable substrate in sourdough fermentation. Front Microbiol 12: 742020. In.

Morris, G., A., Castile, J., Smith, A., Adams, G., G., & Harding, S. E. (2010). The effect of different storage temperatures on the physical properties of pectin solutions and gels. *Polymer Degradation and Stability*, *95*(12), 2670-2673.

Müller-Maatsch, J., Bencivenni, M., Caligiani, A., Tedeschi, T., Bruggeman, G., Bosch, M., Petrusan, J., Van Droogenbroeck, B., Elst, K., & Sforza, S. (2016). Pectin content and composition from different food waste streams. *Food chemistry*, *201*, 37-45.

Mureșan, A. E., Man, S., Socaci, S. A., Pușcaș, A., Tanislav, A. E., Pall, E., Mureșan, V., & Cerbu, C. G. (2024). Functionality of Muffins Fortified with Apple Pomace: Nutritional, Textural, and Sensory Aspects. *Applied Sciences*, *14*(15), 6439.

Naqash, F., Masoodi, F., Dar, B., & Manzoor, N. (2023). Effect of degree of esterification on the encapsulation properties and gut health potential of apple pectin. *Journal of Polymers and the Environment*, *31*(6), 2424-2433.

Naqash, F., Masoodi, F., Gani, A., Nazir, S., & Jhan, F. (2021). Pectin recovery from apple pomace: physico-chemical and functional variation based on methyl-esterification. *International Journal of Food Science & Technology*, *56*(9), 4669-4679.

Padureanu, S., & Patras, A. (2025). Limitations in the Valorization of Food Waste as Fertilizer: Cytogenotoxicity Assessment of Apple and Tomato Juices By-Products. *Agronomy*, *15*(10), 2364.

Perussello, C. A., Zhang, Z., Marzocchella, A., & Tiwari, B. K. (2017). Valorization of Apple Pomace by Extraction of Valuable Compounds. *Comprehensive Reviews in Food Science and Food Safety*, *16*(5), 776-796.

Plamada, D.; Simon, E., Nemes, S., A., Teleky, B.-E., Odocheanu, R., Szabo, K., Ranga, F., Dulf, F. V., & Vodnar, D. C. (2025). Exploring the in vitro prebiotic potential of two different freeze-dried apple pomace cultivars. *Food Bioscience*, *64*, 105892.

Pop, C., Suharoschi, R., & Pop, O. L. (2021). Dietary fiber and prebiotic compounds in fruits and vegetables food waste. *Sustainability*, *13*(13), 7219.

Popescu, A. (2012). Research regarding the trends in Romania's apple market. *Annals of the University of Craiova-Agriculture, Montanology, Cadastre Series*, *42*(2), 408-413.

Rada, E., C., & Andreottola, G. (2012). RDF/SRF: which perspective for its future in the EU. *Waste Management*, *32*(6), 1059-1060.

Rascón-Chu, A., Gomez-Rodriguez, G., H., Carvajal-Millan, E., & Campa-Mada, A. C. (2019). Pectin in drug delivery applications. *Natural Polysaccharides in Drug Delivery and Biomedical Applications*, 249-262.

Rațu, R., N., Veleșcu, I., D., Stoica, F., Usturoi, A., Arsenoaia, V., N., Crivei, I., C., Postolache, A., N., Lipșa, F. D., Filipov, F., & Florea, A. M. (2023). Application of Agri-Food By-Products in the Food Industry. *Agriculture*, *13*(8), 1559.

Rodríguez-Gutiérrez, G., Cardoso, J., C., Rubio-Senent, F., Serrano, A., Borja, R., Fernández-Bolaños, J., & Fermoso, F. G. (2019). Thermally-treated strawberry extrudate: A rich source of antioxidant phenols and sugars. *Innovative Food Science & Emerging Technologies*, *51*, 186-193.

Sereti, V., Kotsiou, K., Ciurlă, L., Patras, A., Irakli, M., & Lazaridou, A. (2024). Valorizing apple pomace as stabilizer of olive oil-water emulsion used for reduction of saturated fat in biscuits. *Food Hydrocolloids*, *151*, 109746.

Spinei, M. & Oroian, M. (2022). Microwave-assisted extraction of pectin from grape pomace. *Scientific Reports*, *12*(1), 12722.

Sridhar, A., Ponnuchamy, M., Kumar, P., S., Kapoor, A., Vo, D., N., & Prabhakar, S. (2021). Techniques and modeling of polyphenol extraction from food: a review. *Environ Chem Lett*, *19*(4), 3409-3443.

Szabo, K., Mitrea, L., Călinoiu, L. F., Teleky, B.-E., Martău, G.; A., Plamada, D.; Pascuta, M.; S., Nemeș, S.; -A., Varvara, R.-A., & Vodnar, D. C. (2022). Natural polyphenol recovery from apple-, cereal-, and tomato-processing by-products and related health-promoting properties. *Molecules*, *27*(22), 7977.

Teleky, B.-E., Mitrea, L., Plamada, D.; Nemes, S., A., Călinoiu, L.-F., Pascuta, M.; S., Varvara, R.-A., Szabo, K., Vajda, P., & Szekely, C. (2022). Development of pectin and poly(vinyl alcohol)-based active packaging enriched with itaconic acid and apple pomace-derived antioxidants. *Antioxidants*, *11*(9), 1729.

Ungureanu, G., Enache, I.-M., Cara, I. G., Motrescu, I., & Patras, A. (2024). Insights into the environmental benefits of using apple pomace for biosorption of lead from contaminated water. *Heliyon*, *10*(17).

Vasiliu, A. E., Mureșan, A., Mureșan, V., Petruț, G., & Muste, S. (2018). Apple and apple pomace chemical compositions: a review.

Velciov, A.-B., Riviș, A., Popescu, G.-S., Cozma, A., Stoin, D., Petcov, A., Anghel, I.-M., Rada, M., & Hădărugă, N.-G. (2022). Preliminary research on the obtaining and nutritional characterization of apple peel powder.

Venkatesan, T., Choi, Y.-W., & Kim, Y.-K. (2019). Impact of different extraction solvents on phenolic content and antioxidant potential of Pinus densiflora bark extract. *BioMed Research International*, *2019*.

Vidot, K., Guyot, S., Maury, C., Siret, R., & Lahaye, M. (2020). Data set on hydroxycinnamic acid ester analysis from the cell walls of apples and grapes. *Data in Brief*, *28*, 104870.

Vlad, C. C., Păcularu-Burada, B., Vasile, A. M., Milea, Ș. A., Bahrim, G.-E., Râpeanu, G., & Stănciuc, N. (2022). Upgrading the functional potential of apple pomace in value-added ingredients with probiotics. *Antioxidants*, *11*(10), 2028.

Vlad, I. M., Butcaru, A. C., Burcea, M., Chiurciu, I., Toma, E., & Stanciu, T. (2022). Assessing the apple sector in Romania and insights on the consumption.

Vodnar, D., C., Călinoiu, L. F., Dulf, F. V., Ștefănescu, B. E., Crișan, G., & Socaciu, C. (2017). Identification of the bioactive compounds and antioxidant, antimutagenic and antimicrobial activities of thermally processed agro-industrial waste. *Food Chemistry*, *231*, 131-140.

Wang, M., Wang, J., Li, Y., Li, Q., Li, P., Luo, L., Zhen, F., Zheng, G., & Sun, Y. (2022). Low-Temperature Pretreatment of Biomass for Enhancing Biogas Production: A Review. *Fermentation*, *8*(10), 562.

Wang, S., Chen, F., Wu, J., Wang, Z., Liao, X., & Hu, X. (2007). Optimization of pectin extraction assisted by microwave from apple pomace using response surface methodology. *Journal of food engineering*, *78*(2), 693-700.

Wang, X., Chen, Q., & Lü, X. (2014). Pectin extracted from apple pomace and citrus peel by subcritical water. *Food Hydrocolloids*, *38*, 129-137.

Wikiera, A., Grabacka, M., Byczyński, Ł., Stodolak, B., & Mika, M. (2021). Enzymatically extracted apple pectin possesses antioxidant and antitumor activity. *Molecules*, *26*(5), 1434.

Wikiera, A., Mika, M., & Grabacka, M. (2015). Multicatalytic enzyme preparations as an effective alternative to acid in pectin extraction. *Food Hydrocolloids*, *44*, 156-161.

Wikiera, A., Mika, M., Starzyńska-Janiszewska, A., & Stodolak, B. (2015a). Application of Celluclast 1.5 L in apple pectin extraction. *Carbohydrate Polymers*, *134*, 251-257.

Wikiera, A., Mika, M., Starzyńska-Janiszewska, A., & Stodolak, B. (2015b). Development of complete hydrolysis of pectins from apple pomace. *Food chemistry*, *172*, 675-680.

Wikiera, A., Mika, M., Starzyńska-Janiszewska, A., & Stodolak, B. (2016). Endo-xylanase and endo-cellulase-assisted extraction of pectin from apple pomace. *Carbohydrate polymers*, *142*, 199-205.

Zarei, M., Ahmadi, Z., A., Saari, N., Ghanbari, R., Nikkhah, M., & Vaziri, M. (2017). Effect of microwave-assisted extraction on the yield and quality of apple pomace and lemon peel pectins. *International Food Research Journal*, *24*(6).