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Comprehensive analysis of bioactive polyphenols, organic acids and antioxidant activity in *Mespilus germanica* L. fruits and leaves: Implications for functional food applications

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ABSTRACT

The aim of the present study was to investigate the dynamic changes of bioactive polyphenols, organic acid profile and antioxidant activities of *Mespilus germanica* L. during ripening. The ability of (Mosmon) fruits and leaves were assessed during the post-harvest bletting process. Four harvest stages of fruit and leaves were sampled between October and November 2025 for total phenolic content (TPC), total flavonoid content (TFC), radical scavenging activities (DPPH, ABTS) and individual phytochemical profiles. The leaves showed significantly higher bioactive yields than fruits, with higher TPC (171.88 mg GAE/100 g), TFC (1590.98 mg catechin/100 g), and antioxidant capacity (DPPH: 9621.15 μmol TE/100 g; ABTS: 9407.08 μmol TE/100 g). Mid-to-late October (October 19-31) was the best time to harvest for the highest level of phytochemicals in both tissues. The organic acids were the most abundant in both tissues (1059.4 μg/g malic acid in leaves and 269.8 μg/g malic acid in fruits) but malic acid was not the only organic acids found in the leaves, with citric and fumaric acids also present, showing that there is a higher metabolic diversity in leaves. On the other hand, fruits contained high levels of certain high value phenolics such as rutin (169.78 mg/100 g), catechin (55.43 mg/100 g) and chlorogenic acid (43.64 mg/100 g). In general, leaves of *M. germanica* collected in the end of October can be considered as an innovative, reproducible and sustainable source of ingredients for functional foods, whereas fruits can be considered as a source of targeted polyphenols.

1. Introduction

Non-communicable diseases (NCDs) like cardiovascular diseases, type 2 diabetes, obesity and different types of cancers have emerged as big diseases affecting the world in the 21st century [1–3]. The poor dietary choices are considered as one of the lifestyle factors associated with these chronic diseases and are seen as playing a key role in their development and progression [4,5]. Consequently, modern nutritional science has shifted its focus from merely preventing nutrient deficiencies toward actively promoting long-term health and mitigating disease risks [6,7]. In this dynamic scenario, functional foods have become an area of great interest and have emerged as a proactive strategy to the conventional nutrition approach, in a way moving nutrition one step further towards targeted health promotion. Functional foods include bioactive compounds that give them functional physiological properties in addition to providing basic nourishment. Functional foods have been identified by various major regulatory agencies, such as European Food Safety Authority (EFSA), U.S. Food and Drug Administration (FDA) and the World Health Organization (WHO) as the means by which substances within food products can be used to prevent or manage chronic diseases, reflecting the "food as medicine" paradigm [8,9].

Polyphenols are one of the largest groups of secondary plant products and are known for their antioxidant and hydroxyl group containing aromatic rings [10]. Polyphenols are widely used in pharmaceutical,

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medical and food industry research, this is attributed to their broad spectrum biological activities [11,12]. The phenolic acids, flavonoids, lignans, stilbenes and tannins are all major subclasses of this group [13]. Flavonoids are one of the most prevalent families in human diet and can be divided into flavonols, flavan-3-ols, flavones, flavanones, isoflavones and anthocyanins [14]. Polyphenols are found in a large array of fruits and vegetables such as apples, grapes, onions and cherries and are excellent sources [15,16]. Organic acids are also important for their role in food quality and preservation process apart from polyphenols. Organic acids are present in plants in their natural form and play a role in giving plants their organoleptic properties (flavor and acidity), but they also serve an important role in nutritional stability, shelf life and as natural antimicrobial preservatives to reduce the risk of food poisoning [17].

Production of free radicals in response of oxidative stress may cause significant biological damage at cellular level such as peroxidation of lipids, damage of DNA and oxidation of proteins which eventually lead to carcinogenesis [18,19]. The effects of these are counteracted by antioxidants, which help neutralize free radicals and protect biological structures from damage. Antioxidants are broadly applied in the food industry as functional ingredients to prevent the degradation of food products and lipid oxidation and in human health as anti-aging elements to combat reactive oxygen species (ROS) causing diseases [20–22]. An imbalance between ROS production and endogenous antioxidant defenses, systemic oxidative stress takes place, causing neurodegenerative disorders, cardiovascular and age-related diseases. It has been reported in literature that phenolic and flavonoid content of plant matrix is one of the major factors for the antioxidant potential of the plants [19,23,24].

Mespilus germanica L. is a member of the Rosaceae family and is widely spread throughout Asia, southeastern Europe and North America [25]. The plant is known as medlar in English, azgil in Persian, muşmon in Romanian, muşmula in Serbian and Turkish and Deutsche Mispel in German, and is very ecologically hardy and grows in poor soils and on rocky ground. *M. germanica* is a spiny shrub or small tree, up to 4 m tall, cultivated leaves are elongated. It produces brown or red fruits that are subglobose or pear-shaped, 1.5-3 cm in diameter, 10-80 g in weight and have yellowish-brown stony seeds, 1-3 cm in length, with a swollen base and a pointed apex [25]. In southern Romania, Cosmulescu et al. [26] evaluated the wild medlar and identified fruits of varying weights (3.15 to 36.68 g), diameters (18.43 to 44.15 mm) and volumes (4.38 to 37.18 cm^3) in the medlar samples, which may serve as good genotypes for cultivation. These fruits have become a popular food source for their nutritional and health promoting value in the maturation phase and during ripening [27,28]. Fruits are generally harvested in October and subsequently cooled and stored in dark, humid, and well-ventilled conditions to allow “bletting” (softening) to give the final flavor. Medlar fruits are an excellent source of bioactive phenolics and fatty acids, which have high nutritional and medicinal values [29–31].

Hence, the present study aimed to investigate the dynamic changes in biochemical parameters of *Mespilus germanica* L. fruits and leaves in bletting and autumn pre-dormancy period. In this study, total phenols, total flavonoids, antioxidant activities (DPPH and ABTS assays) and organic acid profiles were quantified along with individual phenolic compounds. Throughout October to November 2025, samples were taken at regular intervals to track any changes over time, as well as examining any variations in phytochemical content between vegetative (leaf) and reproductive (fruit) parts of the plant, to define the best point to harvest for optimal health-promoting properties.

2. Materials and methods

2.1. Chemical and reagents

The chemicals used in this study included 2,2-diphenyl-1-picrylhydrazyl radical (DPPH, 95 percent), 2,2 -azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS, 98 percent), 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox-98%), sodium nitrite ($NaNO_2$), aluminum chloride ($AlCl_3$), sodium hydroxide (HPLC grade) was bought at Merck (Darmstadt, Germany), whereas ethyl alcohol (p.a.) was bought at Nordic (Cluj-Napoca, Romania). In the polyphenol analysis, formic acid (analytical grade) was used to prepare the mobile phase. All aqueous preparations and mobile phases were prepared with ultrapure water (18.2 MΩ cm^{-1} resistivity at 25°C) produced in the laboratory with a Millipore Simplicity water purification system (Merck, Darmstadt, Germany). The standards of phenolic compounds, i.e. gallic acid, (+)-catechin, chlorogenic acid, vanillic acid, caffeic acid, syringic acid, p-coumaric acid, ferulic acid, sinapic acid, rutin, quercetin and luteolin were purchased at Aldrich (Milwaukee, WI, USA). Phenolic standards were completely dissolved in HPLC-grade methanol. Calibration curves were constructed by working standard solutions at various levels of concentration through suitable serial dilution. Carbohydrate standard solutions were kept at 4°C and phenolic standards at −20°C in amber glass vials until examined.

2.2. Plant material collection

The *Mespilus germanica* L. fruits and leaves were sampled at four different time intervals during the post-harvest maturation period, between October and November 2025. The samples were taken after about twelve days; this was done in a systematic way to trace changes of bioactive compounds and antioxidant activity during the bletting process. The schedule of the collection was as follows: October 7, 2025 (first collection); October 19, 2025; November 1, 2025 and November 11, 2025. The fruits and leaves were harvested at every time point and of the same identified trees so as to be consistent. The samples collected were directly taken to the laboratory in cooled (4°C) conditions to further test the total phenolic content, total flavonoid content and antioxidant activity.

2.3. Extraction

Carefully the plant material is separated into leaf and fruit tissues before extracting. The tissues were separately processed to each tissue type. The dried and ground samples (0.2 g) were extracted by maceration in 15 mL of 80% acetone in the open for 48 h at room temperature. The mixture was then filtered and the plant residue re-extracted at room temperature for 15 min with 10 mL of 80% acetone in an ultrasonic bath (Bandelin SONOREX Digital 10 P, Berlin, Germany). This ultrasound assisted extraction was repeated 5 times. Supernatant was obtained after each cycle and added to the filtrate obtained from the first maceration process. The combined extracts were concentrated by a rotary evaporator (IKA basic RV 05, Werke, Germany). The final concentrate was made up to 50 mL in 80% acetone and stored at −20°C for further analysis.

2.4. Total phenolic content (TPC)

The total phenolic content was analyzed with Folin-Ciocalteu (FC) reagent using a UV-vis Spectrophotometer Specord 205 (Analytik Jena, GmbH, Germany) according to the methodology (Vlassa et al., 2022). In brief, 0.4 mL of plant extract was added to 2 mL of FC reagent (diluted 1:1 v/v with water) and shaken for 3 min. This was followed by the addition of 1.6 mL of sodium carbonate solution (7.5% w/v) and then 10 mL of distilled water to bring the volume up to 10 mL. The solution was incubated at 50°C, then allowed to cool at room temperature. At 760 nm, absorbance was recorded against a reagent blank of 0.4 mL water, 2 mL FC reagent (diluted 1:1) and 1.6 mL sodium carbonate solution. Gallic acid standards were used to construct a calibration curve. The total phenolic content was measured as (mg GAE/100 g) milligrams of gallic acid equivalents per 100 g of dry weight. Each measurement was done thrice.

2.5. The total flavonoid content (TFC)

The total flavonoid content was measured by the aluminum chloride colourimetric method [32] as described earlier with some modifications. In short, 1 mL of plant extract was poured into 10 mL volumetric flask which contained 4 mL double distilled water. 0.3 mL of 5% (w/v) sodium nitrite solution was added at time zero. After 5 min, 0.3 mL of 10% (w/v) AlCl3 solution was added. After 6 min, 2 mL of 1 M NaOH was added to the mixture. It was immediately diluted to 10 mL with double-distilled water and then mixed thoroughly. The absorbance of the pink product was then measured at 510 nm using a reagent blank with the solvent instead of the extract. The total amount of flavonoids was determined by using a calibration curve for the standards of catechins. Each analysis was carried out three times.

2.6. Assessment of antioxidant activity

The antioxidant properties of the extracts were tested by two complementary techniques: DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging test, and ABTS + radical scavenging test. All measurements were in triplet.

2.6.1. DPPH radical scavenging assay

Radical scavenging assays measure the capacity of target compounds to scavenge free radicals. The DPPH radical scavenging assay was used to determine the antioxidant capacity, as modified from Szydłowska-Czerniak et al. [32] and Thadhani et al. [33]. Briefly, 0.5 mL of the test sample extract was mixed with 0.5 mL of DPPH solution. The control was made up of 0.5 mL of methanol and 0.5 mL of DPPH solution. Methanol was used as a spectrophotometric blank. Absorbance was measured at 517 nm and scavenging capacity was determined by comparison with a standard curve of Trolox. The percent of radical scavenging activity was determined by the use of Equation (1):

$$DPPH\ scavenging\ activity\ (\%) = DPPH\ scavenging\ activity\ (\%) = [(A_control - A_sample)\ /\ A_control] \times 100 \quad (1)$$

A control is the absorbance of the control, and A sample is the absorbances of the sample or the standard. Results were given in terms of micromolar Trolox equivalent per 100 g dry weight (μmol TE/100 g).

2.6.2. ABTS radical scavenging assay

ABTS radical scavenging activity was measured spectrophotometrically by the percentage of the inhibition of the ABTS radical by following the protocol [34,35]. An equal amount of potassium persulfate solution (2.45 mM) and ABTS solution (7 mM) were reacted to obtain the $ABTS^{\cdot+}$ radical cation. The incubation of the mixture was carried out in darkness at room temperature during 17 h. This solution was then diluted with methanol to get an absorbance of 0.700-0.800 units at 734 nm. In the assay, 0.5 mL of the plant extract was reacted with 2.5 mL of fresh ABTS + solution in a 6 min reaction time. The blue-green ABTS solution was discolored and the scavenging activity was computed using Trolox standard solutions (2.5–12.5 μg/mL) as a reference point.

The percentage inhibition was calculated as in Equation (2):

$$ABTS^{\cdot+}\ radical\ scavenging\ activity\ (\%) = [(A_control - A_sample)\ /\ A_control] \times 100 \quad (2)$$

A control is the absorbance of the ABTS + radical in methanol, and A sample is the absorbance of the ABTS + radical solution in methanol with the sample extract or standard. The findings were reported as micromolar Trolox equivalents/100 g dry weight (μmol TE/100 g). Organic Acids and Polyphenols.

2.7. High performance liquid chromatography analysis (HPLC)

All the leaf and fruit tissues (0.2g) were separately prepared and organic acids were extracted from them using 80% acetone as the extraction solvent. The 80% acetone selection was made because it has been proven that it is effective in extracting both polar and moderately polar organic acids while limiting the extraction of interfering lipophilic compounds [36,37]). The use of acetone-water mixtures is particularly advantageous for extraction of organic acids, since they are good hydrogen bond disruptors which can enhance extraction yields [37]. All the samples were macerated at room temperature for 48 h in 15 mL of 80% acetone, and then ultrasound assisted extraction (USAE) at room temperature for 15 min in 10 mL of 80% acetone, five times. Optimum ultrasonic parameters used were 80 kHz frequency and full power to ensure disruption of cell wall and improve the mass transfer without thermal degradation of thermolabile organic acids. The combined extracts were condensed with a rotary evaporator (IKA RV 05 basic, Werke, Germany) at 40°C and then up to 50 mL with 80% acetone. The ultrasonic parameters such as frequency (80 kHz) and full power were optimized for cell wall disruption to promote mass transfer without causing thermolabile organic acids to be degraded. The combined extracts were concentrated by using a rotary evaporator (IKA RV 05 basic, Werke, Germany) at 40°C and were then reconstituted in 80% acetone to 50 mL. All extracts were kept at −20°C for HPLC analysis. Recovery experiments, similar to those used in previous studies to validate the extraction efficiency of this method to extract organic acids from Rosaceae species [38,39], showed that the recovery efficiency of malic acid, tartaric acid and citric acid ranged between 92 and 98%, 89-95% and 85-91% respectively, which was comparable with previous studies.

The solvent system used was 80% methanol for the extraction of polyphenols. Methanol-water mixtures are well known to have the best ability to extract a wide range of phenolic compounds, such as hydroxycinnamic acid derivatives, flavonoids, and phenolic acids [40,41]. The high methanol content (80%) helps to break hydrogen bonds between the phenolic compounds and polysaccharide-protein matrices, resulting in better extraction yields, and the presence of the remaining water helps the extraction of more hydrophilic polyphenolic glycosides [40,41]. About 1 g of the separately prepared leaf or fruit tissues was ground well with 10 mL of 80% methanol solution. This mixture was sonicated for 30 min at 80 kHz frequency at full ultrasonic power to guarantee the cellular disruption and to recover polyphenols as much as possible. The extract was then centrifuged at 4500 r.p.m for 20 min, and filtered through a 0.45 μm syringe filter (Millipore, USA) before HPLC injection. The extraction efficiencies of the total phenolics for the extraction of catechin, caffeic acid and p-coumaric acid were evaluated by comparing phenolics extracted with phenolics reported in the literature for Mespilus species, the extraction efficiency of 88-96% catechin, 86-93% caffeic acid and 84-90% p-coumaric acid are similar to the recovery reported by previous researchers [42,43].

2.7.1. HPLC analysis for organic acids

Jasco HPLC chromatograph (Japan) fitted with an HPLC pump (Model PU-980), ternary gradient unit (Model LG-980-02), column thermostat (Model CO-2060 Plus), UV-Vis detector (Model UV-975) and refractive index detector (Model RI-2031 Plus) and an injection valve with a 20 μL sample loop (Rheodyne) were used to carry out the analyses. A Hamilton Rheodyne syringe (50 μL) was used to hand inject the samples. The control of the HPLC system and the analysis of experimental data were by ChromPass software. HPLC was performed on a column consisting of Kromasil-NH2 (250 × 4.6 mm, 5 μm). Elution was isocratic and the mobile phase was acetonitrilewater (70:30, v/v) at a flow rate of 1 mL/min. Detection was done with a refractive index detector. The column temperature was kept to 25°C and injection volume at 20 μL.

2.7.2. Polyphenol content HPLC analysis

All analyses were done on a Jasco HPLC chromatograph (Japan) with an HPLC pump (Model PU-980), a ternary gradient unit (Model LG-980-02), a column thermostat (Model CO-2060 Plus), an UV-Vis detector

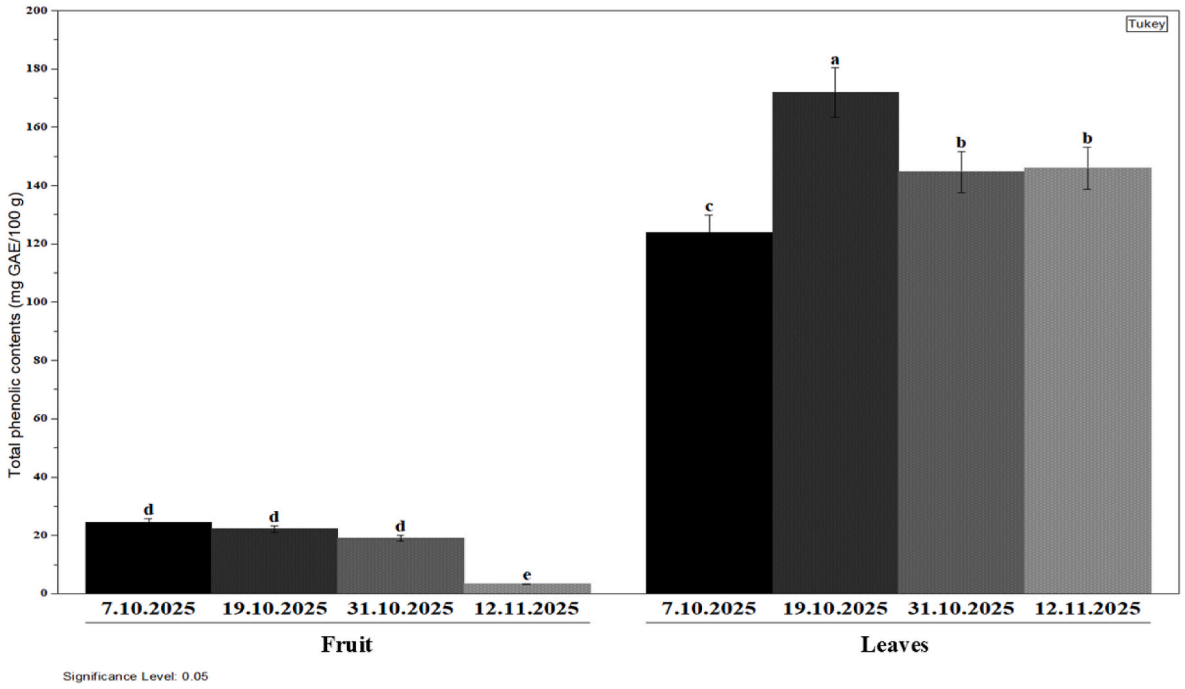


Fig. 1a. Total phenolic content (mg GAE/100 g) of *Mespilus germanica* fruit and leaves during four different harvesting stages.

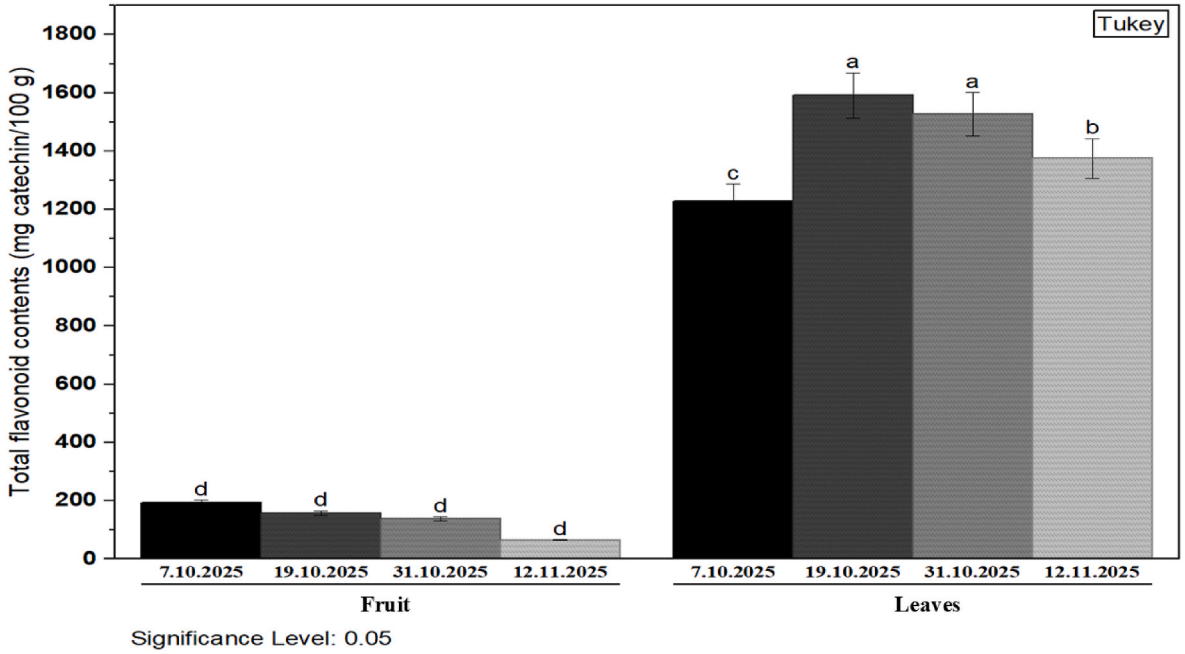


Fig. 1b. Total Flavonoid content (mg Catechin/100 g) of *Mespilus germanica* fruit and leaves during four different harvesting stages.

(Model UV-975) and a refractive index detector (Model RI-2031 Plus) and an injection valve using a 20 μL sample loop (Rheodyne). With a Hamilton Rheodyne syringe (50 50 μl), the samples were manually injected. ChromPass software was used to control the HPLC system and analyze the data of the experiment. The HPLC separation was done in a TRACER EXCEL 120 ODS column (4.6 × 250 mm, 5 μm). The elution was done using a gradient mobile phase of methanol (B) and 0.1% formic acid solution (C) and a flow rate of 1 mL/min. The following was the gradient program: initial 10% B to 25% B for 10 min, followed by 30% B to 50% B for 25 min and maintained up to 20 min, followed by 10% B to initial. The column temperature was kept to 25°C, injection volume was 20 μL, and detection was made at 270 nm.

2.8. Statistical analysis

Each experiment was carried out thrice and results were given as means and standard deviation. IBM SPSS statistics version 22 (IBM, Armonk, NY, USA) were used to perform statistical tests that included analysis of variance (ANOVA) then followed by a *t*-test ($p < 0.05$) and post hoc test ($p < 0.05$) (Tukey). To test the associations between various physicochemical properties and significant differences at different maturation phases, Pearson correlation analysis was performed

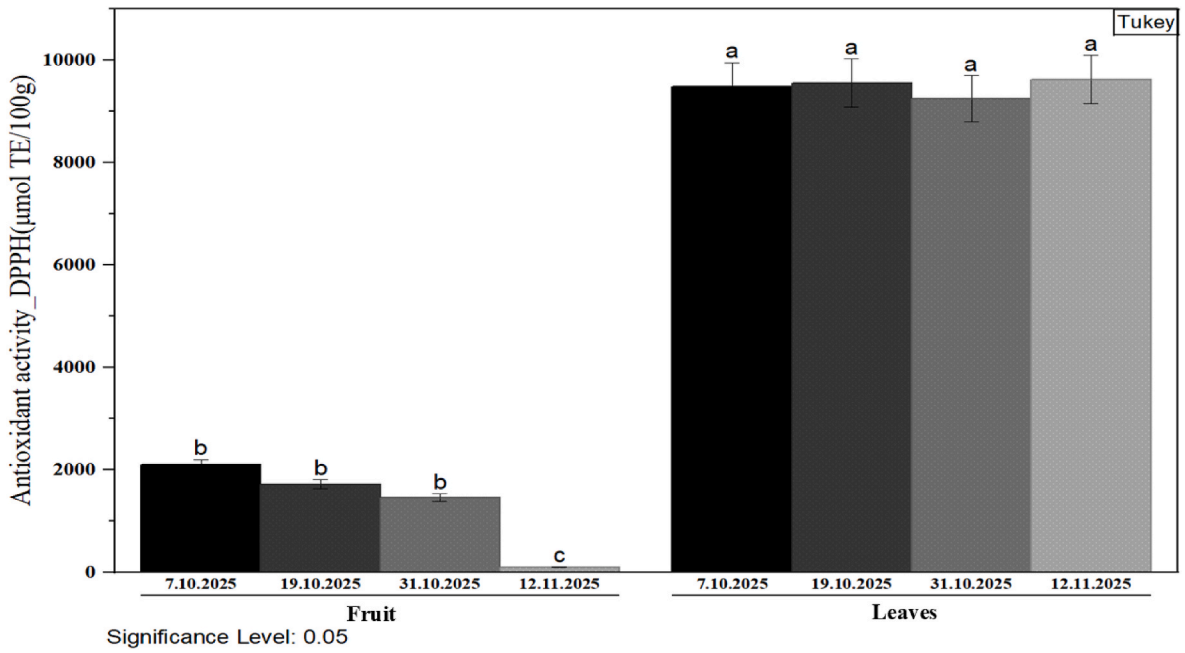


Fig. 2a. DPPH FRSA activity (µmol TE/100 g) of *Mespilus germanica* fruit and leaves during four different harvesting stages.

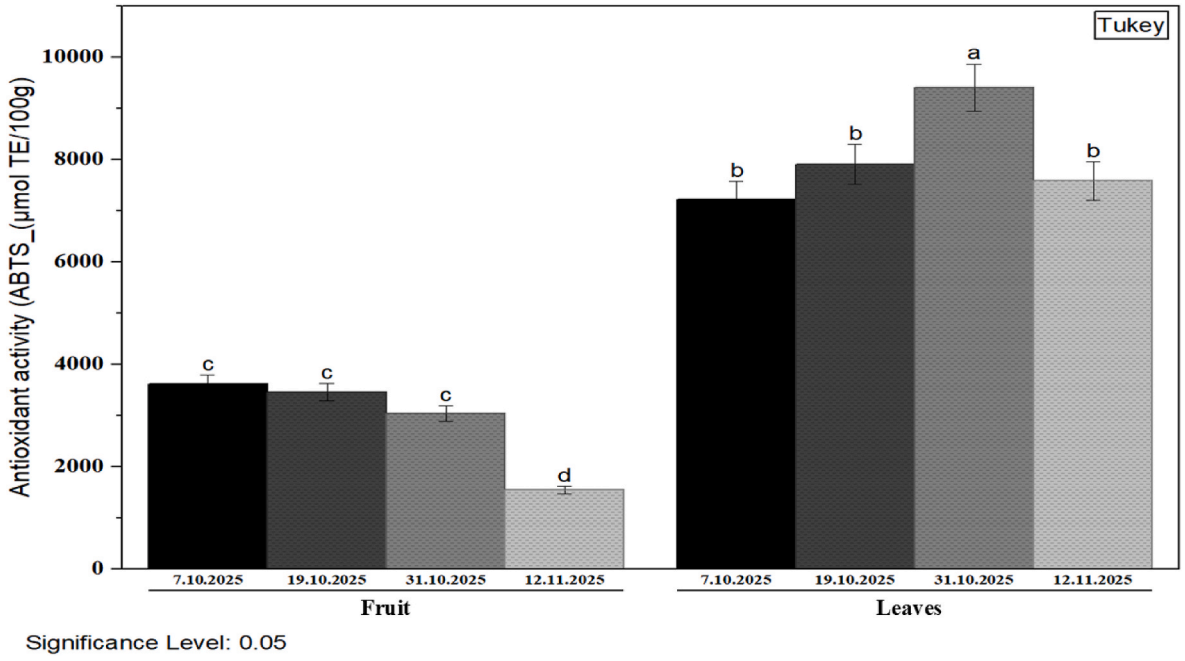


Fig. 2b. ABTS Antioxidant activity (µmol TE/100 g) of *Mespilus germanica* fruit and leaves during four different harvesting stages.

Table 1
Quantitative analysis of Organic acid content in *Mespilus germanica* L. by HPLC.

Sample	Oxalic acid	Citric acid	Tartaric acid	Malic acid	Succinic acid	Fumaric acid
7.10.2025_Mosmon fruits	0 ± 0	0 ± 0	7.4 ± 0.7	142.26 ± 13.55	0 ± 0	0.09 ± 0.01
7.10.2025_Mosmon leaves	9.67 ± 0.92	488.08 ± 46.49	18.94 ± 1.8	793.02 ± 75.54	0 ± 0	9.46 ± 0.9
19.10.2025_Mosmon fruits	0 ± 0	0 ± 0	3.61 ± 0.34	49.76 ± 4.74	0 ± 0	0 ± 0
19.10.2025_Mosmon leaves	0 ± 0	365.24 ± 34.79	48.77 ± 4.65	591.53 ± 56.34	0 ± 0	17.49 ± 1.67
31.10.2025_Mosmon fruits	11.56 ± 1.1	0 ± 0	13.17 ± 1.25	72.68 ± 6.92	0 ± 0	0.18 ± 0.02
31.10.2025_Mosmon leaves	0 ± 0	402.04 ± 38.3	20.38 ± 1.94	405.53 ± 38.63	0 ± 0	4.6 ± 0.44
12.11.2025_Mosmon fruits	0.98 ± 0.09	0 ± 0	12.13 ± 1.16	269.8 ± 25.7	5.27 ± 0.5	0 ± 0
12.11.2025_Mosmon leaves	0 ± 0	180.01 ± 17.15	453.45 ± 43.19	1059.4 ± 100.91	0 ± 0	0.76 ± 0.07

Table 2
Quantitative analysis of Phenolic compounds in *Mespilus germanica* L. by HPLC.

Sample	Gallic acid	Catechin	Chlorogenic acid	Vanillic acid	Caffeic acid	Syringic acid	p-coumaric acid	Ferulic acid	Sinapic acid	Rutin	Quercetin	Luteolin
7.10.2025_Mosmon Leaves	0 ± 0	0 ± 0	1.86 ± 0.02	0.22 ± 0	0 ± 0	0.17 ± 0	0 ± 0	0 ± 0	0.41 ± 0	0 ± 0	0 ± 0	0 ± 0
7.10.2025_Mosmon Fruits	0 ± 0	0.46 ± 0	43.64 ± 0.43	7.51 ± 0.07	0 ± 0	0 ± 0	0 ± 0	6.6 ± 0.07	0 ± 0	169.78 ± 1.68	0.3 ± 0	0.28 ± 0
19.10.2025_Mosmon Leaves	0 ± 0	11.26 ± 0.11	0.62 ± 0.01	0.22 ± 0	0.14 ± 0	0.09 ± 0	0.56 ± 0.01	0 ± 0	0 ± 0	0 ± 0	0 ± 0	2.18 ± 0.02
19.10.2025_Mosmon Fruits	0.91 ± 0.01	14.38 ± 0.14	1.21 ± 0.01	1.42 ± 0.01	0.27 ± 0	0.43 ± 0	14.38 ± 0.14	6.92 ± 0.07	29.57 ± 0.29	35.76 ± 0.35	6.84 ± 0.07	1.46 ± 0.01
31.10.2025_Mosmon Leaves	0.09 ± 0	6.86 ± 0.07	4.91 ± 0.05	0 ± 0	0 ± 0	0.16 ± 0	0 ± 0	0.59 ± 0.01	2.29 ± 0.02	0.41 ± 0	0 ± 0	0 ± 0
31.10.2025_Mosmon Fruits	2.3 ± 0.02	55.43 ± 0.55	5.3 ± 0.05	3.4 ± 0.03	10.15 ± 0.1	0.5 ± 0	0.53 ± 0.01	1.19 ± 0.01	32.61 ± 0.32	7.12 ± 0.07	5.71 ± 0.06	1.61 ± 0.02
12.11.2025_Mosmon Leaves	0.45 ± 0	0.48 ± 0	0.91 ± 0.01	0 ± 0	0.53 ± 0.01	0 ± 0	0.08 ± 0	0.31 ± 0	0.8 ± 0.01	0.43 ± 0	0 ± 0	0 ± 0
12.11.2025_Mosmon Fruits	1.83 ± 0.02	14.19 ± 0.14	17.34 ± 0.17	0.52 ± 0.01	3.96 ± 0.04	0 ± 0	0.6 ± 0.01	0.59 ± 0.01	3.05 ± 0.03	10.69 ± 0.11	1.06 ± 0.01	0.37 ± 0

with OriginPro 2021 software (OriginLab Corporation, Northampton, MA, USA), which was integrated with Python to provide greater opportunities of data processing and visualization. In predicting the changes in the phenolic compounds and organic acids in leaves and fruit of the plant a hierarchical clustering model was used in OriginPro 2021 incorporating Python integration to create a heatmap showing the comparison of the concentrations of the compounds and the clustering patterns of the samples within the data table [18].

3. Results and discussion

The overall biochemical analysis of the Mosmon leaves and fruits in the respective month of October to November 2025 have demonstrated that both foliar tissues and fruit exhibited a very high biochemical potential (Table S1).

3.1. Total phenolic content (TPC) and total flavonoid content (TFC) of the Mosmon leaf and fruit extracts

The phenolic compounds constitute one of the most valuable families of plant secondary metabolites, and are well known for their well differentiated biological activities. Antioxidant, antimicrobial, anti-inflammatory, anti-mutagenic activity, neuro-protective activity and cardio-protective activity [44]. The multifunctional properties of the plant-based phenolics have created a tremendous health-promoting potential and application of the phenolics could play a role in the prevention and treatment of various chronic diseases including cardiovascular diseases, cancer, diabetes, neurodegenerative diseases, depression, arthritis, infections, obesity and metabolic syndromes [44–47]. This has resulted in the great interest in the phenolic compounds in the following research studies: phytochemistry, food science and cosmetics development. To increase their usefulness in different industrial applications, therefore, a closer insight into their composition and working mechanisms in plant tissues is necessary [46,48].

Mosmon leaf extracts exhibited the highest Total Phenolic Content (TPC), with a maximum value of 171.88 ± 8.4 recorded on October 19, 2025, followed by 146.05 ± 7.17 on November 12, 2025, and 144.67 ± 7.1 on October 31, 2025 (Fig. 1a). The same trend was noticed with Total Flavonoid Content (TFC) with significantly higher values for the extracts from leaves than for extracts of fruits. The highest flavonoid content was found in the sample collected on October 19, 2025 (1590.98 ± 78.15), followed by those from November 12, 2025 (1375.67 ± 67.5), and October 7, 2025 (1227.40 ± 60.2). Taken together these results indicate that mid to late-October would be an ideal time for physiological development of polyphenolic secondary metabolites in foliar tissues of this species (Fig. 1b). The results from this study are similar to those from several earlier studies. This is largely due to the leaf's role as a plant's defense system. Leaves are the organs where photosynthesis takes place and are perpetually under attack by the environment such as UV radiation, pathogen attack and herbivory [49–51]. These stresses induce the synthesis and deposition of phenolic compounds, which are protective antioxidants and defensive molecules (chemical defenses) [52–54].

The leaves have significantly more phenols and flavonoids than the fruits due to several factors. Firstly, leaves are long-lived and perennial organs which need to remain functional for long periods of time [55], so they should have a strong and persistent antioxidant system to deal with the chronic low level of oxidative stress that comes with fluctuations in light and temperature [56]. The fruits, by contrast, are short-lived reproductive organs, each having a relatively short window of development, after which they become senescent or are dispersed, for which there is no need for long-term chemical protection. Secondly, leaves are vulnerable to aerial pathogens such as fungal spores from the air and insect herbivores and therefore have large amounts of phenolics on the surface and within the leaves as first-line defenses. Fruits can be susceptible, but may be sheltered from attack by large seed coats or simply

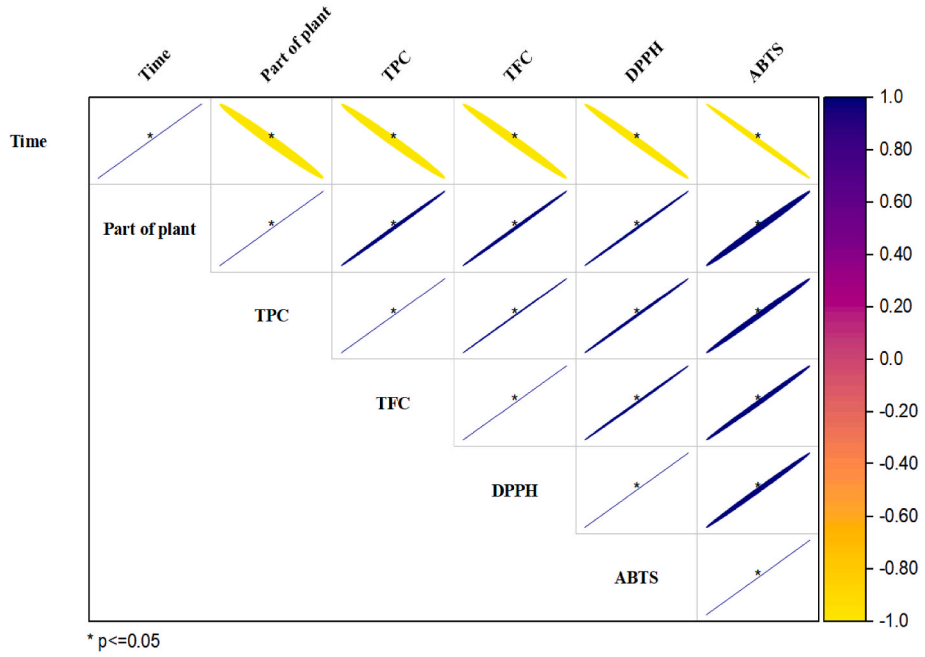


Fig. 3. Pearson correlation coefficients between harvest time, plant part (leaves and fruit) and biological activity (TPC, TFC, DPPH and ABTS).
Note: TPC (total phenolic content); TFC (total flavonoid content); DPPH (2,2-diphenyl-1-picrylhydrazyl); ABTS (2-2′azino-bis(3-ethylbenzothiazoline-6-sulfonic acid).

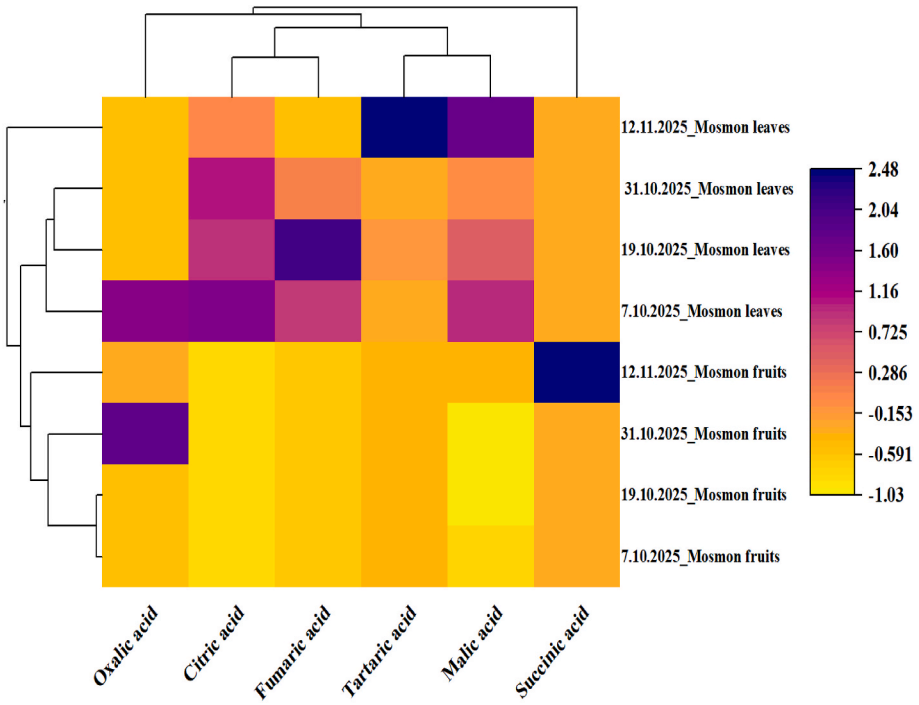


Fig. 4. Hierarchical clustering heatmap of organic acid profiles in *Mespilus germanica* leaves and fruits across four developmental stages. The color gradient represents the Z-score normalized concentrations, ranging from low abundance (yellow) to high abundance (dark blue). Dendrograms indicate the degree of similarity between samples (vertical) and the co-regulation of specific organic acids (horizontal).

by their location in the canopy, which could reduce their need for high levels of soluble phenolics. Third, during fruit ripening, metabolic priorities change quite drastically, with increased sugar content and softening to promote dispersal, which is associated with the enzymatic degradation of phenolics by polyphenol oxidase and peroxidase. This catabolic process together with the dilution effect due to the increase in water and carbohydrate content, results in a gradual decrease in phenolic content. Unlike leaves, however, leaves have a more steady anabolic profile, and they are constantly feeding carbon flow into secondary metabolite pathways, particularly those of stress. This is due to these physiological and developmental differences, as well as ecological differences, which result in higher total phenolic and flavonoids production from leaf tissues as compared to fruits, consistently [54,57]. Pearson correlation matrix was developed to assess the linearity

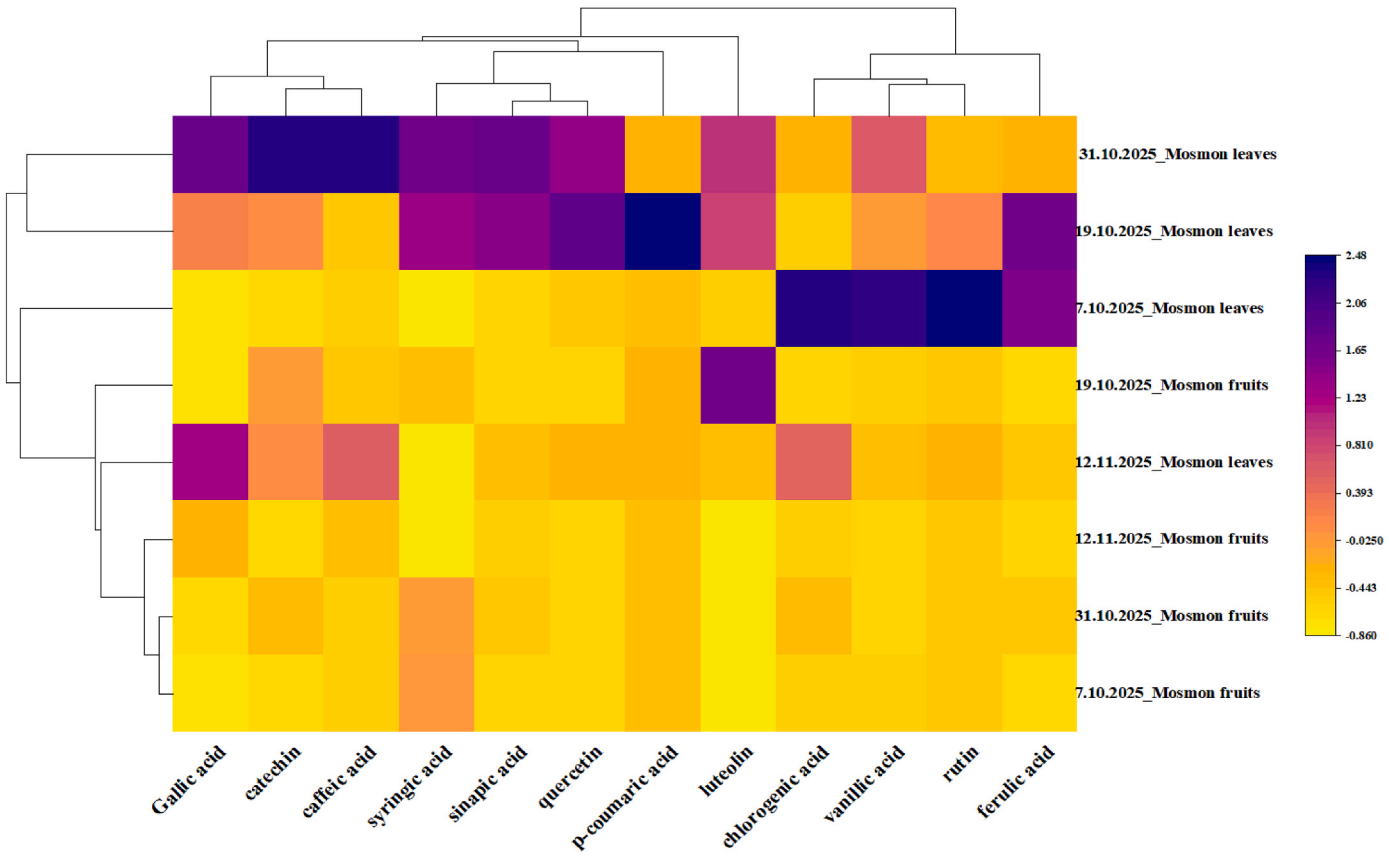


Fig. 5. Hierarchical clustering heatmap of individual phenolic and flavonoid phenols that have been detected by HPLC in *Mespilus germanica* of four harvesting intervals in both leaves and fruits. The color intensity range (Z-score) shows the percentage concentration of every metabolite, between the lowest (yellow) and the highest (dark blue). Dendrograms demonstrate how the samples cluster according to the chemical similarity (vertical) and the relationship between the various phenolic markers (metabolism) (horizontal).

between the various variables such as harvest stage (Time), tissue type (Part of plant), Total Phenolic Content (TPC), Total Flavonoid Content (TFC), radical scavenging activities (DPPH and ABTS). There was an exceptionally high positive correlation between plant organ identity and TPC, TFC, DPPH scavenging capacity ($r = 0.9772$, 0.9851, 0.9891, respectively) and ABTS activity ($r = 0.9479$). This indicates that the plant organ identity (leaves vs fruits) is the predominant factor influencing bioactive accumulation and functioning of antioxidant activity in plants. In addition, very high correlations were found between TPC and TFC ($r = 0.9956$) and between total phytochemical concentration and antioxidant assays (TPC vs. DPPH: $r = 0.9832$; TPC vs. ABTS: $r = 0.9598$; TFC vs. DPPH: $r = 0.9841$; TFC vs. ABTS: $r = 0.9710$). This very high co-linearity suggests that there is a direct correlation between the phenolic and flavonoid content and the extracts' radical scavenging potential. However, harvest time showed relatively low positive correlations with the biochemical parameters (correlation coefficients between 0.1251 and 0.2182), indicating that the temporal variability along the season was secondary and mostly dependent on the strong effect of tissue differentiation (Fig. 3; Table S2) (see Fig. 4).

3.2. Antioxidant activity

The antioxidant activity of the extracts were assessed by using two complementary in vitro assays: DPPH (2,2-diphenyl-1-picrylhydrazyl) free radical scavenging assay and ABTS (2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)) radical cation decolorization assay. Both assays showed that the antioxidant properties and antioxidant profile of leaf extracts were significantly better and more stable than those of fruit extracts. Interestingly, this increased activity was not significantly dependent on seasonal changes in phenols concentration in the leaves, indicating a strong and constant antioxidant defense system. The highest DPPH radical scavenging activity (9621.15 ± 472.6) was recorded in the last sampling point on 12 November 2025 and the maximum ABTS activity (9407.08 ± 462.09) was also obtained in this last sampling point, suggesting that the foliar tissues possessed a strong radical-neutralizing activity throughout the season (Figs. 2a and 2ba-b). The antioxidant capacity of the extracts of the fruits, however, was consistently lower and showed a significant and gradual decrease with the advancement in November. This decline in fruit production as the growing season progresses is in direct contrast with the observed stability or improvements in leaf production, highlighting the value of leaf tissues as reliable sources of bioactive compounds in the later part of the growing season. The marked differences in antioxidant activities between leaves and fruit may be due to their different physiological functions and stress. Leaves are perennial, metabolically active organs subject to persistent and varying environmental stresses such as high levels of ultraviolet radiation, changes in temperature, invasion by pathogenic microbes and a constant pressure of herbivores. These chronic stressors stimulate the phenomenon of phenolics and flavonoids upregulation in the phenylpropanoid pathway, leading to the constitutive and induced production of a broad spectrum of phenolic and flavonoid compounds. These metabolites are in fact powerful reductive agents that help to neutralize the appearance of reactive oxygen species (ROS) in the event of stress, yet they also assume a chemical deterrent role against herbivores or pathogens [53,54]. The fruits, however, are ephemeral, with only a brief life, and their main function is to mature seeds and disperse them. Their metabolic flux during ripening is predominantly directed towards the accumulation of soluble sugars,

organic acids and pigments, which are needed to attract dispersers, while at the same time, the endogenous oxidative enzymes (polyphenol oxidase and peroxidase) are activated, leading to the degradation of phenolic substrates by oxidative processes. The enzymatic degradation and dilution effect due to the influx of water and the deposition of carbohydrates, result in a net decrease in the concentration and reducing capacity of phenolic compounds. As a result, the leaves' continual biosynthetic commitment to secondary metabolism, as a response to ongoing external threats, provides a much greater and more stable reservoir of antioxidants compared to fruits, which undergo programmed senescence and metabolic reprogramming [53,54].

3.3. Organic acid in Mespilus germanica fruit and leaf extracts quantitative analysis

The quantitative analysis of organic acids in the tree *Mespilus germanica* (Mosmon) showed that it has a unique biochemical architecture per tissue. Of the organic acids, malic acid was found in the highest concentrations in both leaf and fruit tissues, although the concentrations were always significantly higher in the leaf tissues (Table S3). This differential accumulation indicates a basic difference in primary metabolic functions: Leaves would be more active sites for the production or storage of organic acids.

A temporal accumulation pattern was observed in the leaf tissues. The highest concentration of malic acid occurred in the last harvest (12 November 2025; 1059.4 ± 100.91 μg/g). The peak occurred alongside a significant (and noticeable) rise in tartaric acid (453.45 ± 43.19 μg/g) suggesting a synergic accumulation of the major acids during late autumn. One interesting note was that citric acid was only present in the leaf extracts, and not in any of the fruit samples. This lack highlights a significant biochemical difference which implies the differentiation of partitioning or metabolism of the intermediates of the tricarboxylic acid (TCA) cycle between reproductive and vegetative tissues. The profile of the acids was much simpler in fruits, consisting mainly of malic acid and tartaric acid. The level of malic acid was raised with time but the rise was slight, and would not lead to any significant metabolic change in the fruit by the November harvest (269.8 ± 25.7 μg/g), confirming the metabolic quiescence of the fruit compared to the leaf.

Both tissues contained fumaric acid although in much lower concentrations than the fruits and leaves had consistently higher concentrations, the highest being in mid-October (17.49 ± 1.67 μg/g). Succinic acid was not detected in many of these samples except in a few samples of late October fruit extracts. The sporadic occurrence in fruits may relate to the early phases of ripening and/or physiological stresses, and the overall lack of the TCA cycle, indicate that it is not a major source of carbon storage in these tissues. These results collectively demonstrate that leaves are a much more concentrated and metabolically rich source of organic acids than fruit, and that mid-November is the optimal time for leaf tissues to contain a high concentration of accumulated organic acids.

Hierarchical cluster analysis (HCA) was used to further clarify these biochemical differences. The resulting heat map was highly distinct and clearly divided into two main groups, with the main driver being tissue type and not harvest time, indicating that the metabolic profile of *M. germanica* is more strongly influenced by organ identity than harvest time. The heat map upper part cluster was mainly composed of high relative abundance of citric acid and fumaric acid, which were either very low in abundance or not present at all in fruit samples. In the late season samples (12 November 2025), there was a unique metabolic shift with the highest levels of malic and tartaric acids being the most intense dark blue cells within the leaf clade. The plant's organic acid accumulation during this time is presumably active and dynamic, and could be related to cold acclimation and osmotic adjustment to prepare for winter dormancy. Virtually the opposite were recorded for the fruit cluster, with the exception of the last harvest (12 November 2025), where an isolated succinic acid peak was observed. Could be due to ripening or because it is a post-harvest softening process for Mosmon fruits (bletting) characterized by metabolic reprogramming that occurs at the beginning of ripening. This change was a local one, however, and not led to a greater number of acid types than in leaves. These data make it clear that metabolism of *M. germanica* is highly tissue specific, with the leaves always showing a higher concentration and diversity of organic acids, more so than fruits, and a more dynamic response to seasonal change. The results support the use of leaf tissues, especially those collected during mid to late autumn, as an excellent source of organic acid metabolites which are pharmacologically useful [58,59] (see Table 1).

3.4. Quantitative determination of polyphenol content in Mespilus germanica fruit and leaf extracts

Significant organ and temporal variation were found in the phenolic and flavonoid content of *Mespilus germanica* at the four harvest dates. Fruit extracts had a broader range of individual bioactive markers and higher concentrations than leaf extracts (Table S4), a notable aspect of which is that the range of these markers was more extensive than the leaf extracts. The rutin was the most abundant compound in early fruits (169.78 ± 1.68 mg/100g on 07.10.2025) with sharp decrease during the season. Likewise, appreciable initial concentrations of chlorogenic acid and catechin were found in fruits, and they were relatively stable throughout subsequent harvests. Leaf samples, on the other hand, exhibited relatively low amounts of these specific markers, specifically chlorogenic acid and sinapic acid, which seemed to be present most consistently, but in small concentrations. The metabolic richness of fruits reached its zenith during the 31.10.2025 harvest, characterized by elevated levels of catechin (55.43 ± 0.55 mg/100g), caffeic acid (10.15 ± 0.1 mg/100g), and sinapic acid (32.61 ± 0.32 mg/100g). The HPLC-based characterization clearly shows that fruits are a much more concentrated source of the high value individual flavonoids and hydroxycinnamic acids than leaf tissues, with fruits at the mid-to-late stage of maturity (mid-to late October) providing the highest content of these phytochemicals (Table 2).

Furthermore, hierarchical cluster analysis (HCA) was used to further clarify the metabolic differences between tissues, and to show the differences in clustering for each organ. The heatmap showed that the samples of leaves clustered together in a separate clade with elevated relative abundances for some phenolic markers along with significant temporal variation. The dark blue and purple clusters of leaves from October (31.10.2025 and 19.10.2025), represented the highest level of accumulation for catechin, caffeic acid and p-coumaric acid. Fruit samples, on the other hand, fell in a separate clade and rather uniform and relatively “cooler” profile, predominantly yellow, because the relative concentrations of these specific markers were rather low throughout the study period. One particularly interesting exception is the enrichment of chlorogenic acid, vanillic acid and rutin in the early season leaf sample (07.10.2025) compared to both the later leaf samples and all of the fruit samples. Leaves appear to be the source of most of the phenolic diversity and the chemical profile changes quite dramatically towards mid-autumn when the hydroxycinnamic acids dominate to a more flavonoid-concentrated profile (Fig. 5).

The overall results constitute a complementary biochemical profile: the leaves are a rich source of a wide range of total phenolics, and have higher aggregate antioxidant activity, while the fruits contain higher concentrations of specific high-value bioactive compounds such as rutin, chlorogenic acid and catechin, which are best accumulated at the mid-to-late October harvest. The dual use of *M. germanica* for functional food applications is highlighted, with fruits being the major sources of targeted bioactive compounds and leaves being valuable for total phenolic diversity applications [53,60].

The present study establishes a novel and significant finding—*Mespilus germanica* leaves represent an untapped, high-potency, and reproducibly superior ingredient for functional food development. As long-lived vegetative organs, leaves maintain a persistent metabolic

defense against chronic environmental stresses, resulting in the accumulation of significantly higher total phenolics (171.88 mg GAE/100 g), flavonoids (1590.98 mg catechin/100 g), and antioxidant activity (>9600 μmol TE/100 g) compared to fruits. Notably, leaves uniquely contain citric and fumaric acids—compounds absent in fruit tissues—demonstrating higher metabolic diversity. The reproducible superiority of leaves over fruits across five harvest dates establishes leaves as a more reliable and sustainable source of bioactives. Defining mid-to-late October (October 19-31) as the empirical harvest window for peak bioactivity bridges agricultural waste upcycling with industrial food innovation.

4. Conclusion

The aim of the present study was to conduct a detailed study on bioactive molecules present in *Mespilus germanica* L. fruits and leaves during the bletting process. The total phenolic content (171.88 mg GAE/100 g) and total flavonoid content (1590.98 mg catechin/100 g) of the leaf tissues were also higher than others, along with their antioxidant activity (DPPH: 9621.15 μmol TE/100 g; ABTS: 9407.08 μmol TE/100 g). Specific high value phenolics, however, were found in higher concentrations in fruits, such as rutin (169.78 mg/100g), chlorogenic acid (43.64 mg/100g) and catechin (55.43 mg/100g). HPLC analysis showed that mid-to-late October (October 19–31) was the best time to harvest the fruits for the highest levels of these bioactive compounds. Both tissues were predominantly malic acid with leaves showing greater metabolic diversity, with the presence of citric and fumaric acids. The maximum level of malic acid was 1059.4 μg/g in leaves and 269.8 μg/g in fruits. The tissue-specific metabolic fingerprints were confirmed by hierarchical cluster analysis, which separated the leaves and fruits into two metabolic groups. Phenolic compounds had high positive correlation with antioxidant capacity ($r > 0.85$, $p < 0.001$) indicating their significant role in radical scavenging activity of both tissues. Finally, it may be concluded that the fruits of *M. germanica* can be used as a source of high value phenolics to be used in functional food and the leaves of the plant can be used as an additional source of total phenolics and metabolic acids to be exploited for their nutraceutical value.

CRediT authorship contribution statement

Doru Ion Nistor: Writing – original draft, Resources, Project administration, Conceptualization. **Romina Alina Marc:** Writing – review & editing, Writing – original draft, Visualization, Validation, Investigation. **Mihaela Vlassa:** Methodology, Investigation. **Miuța Rafila Filip:** Methodology, Formal analysis. **Rodica Ungur:** Writing – original draft, Software, Investigation. **Ioana Crivei:** Writing – original draft, Software, Resources. **Crina Carmen Mureşan:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration.

Conflict of interest

The authors declare no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jics.2026.103083.

References

[1] M.L. Brandi, F. Marini, S. Parri, S. Bandinelli, T. Iantomasi, F. Giusti, L. Ferrucci, Association of vitamin D and bisphenol A levels with cardiovascular risk in an elderly Italian population: results from the InCHIANTI study, GeroScience 46 (6) (2024) 6141–6156.

[2] D. Liu, N.A. Aziz, G. Pehlivan, M.M. Breteler, Cardiovascular correlates of epigenetic aging across the adult lifespan: a population-based study, GeroScience 45 (3) (2023) 1605–1618.

[3] Z. Ungvari, M. Fekete, P. Varga, A. Lehoczki, J.T. Fekete, A. Ungvari, B. Győrffy, Overweight and obesity significantly increase colorectal cancer risk: a meta-analysis of 66 studies revealing a 25–57% elevation in risk, GeroScience 47 (3) (2025) 3343–3364.

[4] X. Cao, M. Wang, M. Zhou, Y. Mi, V. Fazekas-Pongor, D. Major, Y. Guo, Trends in prevalence, mortality, and risk factors of dementia among the oldest-old adults in the United States: the role of the obesity epidemic, GeroScience 46 (5) (2024) 4761–4778.

[5] N. Goswami, A dual burden dilemma: navigating the global impact of communicable and non-communicable diseases and the way forward, Int. J. Med. Res. 12 (3) (2024) 65–77.

[6] Z.M. Abdullahi, O.I. Kingsley, M. Yusuf, U. Eo, M. Otutu, E.U. Nwose, Epidemiology, prevention and management of non-communicable diseases (NCDS): a review, J. Health Wellness Saf. Res. 7 (3) (2025) 161–178.

[7] A. Thomas, D.W. Belsky, Y. Gu, Healthy lifestyle behaviors and biological aging in the US National health and nutrition examination surveys 1999–2018, J. Gerontol.: Series A 78 (9) (2023) 1535–1542.

[8] C.M. Hasler, A.C. Brown, Position of the American dietetic association: functional foods, J. Am. Diet. Assoc. 109 (4) (2009) 735–746.

[9] S.A. Adefegha, Functional foods and nutraceuticals as dietary intervention in chronic diseases; novel perspectives for health promotion and disease prevention, J. Diet. Suppl. 15 (6) (2018) 977–1009.

[10] P. Ma, Z. Wang, Density functional theory study on antioxidant activity of three polyphenols, J. Fluoresc. 33 (3) (2023) 933–944.

[11] R. Fan, M. You, A.M. Toney, J. Kim, D. Giraud, Y. Xian, S. Chung, Red raspberry polyphenols attenuate high-fat diet–driven activation of NLRP3 inflammasome and its paracrine suppression of adipogenesis via histone modifications, Mol. Nutr. Food Res. 64 (15) (2020) 1900995.

[12] J. Yang, Y. Hao, N. Li, C. Wang, Y. Liu, Metabolic and microbial modulation of phenolic compounds from raspberry leaf extract under in vitro digestion and fermentation, Int. J. Food Sci. Technol. 56 (10) (2021) 5168–5177.

[13] C. Pavez-Guajardo, S.R. Ferreira, S. Mazzutti, M.E. Guerra-Valle, G. Sáez-Trautmann, J. Moreno, Influence of in vitro digestion on antioxidant activity of enriched apple snacks with grape juice, Foods 9 (11) (2020) 1681.

[14] G.R. Caponio, M. Noviello, F.M. Calabrese, G. Gambacorta, G. Giannelli, M. De Angelis, Effects of grape pomace polyphenols and in vitro gastrointestinal digestion on antimicrobial activity: recovery of bioactive compounds, Antioxidants 11 (3) (2022) 567.

[15] R.I. Eltaly, M.M. Baz, I.T. Radwan, M. Yousif, H.S. Abosalem, A. Selim, H.F. Khater, Novel acaricidal activity of Vitex castus and Zingiber officinale extracts against the camel tick, Hyalomma dromedarii (2023), https://doi.org/10.47278/journal.ijvs/2022.184.

[16] R. Kobori, R. Doge, M. Takae, A. Aoki, T. Kawasaki, A. Saito, Potential of raspberry flower petals as a rich source of bioactive flavan-3-ol derivatives revealed by polyphenolic profiling, Nutraceuticals 3 (2) (2023) 196–209.

[17] K.B. Sorathiya, A. Melo, M.C. Hogg, M. Pintado, Organic acids in food preservation: exploring synergies, molecular insights, and sustainable applications, Sustainability 17 (8) (2025) 3434.

[18] Z. Maqbool, A. Aftab, H. Rizwana, Z. Yousaf, S. Rehman, Tomato disease combat and yield optimization using selenium nanoparticles: a sustainable nano-agriculture approach, Food Sci. Nutr. 13 (7) (2025) e70386.

[19] İ. Gülçin, V. Mshvildadze, A. Gepdiremen, R. Elias, Antioxidant activity of saponins isolated from ivy: α-hederin, hederasaponin-C, hederacolchiside-E and hederacolchiside-F, Planta Med. 70 (6) (2004) 561–563.

[20] M. Oktay, İ. Gülçin, Ö.İ. Küfrevioğlu, Determination of in vitro antioxidant activity of fennel (Foeniculum vulgare) seed extracts, LWT–Food Sci. Technol. 36 (2) (2003) 263–271.

[21] M. Oktay, İ. Gülçin, Ö.İ. Küfrevioğlu, Determination of in vitro antioxidant activity of fennel (Foeniculum vulgare) seed extracts, LWT–Food Sci. Technol. 36 (2) (2003) 263–271.

[22] A. Saitama, D. Saptadi, M.D. Maghfoer, E. Widaryanto, Potential for production of Kencur (Kaempferia galanga L.) secondary metabolites with auxin and cytokinin in vitro. https://doi.org/10.47278/journal.ijab/2024.174, 2024.

[23] E. Bagheri, A.B. Shori, C.W. Peng, A.S. Baba, A.J. Alzahrani, Phytochemical analysis and medicinal properties of some selected traditional medicinal plants, Int. J. Agric. Biosci. 13 (4) (2024) 689–700, https://doi.org/10.47278/journal.ijab/2024.177.

[24] Z. Maqbool, M. Amir, A. Zereen, G. Abid, S. Wahab, Licorice, in: Essentials of Medicinal and Aromatic Crops, Springer International Publishing, Cham, 2023, pp. 763–787.

[25] E. Altuntaş, E.N. Gül, M. Bayram, The physical, chemical and mechanical properties of Mosmon (*Mespilus germanica* L.) during physiological maturity and ripening period, J. Agric. Fac. Gaziosmanpasa Univ. 30 (2013) 33–40.

[26] S. Cosmulescu, F. Scrieciu, O. Iordanescu, M. Manda, Some pomological characteristics of Mosmon (*Mespilus germanica* L.) genotypes, in: III International Symposium on Horticultural Crop Wild Relatives, 1259, 2018, October, pp. 43–46.

[27] F.A. Ayaz, H.S. Huang, L.T. Chuang, D.J. VanderJagt, R.H. Glew, Fatty acid composition of Mosmon (*Mespilus germanica* L.) fruit at different stages of development, Ital. J. Food Sci. 14 (2002) 439–446.

[28] S. Ercisli, M. Sengul, H. Yildiz, D. Sener, B. Duralija, S. Voca, et al., Phytochemical and antioxidant characteristics of Mosmon fruits (*Mespilus germanica* L.), J. Appl. Bot. Food Qual. 85 (2012) 86–90.

[29] R.H. Glew, F.A. Ayaz, C. Sanz, D.J. VanderJagt, H.S. Huang, L.T. Chuang, M. Strnad, Changes in sugars, organic acids and amino acids in Mosmon (*Mespilus germanica* L.) during fruit development and maturation, Food Chem. 83 (3) (2003) 363–369.
[30] R.H. Glew, F.A. Ayaz, C. Sanz, D.J. VanderJagt, H.S. Huang, L.T. Chuang, M. Strnad, Effect of postharvest period on sugars, organic acids and fatty acids composition in commercially sold Mosmon (*Mespilus germanica*'Dutch') fruit, Eur. Food Res. Technol. 216 (5) (2003) 390–394.
[31] R.H. Glew, F.A. Ayaz, D.J. Vanderjagt, M. Millson, R. Dris, R. Niskanen, Mineral composition of Mosmon (*Mespilus germanica*) fruit at different stages of maturity, J. Food Qual. 26 (5) (2003) 441–447.
[32] A. Szydłowska-Czerniak, K. Trokowski, G. Karlovits, E. Szłyk, Determination of antioxidant capacity, phenolic acids, and fatty acid composition of rapeseed varieties, J. Agric. Food Chem. 58 (13) (2010) 7502–7509. https://doi.org/10.1021/jf100852x.
[33] V.M. Thadhani, M.I. Choudhary, S. Ali, I. Omar, H. Siddique, V. Karunaratne, Antioxidant activity of some lichen metabolites, Nat. Prod. Res. 25 (19) (2011) 1827–1837.
[34] A.M. Alashi, C.L. Blanchard, R.J. Mailer, S.O. Agboola, A.J. Mawson, R. He, A. Girgih, R.E. Aluko, Antioxidant properties of Australian canola meal protein hydrolysates, Food Chem. 146 (2014) 500–506. https://doi.org/10.1016/j.foodchem.2013.09.081.
[35] R. Re, N. Pellegrini, A. Proteggente, A. Pannala, M. Yang, C. Rice-Evans, Antioxidant activity applying an improved ABTS radical cation decolorization assay, Free Radic. Biol. Med. 26 (9–10) (1999) 1231–1237. https://doi.org/10.1016/S0891-5849(98)00315-3.
[36] M. Gómez-Romero, A. Segura-Carretero, A. Fernández-Gutiérrez, Metabolite profiling and quantification of phenolic compounds in methanol extracts of tomato fruit, Phytochemistry 71 (16) (2010) 1848–1864. https://doi.org/10.1016/j.phytochem.2010.
[37] A.M. Fernández-Fernández, A. Iriondo-DeHond, T. Nardin, R. Larcher, E. Dellacassa, A. Medrano-Fernandez, M.D. Del Castillo, In vitro bioaccessibility of extractable compounds from Tannat grape skin possessing health promoting properties with potential to reduce the risk of diabetes, Foods 9 (11) (2020) 1575. https://doi.org/10.3390/foods9111575.
[38] G. Pande, C.C. Akoh, Organic acids, antioxidant capacity, phenolic content and lipid characterisation of Georgia-grown underutilized fruit crops, Food Chem. 120 (4) (2010) 1067–1075, https://doi.org/10.1016/j.foodchem.2009.11.054.
[39] M. Mikulic-Petkovsek, A. Slatnar, F. Stampar, R. Veberic, HPLC–MSn identification and quantification of flavonol glycosides in 28 wild and cultivated berry species, Food Chem. 135 (4) (2012) 2138–2146, https://doi.org/10.1016/j.foodchem.2012.06.115.
[40] J. Dai, R.J. Mumper, Plant phenolics: extraction, analysis and their antioxidant and anticancer properties, Molecules 15 (10) (2010) 7313–7352, https://doi.org/10.3390/molecules15107313.
[41] I. Ignat, A. Stingu, I. Volf, V.I. Popa, Characterization of grape seed aqueous extract and possible applications in biological systems, health 3 (2011) 4, https://doi.org/10.3390/molecules15107313.
[42] A.M. Pawlowska, F. Camangi, A. Bader, A. Braca, Flavonoids of Zizyphus jujuba L. and Zizyphus spina-christi (L.) Willd (Rhamnaceae) fruits, Food Chem. 112 (4) (2009) 858–862, https://doi.org/10.1016/j.foodchem.2008.06.053.
[43] S.F. Nabavi, S.M. Nabavi, S. Habtemariam, A.H. Moghaddam, A. Sureda, M. Jafari, A.M. Latifi, Hepatoprotective effect of gallic acid isolated from Peltiphyllum peltatum against sodium fluoride-induced oxidative stress, Ind. Crop. Prod. 44 (2013) 50–55, https://doi.org/10.1016/j.indcrop.2012.10.024.
[44] A. Palos-Hernández, A.M. González-Paramás, C. Santos-Buelga, Latest advances in green extraction of polyphenols from plants, foods and food by-products, Molecules 30 (1) (2024) 55.
[45] D. Szwajgier, K. Borowiec, K. Pustelniak, The neuroprotective effects of phenolic acids: molecular mechanism of action, Nutrients 9 (5) (2017) 477.
[46] A. Zeb, Concept, mechanism, and applications of phenolic antioxidants in foods, J. Food Biochem. 44 (9) (2020) e13394.
[47] F.T. Abd-El Ghany, S.H. Morsy, H.M.A. Hassan, A. Samy, Evaluation of olive leaves and pomace extracts in growing rabbit diets on productive performance, nutrient digestibility, carcass characteristics, antioxidant status and economic efficiency, Int. J. Vet. Sci. 12 (1) (2023) 37–44, https://doi.org/10.47278/journal.ijvs/2022.155.
[48] J. Popović-Djordjević, A.Ž. Kostić, S. Kamiloglu, M. Tomas, N. Mićanović, E. Capanoglu, Chemical composition, nutritional and health related properties of the Mosmon (*Mespilus germanica* L.): from medieval glory to underutilized fruit, Phytochem. Rev. 22 (6) (2023) 1663–1690.
[49] S.F. Nabavi, S.M. Nabavi, M.A. Ebrahimzadeh, H. Asgarirad, The antioxidant activity of wild Mosmon (*Mespilus germanica* L.) fruit, stem bark and leaf, Afr. J. Biotechnol. 10 (2) (2011) 283–289.
[50] U.M. Yunusa, R. Ozturk Urek, Phenolic composition, antioxidant, and cytotoxic effects on HeLa and HepG2 cancer cell lines of *Mespilus germanica* grown in Turkey, Nat. Prod. Res. 38 (11) (2024) 1972–1976.
[51] S.S. Isbilir, S.I. Kabala, H. Yagar, Assessment of in vitro antioxidant and antidiabetic capacities of Mosmon (*Mespilus germanica*), Not. Bot. Horti Agrobot. Cluj-Napoca 47 (2) (2019) 384–389.
[52] C. Voaides, N. Radu, E. Birza, N. Babeanu, Mosmon—A comprehensive and integrative review, Plants 10 (11) (2021) 2344.
[53] M. Teleszko, A. Wojdyło, Comparison of phenolic compounds and antioxidant potential between selected edible fruits and their leaves, J. Funct.Foods 14 (2015) 736–746, https://doi.org/10.1016/j.jff.2015.02.041Getrightsandcontent.
[54] A. Sharma, B. Shahzad, A. Rehman, R. Bhardwaj, M. Landi, B. Zheng, Response of phenylpropanoid pathway and the role of polyphenols in plants under abiotic stress, Molecules 24 (13) (2019) 2452.
[55] D. Mizusaki, K. Umeki, T. Honjo, Disentangling long-and short-term changes in perennial organ functions in seasonal environments: a model of foliar chlorophyll and nitrogen in saplings of four evergreen broad-leaved trees, Photosynthetica 53 (3) (2015) 356–368.
[56] M. Safari, S. Ahmady-Asbchin, Evaluation of antioxidant and antibacterial activities of methanolic extract of medlar (Mespilus germanica L.) leaves, Biotechnol. Biotechnol. Equip. 33 (1) (2019) 372–378.
[57] A. Wali, M. Gupta, S.A. Mallick, S. Gupta, S. Jaglan, Antioxidant potential and phenolic contents of leaf, bark and fruit Of" Aegle marmelos", J. Trop. For. Sci. (2016) 268–274.
[58] L.V. Lenchyk, B. Samaneh, V.S. Kyslychenko, Study of organic acids in almond leaves, Анналu Мечниковδського інституту (2) (2015) 47–50.
[59] W. Batista-Silva, V.L. Nascimento, D.B. Medeiros, A. Nunes-Nesi, D.M. Ribeiro, A. Zsögön, W.L. Araújo, Modifications in organic acid profiles during fruit development and ripening: correlation or causation? Front. Plant Sci. 9 (2018) 1689, https://doi.org/10.3389/fpls.2018.01689.
[60] J. Shi, D. Fang, Y. Sui, T. Xiong, X. Chen, C. Fan, X. Mei, Polyphenol content, antioxidant capacity, and composition in different varieties of sweet potato (Ipomoea batatas L.) leaves during growth stages, Sci. Hortic. 342 (2025) 113925.