



Comparative analysis of phytochemical profiles and antioxidant potential of kiwifruit cultivars

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Abstract

This study explores the phytochemical composition and antioxidant potential of various kiwifruit cultivars (*Actinidia* spp.) cultivated in South Korea. The nine cultivars analyzed were ‘Octogreen,’ ‘Garmrok,’ ‘Haegeum,’ ‘Goldone’ (GO), ‘Garmhwang’ (GH), ‘Sweet Gold’ (SG), ‘Sunfl’ (SF), ‘Nokong’, and ‘Hayward’. The results revealed significant variation in total phenolic content (TPC) and total flavonoid content (TFC) among the cultivars. TPC ranged from 6.43 to 11.23 mg tannic acid equivalent/g extract (TAE), while TFC ranged from 1.25 to 4.41 mg quercetin equivalent/g extract. Antioxidant activity was evaluated using 2,2-diphenyl-1-picrylhydrazyl and 2,2’-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) radical scavenging assays. SG exhibited the highest scavenging activity, whereas certain other cultivars showed relatively lower antioxidant potential. High-performance liquid chromatography was used to quantify key bioactive compounds known for their health benefits. Neochlorogenic acid (**1**) was among the most abundant, with the highest concentrations observed in GO (0.90 mg/g) and SF (0.66 mg/g), while epicatechin (**4**) was particularly abundant in GH (0.74 mg/g). These findings highlight the importance of genetic diversity in kiwifruit and provide valuable insights for breeding programs focused on enhancing the nutritional and functional qualities of new cultivars. A deeper understanding of the chemical composition can support the development of kiwifruit cultivars targeted for specific health benefits, contributing to healthier dietary choices.

Keywords *Actinidia* spp. · Antioxidant · HPLC · Kiwifruit · Polyphenol · Flavonoid

1 Introduction

Kiwifruit (*Actinidia*), also known as Chinese gooseberry, is a woody vine berry belonging to the family Actinidiaceae (Wang et al. 2021). The name “Chinese gooseberry” was used when the fruit was still regarded as a wild species. In

ancient China, it was highly prized by the nobility, prompting servants to venture into the wilderness to collect the fruit (Richardson et al. 2018). It did not take long for the fruit to capture the interest of the West. Missionaries and scholars from various countries brought specimens and seeds back from China to their homelands, which laid the foundation for the development of the cultivated kiwifruits we are familiar with today. Currently, the genus *Actinidia* comprises 75 taxa, including 54 species and 21 varieties, according to the most recent classification (Yuan et al. 2022; Lee et al. 2020). The two most commercially important species are *A. chinensis* and *A. deliciosa* (Follett et al. 2019). These species include various cultivars that differ in fruit shape, size, weight, eating quality (aroma, texture, and flavor), skin characteristics (thickness, color, hairiness or smoothness), and shelf life (Sivakumaran et al. 2016; Ryu et al. 2024).

Arguably the most well-known cultivar is ‘Hayward’ (*A. deliciosa*), which is recognized for its exceptionally juicy pulp, vibrant green color, and pleasant flavor profile (Pinto and Vilela 2018). Although ‘Hayward’ was originally

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developed in New Zealand and is now widely cultivated around the world, South Korea has also developed several competitive cultivars. Notable among them are ‘Haehyang,’ ‘Haegeum,’ ‘Haewon,’ and ‘Garmhwang’ (Lim et al. 2014).

Another well-known kiwifruit cultivar is ‘Hongyang’ (*A. chinensis*), characterized by its smooth, nearly hairless skin. Compared to ‘Hayward,’ ‘Hongyang’ has a higher vitamin C content, although its fruits are smaller in size and the plants are more susceptible to bacterial canker. As a result, the market value of ‘Hongyang’ often exceeds that of ‘Hayward’ (Li et al. 2021).

Over the past decade, extensive research has highlighted the health benefits of kiwifruit consumption, showing its potential to improve not only nutritional status but also immune, digestive, and metabolic health (Billows et al. 2022; Kang et al. 2021). The well-established advantages of including fruit in a regular diet further emphasize the value of incorporating kiwifruit into everyday eating habits (Conner et al. 2020). Like many fruits, kiwifruits are rich in secondary metabolites, particularly polyphenols, which serve as powerful antioxidants. The polyphenolic compounds quantified in the present study are among the most notable antioxidants found in kiwifruit. These compounds enhance and complement the activity of antioxidant vitamins and enzymes, helping to reduce oxidative stress caused by excessive reactive oxygen species (Li et al. 2023). As awareness of these health benefits grows, consumer demand for higher-quality kiwifruit has steadily increased. However, despite the availability of numerous kiwifruit cultivars on the market, there remains a lack of research on the nutritional diversity among them. In particular, many recently developed and commercially successful cultivars have yet to be thoroughly evaluated in this context.

To address this gap, this study sought to identify which cultivars offer superior nutritional and functional qualities. To this end, we examined nine kiwifruit cultivars, assessing their total polyphenol and flavonoid contents (TPC and TFC), along with their antioxidant capacities using 2,2-diphenyl-1-picrylhydrazyl (DPPH) and 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS⁺) radical scavenging assays. The phytochemicals responsible for these activities were then identified and quantified using high-performance liquid chromatography (HPLC). A better understanding of the chemical composition across different kiwifruit cultivars can support breeding programs aimed at developing varieties with enhanced nutritional profiles, such as higher levels of specific bioactive compounds or improved antioxidant activity. This could ultimately lead to the cultivation of kiwifruit cultivars tailored for targeted nutritional or functional purposes.

2 Materials and methods

2.1 Plant materials

Nine fresh kiwifruit cultivars (*Actinidia* spp.) were cultivated at the Namhae Branch of the National Institute of Horticultural and Herbal Science in 2023 and harvested in late October of the same year. The cultivars analyzed in this study were ‘Octogreen’ (OG), ‘Garmrok’ (GR), ‘Haegeum’ (HG), ‘Goldone’ (GO), ‘Garmhwang’ (GH), ‘Sweet Gold’ (SG), ‘Sunfl’ (SF), ‘Nokong’ (NK), and ‘Hayward’ (HW) (Fig. 1).

2.2 Instruments and reagents

HPLC analysis was conducted using an Agilent Technologies 1260 Infinity II system (Santa Clara, CA, USA), equipped with a pump, auto-sampler, and ultraviolet (UV) detector. HPLC-grade solvents, including trifluoroacetic acid (TFA) and acetonitrile (ACN), were purchased from J.T. Baker (Radnor, PA, USA). Tannic acid, quercetin, and six standard compounds, neochlorogenic acid (**1**), chlorogenic acid (**2**), caffeic acid (**3**), epicatechin (**4**), peltatoside (**5**), and rutin (**6**) (Fig. 2), were generously provided by the Natural Product Institute of Science and Technology (www.nist.re.kr), Anseong, Korea.

2.3 Sample extraction

The nine kiwifruit cultivars were first sliced into small pieces and immediately frozen at -80°C for 48 h to preserve phytochemical integrity. Frozen samples were subsequently lyophilized for 7 days using an Eyela FDU-1200 Freeze Dryer (Tokyo, Japan) under a vacuum of ~ 0.1 mbar and a shelf temperature gradually increased from -40°C to 25°C . Ten grams of each freeze-dried sample were extracted three times with 200 mL of 95% ethanol (EtOH) under reflux 50°C for 3 h per extraction. After each extraction, solutions were filtered through Whatman No. 1 filter paper and concentrated under reduced pressure using an Eyela N-1210BVF Rotary Evaporator (Tokyo, Japan) at 40°C . The resulting extracts were stored in a desiccator until further analysis.

2.4 TPC analysis

The quantification of TPC in the nine kiwifruit cultivar extracts was conducted using a method previously described by the same authors, with slight modifications to suit the current study. Briefly, 60 μL of each extract was mixed with 40 μL of Folin–Ciocalteu reagent (Sigma-Aldrich, St. Louis, MO, USA). Subsequently, 100 μL of 7.5% Na_2CO_3



Fig. 1 Representative images of the different green and golden kiwifruit cultivars: OG (A), GR (B), HG (C), GO (D), GH (E), SG (F), SF (G), NK (H), and HW (I)

solution was added, and the mixtures were incubated at 37 °C for 30 min in the dark. Absorbance was then measured at 760 nm using a microplate reader (Epoch; BioTek, Winooski, VT, USA). TPC was calculated based on a standard curve generated using various concentrations of tannic acid.

2.5 TFC analysis

TFC was determined using a previously reported method with minor adjustments. In brief, 100 µL of a 2% aluminum chloride hexahydrate solution was added to 100 µL of each extract. The mixture was incubated at 37 °C for 10 min.

After incubation, absorbance was measured at 430 nm using a microplate reader (Epoch; BioTek, Winooski, VT, USA). TFC was quantified using a standard curve prepared from a range of quercetin concentrations.

2.6 DPPH radical scavenging assay

The DPPH radical scavenging activity was assessed following a modified version of a previously published method. A 0.2 mM DPPH working solution was prepared by diluting a DPPH stock solution with 95% ethanol. Then, 10 µL of each plant extract was added to 200 µL of the DPPH working solution in a 96-well plate. Each sample was analyzed

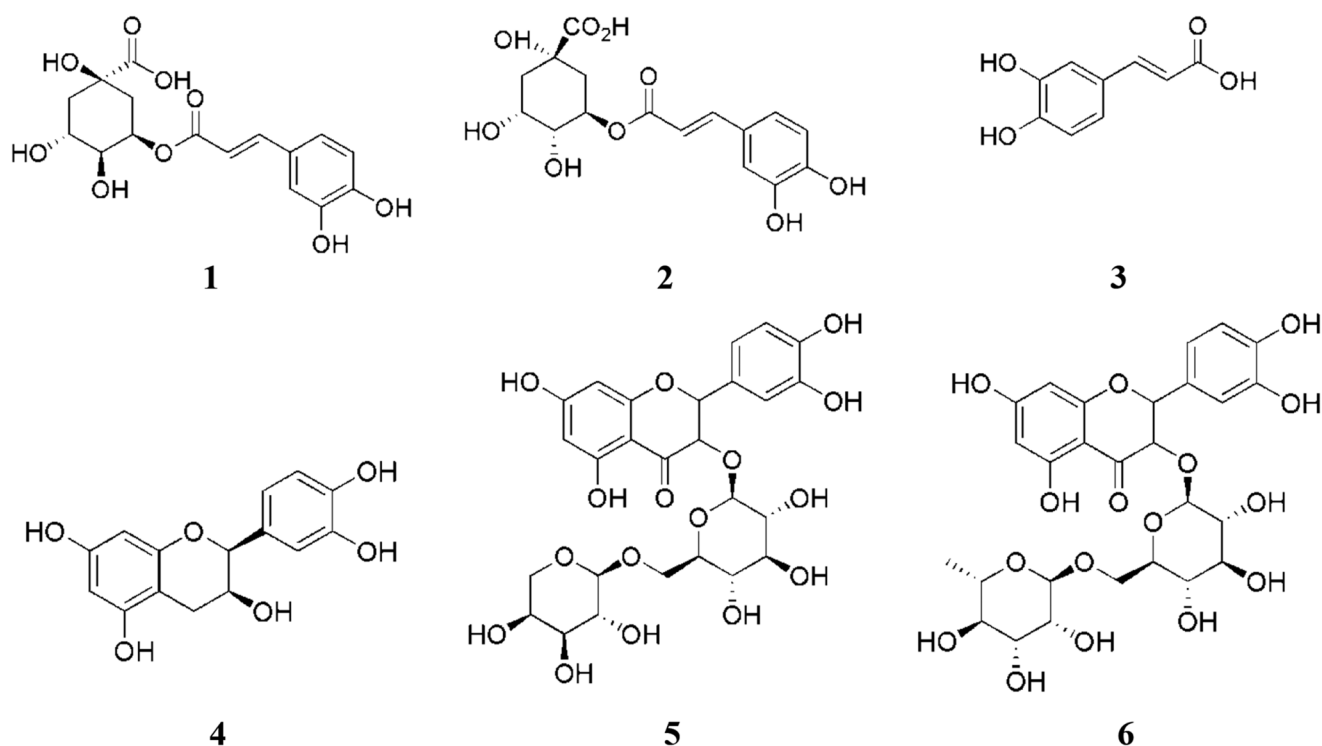


Fig. 2 Chemical structures of compounds 1–6: neochlorogenic acid (1), chlorogenic acid (2), caffeic acid (3), epicatechin (4), peltatoside (5), and rutin (6)

in triplicate. After mixing on a microplate shaker, the plate was incubated in the dark at 37 °C for 30 min. Absorbance was measured at 514 nm using a microplate reader. Ascorbic acid was used as a standard, and the DPPH radical scavenging activity (%) was calculated based on optical density (OD) values using the following equation:

$$\text{DPPH radical scavenging activity (\%)} = \frac{(\text{Blank OD} - \text{Sample OD})}{\text{Blank OD}} \times 100$$

2.7 ABTS⁺ radical scavenging assay

The ABTS⁺ assay was conducted following a method previously described by the authors, with minor modifications. The ABTS⁺ solution was first diluted with distilled water to prepare the working solution. Then, 10 µL of each plant extract was added to 200 µL of the ABTS⁺ working solution in a 96-well plate. Each assay was performed in triplicate for accuracy. After thorough mixing, the plate was incubated in the dark at 37 °C for 30 min. Absorbance was measured at 734 nm using a microplate reader. Ascorbic acid was used as a positive control. The ABTS⁺ radical scavenging activity was calculated using the following equation:

$$\text{ABTS}^+ \text{ radical scavenging activity (\%)} = \frac{(\text{Blank OD} - \text{Sample OD})}{\text{Blank OD}} \times 100$$

2.8 HPLC sample and standard solutions preparation

The nine kiwifruit extracts and six standard compounds were dissolved in HPLC-grade methanol (MeOH) to final concentrations of 30 mg/mL for the extracts and 1 mg/mL for the standards. The solutions were sonicated for 10–20 min and filtered through 0.45 µm polyvinylidene fluoride (PVDF) membrane filters. Standard solutions were subsequently diluted to appropriate concentrations for quantitative analysis.

2.9 HPLC conditions

Quantitative analysis of the nine *Actinidia* spp. extracts was performed using an Agilent 1260 Infinity II HPLC system (Santa Clara, CA, USA) equipped with a quaternary pump and a variable wavelength detector. Separation was achieved on a YMC Pack-Pro C18 column (250 mm × 4.6 mm, 5 µm) with a 10 µL injection volume and a flow rate of 1.0 mL/min. The mobile phase consisted of 0.1% trifluoroacetic acid (TFA) in water (solvent A) and acetonitrile (solvent B),

Table 1 Calibration data for compounds 1–6

Compound	t_R (min)	Regression equation ^a	Coefficient of determination, R^2 ^b
1	19.1	$Y = 10.42x + 6.1458$	0.9979
2	23.8	$Y = 10.011x - 0.4333$	0.9996
3	25.6	$Y = 24.162x + 1.8583$	0.9998
4	27.1	$Y = 4.9848x + 2.7375$	0.9998
5	30.8	$Y = 15.307x + 136.9$	0.9994
6	32.1	$Y = 18.904x + 0.4208$	0.9999

Neochlorogenic acid (1), chlorogenic acid (2), caffeic acid (3), epicatechin (4), peltatoside (5), and rutin (6)

Table 2 Extraction yields of the Kiwifruit samples used in this study

Sample	Total sample weight (g)	Total extract weight (g)	Extraction yield (%)
OG	9	5.1	56.67%
GR	9	6.5	72.22%
HG	9	7.2	80.00%
GO	9	6.9	76.67%
GH	9	6.5	72.22%
SG	9	6.3	70.00%
SF	9	6.2	68.89%
NK	9	7.3	81.11%
HW	9	5.9	65.56%

applied in the following gradient: 95% A (0–10 min), 67% A (at 40 min), 0% A (at 45 min), and 95% A (55–65 min). Detection was performed at 270 and 330 nm.

2.10 Calibration curve

Standard curves were established using five concentrations of each standard compound. Linearity was assessed using the coefficient of determination (R^2), and the concentrations of target compounds in the samples were calculated based on the regression equations derived from these curves. In the calibration functions, the x -axis represents concentration ($\mu\text{g/mL}$) and the y -axis represents peak area. Results are expressed as mean $\pm$ standard deviation (SD) ($n=3$) (Table 1).

2.11 Statistical analysis

All quantitative results are expressed as mean $\pm$ SD from three independent experiments ($n=3$). The data were normalized, and a one-way analysis of variance (ANOVA) was then applied to compare differences among multiple groups. When ANOVA indicated significant differences ($p < 0.05$), Tukey's post hoc test was performed to identify specific group differences, with a 95% confidence interval. All analyses, including calculation of SD, ANOVA, and post

hoc testing, were conducted using GraphPad Prism version 8.0.2 (GraphPad Software, Boston, MA, USA). Graphical results were generated in the same software.

3 Results and discussion

3.1 Reflux extraction

Reflux extraction was employed to isolate the compounds of interest in this study. As shown in Table 2, all samples yielded more than 50%, with NK (81.11%) exhibiting the highest yield, followed by HG (80.00%), GO (76.67%), GH (72.22%), GR (72.22%), SG (70.00%), SF (68.89%), HW (65.56%), and OG (56.67%). These results indicate that the extraction method used is highly effective for kiwifruit cultivars. This method of extraction is relatively uncommon for kiwifruits, as most previous studies have utilized techniques such as Soxhlet extraction (Silva et al. 2023), microwave-assisted extraction (Carbone et al. 2020), or supercritical fluid extraction (Liu et al. 2023) for phytochemical analysis.

3.2 TPC and TFC

Polyphenols are a class of secondary metabolites widely found in plants and plant-derived products, including fruits, vegetables, herbs, and spices (Rudrapal et al. 2022). In addition to their antioxidant activity, polyphenolic compounds exhibit a broad spectrum of bioactive properties. Strong pre-clinical and clinical evidence supports the protective role of polyphenol-rich diets against the development of various chronic diseases, such as cancer, diabetes, cardiovascular diseases, and neurodegenerative disorders (Khan et al. 2021).

The results demonstrated that TPC varied significantly among the different kiwifruit cultivars. As illustrated in Fig. 3A, the TPC of the nine cultivars ranged from 6.43 to 11.23 mg tannic acid equivalent (TAE)/g extract. Specifically, the TPC values for GO, GH, SG, SF, and NK were 9.77, 10.05, 9.10, 9.98, and 11.23 mg TAE/g extract, respectively. These cultivars did not exhibit statistically significant differences among themselves. However, their TPC values were significantly higher than those of HG (7.56 mg TAE/g extract), HW (7.56 mg TAE/g extract), OG (6.98 mg TAE/g extract), and GR (6.43 mg TAE/g extract). Overall, gold kiwifruit cultivars generally tended to have higher TPC than green ones. Although gold cultivars generally tended to accumulate higher TPC, an exception was observed in NK (Lee et al. 2025), a green cultivar that recorded the highest value (11.23 mg TAE/g extract). In contrast, HG, a gold cultivar, showed one of the lowest (7.56 mg TAE/g extract). These cultivar-specific differences are likely linked to

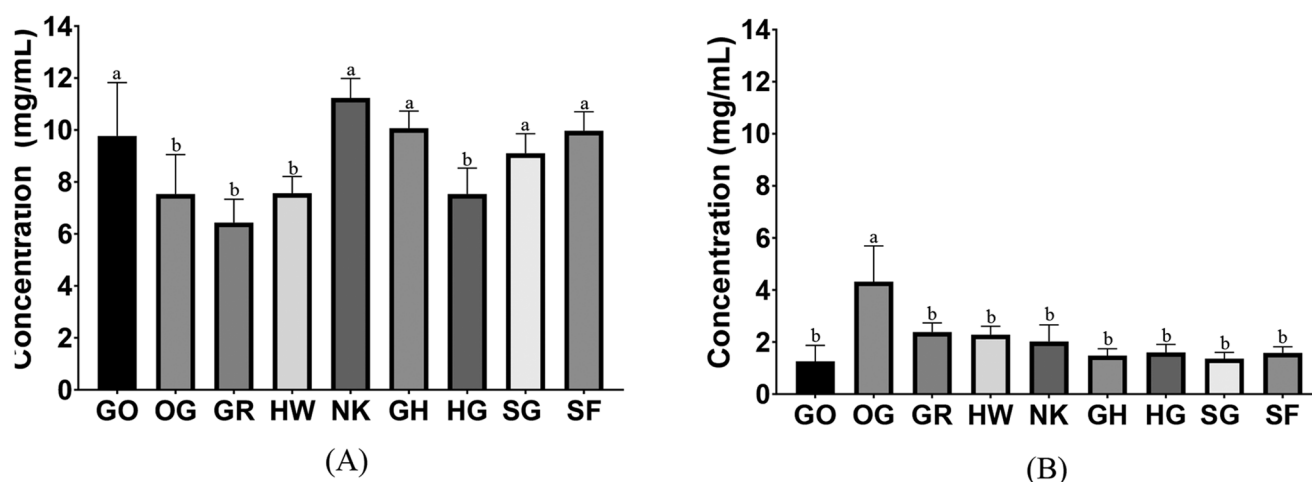


Fig. 3 Total polyphenol content (**A**) and total flavonoid content (**B**) of the kiwifruit cultivars: GO, OG, GR, HW, NK, GH, HG, SG, and SF (mean $\pm$ SD; $n=3$). Bars marked with different letters indicate statistically significant differences among cultivars ($p<0.05$)

genetic variation in phenylpropanoid metabolism. Previous reports indicate that green kiwifruit can accumulate higher levels of hydroxycinnamic acids, whereas golden cultivars typically contain higher levels of flavan-3-ols and other polyphenols (Abudurehman et al. 2022). Similar findings were reported in a previous study, which found that gold kiwifruit cultivars generally contained higher levels of polyphenols and vitamin C compared to their green counterparts (Du et al. 2009). However, a recent study found that green kiwifruits tend to have higher TPC compared to their golden counterparts (Zhu et al. 2021). In addition, environmental and agronomic factors, including light exposure, soil nutrients, and harvest timing, may influence the accumulation of different phenolic subclasses, thereby explaining why NK deviates from the general trend observed in gold cultivars (Li et al. 2018).

Flavonoids, a major subclass of polyphenols, play important roles in plants by contributing to UV protection, pollinator attraction, pathogen defense, and pigmentation (Yu et al. 2020). In addition to their roles in plant physiology, flavonoids affect the flavor profile of fruit crops and are considered potent antioxidants beneficial to humans (Ullah et al. 2020). In this study, the TFC of the nine kiwifruit cultivars ranged from 1.25 to 4.41 mg quercetin equivalent (QE)/g extract. Unlike the TPC results, the TFC values did not exhibit substantial variation across most of the cultivars. Specifically, the TFCs of GR, HG, GO, GH, SG, SF, NK, and HW were 2.39, 1.61, 1.25, 1.48, 1.35, 1.56, 2.03, and 2.29 mg QE/g extract, respectively. These values were not significantly different from one another (Fig. 3B). However, the TFC of OG, at 4.41 mg QE/g extract, was significantly higher than that of all other cultivars. Despite this, the green cultivars generally exhibited higher TFC values compared to the golden cultivars. These findings are consistent with

a previous study by Lee et al. (2018), which investigated the total flavonoid and vitamin C contents in green kiwifruit (*Actinidia deliciosa* cv. Hayward) and golden kiwifruit (*Actinidia chinensis* cv. Hort16A) treated with *doenjang* and *gochujang*. Similar to the present results, their study reported significantly higher total flavonoid content in golden kiwifruit compared to green kiwifruit.

Intriguingly, TPC and TFC values do not always correlate closely, despite the fact that flavonoids are a subclass of polyphenols. While it might seem logical to expect that a higher total polyphenol content would correspond to higher flavonoid content, several factors can account for the discrepancies observed between TPC and TFC measurements.

Firstly, the polyphenolic composition of a plant can vary considerably among cultivars, with each cultivar containing distinct types and proportions of polyphenolic compounds (McClure et al. 2019). For instance, although flavonoids constitute one major class of polyphenols, other compounds such as phenolic acids, lignans, and stilbenes also contribute to the total polyphenol content but are not captured by the TFC assay. Furthermore, environmental factors such as climate, soil composition, vineyard location, and cultivation practices significantly influence the accumulation of polyphenols and phenolic acids in kiwifruits, even though certain compound classes may be genetically regulated (Šikuten et al. 2020).

Moreover, TPC is commonly assessed using the Folin–Ciocalteu assay, which measures the total reducing capacity of phenolic compounds and thus captures a broad range of polyphenols. In contrast, TFC is typically measured using aluminum chloride colorimetric methods, which are more specific to flavonoid compounds (Aisa and Tukiran 2023). This difference in assay specificity can lead to disparities between TPC and TFC values. Additionally, variations in

extraction methods can affect the efficiency of polyphenol isolation. Certain solvents or extraction conditions may preferentially extract specific types of polyphenols, thereby influencing the resulting TPC and TFC measurements (Silva et al. 2023; Carbone et al. 2020; Liu et al. 2023). In summary, although flavonoids are a subset of polyphenols, variations in plant genetics, environmental factors, assay specificity, and extraction efficiency can all contribute to the differences observed between TPC and TFC values in kiwifruit cultivars.

3.3 DPPH and ABTS⁺ radical scavenging activity

The antioxidant potential of all cultivars was assessed based on their ability to scavenge DPPH and ABTS⁺ radicals (Fig. 4). Results are expressed as IC₅₀ values, where a lower IC₅₀ indicates stronger antioxidant activity (Berrouet et al. 2020). A linear relationship was observed between extract concentration and radical scavenging activity, with higher extract concentrations leading to increased antioxidant activity.

In the DPPH assay, the cultivar SG exhibited the strongest antioxidant capacity, with an IC₅₀ value of 3.98 mg/mL, followed by GH (4.27 mg/mL), HW (6.49 mg/mL), OG (7.82 mg/mL), NK (9.28 mg/mL), SF (9.51 mg/mL), and GO (9.81 mg/mL). Two cultivars, GR and HG, demonstrated minimal activity in this assay, and their IC₅₀ values could not be calculated. In contrast, all cultivars showed measurable activity in the ABTS⁺ assay. GH exhibited the strongest activity with an IC₅₀ of 3.47 mg/mL, followed by HW (3.86 mg/mL), OG (5.51 mg/mL), SG (6.02 mg/mL), HG (6.18 mg/mL), NK (6.32 mg/mL), GO (8.03 mg/mL), SF (8.38 mg/mL), and GR (8.52 mg/mL). In both assays, the positive control, ascorbic acid, displayed the

highest antioxidant potential with IC₅₀ values of 0.14 mg/mL (DPPH) and 0.11 mg/mL (ABTS⁺), as expected.

These results partially align with findings by Wang et al. (2018), who assessed the antioxidant potential of different kiwifruit parts and found that ‘Jinlong’ (a golden cultivar) exhibited the highest ABTS⁺ scavenging activity, while ‘Jinxiang’ (a green cultivar) showed the lowest. Their results were consistent across both ABTS⁺ and DPPH assays, with golden cultivars consistently ranking higher. While this trend was partially observed in the present study’s ABTS⁺ results, it did not hold in the DPPH assay, where SG (a golden cultivar) ranked highest, but other golden cultivars did not show similarly strong activity.

It is important to note that various factors could account for these differences. For instance, compound degradation during sample processing may affect antioxidant levels (Gómez-Gaete et al. 2024). Additionally, kiwifruits are climacteric and highly perishable once harvested (Paul and Pandey 2011). According to Wang et al. (2022), the degree of ripeness significantly influences antioxidant activity: ripe fruits exhibited the highest total antioxidant activity (42.9%), followed by unripe (31.35%) and overripe fruits (25.75%). This suggests that the ripeness stage at the time of testing could significantly impact antioxidant assay results.

3.4 HPLC analysis

To obtain a detailed profile of the phenolic composition in the kiwifruit cultivars, HPLC analysis was performed. Previous studies have identified flavan-3-ols (e.g., catechin), hydroxycinnamic acids (such as neochlorogenic acid, chlorogenic acid, and caffeic acid), and flavonols (including quercetin-3-O-glucoside, quercetin-3-rhamnoside, and rutin) as predominant phenolic constituents in kiwifruits (Liang et al. 2021). Based on this knowledge, six commercially available

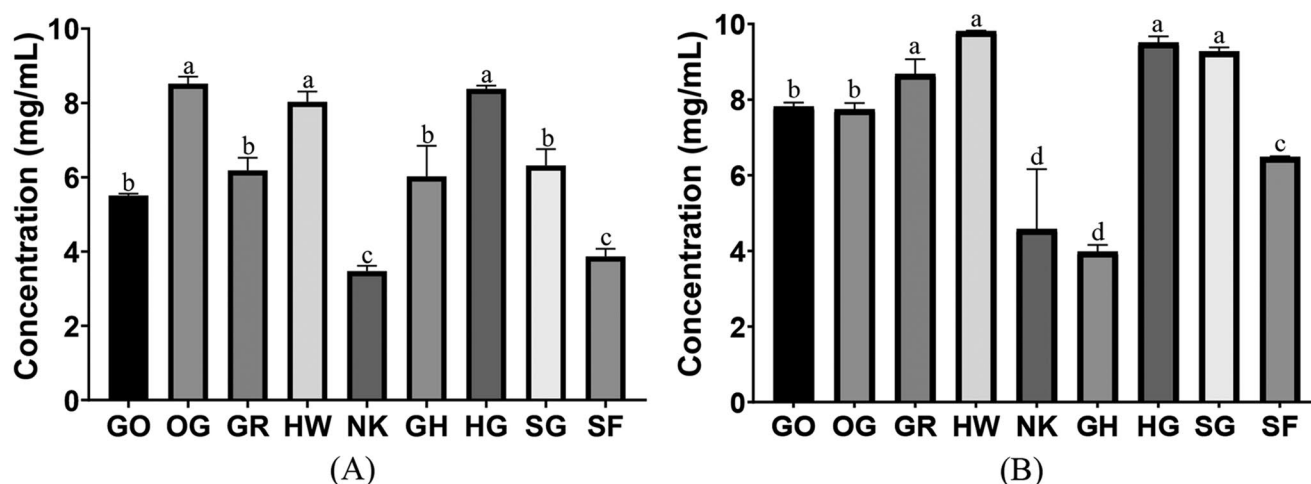


Fig. 4 IC₅₀ values from the ABTS⁺ (A) and DPPH (B) radical scavenging assays of the kiwifruit cultivars: GO, OG, GR, HW, NK, GH, HG, SG, and SF (mean ± SD; n = 3). Bars marked with different letters indicate statistically significant differences among cultivars ($p < 0.05$)

phenolic compounds, neochlorogenic acid (**1**), chlorogenic acid (**2**), caffeic acid (**3**), epicatechin (**4**), peltatoside (**5**), and rutin (**6**), were selected for quantification in the kiwifruit extracts.

Of the six standards, five compounds, neochlorogenic acid (**1**), chlorogenic acid (**2**), caffeic acid (**3**), epicatechin (**4**), and rutin (**6**), were detected across the nine kiwifruit

cultivars analyzed (Fig. 5). The GO cultivar exhibited the highest total phenolic content (1.35 mg/g), followed by SF (1.25 mg/g) and GH (0.97 mg/g). Notably, no detectable levels of any of the six compounds were found in the NK sample (Table 3).

Neochlorogenic acid (**1**) was the most abundant compound, with GO and SF showing particularly high

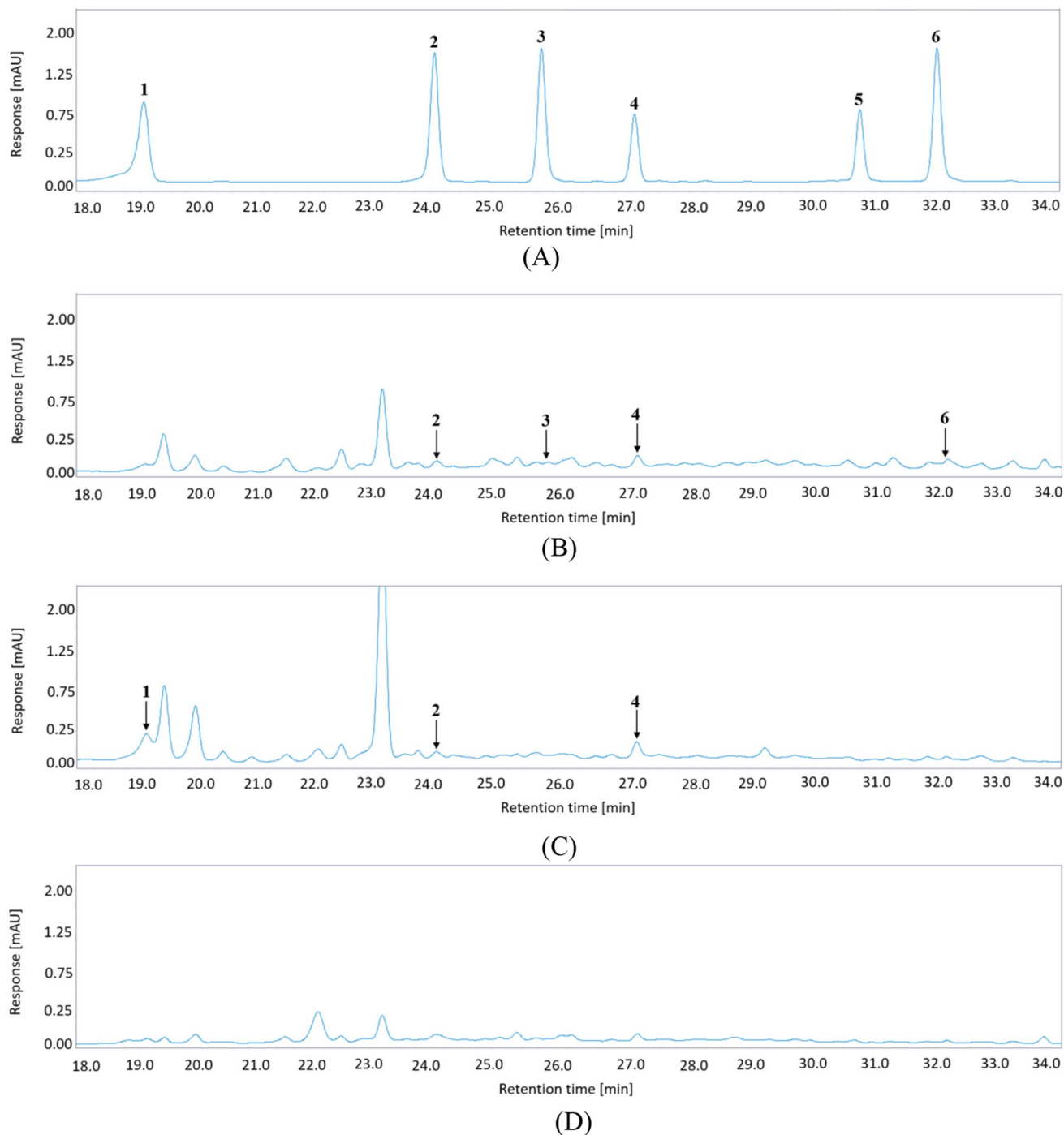


Fig. 5 HPLC chromatograms of compounds 1–6 (A), GR (B), GO (C), and NK (D): neochlorogenic acid (1), chlorogenic acid (2), caffeic acid (3), epicatechin (4), peltatoside (5), and rutin (6)

Table 3 Content of compounds 1–6 in each Kiwifruit cultivar

Sample	Content (mg/g)						Total
	1	2	3	4	5	6	
OG	ND	ND	0.12±0.00	0.23±0.01	ND	0.08±0.00	0.43
GR	ND	0.15±0.00	0.04±0.00	0.22±0.00	ND	0.10±0.00	0.51
HG	0.20±0.00	ND	ND	0.20±0.00	ND	ND	0.40
GO	0.90±0.00	0.14±0.00	ND	0.31±0.00	ND	ND	1.35
GH	0.23±0.01	ND	ND	0.74±0.00	ND	ND	0.97
SG	0.26±0.00	ND	ND	0.33±0.18	ND	ND	0.59
SF	0.66±0.01	0.12±0.00	ND	0.47±0.01	ND	ND	1.25
NK	ND	ND	ND	ND	ND	ND	ND
HW	ND	ND	0.06±0.00	0.38±0.01	ND	ND	0.44

tr: trace; ND; not detected. Results are expressed as mean±SD ($n=3$). Mean±SD values within each column followed by different letters indicate significant differences ($p<0.05$). Neochlorogenic acid (1), chlorogenic acid (2), caffeic acid (3), epicatechin (4), peltatoside (5), and rutin (6)

concentrations (0.90 mg/g and 0.66 mg/g, respectively). Chlorogenic acid (2) was detected only in GR, GO, and SF, with GR containing the highest amount (0.15 mg/g). Caffeic acid (3) was present at relatively low levels (0.04–0.12 mg/g) in OG, GR, and HW. Epicatechin (4) was identified in all samples except NK and HW, with GH showing the highest content (0.74 mg/g). Rutin (6) was detected only in OG and GR, both at low concentrations (≤ 0.10 mg/g). Peltatoside (5) was not detected in any of the samples.

These findings reveal substantial differences in phenolic profiles among the kiwifruit cultivars, likely influenced by genetic background, geographical origin, and cultivation practices (Zhou et al. 2023). The high concentrations of neochlorogenic acid in GO and SF suggest that these cultivars may serve as rich sources of this compound, which has been associated with strong antioxidant and anti-inflammatory properties (Navarro-Orcajada et al. 2021). The dominance of neochlorogenic acid is consistent with previous reports identifying it as a key phenolic compound in *Actinidia* species.

Interestingly, epicatechin (4), a flavanol known for its cardiovascular benefits, was most abundant in GH, suggesting that cultivation under controlled greenhouse conditions may enhance the accumulation of specific polyphenols (Connolly et al. 2023). This could be attributed to reduced environmental stress, which may favor the biosynthesis of flavanols over other phenolic classes. The exclusive detection of rutin (6) in OG and GR indicates a cultivar-specific accumulation pattern for this flavonol. Rutin has been associated with vascular health and is recognized for its capillary-strengthening properties, making its presence in these cultivars particularly relevant from a nutraceutical standpoint (Qanash et al. 2023; Al-Rajhi and Ghany 2023). Although chlorogenic acid (2) and caffeic acid (3) were detected in fewer samples, they may still contribute significantly to the overall antioxidant profile, especially in GR, which contained all three hydroxycinnamic acid

derivatives: chlorogenic, neochlorogenic, and caffeic acids (Lee et al. 2023; Park et al. 2024).

The absence of detectable levels of peltatoside (5) in all samples was unexpected and may suggest either concentrations below the detection limit or a complete absence in the examined cultivars. Further studies employing more sensitive analytical techniques or expanded compound libraries may be necessary to clarify its presence. Collectively, these findings highlight GO and SF as promising sources of dietary polyphenols, particularly neochlorogenic acid (1), while GH is notable for its high epicatechin (4) content. These compositional differences could be strategically utilized in breeding programs or marketing efforts aimed at promoting health-beneficial kiwifruit cultivars.

It should be noted that this study did not experimentally control for environmental parameters such as soil composition, ripening stage, and seasonal fluctuation. Therefore, it is impossible to completely rule out the possibility that these outside variables have an impact, even though the differences across cultivars are probably due to natural genetic variation. To more accurately separate genetic impacts from environmental factors, future research using consistent sample settings and controlled culture will be crucial.

4 Conclusion

This study underscores the importance of investigating the phytochemical composition and antioxidant properties of various kiwifruit cultivars. The notable variability in phenolic profiles and antioxidant capacities among the cultivars reflects the significant roles of genetic background, environmental conditions, and cultivation practices in shaping the accumulation of bioactive compounds. The observed antioxidant potential of several cultivars indicates their promise as candidates for future research into functional food and nutraceutical applications, rather than immediate direct use. These findings offer valuable insights for breeding programs

aimed at enhancing the health-promoting qualities of kiwifruit. Moreover, understanding the effects of genetic variation, cultivation environments, and post-harvest handling can inform strategies to optimize the retention and efficacy of beneficial phytochemicals. Collectively, this research lays a foundation for future studies to evaluate bioavailability, safety, and clinical relevance, thereby clarifying the nutritional and functional potential of kiwifruit.

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Author contributions N.P.U. conducted the HPLC analysis and drafted the manuscript. M.L. analyzed the data and contributed to resource preparation. H.K. conducted antioxidant activity experiments. S.L. designed the experiments and contributed to manuscript writing.

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Data availability All data are available upon request to the corresponding author.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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