

Solvent-dependent Phytochemicals and Total Antioxidant Capacity of Pineapple (*Ananas comosus*) and Apple (*Malus domestica*) Fruit Flesh: Implications for Functional Foods

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Abstract

Phytochemical analysis and total antioxidant capacity (TAC) of dried *Ananas comosus* (AC), Granny Smith (GS), and Red Delicious (RD) fruit flesh were investigated using high-performance liquid chromatography (HPLC) and ABTS radical cation decolorization assay, respectively. Fresh and ripe fruits were collected, identified, authenticated, dried, macerated, and filtered to obtain dried AC flesh methanolic extract (DACFME), dried AC flesh aqueous extract (DACFAE), dried GS flesh methanolic extract (DGSFME), dried GS flesh aqueous extracts (DGSFAE), dried RD flesh methanolic extract (DRDFME) and dried RD flesh aqueous extract (DRDFAE). Data were analyzed using one-way analysis of variance (ANOVA), followed by Duncan's post-hoc test; significance was set at $p < 0.05$. TAC of DACFME (5 and 10 $\mu\text{g/mL}$) and DACFAE (25 and 50 $\mu\text{g/mL}$) were markedly ($p < 0.05$) higher than those for their corresponding DACFAE and DACFME, respectively. TAC of DGSFME and DRDFME (5, 25, 50, and 100 $\mu\text{g/mL}$) were markedly ($p < 0.05$) higher than those for their corresponding DGSFAE and DRDFAE, respectively. Caffeic acid, quercetin, gallic acid, p-coumaric acid, salicylic acid, maleic acid, rutin hydrate, tannic acid, saponins, kaempferol, and naringin were identified from all 6 extracts, but at varying concentrations. Thus, phytochemical extraction and TAC are influenced by solvent type and polarity, indicating potential application of the selected dried fruits' flesh in nutraceutical and functional food development.

Keywords: Antioxidant capacity; apple flesh; phytochemicals; pineapple flesh; solvent-dependent variation.

INTRODUCTION

The increasing interest in plant-derived compounds with biological activity has stimulated extensive research into natural antioxidants and their impact on combating disorders linked with oxidative stress (Shoab et al. 2023; Adefuye et al. 2026). Oxidative stress reportedly stems from a disruption in the body's antioxidant defense system (Engwa et al. 2022) due to overwhelming generation of reactive oxygen species (ROS) (Babalola et al. 2020), leading to cellular damage, lipid peroxidation, DNA mutations, and protein degradation (Olajide et al. 2022). This oxidative stress has been associated with the on-set of chronic diseases "cancer, cardiovascular issues, diabetes mellitus, inflammatory disorders, and neurodegenerative diseases" (Giampieri et al. 2017; Cebeci and Şahin-Yeşilçubuk 2023). Therefore, natural antioxidants obtained from fruits and vegetables have attracted considerable attention because of their potential to neutralize deleterious radical anions, limit oxidative damage, and maintain redox homeostasis in cells (Tomas-Barberán and Gil 2016).

Among antioxidant-rich fruits, *Malus domestica* (apple) and *Ananas comosus* (pineapple) are widely consumed and recognized for their high nutritional and phytochemical contents. Pineapple contains several bioactive constituents including phenolic acids, flavonoids, bromelain, vitamins, organic acids, and dietary fibers that confer antioxidant and medicinal therapy (Wali 2019). Similarly, apples contain polyphenolic compounds, including catechin, chlorogenic acid, quercetin, rutin, and phloridzin, which have been associated with antioxidant and anti-inflammatory activities and modulation of processes related to cardiovascular health (McGhie et al. 2005; Arnold and Gramza-Michalowska, 2024). These phytochemicals exert antioxidant activity by scavenging ROS, chelating transition metals, and modulating signaling pathways implicated in oxidative stress (Oluwole et al. 2022).

Moreover, Asale et al. (2021) reported marked variations in phytochemical contents and antioxidant potential among distinct cultivars of apple grown in

Ethiopia. Likewise, Cvetković et al. (2024) observed cultivar-specific differences in antioxidant properties and phenolic profiles of apples, emphasizing the influence of genotype and environmental factors on phytochemical accumulation. In pineapple, bioactive constituents such as bromelain and phenolic acids substantially contribute antioxidant and therapeutic effects (Varilla et al. 2021). Furthermore, Adefuye et al. (2026) reported that methanolic and aqueous extracts of dried *Ananas comosus* flesh possessed appreciable levels of phenolics and flavonoids with strong antioxidant activity at varying concentrations, thereby supporting the relevance of *Ananas comosus* in medicinal therapy.

The extraction efficiency of phytochemicals is highly dependent on the type/form of solvent used for extraction. Polarity of solvents significantly affects the recovery of flavonoids, phenolics glycosides, tannins, and other antioxidant constituents from plant materials (Babbar et al. 2014). Methanol is widely regarded as an effective solvent for extracting phenolic acids and flavonoids because of its intermediate polarity and ability to penetrate plant tissues efficiently (Dhawan and Gupta 2017). In contrast, aqueous solvents are highlighted to be more suitable for extracting hydrophilic and highly polar constituents, such as saponins, glycosides, and sugars (Burgos et al. 2018). Consequently, solvent selection plays specific and irrefutable roles when estimating the phytochemical profile and the total antioxidant capacity (TAC) of extracts from dried fruit.

Do et al. (2014) reported significant differences in the polyphenol content and capacity to detoxify oxidants by apple extracts (juice) using distilled water and methanol. Similarly, Lim et al. (2024) and Sharifi et al. (2025) also emphasized that solvent-dependent extraction significantly affects the discovery of phenolic and flavonoid compounds, and antioxidant activities in *Scutellaria baicalensis* hairy roots. Moreover, comparative analyses on the phytochemicals and total antioxidant capacity of the Smooth Cayenne (variant of pineapple), Red Delicious and Granny Smith (variants of apple) remain relatively limited. In addition, limited information exists regarding the comparative influence of distilled water and methanol on the identification and quantification of phytochemicals and determination of TAC of dried flesh obtained from most commonly consumed fruits.

Therefore, this research comparatively evaluated the phytochemical profile and TAC of aqueous and methanolic extracts of dried flesh from *Ananas comosus* (Smooth Cayenne variant) and *Malus domestica* (Red Delicious and Granny Smith variants). High-performance liquid chromatography (HPLC) analysis was utilized to identify/qualify and quantify bioactive compounds from the samples, whereas the 2,2'-azino-bis-3-ethylbenzthiazoline-6-sulphonic acid (ABTS) radical cation decolorisation test was adopted to determine the TAC of the samples. The findings from this research will

provide valuable insight into solvent-dependent phytochemical distribution/profile and their implications on the development of nutraceuticals, pharmaceuticals, and functional food products.

MATERIALS AND METHODS

Chemicals and reagents

All chemicals and reagents utilized in this research were of pure and analytical grade and were procured from reputable outlets. ABTS was purchased from Sigma Aldrich, Chemical Co., U.S.A. All additional chemicals used were purchased from outlets with a good reputation.

Plant collection, authentication, and handling

Two distinct variants of *Malus domestica* (Granny Smith and Red Delicious) and the *Ananas comosus* (Smooth Cayenne cultivar/variant) fruits that were viable, ripe, and fresh were purchased from a respectable market in Ogun State, Nigeria. Fruits that were selected and utilized for this research were fully coloured, mature, and tender when handled. The selected fruit samples were identified and authenticated at the Herbarium Laboratory, Department of Forestry and Wildlife Management, College of Environmental Resources Management, Federal University of Agriculture, Abeokuta, Ogun State, Nigeria, with a registered voucher ID UAHA/FWM/025/05/001 (for *Ananas comosus*), UAHA/FWM/025/05/002 (for Red Delicious), and UAHA/FWM/025/05/003 (for Granny Smith). All fruits were collected with absolute care; rinsed with tap water that was clean, and then rinsed again with distilled water. Before processing, the fruits were handled carefully to prevent squeezing and refrigerated at 10–13°C to extend their shelf lives.

Processing of fruits flesh

Every fruit sample was cut into tiny pieces after being peeled. After that, they were subjected to controlled drying by using an electronic food dehydrator (BS-6608) at 60°C to obtain a constant mass. The dried samples were blended (pulverised) electronically using a QBL-20L330 into a consistent coarse product and kept in a container that was air-tight.

Methanolic and aqueous extraction of fruits flesh

A solid-to-solvent ratio of 200 g/500 mL (w/v) was adopted for maceration of Dried and ground *Ananas comosus* flesh (ACF), Red Delicious flesh (RDF), and Granny Smith flesh (GSF) using 80% (v/v) methanol at 25°C for 72 hours with intermittent stirring at 4-h intervals. To reduce the possibility of light-sensitive phytochemicals (namely, phenolics and flavonoids) degrading, the extraction vessels and apparatus were shielded from light. The product from maceration was cleanly filtered through a funnel lined with cotton wool and a 0.1 mm muslin cloth. A clear filtrate was obtained

and stored for further action. Methanol was removed from the filtrates by rotary evaporation (RotoVap 110) at 40°C, and the resultant semi-solid/ slurry products were carefully collected into storage containers. Same protocol was followed using distilled water to obtain the aqueous extract of each fruit flesh. The concentrated forms of dried *Ananas comosus* flesh methanolic extract (DACFME), dried *Ananas comosus* flesh aqueous extract (DACFAE), dried Granny Smith flesh methanolic extract (DGSFME), dried Granny Smith flesh aqueous extract (DGSFAE), and dried Red Delicious flesh methanolic extract (DRDFME), and dried Red Delicious flesh aqueous extract (DRDFAE) samples were stored in distinctly dry, air-tight containers until they were required for the next action.

Determination of total antioxidant capacity (TAC)

According to Re et al. (1999), the ABTS radical cation decolorisation procedure was adopted to determine the TAC of DACFME, DACFAE, DGSFME, DGSFAE, DRDFME, and DRDFAE. To create the radical cation of ABTS (ABTS⁺), an ABTS solution (7 mM) was produced and combined in equal amounts with potassium persulfate (2.45 mM). For the radical to fully develop, the preceding mixture was incubated in the dark at room temperature for 14 hours. Prior to measurement, ethanol was used to dilute the ABTS⁺ solution until the spectrophotometer (at 734 nm) yielded an absorbance of 0.70 ± 0.02 . After that, each extract was separately introduced (using different test tubes) into the diluted ABTS working solution, thoroughly mixed, and left to react for six minutes at room temperature. Absorbance value was taken at 734 nm in comparison to a reagent blank. Trolox concentrations were used to create a standard calibration curve. By comparing each extract's drop in absorbance with the Trolox standard curve, the total antioxidant capacity of each sample was ascertained. The Total Antioxidant Capacity (TAC) of DACFME, DACFAE, DGSFME, DGSFAE, DRDFME, and DRDFAE was expressed as Trolox equivalent antioxidant capacity (TEAC), in mmol TE/g DW.

Phytochemical screening of the extracts

Phenolic acids and flavonoid compounds in the aqueous and methanolic extracts were analyzed using high-performance liquid chromatography (HPLC). The analysis was performed using an Agilent 1260 Infinity II HPLC system equipped with a G7130 column oven, G7115A diode array detector (DAD), G7111A quaternary pump, and G7129A autosampler. Chromatographic separation was achieved using a Poroshell 120 EC-C18 column (4.6 × 150 mm, 4 µm particle size). The mobile phase consisted of formic acid and methanol delivered using a gradient elution programme. The column was maintained at ambient temperature, and detection was performed at 210 nm using the DAD. Reference standards comprising caffeic acid, ferulic acid, maleic acid, salicylic acid, gallic acid,

tannic acid, rutin hydrate, kaempferol, naringin, quercetin, and p-coumaric acid were used to assist in compound identification. Phenolic acids and flavonoid compounds were identified by comparing the chromatographic characteristics, particularly retention times, of the sample peaks with those of the corresponding reference standards.

RESULTS AND DISCUSSION

Results

According to Table 1, the TAC of dried *Ananas comosus* flesh methanolic extract (5 and 10 µg/mL) was markedly ($p < 0.05$) higher than the corresponding concentration of dried *Ananas comosus* flesh aqueous extract, whereas the TAC of dried *Ananas comosus* flesh aqueous extract (25 and 50 µg/mL) was markedly ($p < 0.05$) higher than the corresponding concentration of dried *Ananas comosus* flesh methanolic extract. However, there was no significant difference between the TAC of dried *Ananas comosus* flesh aqueous and methanolic extracts at 100 µg/mL.

Table 1. TAC of methanolic and aqueous extracts of *Ananas comosus* flesh.

Concentration	Total Antioxidant Capacity (mmol TE/g DW)	
	DACFME	DACFAE
5 µg/mL	0.220 ± 0.004^{bc}	0.168 ± 0.001^a
10 µg/mL	0.240 ± 0.003^c	0.208 ± 0.004^b
25 µg/mL	0.309 ± 0.008^d	0.331 ± 0.008^e
50 µg/mL	0.333 ± 0.005^e	0.390 ± 0.013^f
100 µg/mL	0.487 ± 0.008^g	0.497 ± 0.011^g

Note: Values of TAC were expressed as mean ± SEM of three technical replicates as mmol TE/g DW. Values having distinct letters (as their superscripts) are statistically significant from each other at $p < 0.05$. DACFME - Dried *Ananas comosus* Flesh Methanolic Extract; DACFAE - Dried *Ananas comosus* Flesh Aqueous Extract

According to Table 2, the TAC of dried Granny Smith flesh methanolic extract (5, 25, 50, and 100 µg/mL) was markedly ($p < 0.05$) elevated relative to the corresponding concentration of dried Granny Smith flesh aqueous extract. There was no significant difference between the TAC of dried Granny Smith flesh aqueous and methanolic extract at 10 µg/mL.

Table 2. TAC of methanolic and aqueous extracts of Granny Smith flesh.

Concentration	Total Antioxidant Capacity (mmol TE/g DW)	
	DGSFME	DGSFAE
5 µg/mL	0.161 ± 0.001^b	0.078 ± 0.004^a
10 µg/mL	0.230 ± 0.003^c	0.228 ± 0.002^c
25 µg/mL	0.316 ± 0.009^e	0.242 ± 0.003^{cd}
50 µg/mL	0.386 ± 0.016^f	0.264 ± 0.002^d
100 µg/mL	0.481 ± 0.011^g	0.317 ± 0.009^e

Note: Values of TAC were expressed as mean ± SEM of three technical replicates as mmol TE/g DW. Values having distinct letters (as their superscripts) are statistically significant from each other at $p < 0.05$. DGSFME - Dried Granny Smith Flesh Methanolic Extract; DGSFAE - Dried Granny Smith Flesh Aqueous Extract.

According to Table 3, the TAC of dried Red delicious flesh methanolic extract (5, 10, 25, 50, and 100 µg/mL) was markedly ($p < 0.05$) elevated relative to the corresponding concentration of dried Red delicious flesh aqueous extract. By observing tables 1, 2, and 3, DACFME had the highest TAC at 5 µg/mL, DRDFME had the highest TAC at 10 µg/mL, and DACFAE had the highest TAC at 25, 50, and 100 µg/mL.

Table 3. TAC of methanolic and aqueous extracts of Red Delicious flesh.

Concentration	Total Antioxidant Capacity (mmol TE/g DW)	
	DRDFME	DRDFAE
5 µg/mL	0.162 ± 0.001 ^b	0.077 ± 0.002 ^a
10 µg/mL	0.244 ± 0.027 ^d	0.207 ± 0.004 ^c
25 µg/mL	0.315 ± 0.009 ^f	0.234 ± 0.002 ^{cd}
50 µg/mL	0.343 ± 0.001 ^f	0.285 ± 0.004 ^e
100 µg/mL	0.401 ± 0.005 ^g	0.343 ± 0.013 ^f

Note: Values of TAC were expressed as mean ± SEM of three technical replicates as mmol TE/g DW. Values having distinct letters (as their superscripts) are statistically significant from each other at $p < 0.05$. DRDFME - Dried Red Delicious Flesh Methanolic Extract; DRDFAE - Dried Red Delicious Flesh Aqueous Extract

According to Table 4, the concentration of gallic acid, maleic acid, tannic acid, caffeic acid, saponins, and kaempferol was significantly increased in dried *Ananas comosus* flesh methanolic extract compared to dried *Ananas comosus* flesh aqueous extract, whereas the concentration of salicylic acid, ferulic acid, naringin, quercetin, and p-coumaric acid was significantly higher in dried *Ananas comosus* flesh aqueous extract compared to dried *Ananas comosus* flesh methanolic extract. There was no significant difference between the concentration of rutin hydrate in both extracts of dried *Ananas comosus* flesh.

Table 4. The compounds identified from methanolic and aqueous extracts of *Ananas comosus* flesh.

Compounds	Concentration of phytochemicals (mg/L)	
	DACFME	DACFAE
Caffeic Acid	28.207 ± 0.008 ^p	7.081 ± 0.002 ^g
Ferulic Acid	ND	73.220 ± 0.022 ^r
Maleic Acid	710.125 ± 0.213 ^v	319.187 ± 0.096 ^u
Salicylic Acid	81.797 ± 0.025 ^s	94.491 ± 0.028 ^t
Gallic Acid	68.351 ± 0.021 ^q	16.230 ± 0.005 ⁿ
Tannic Acid	10.143 ± 0.003 ^j	8.805 ± 0.003 ^h
Saponins	6.581 ± 0.002 ^f	5.542 ± 0.002 ^e
Rutin Hydrate	4.380 ± 0.001 ^d	4.363 ± 0.001 ^d
Kaempferol	20.215 ± 0.006 ^o	11.636 ± 0.003 ^k
Naringin	3.368 ± 0.001 ^c	11.345 ± 0.003 ^j
Quercetin	2.272 ± 0.001 ^b	3.411 ± 0.001 ^c
p-Coumaric Acid	12.727 ± 0.004 ^l	13.023 ± 0.004 ^m

Note: Values are expressed as mean ± SEM of three technical replicates as mg/L. Values having distinct letters (as their superscripts) are statistically significant from each other at $p < 0.05$. ND - Not Detected; DACFME - Dried *Ananas comosus* Flesh Methanolic Extract; DACFAE - Dried *Ananas comosus* Flesh Aqueous Extract

According to table 5, the concentration of ferulic acid, maleic acid, caffeic acid, salicylic acid, rutin hydrate, tannic acid, naringin, gallic acid, and p-coumaric acid were significantly increased in dried Granny smith flesh methanolic extract compared to dried Granny smith flesh aqueous extract whereas the concentration of saponins, kaempferol, and quercetin were observed to be significantly higher in dried Granny smith flesh aqueous extract compared to dried Granny smith flesh methanolic extract.

Table 5. The compounds identified from methanolic and aqueous extracts of Granny Smith flesh.

Compounds	Concentration of phytochemicals (mg/L)	
	DGSFME	DGSFAE
Caffeic Acid	25.349 ± 0.008 ⁿ	9.294 ± 0.003 ^k
Ferulic Acid	92.220 ± 0.028 ^r	2.206 ± 0.001 ^d
Maleic Acid	1089.634 ± 0.327 ^t	441.000 ± 0.132 ^s
Salicylic Acid	48.184 ± 0.014 ^p	43.643 ± 0.013 ^o
Gallic Acid	49.134 ± 0.015 ^q	23.448 ± 0.007 ^m
Tannic Acid	9.685 ± 0.003 ^l	7.224 ± 0.002 ^j
Saponins	1.460 ± 0.000 ^b	2.335 ± 0.001 ^d
Rutin Hydrate	3.649 ± 0.001 ^f	0.694 ± 0.000 ^a
Kaempferol	2.209 ± 0.001 ^d	5.488 ± 0.002 ^h
Naringin	6.468 ± 0.002 ⁱ	3.946 ± 0.001 ^g
Quercetin	1.561 ± 0.000 ^b	3.094 ± 0.001 ^e
p-Coumaric Acid	1.761 ± 0.001 ^c	0.886 ± 0.000 ^a

Note: Values are expressed as mean ± SEM of three technical replicates as mg/L. Values having distinct letters (as their superscripts) are statistically significant from each other at $p < 0.05$. DGSFME - Dried Granny Smith Flesh Methanolic Extract; DGSFAE - Dried Granny Smith Flesh Aqueous Extract

According to table 6, the concentration of caffeic acid, kaempferol, maleic acid, naringin, salicylic acid, saponins, tannic acid, gallic acid, rutin hydrate, ferulic acid, and p-coumaric acid were significantly increased in dried Red delicious methanolic extract compared to dried Red delicious flesh aqueous extract whereas the concentration of only quercetin was markedly ($p < 0.05$) higher in dried Red delicious flesh aqueous extract compared to dried Red delicious flesh methanolic extract.

Table 6. The compounds identified from methanolic and aqueous extracts of Red Delicious flesh.

Compounds	Concentration of phytochemicals (mg/L)	
	DRDFME	DRDFAE
Caffeic Acid	19.148 ± 0.006 ^s	8.520 ± 0.0030 ^o
Ferulic Acid	47.295 ± 0.014 ^t	ND
Maleic Acid	679.177 ± 0.204 ^w	337.414 ± 0.101 ^v
Salicylic Acid	55.568 ± 0.017 ^u	7.422 ± 0.002 ⁿ
Gallic Acid	17.993 ± 0.005 ^r	15.239 ± 0.005 ^q
Tannic Acid	13.466 ± 0.004 ^p	4.899 ± 0.001 ^l
Saponins	2.572 ± 0.001 ⁱ	1.479 ± 0.000 ^d
Rutin Hydrate	2.030 ± 0.001 ^f	0.949 ± 0.000 ^c
Kaempferol	5.884 ± 0.002 ^m	2.179 ± 0.001 ^g
Naringin	2.336 ± 0.001 ^h	1.013 ± 0.000 ^c
Quercetin	1.745 ± 0.001 ^e	2.773 ± 0.001 ^j
p-Coumaric Acid	3.937 ± 0.001 ^k	0.293 ± 0.000 ^b

Note: Values are expressed as mean $\pm$ SEM of three technical replicates as mg/L. Values having distinct letters (as their superscripts) are statistically significant from each other at $p < 0.05$. ND - Not Detected; DRDFME - Dried Red Delicious Flesh Methanolic Extract; DRDFAE - Dried Red Delicious Flesh Aqueous Extract

Table 7 provides the molecular weight (in g/mol) and chemical formulae for all the compounds identified from methanolic and aqueous extracts of *Ananas comosus*, Granny Smith, and Red Delicious flesh.

Table 7. The molar mass (in g/mol) and chemical formulae for compounds identified from DACFME, DACFAE, DGSFME, DGSFAE, DRDFME, and DRDFAE.

Compounds	Molar mass (g/mol)	Chemical formulae
Caffeic Acid	180.16	C ₉ H ₈ O ₄
Ferulic Acid	194.18	C ₁₀ H ₁₀ O ₄
Maleic Acid	116.07	C ₄ H ₄ O ₄
Salicylic Acid	138.12	C ₇ H ₆ O ₃
Gallic Acid	170.12	C ₇ H ₆ O ₅
Tannic Acid	1701.20	C ₇₈ H ₅₂ O ₄₆
Saponins	Usually 600 – 1500+	Variable
Rutin Hydrate	610.52 + 18x	C ₂₇ H ₃₀ O ₁₆ .xH ₂ O
Kaempferol	286.24	C ₁₅ H ₁₀ O ₆
Naringin	580.53	C ₂₇ H ₃₂ O ₁₄
Quercetin	302.24	C ₁₅ H ₁₀ O ₇
p-Coumaric Acid	164.16	C ₉ H ₈ O ₃

DACFME - Dried *Ananas comosus* Flesh Methanolic Extract;
 DACFAE - Dried *Ananas comosus* Flesh Aqueous Extract;
 DGSFME - Dried Granny Smith Flesh Methanolic Extract;
 DGSFAE - Dried Granny Smith Flesh Aqueous Extract;
 DRDFME - Dried Red Delicious Flesh Methanolic Extract;
 DRDFAE - Dried Red Delicious Flesh Aqueous Extract

Discussion

Medicinal plants and fruits represent an important contain bioactive phytochemicals with promising nutritional, therapeutic, and health-promoting potentials (Asale et al. 2021; Adegbesan et al. 2024; Adefuye et al. 2026). The proposed use of medicinal plants in therapy has been widely reported due to their antioxidant and pharmacological activities. Thus, medicinal plants are very relevant in developing plant-based nutraceuticals, and functional foods. Unlike many previous studies that primarily report total phenolic content and overall antioxidant activity, the present investigation combined ABTS antioxidant evaluation with HPLC-based characterization of individual phytochemicals in two commercially important apple cultivars and pineapple under identical extraction conditions.

The present study provides important insights into the phytochemical profile/composition and TAC of dried Smooth Cayene, Granny Smith, and Red Delicious flesh aqueous and methanolic extracts. The comparative evaluation revealed that solvent type (distilled water and methanol) significantly influenced the extraction efficiency, distribution, and concentration of bioactive compounds identified through HPLC analysis. The results from our study demonstrate significant variations

in total antioxidant capacity (TAC) of the aqueous and methanolic extracts of apple and pineapple varieties. Therefore, the detection of antioxidant capacities in methanolic and aqueous extracts of *Ananas comosus*, Granny Smith, and Red Delicious apples at varying degrees suggest the identification of potent bioactive compounds, which qualify the plants as source of nutraceuticals and functional foods. As observed, DACFME exhibited the highest TAC at 5 μ g/mL (Table 1) than other five extracts. DRDFME showed the highest TAC at 10 μ g/mL (Table 3) than other five extracts. DACFAE demonstrated the highest TAC at 25, 50, and 100 μ g/mL (Table 1) than other five extracts.

As noticed in Table 1, methanolic extract of dried *Ananas comosus* flesh produced significantly higher TAC relative to aqueous extracts at 5, and 10 μ g/mL whereas the TAC in aqueous extracts of dried *Ananas comosus* flesh was significantly higher relative to methanolic extracts at 25, and 50 μ g/mL. The ability of 25 and 50 μ g/mL aqueous extracts of *Ananas comosus* to exhibit significantly higher TAC relative to corresponding methanolic extracts of *Ananas comosus* suggests that hydrophilic antioxidants such as ascorbic acid, sugars, glycosides, and highly polar phenolics may contribute substantially to antioxidant activity under aqueous extraction conditions.

In addition, Alamgir (2018) noted that aqueous solvents preferentially extract glycosides, saponins, and other polar secondary metabolites because of their strong hydrophilic nature. Biphasic antioxidant behavior by methanol and distilled water indicates that both hydrophilic antioxidants (from aqueous extracts) and lipophilic antioxidants (from methanolic extracts) contribute to total antioxidant potential. Interactions among phytochemicals obtained from medicinal plants have been reported to enhance antioxidant effectiveness by the regeneration of oxidized phenolics, stabilization of radical intermediates, and enhancement of bioavailability (Chen et al. 2022).

Conversely, from the perspective of *Malus domestica*, our findings show that methanolic extract produced significantly higher TAC relative to aqueous extracts (Table 2 and Table 3). Our observations are in line with previous studies that demonstrated that methanolic extraction improves the recovery of antioxidants and phytochemicals responsible for mitigation of oxidative stress and free radical neutralization (Shahidi and Ambigaipalan 2018; Ibe et al. 2022). Our observations also align with reports of increased levels of phenolics and antioxidant activity in methanolic extracts in comparison to aqueous extracts (Do et al. 2014).

Furthermore, the results for HPLC reveal solvent-dependent phytochemical solubility and extraction. Higher concentrations of caffeic acid, gallic acid, saponins, rutin hydrate, and kaempferol were observed in DACFME (Table 4), while maleic acid and ferulic acid were highest in DGSFME (Table 5). In contrast, salicylic acid, quercetin, naringin, and p-coumaric acid showed

higher concentrations in DACFAE (Table 4), whereas tannic acid was highest in DRDFME (Table 6). In corroboration of previous findings (Engwa et al. 2022 and Olajide et al. 2022), our results suggest selective solubilization of phytochemicals based on solvent polarity. Caffeic, ferulic, and gallic acids are linked with potent antioxidant properties through single electron transfer (SET) and hydrogen atom transfer (HAT) mechanisms, which inhibit the peroxidation of lipid due to free radical scavenging (Oluwole et al. 2022). Furthermore, phenolics play vital roles in mitigating oxidative stress implicated in several diseases and health challenges (Engwa et al. 2022 and Olajide et al. 2022). Moreover, quercetin, rutin, and naringin possess neuroprotective, anti-inflammatory, and enzyme inhibitory activities associated with oxidative stress modulation (Shoaib et al. 2023).

The phytochemical profile observed in the present study is consistent with reports that *Malus domestica* fruits are naturally rich in hydroxycinnamic acids, flavan-3-ols, flavonols, and dihydrochalcones (McGhie et al. 2005; Arnold and Gramza-Michalowska 2024). Major phenolic constituents commonly reported in apples include chlorogenic acid, caffeic acid, p-coumaric acid, catechin, epicatechin, rutin, quercetin glycosides, and phloridzin (McGhie et al. 2005; Cebeci and Şahin-Yeşilçubuk 2023; Arnold and Gramza-Michalowska 2024). In the present study, caffeic acid, gallic acid, ferulic acid, rutin hydrate, quercetin, kaempferol, naringin, and p-coumaric acid were identified in varying concentrations across the extracts. The predominance of caffeic acid, ferulic acid, gallic acid, and rutin hydrate in the methanolic extracts suggests that methanol promoted more efficient recovery of moderately polar phenolic compounds. These compounds are known to contribute substantially to antioxidant activity through hydrogen atom transfer (HAT), single-electron transfer (SET), and metal-chelating mechanisms (Oluwole et al. 2022). Similar observations have been reported in recent investigations of apple phytochemistry, where phenolic acids and flavonoids were identified as major contributors to antioxidant functionality and health-promoting properties of apples (Cvetković et al. 2024; Arnold and Gramza-Michalowska 2024).

The higher concentrations of saponins and glycosylated flavonoids in aqueous extracts of DACF (Table 4) may also be associated with improved extraction of amphiphilic and membrane associated phytochemicals. Such compounds can modulate membrane permeability and influence antioxidant interactions at cellular membranes (Efimova and Ostroumova 2023). Additionally, saponins possess surfactant-like properties that may enhance solubility and bioavailability of other biologically active components locked-up within medicinal plants (Sadasivam et al. 2025). The coexistence of multiple phenolics, flavonoids, tannins, and saponins across all extracts investigated in

this study therefore suggests possible synergistic antioxidant interactions that collectively contribute to enhanced total antioxidant capacity.

Importantly, our observations for both TAC and phytochemical contents indicate that solvent polarity strongly influences the extraction efficiency of antioxidant phytochemicals. Methanol, owing to its intermediate polarity, has been reported to extract a broader spectrum of phenolic acids and flavonoids than water, “particularly compounds having low to moderate polarity” (Do et al. 2014; Lim et al. 2024). Similarly, Sharifi et al. (2025) reported that solvent systems significantly alter the profiles of specific phytochemicals and antioxidant activities of plant extracts, thereby emphasizing the importance of solvent selection during phytochemical extraction. The findings demonstrated solvent-dependent variations not only in antioxidant capacity but also in the distribution of specific phenolic acids and flavonoids, including caffeic acid, ferulic acid, gallic acid, rutin hydrate, quercetin, kaempferol, and naringin. These observations provide analytical insight into how extraction solvent influences phytochemical recovery and may assist in the optimization of extraction strategies for functional food and nutraceutical applications.

CONCLUSION

The dried flesh of Smooth Cayenne (variant of *Ananas comosus*), Granny Smith, and Red Delicious (variants of *Malus domestica*) contains phenolic compounds and flavonoids with antioxidant activity under the experimental conditions used. The selection of a solvent for extraction is dependent on the targeted phytochemical(s). These observations are important for optimizing phytochemical extraction protocols in nutraceutical, pharmaceutical, and functional food applications. Thus, the phytochemical distribution of different samples directly influences their total antioxidant capacities. Therefore, dried *Ananas comosus*, Granny Smith, and Red Delicious flesh have potential for oxidative stress modulation and may be beneficial for health promotion.

Recommendation

Future studies should investigate the biological effects and mechanisms of action of the dried *Ananas comosus*, Granny Smith, and Red Delicious flesh using appropriate in-vivo and clinical models. For potential pharmaceutical applications, further research should isolate, purify, and characterize the individual bioactive compounds with antioxidant properties from dried *Ananas comosus*, Granny Smith, and Red Delicious flesh responsible for the observed antioxidant activities and other health promotion benefits.

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