Comparison of phenolic profiles and antioxidant activity of some culinary herbs and Pomegranate peel and juice

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Abstract

Oxidative stress, caused by excessive production of reactive oxygen species, represents a major factor associated with numerous chronic diseases, including cardiovascular disorders, metabolic syndrome, cancer, and aging. Plant-derived antioxidants can effectively counteract oxidative stress. Due to differences in the antioxidant capacity among plant species which based on their phytochemical composition. Accordingly, the current study aims to compare the phytochemical analysis and antioxidant capacity assessment of nine botanicals including: Thyme (Thymus vulgaris) (Powdered and Fresh), Rosemary (Saliva rosmarinus), (Powdered and Fresh), Oregano (Origanum valgare), Ginger (Zingiber officinale), Cinnamon (Cinnamomum verum), and Pomegranate (Punica granatum) dreivatives (Peel and Juice). To achieve that, Total Phenol Content (TPC), Total Flavonoid Content (TFC), and antioxidant activity (via DPPH assay) were evaluated across the selected plants extracts. The results revealed that powdered pomegranate peel exhibited the highest TPC (8599 mg GAE/100g), TFC (4950 mg/100g), and antioxidant capacity (285.15 umol TE/g). Among the culinary herbs, powdered oregano and powdered rosemary demonstrated superior phenolic levels, while fresh sample consistently showed lower concentrations for the all parameters, due to their high moisture content.HPLC analysis identified punicalagin (15000 mg/Kg) as a dominant in pomegranate peel and rosmarinic acid, carnosic acid and thymol are dominated in oregano, rosemary, and thyme respectively, while cinnamon was mainly rich in cinnamaldehyde and cinnamic acid derivatives and fresh ginger exhibited a unique phenolic profile dominated by gingerol compounds. These results provide a quantitative basis for selecting specific plant materials as natural functional ingredients for food preservation and health promotion.

Keywords: antioxidant capacity; culinary herbs; HPLC analysis; phenolic compound; pomegranate.

ISSN 2072-3857

Introduction

Oxidative stress is a biological condition that occurs when there is an imbalance between reactive oxygen species (ROS) and the body's ability to neutralize them using antioxidant defenses. It is associated with numerous chronic diseases, including cardiovascular disorders, metabolic syndrome, cancer, Neurodegenerative disorders (e.g., Alzheimer's) and aging. Antioxidants are used that neutralize ROS by donating electrons to stabilize free radicals, chelating metal ions (like Fe^{2+}) that generate radicals and enhancing endogenous defense enzymes. Antioxidants are usually classified into enzymatic and non-enzymatic. The enzymatic antioxidant system comprises a series of enzymes that prevent cell damage, including superoxide dismutase, catalase, glutathione peroxidase, and glutathione reductase **[30]**. The nonenzymatic antioxidant system consists of compounds of endogenous origin including blood plasma proteins, transferrin, albumin, ceruloplasmin, and ferritin. In addition, this balance can be significantly influenced by dietary antioxidant including vitamins (vitamin C, E, β-carotene) and other compounds of plant origin, such as polyphenols **[39]**. These polyphenols have attracted considerable attention due to their strong radical-scavenging activity that mitigating oxidative stress damage by modulating cellular redox status. Plant-based dietary antioxidants, have emerged as particularly rich sources of bioactive phytochemicals with potent antioxidant properties. In addition to their wide application in gastronomy and the food industry, they are also used in herbal medicine **[67]**. They regulate the functioning of the digestive tract **[34]**, regulate blood pressure, reduce the risk of atherosclerosis, lower total cholesterol level and have anti-diabetic properties **[49]**. In addition, they exhibit antimicrobial and anti-inflammatory activities **[26]**.

Among Plant-based dietary antioxidants, pomegranate (*Punica granatum* L.) has been described as a “super food” and classified among the top ten fruits with high nutraceutical value. The juice is a rich source of polyphenols, flavonoids and tannins, with deferent contents between varieties, agronomical conditions, climate, post-harvest times and juice obtaining method **[44]**. Experimental studies have demonstrated that pomegranate peel contain high concentrations rich of flavonoids, tannins and phenolic acid with antioxidant activities **[56]**. Due to their rich sources of phenolics copounds, culinary herbs also expected their antioxidant capacities. Thyme, rosemary, and oregano (Lamiaceae family) are rich sources of phenolic compounds, particularly rosmarinic acid, caffeic acid,

ISSN 2072-3857

flavonoids, and phenolic diterpenes, whereas cinnamon provides cinnamic acid, gallic acid, and related polyphenols and ginger contributes pungent phenolics such as gingerols and shogaols. All these compounds enhance redox activity through hydrogen atom transfer, single-electron transfer, and metal-chelation mechanisms that increase their antioxidant activity. Despite the recognized antioxidant potential of both herbs and pomegranate derivatives, however, there are limit comparative studies between them. Prior comparative work has compared other fruit extract of grape, olive, tomato, lemon with pomegranate peel, for phenolics and antioxidant activity **[59]** or compared pomegranate peel powder blending with certain spices **[42]**. Other investigations have ranked antioxidant potential across deferens kinds of herbs **[21]**.

The objective of the present study is to conduct a controlled comparative phytochemical analysis and antioxidant capacity assessment of Thyme (*Thymus vulgaris*), rosemary (*Salvia rosmarinus*), (fresh and powdered),oregano (*Origanum vulgare*), ginger (*Zingiber officinale*), pomegranate (*Punica granatum, local cultivar from Halbcha*) (peel and juice) , and cinnamon (*Cinnamomum verum*) .Understanding the comparative phytochemical profiles and antioxidant capacities of these botanicals is essential for optimizing their nutritional applications for health promotion.

2. Materials and Methods

2.1. Plant material preparation

Fresh samples of Wild Rosemary (*Rosmarinus officinalis*) and Wild Thyme (*Thymus vulgaris*) were manually collected from the mountainous regions of [Qaradakh / Sulaymaniyah, Kurdistan Region of Iraq] during the spring season of 2024.The collected samples were divided into two groups: fresh leaves were immediately frozen in liquid nitrogen and for dried samples, they were shade-dried at room temperature (37 ± 2°C) in a well-ventilated area for 10 days until a constant weight was achieved. This method was chosen to prevent the thermal degradation of thermolabile antioxidant compounds. Leaf samples were finely ground using a mortar and pestle with liquid nitrogen **[10]** and the whole sample was stored at −20 ◦C until use. Commercial dried Oregano (*Origanum vulgare*) and Cinnamon (*Cinnamomum verum)* powder were purchased from a local Sulaymaniyah market. 50 g of each powder was blended in a laboratory-scale mixer for 2 minutes before weighing **[1]**.

ISSN 2072-3857

Ginger rhizomes (*Zingiber officinale*) were peeled, washed, and sliced into 2–3 mm thicknesses **[3]**. For extraction purposes, these materials were either used immediately to represent "fresh" state or stabilized via freeze-drying at -20°C to prevent the degradation of thermolabile volatile compounds **[11].** Regarding Pomegranate**,** Salakhani, a local cultivar, well-known from the Halabja of Kurdistan Region of Iraq, was selected after washing, manually peeled. The inner white spongy membranes were removed, and only the outer colored shade-dried at room temperature until crisp, then ground into a fine powder **[63]**. Fresh pomegranate juice was extracted using Oster blender (Oster, Fort Lauderdale, FL) a mechanical press, to remove any remaining pulp or solid particles, the crude juice was filtered through a double-layered muslin cloth. The fresh juice was stored in light-protected amber glass bottles at -20°C to prevent the degradation of anthocyanins and ascorbic acid. The plant extracts were prepared according to **Tahir *et al* [57]** as follows: Tissue (1 g) was ground in a mortar with a pestle and liquid nitrogen, then 0.1 g of fresh powder is used for extraction with 0.7 mL of 80% (v/v) methanol at 4 °C for 16 h. The mixture was then centrifuged at 14000 rpm at 4 °C for 10 min. The supernatant solution was used for total phenolic content (TPC), total flavonoid content (TFC) and Antioxidant capacity (AC).

2.2. Bioactive Compounds and Antioxidant Capacity of Selected Plants.

2.2.1. Total phenolic content

The content of total phenolic compounds in each extract is determined according to the Folin-Ciocalteu method Blank: An aliquot of 150 µl of dH_2O was mixed with 1.1 mL of Folin–Ciocalteu phenol reagent (10 × diluted in water) and allowed to react for 7 min. Then 0.9 mL of 10% saturated Na_2CO_3 solution is added and allowed to stand for 50 mins in the dark at 40ºC. The absorbance of the reaction mixture is read at 750 nm. A gallic acid standard curve was used to calculate the phenolic content. The total polyphenol content (TPC) of each extract was expressed as g gallic acid equivalents per 100gram of fresh weight or dry weight.

2.2.2. Total flavonoid content

Four hundred µL of the extract solution was mixed with 0.9 mL methanol (80%), 0.3 mL of 2% aluminum chloride ($AlCl_3$), 0.07 mL, 1 M potassium acetate (CH_3COOK), and 1.7 mL of deionized water.

Distilled water was added instead of extract solution in blank sample (as a control). After incubation at room temperature for 30 min, absorbance of the reaction mixture was measured at 415 nm. A quercetin standard curve was used to calculate the TFC of each extract which was expressed as mg quercetin equivalents per 100gram of fresh weight or dry weight.

2.2.3. Antioxidant capacity evaluation (DPPH Assay)

The antioxidant activity of the plant extracts was determined according **Jamal *et al* [32]** using the DPPH (2,2-diphenyl-1-picrylhydrazyl) free radical scavenging assay. Briefly, 200 µL of each extract was mixed with 2 mL of a methanolic DPPH solution (0.1 mM). For the control, 200 µL of methanol was added to 2 mL of the DPPH solution to account for the initial radical absorbance. The mixtures were shaken vigorously and incubated in the dark at room temperature for 30 minutes. The absorbance was then measured at 517 nm using a spectrophotometer. All experiments were performed in triplicate. The antioxidant capacity (AC) was calculated based on a Trolox standard curve and the results were expressed as µmol Trolox equivalents (TE) per gram of fresh weight (FW) or dry weight (DW).

2.2.4. HPLC Conditions

Before application of HPLC technique, sample extraction is needed which applied according to **Ngamsuk *et al* [47]** as follows: Three gm of samples, finely powdered, was blended with 60 mL of methanol/water (40/60) during 24h. The mixture was filtered and the filtrate concentrated under vacuum (40°C) to a volume of 5 mL. This solution was hydrolyzed with 5 mL of 2N NaOH for 30 min. The pH of the mixture was adjusted to pH 7.00 with 2N HCl and the phenolic acids were extracted by liquid/liquid extraction with ethyl acetate (20mLx3). The extracts were then combined and the ethyl acetate removed under reduced pressure. The residue was dissolved in 7 mL of methanol for HPLC analysis.

HPLC analysis was conducted on a SYKAM HPLC system (Germany) equipped with a C18-ODS column (250 × 4.6 mm, 5 µm). Samples (100 µL) were injected into the system. The mobile phase was composed of 95% acetonitrile + 0.01% Triflouroacetic acid (solvent A) and 5% acetonitrile + 0.01% Triflouroacetic acid (solvent B) at 1 mL/min. The gradient program was as follows: 10% A from 0–5 min; 25% A from 5-7 min; 40% A from 7–13 min; then returning to initial conditions. Detection of phenolic

ISSN 2072-3857

compounds was carried out with a UV-visible detector at 278 nm.

2.3. Data analysis

Statistical analysis was performed using the XLSTAT software. All experimental measurements were carried out in triplicate (n = 3), and results are reported as mean ± standard deviation (SD). Data were analyzed using one-way analysis of variance (ANOVA). To identify significant differences between the treatment means, Duncan's Multiple Range Test (DMRT) was applied at a significance level of $p < 0.05$. All graphical representations were prepared using Microsoft Excel.

3. Result and discussion

3.1. Total Phenolic Content of Selected Plants

The Total Phenolic Content (TPC) of the studied samples are measured using the Folin-Ciocalteu colorimetric assay and expressed in milligrams of Gallic Acid Equivalents (GAE) per gram of weight. As shown in table 1, a significant variation in TPC among the studies plant materials, that strongly influenced by plant species and processing state (fresh vs powdered). Among them, powdered pomegranate peel (PPP) exhibited the highest TPC (8597.00 mg GAE/100 g), confirming its well-documented richness in hydrolysable tannins, particularly punicalagins and ellagic acid **[51].** High TPC value of PPP also obtained in other studies **[22; 65 and18].**

After PPP, Oregano (6967.66 mg GAE/100 g) and rosemary (5527.33 mg GAE/100 g) showed elevated phenolic levels among powdered herbs used in the current study which is close to that recorded in other studies **[41; 46 and 40]**, and this is due to their high content of phenolic acids and diterpenes such as rosmarinic and carnosic acids. Cinnamon powder (3265.00 mg GAE/100 g) and powdered thyme (3819.66 mg GAE/100 g) exhibited moderate TPC which consistent with previous studies **[43; 17]**, reflecting differences in their structure and dominant phenolic profiles.

In contrast, fresh samples consistently showed lower TPC values. Fresh thyme (650.00 mg GAE/100 g) and fresh ginger (449.33 mg GAE/100 g) contained moderate phenolic levels, whereas pomegranate juice (350.00 mg GAE/100 g) and fresh rosemary (117.66 mg GAE/100 g) exhibited the lowest values. These results are fully consistent with other studies **[12]; [11]**, the reduction in TPC

values of fresh samples is due to high moisture content, since fresh plant materials generally possess a moisture content ranging from 75% to over 90%, which significantly dilutes the concentration of bioactive constituents per unit of mass including phenols. Drying processes, when performed correctly, remove this aqueous phase, thereby concentrating the phenolic compounds **[52],** even the study of **[58]** revealed that some drying methods may influences the stability of phenolic compounds, that are sensitive to heat, oxygen, light, and enzymatic activity. The impact of drying on phenolic degradation depend on plant species, drying technique, heating time and temperature. Ginger also exhibit low TPC, as it's phenolic profile is unique due to the presence of gingerols, which are phenolic ketones responsible for its pungent flavor.

The determination of the Total Phenolic Content (TPC) within plant extract constitutes a fundamental procedure in the characterization of their antioxidant potential and overall bioactive density. Phenolic compounds, characterized by at least one aromatic ring hydroxylated with one or more hydroxyl groups, serve as critical secondary metabolites in plants, providing defense against ultraviolet radiation, pathogenic incursion, and oxidative stress. Total phenolic content refers to the cumulative concentration of all phenolic compounds, including phenolic acids and flavonoids.

Table1: Total polyphenols content (mg GAE/100 g) in the selected plant extracts used in this study

Sample	Mean ± SD mg GAE/100 g W
Powdered Pomegranate Peel	**8597.00 ± 2.00^{a}**
Powdered Oregano	**6967.67 ± 2.52^{b}**
Powdered Rosemary	**5527.33 ± 2.52^{c}**
Powdered Thyme	**3819.67 ± 2.52^{d}**
Powdered Cinnamon	**3265.00 ± 2.00^{e}**
Fresh Thyme	**650.00 ± 2.00^{f}**
Fresh Ginger	**449.33 ± 3.06^{g}**
Pomegranate Juice	**350.00 ± 2.00^{h}**
Fresh Rosemary	**117.67 ± 2.52^{i}**

Note: Values are expressed as Mean ± SD (n=3). Means with different superscript letters in the same column are significantly different ($p < 0.05$).

3.2. Total Flavonoid Content of Selected Plants

The measurement of flavonoids typically utilizes the aluminum

ISSN 2072-3857

chloride (AlCl_3) colorimetric assay that relies on the formation of stable acid-tolerant complexes between the aluminum ion and the C-4 keto group and either the C-3 or C-5 hydroxyl group of flavones and flavonols. The resulting bathochromic shift allows for spectrophotometric quantification at wavelengths between 415 nm and 510 nm **[16].**

The results in table 2 show significant variation in the TFC values between the selected plant extracts used in this study, which were strongly dependent on the plant species and processing form (fresh versus dried). Among all selected plant extracts samples, pomegranate peel exhibited the highest total flavonoid levels. High flavonoid concentration were also found in PPP in other studies **[4; 35]**. This finding is consistent with the biological role of the peel as a protective tissue, where flavonoids (punicalagin, quercetin, rutin, and kaempferol) with other phenolic accumulate to defend against environmental stress and microbial attack. In contrast, pomegranate juice, which is characterized by high water and sugar content, contained substantially lower flavonoid concentrations. Previous studies **[68; 5]** also highlighted that pomegranate peels contain a richer flavonoid compared to edible juices, supporting their use as potent antioxidant sources in food systems.

Oregano powdered consistently ranked among the highest flavonoid-containing herbs in the current study followed by thyme, and rosemary which is consistence with other studies **[11; 40]**. Oregano and thyme rich in luteolin and apigenin whereas rosemary rich in flavonoids like Qurcetine and Catechine, however its phenolic profile dominates rather than flavonoids **[16]**. The flavonoid in powdered samples of thyme, and rosemary was higher than that of fresh sample, which attributed to both moisture removal during drying and the natural abundance of flavone derivatives in their leaf tissues. Regarding to the flavonoid content of cinnamon, which is higher significantly from the fresh herb samples and pomegranate juice, is attributed to its high contents of Catechine and Epicatechin **[23; 29]**.

Fresh ginger exhibited relatively low total flavonoid content (Qurcetine and Catechine), its biological activity is primarily associated with non-flavonoid phenolic compounds such as gingerols. This highlights that bioactivity in plant materials is governed by overall phenolic

ISSN 2072-3857

composition rather than flavonoid concentration alone **[6].**

Table 2: Total Flavonoid content (mg/100 g) in the selected plant extracts used in this study.

Sample	Mean ± SD TFC (mg/100 g)
Powdered Pomegranate Peel	**4950.00 ± 2.00^{a}**
Powdered Oregano	**3860.00 ± 3.00^{b}**
Powdered Rosemary	**2901.33 ± 3.21^{c}**
Powdered Thyme	**2530.00 ± 2.00^{d}**
Powdered Cinnamon	**1840.33 ± 2.52^{e}**
Fresh Thyme	**341.33 ± 3.21^{f}**
Fresh Rosemary	**260.67 ± 3.06^{g}**
Pomegranate Juice	**180.00 ± 2.00^{h}**
Fresh Ginger	**60.00 ± 2.00^{i}**

Note: Values are expressed as Mean ± SD (n=3). Means with different superscript letters in the same column are significantly different ($p < 0.05$).

3.3. The antioxidant capacity of selected plants

The results presented in table3 show high significant differences in antioxidant capacity among the selected plant extracts samples used in this study, reflecting variations in their phytochemical composition. Among them, powdered pomegranate peel exhibits a highest antioxidant capacity (285.18 µmol \ TE/g). The exceptional value recorded for powdered pomegranate peel aligns with the study of **[50]** who estimated the antioxidant capacity of pomegranate peel with 358.67 µmol trolox/g dried sample, using the DPPH based method .This high antioxidant activity is attributed with higher concentrations of total phenols, flavonoids in pomegranate peel recorded in the current study, especially punicalagins, which account for approximately 87% of the total antioxidant activity found in pomegranate derivatives **[13].**

In contrast, pomegranate juice exhibits low antioxidant capacity (12.45 µmol \ TE/g) compared to the peel. These results are close to the study of **[33].** Antioxidant power of the juice are highly dependent on the variety, ripening stage and processing conditions. The juice's antioxidant capacity is primarily driven by anthocyanins, Ascorbic acid and the soluble portion of punicalagins that leach from the peel during the pressing process.

High antioxidant capacities also detected in the three species examined from Lamiaceae family (oregano (199.67 µmol \ TE/g), rosemary (198.50 µmol \ TE/g), and thyme (190.57 µmol \ TE/g)—),

used in the current study, particularly in their dried powder forms indicates a significant concentration effect resulting from the dehydration process **[20]**.

Recording high antioxidant capacities in Oregano extracts which is consistent with other studies **[36; 24]** is due to them contain of phenols like rosmaric acid and quercetin, and in rosemary is largely derived from its unique phenolic diterpenes including carnosol, carnosic acid **[38; 64]**. Whereas Thyme's antioxidant activity is driven by thymol **[7; 25].**

Cinnamon powder (195.95 µmol \ TE/g) and fresh ginger (12.81µmol \ TE/g) represent different botanical structures (bark vs. rhizome) and processing states in the dataset. The high antioxidant activity (195.95 µmol \ TE/g) of cinnamon, possibly from Cinnamomum verum, which exhibits superior antioxidant profiles compared to C. cassia, is attributed to its rich content of cinnamaldehyde. Cinnamon bark is a particularly stable matrix; its antioxidants have been shown to maintain their efficacy even after exposure to 165 °C, making it a valuable antioxidant in processed foods **[9; 60].**Fresh ginger's lower value (12.81 µmol \ TE/g) is primarily a result of its high water content that dilute the primary bioactives in ginger (gingerols) that are potent antioxidants agents, **[61]; [54].** For the same reason the antioxidant capacity of fresh rosemary and thyme were less than their powdered form.

Table3: Antioxidant Capacity DPPH (µmol TE/g) in the selected plant extracts used in this study

Samples	Mean ± SD DPPH (µmol TE/g)
Powdered Pomegranate Peel	**285.18±1.25^{a}**
Powdered Oregano	**199.67±0.58^{b}**
Powdered Rosemary	**198.50±0.75^{b}**
Powdered Cinnamon	**195.95±0.45^{c}**
Powdered Thyme	**190.57±0.51^{d}**
Fresh Thyme	**22.13±0.32^{e}**
Fresh Ginger	**12.81±0.15^{f}**
Pomegranate Juice	**12.45±0.20^{f}**
Fresh Rosemary	**3.53±0.12^{g}**

Note: Values are expressed as Mean ± SD (n=3). Means with different superscript letters in the same column are significantly different ($p < 0.05$).

Phenolic Composition of Plant Extracts Determined by HPLC

Table 4 show HPLC analysis revealed the marked differences in the qualitative and quantitative distribution of individual Phenolic components among the plant extracts used in the current study including: rosemary, thyme (fresh and powdered), pomegranate (peel and juice), oregano powder, cinnamon powder, and ginger), reflecting their distinct phytochemical compositions.

The pomegranate samples **(**peel and juice) distinguish from the other samples used in the current study, due to their exceptionally high content of hydrolyzable tannins, Punicalagin and punicalin which predominant in pomegranate peel, far exceeding those found in the juice. This pattern reflects the protective function of the peel, which accumulates ellagitannins to defend against environmental stress. Punicalagins (α and β isomers) are non-cytotoxic at therapeutic concentrations and serve as precursors to ellagic acid and urolithins, which extend the antioxidant effect within the human gut **[28].** The peel also contained appreciable amounts of ellagic acid (650.2) and gallic acid (320.4**)**, further contributing to its antioxidant potency. The concentrations of these phenolic compounds in the juice were markedly lower than that in the peel, due the juice, representing the edible fraction, contains lower phenolic concentrations. These findings align with previous studies **[19; 2; and 55]** in detecting higher phenolic concentrations in the peel compared with juice.

Among the Lamiaceae herbs (thyme, rosemary, and oregano), Rosmarinic acid was a consistently abundant marker in all of them, contributing significantly to their radical-scavenging capacities. Flavonoids such as luteolin and apigenin were especially prominent in oregano and thyme, consistent with their reported antioxidant and anti-inflammatory properties. Similar phenolic profiles have been reported in previous studies **[27; 53 and 37]** on thyme extracts and others **[8; 48]** applied on rosemary extract and others **[62; 30]** on oregano extracts. In general, Phenolic concentrations are considerably higher in dried samples (thyme and rosemary) than in fresh leaves due to moisture removal during drying, which concentrates phenolic constituents. In contrast, cinnamon **(**Cinnamomum verum**)** displayed a markedly different phenolic profile which characterized

by high levels of phenylpropanoid derivatives, particularly cinnamaldehyde and cinnamic acid, as well as relatively abundant flavan-3-ols including catechin and epicatechin. These compounds are well documented to contribute to cinnamon's strong radical-scavenging activity and antimicrobial functionality, which consistent with other studies **[14; 45]**.

Fresh ginger exhibited a phenolic profile distinct from both herbs and cinnamon. its phenolic composition was dominated by gingerol-type that are responsible for ginger's characteristic aroma, taste, and antioxidant and anti-inflammatory effects, confirming findings reported in recent ginger phytochemistry research **[15; 66].**

Hence, among the phenols, Gallic acid with antioxidant potency was detected in the most of the samples followed by Caffeic acid, then ferulic acid, whereas Ellagic acid and punicalagin were characteristic of pomegranate (peel and juice). The high punicalagin concentration (15000 mg/Kg in peel) reinforces the exceptional antioxidant and antimicrobial properties of pomegranate by-products. Regarding to flavonoid Composition of the studied plant extract in this study Catechin was predominantly found in most of them, whereas Gingerol just found in ginger with the highest overall concentration among all compounds (451.6 mg/Kg) in ginger, highlighting its unique potent antioxidant and anti-inflammatory activities. Collectively, the comparative HPLC analysis illustrate that the phenolic profiles are highly dependent on plant species, plant part, and processing form. Pomegranate peel emerged as the richest source of phenolic antioxidants overall. Among culinary herbs and spices, oregano and thyme exhibited a broader diversity of flavonoids and hydroxycinnamic acids, while cinnamon and ginger featured unique phenylpropanoid and gingerol-type phenolics, respectively. These profiles provide a biochemical basis for the differential antioxidant, antimicrobial, and health-promoting activities support the targeted use of these plant materials in functional foods, nutraceutical formulations, and natural preservative systems.

ISSN 2072-3857

Table 4: Phenolic profile of the selected plant extracts used in this study using HPLC analysis

ne Kg	Chemical class	Fresh Rosemary	Rosemary Powder	Pomegranate peel	Pomegranate juice	Fresh Thyme	Powder Thyme	Oregano	Cinnamon powder	Gi
genin	Flavone	23.4	64.6			23.4	65.2	54.6		
feic acid	Hydroxycinnamic acid	43.2	160.5	50.6	1.6	70.4	190.	280 .3	93	11.
nosol	Phenolic diterpene	375.3	1400							
nosic acid	phenolic diterperne	1100	8500							
echine	Flavan-3-ol	43.2	95.4	167.5	5.8	63	175	130	525	27
catechin	Flavan-3-ol	23.4	65.3	76.3	8.6	25	83	75	420	
n	Flavonoid glycoside			35.4	6.7					
gic acid	hydroxybenzoic acid derivative			650.2	75					
ulic acid	hydroxycinnamic acid	34.2	105.3	27.4	3.7	30.4	110	85	160	7.6
ic acid	Hydroxybenzoic acid	35.2	99.7	320.4	75	55.6	112.5	185	720	18
eolin	Flavone	45.1	88.2			35.7	96.5	123.6		
icalagin	ellagitannins			15000	41.5					
icalin	Ellagitannin (Hydrolyzable Tannin)			780	5.5					
emaric acid	Hydroxycinnamic acids	475,5	2100			702	3800	5450		
pic acid	hydroxycinnamic acid	73.5	61.0							
cetine	Flavanol	33,4	92.4	85.2	3.8	23	85.9	93	42	9.3
umaric acid	Hydroxycinnamic acid	34.7	98.2	80.8		40	110	69.3	35	6.3
gerol	Phenolic ketone									451
gerone	Phenolic ketone									25.
mol	Monoterpenoid phenol					540.7	1100			
vacrol	monoterpenoid phenol					375.3	890.8			
namaldehyde	Phenylpropanoid aldehyde								14000	
namic acid	Phenylpropanoid							15	620	

4. Conclusions

This study highlights the significant variability in phytochemical profiles and antioxidant capacities among common culinary herbs and

pomegranate derivatives, influenced heavily by plant species, tissue type, and processing atate. Pomegranate peel emerged as the most potent source of bioactive compounds, significantly outperforming its juice counterpart in both phenolic density and radical-scavenging activity. The Lamiaceae family—specifically oregano, rosemary, and thyme—demonstrated high antioxidant potential, particularly in powdered forms where dehydration effectively concentrates secondary metabolites like rosmarinic and caffeic acids.

HPLC profiling confirmed that each botanical possesses a unique "phenolic signature," such as punicalagin and punicalin in pomegranate peel, whereas pomegranate juice contained lower levels of rosmarinic acid, carnosic acid and thymol respectively, while cinnamon was mainly rich in cinnamaldehyde and cinnamic acid derivatives and fresh ginger exhibited a unique phenolic profile dominated by gingerol compounds, which governs its specific biological functionality. While powdered materials exhibited higher absolute concentrations per unit of mass, the broader spectrum of compounds detected in fresh samples indicates that thermal processing may lead to the degradation of certain heat-sensitive antioxidants. Ultimately, these results provide a quantitative basis for selecting specific plant materials as natural functional ingredients for food preservation and health promotion.

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ISSN 2072-3857