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Note

Lignan Content and Antioxidant Capacity of Eight Sesame Varieties Cultivated in Korea

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ABSTRACT: The objective of this study was to examine the lignan content and antioxidant activity of eight Korean sesame seed varieties. We analyzed the lignan content using two different techniques: (1) liquid chromatography coupled with tandem mass spectrometry, and (2) high-performance liquid chromatography coupled with ultraviolet detection. We identified that in sesame seeds, the sesamolin lignan occurs at the highest concentration (ranging between 4.427 mg/g and 10.258 mg/g). Further, the lignan content was highest in the sesame variety Haniall (ranging between 5.220 mg/g and 12.684 mg/g). The Ansan sesame variety showed the greatest antioxidant activity in the relevant tests, exhibiting superior scavenging activities toward 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) and 2,2-diphenyl-1-picrylhydrazyl radicals, along with a higher total polyphenol concentration. In addition, we found that the total polyphenol content of sesame is strongly and positively correlated with its radical scavenging activity, especially against ABTS radicals. These findings highlight that different sesame varieties can be potentially be used as functional foods with antioxidant activities.

Keywords: antioxidants, correlation study, high-performance liquid chromatography, lignans, *Sesamum*

INTRODUCTION

Sesame (*Sesamum indicum* L.) is a traditional crop, whose seeds and seed oil are widely used in African and Asian cuisines (Wei et al., 2022). Roasted sesame seeds and sesame oil are also commonly used in Korean cuisine for their nutty flavor (Yin et al., 2020). Sesame seed is well known for its exceptional medicinal properties and nutritional value (Majdalawieh et al, 2017; Dravie et al., 2020). Sesame seed is rich in nutrients such as unsaturated fatty acids, vitamins, minerals, and essential amino acids (Cardoso et al., 2018; Afroz et al., 2019). With increasing interest in plant-based diets and natural health products, sesame seed could gain a role in health industry as a functional food that can prevent chronic diseases such as diabetes, cardiovascular diseases, and cancer (Gouveia Lde et al., 2016; Jayaraj et al., 2020).

The major lignans in sesame seeds—including sesamin (Ses), sesamol (Sem), and sesamolin (Sel)—have garnered significant attention due to their potential therapeutic applications (Pathak et al., 2014; Michailidis et al., 2019). Other lignans such as secoisolariciresinol (Seco), matairesinol (Mat), pinoresinol (Pin), medioresinol (Med), lariciresinol (Lar), syringaresinol (Syr), 7'-hydroxymatairesinol, and isolariciresinol are natural compounds found in minor amounts in sesame seeds. Lignans have antioxidant activities; they scavenge radicals and reduce oxidative stress (Cornwell et al., 2004). For instance, Sel—a furfuran lignan primarily found in sesame seeds—exhibits various pharmacological activities, such as antioxidant, anticancer, antibacterial, neuroprotective, and melanin production inhibitory activities (Miyahara et al., 2001; Ghafoorunissa et al., 2004; Cheng et al., 2006; Srisayam et al., 2017). Another lignan, Ses, has anti-inflammatory effects; it lowers cholesterol by regulating lipid metabolism (Majdalawieh et al., 2020). Moreover, sesame lignans can alleviate menopausal symptoms because of their estrogenic and antiestrogenic activities (Pianjing et al., 2011). Thus, given the health benefits associated with sesame lignans, there is a growing interest in understanding them and discovering their potential therapeutic applications (Rosalina and Weerapreeyakul, 2021). Sesame seed coat color varies with source plant variety; it can be white, brown, yellow, or black. Moreover, the

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coat color is associated with varied biochemical profiles of molecules such as proteins, fats, and lignans; it is also associated with differing levels of antioxidant and disease resistance activities (Ghotbzadeh Kermani et al., 2019; Wang et al., 2020). The National Institute of Crop Science (NICS) has developed various sesame varieties, which differ in their environmental adaptability, seed yield, disease resistance, antioxidative and other functional properties (Shim et al., 2013; Kim et al., 2020b; Shim et al., 2021). Among these, the "Haniall" variety has a pure white seed coat and higher crude fat content than the "Ansan" variety (Kim et al., 2022c). The "Goenbaek" variety (which also has a white seed coat, and higher fat and Ses content than the "Yangbaek" variety) is used for oil extraction (Kim et al., 2018). The Ses and Sel contents of the "Kangyou" variety are similar as "Goenbaek," but the fat content is higher (Kim et al., 2023). Further, the "Kumok" and "Nuri" varieties (have white seed coats) are resistant to wilt and powdery mildew (Kim et al., 2019; 2022b). The "Daheuk" variety has black seed coats, lower lignan content than the "Goenbaek," and protects the liver from oxidative stress (Kim et al., 2022a). Various studies which investigate the lignan content in sesame seeds, exist. However, they mostly focus on how food processing factors change sesame seed lignan profiles; i.e., research on the lignan profile of unprocessed sesame seeds is limited (Chen et al., 2019; Ji et al., 2019). Moreover, the composition of sesame seeds might differ based on environmental conditions such as cultivar type and cultivation region (Mondal et al., 2010; dos Santos et al., 2018).

Thus, here, we aimed to compare the lignan contents and antioxidant activities of eight sesame varieties (cv. Ansan, Daheuk, Goenbaek, Kumok, Haniall, Kangan, Kangyou, and Nuri) cultivated in Korea. Further, to identify differences in the functional component profiles and antioxidant potential among these eight varieties, we also investigated the correlations between their lignan content and their antioxidant activities. Therefore, here we aimed to compare the lignan content and antioxidant activity of eight sesame varieties cultivated in Korea and explored the correlation between lignan content and antioxidant activity.

MATERIALS AND METHODS

Materials and chemicals

Sesame seeds from eight different varieties (cv. Ansan, Daheuk, Goenbaek, Kumok, Haniall, Kangan, Kangyou, and Nuri) were cultivated in 2023 by the Southern Crop Department of the NICS and the harvested seeds were provided to us in January 2024. Before analysis, all seed samples were washed with deionized water, dried, ground, and stored at −20°C until further analysis. Syr and Med were obtained from ChemFaces. Seco, Mat, (+)-Lar, (+)-Pin, Ses, Sem, and Sel were purchased from Sigma-Aldrich. Acetonitrile was obtained from Merck, and methanol was sourced from Honeywell Burdick and Jackson. The water was deionized using a Milli-Q water purification system (Millipore). Gallic acid, Folin-Ciocalteu reagent, 2,2-diphenyl-1-picrylhydrazyl (DPPH), 2,2'-azinobis(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS), and ethanol were purchased from Sigma-Aldrich. All chemicals and solvents used were of analytical and high-performance liquid chromatography (HPLC) grades.

HPLC analysis of the major lignans in sesame seeds

For the HPLC analysis of the major lignans (Ses, Sem, and Sel), 0.1 g of the powdered sample was extracted with 10 mL of methanol in an ultrasonic water bath (WUC-D10H, Daihan Scientific) at room temperature for 1 h. The extract was then centrifuged at 25,160 *g*, and the supernatant was filtered through a 0.22-μm nylon filter (Whatman) before analysis. The HPLC conditions used for the lignan analysis are detailed in Table 1.

LC-MS/MS quantitative analysis of six minor lignans in sesame seeds

The six minor lignans (Seco, Mat, Lar, Pin, Syr, and Med) were extracted using the method modified by Kim et al. (2024). Briefly, 0.1 g of the powdered sample was mixed with 1 mL of 84% methanol and extracted using an ultrasonic water bath (WUC-D10H, Daihan Scientific) at 40°C for 1 h. After centrifugation at 25,160 *g*, the supernatant was filtered through a 0.22-μm nylon filter for liquid chromatography-tandem mass spectrometry (LC-MS/MS) analysis. The LC-MS/MS analysis was performed using a Shimadzu LCMS-8050 triple quadrupole mass spectrometer in the negative ion mode. The data were detected using the multiple reaction monitoring (MRM) mode, with the MRM chromatograms of the six lignans in the standard solution shown in Fig. 1. Detailed parameters are provided in Table 2 and Table 3.

Table 1. HPLC-UV conditions of sesamol, sesamin, and sesamolin analysis

Instrument (HPLC-UV)	Hitachi 5000 chromaster (Hitachi LTD)
Column	Agilent Zorbax Eclipse XDB-C18 column (5 μm, 150 mm×4.6 mm)
Column oven temperature	30°C
Injection volume	20 μL
Flow rate	0.7 mL/min
Mobile phase	Distilled water : MeOH (3 : 7, v/v)

HPLC-UV, high-performance liquid chromatography-ultraviolet.

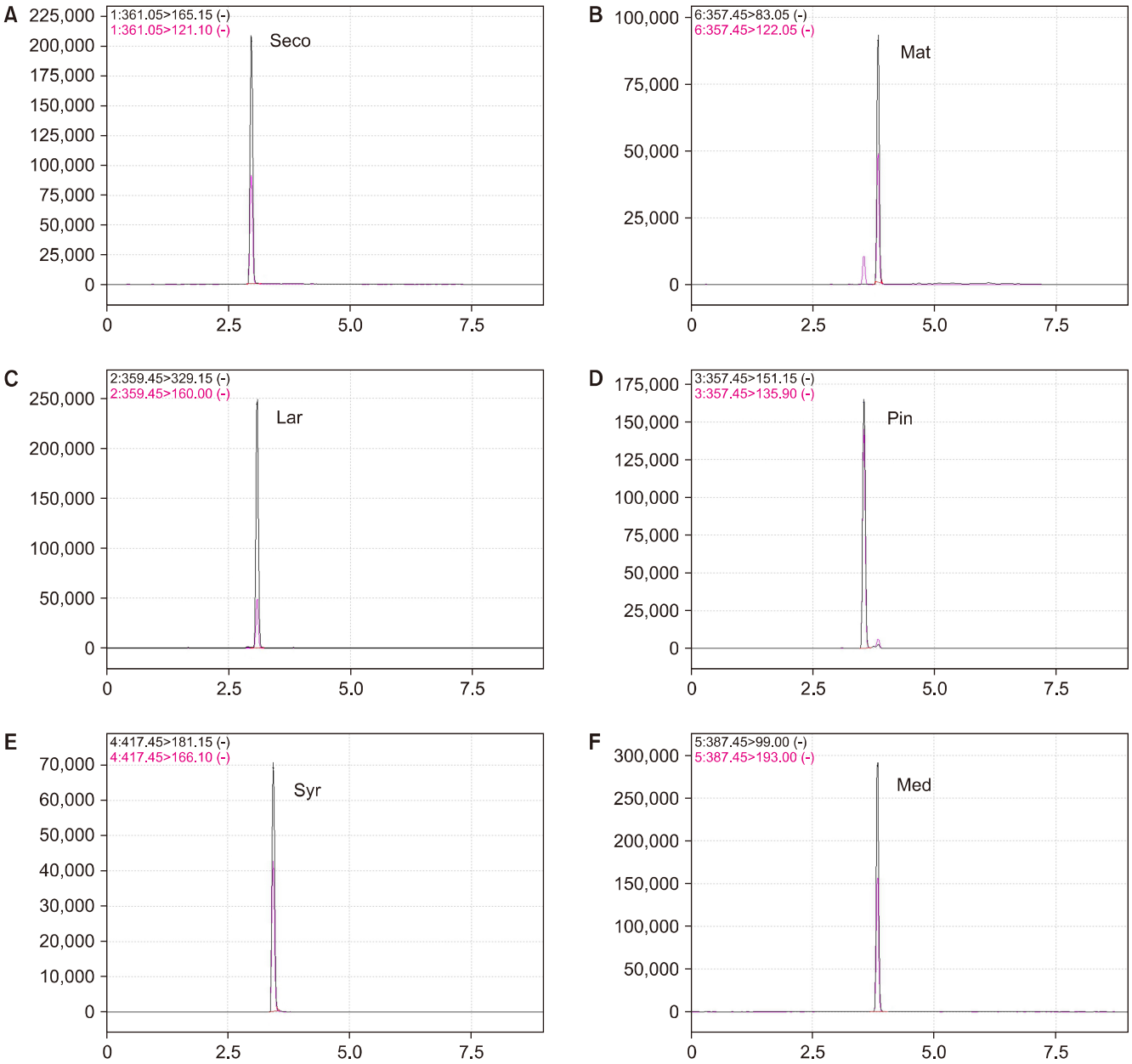

Fig. 1. Identifying the lignan components in the sesame seed extracts. (A–F) Multiple reaction monitoring (MRM) chromatograms with the mass transition from the standard solution of the six lignans at a concentration of 100 ng/mL. Seco, secoisolariciresinol; Mat, matairesinol; Lar, lariciresinol; Pin, pinoresinol; Syr, syringaresinol; Med, medioresinol.

Determination of the total polyphenol content of sesame seeds

The total polyphenol content (TPC) was determined using the Folin and Denis (1912) method. For the TPC assay, 50 μL of methanol extract was mixed with 1 mL of 2% $NaHCO_3$, followed by the addition of 100 μL of 1 N Folin-Ciocalteu reagent. The mixture was incubated in the dark for 5 min, and the absorbance was measured at 750 nm using a spectrophotometer (Thermo Scientific Ltd.). A standard calibration curve was constructed with gallic acid, and the results were expressed as mg of gallic acid equivalent (GAE) per mL of sample.

Determination of the free radical scavenging activity of sesame seeds

The ABTS radical scavenging activity was assessed following the method described by Re et al. (1999). Briefly, a solution of 7.4 mM ABTS was mixed with 2.6 mM potassium persulfate and incubated in the dark for more than 12 h. Subsequently, the ABTS solution was diluted with distilled water, resulting in an absorbance of 1.0 at 735 nm. The sample extract of 25 μL was mixed with 500 μL of the diluted ABTS solution and incubated for 30 min in the dark. The absorbance was measured at a wavelength of 735 nm using a spectrophotometer.

The DPPH radical scavenging activity was evaluated using the method established by Blois (1958), with slight

Table 2. LC-MS/MS conditions used in the analysis of the six lignans

Instrument (HPLC)	Shimadzu Nexera X3 system
Column	Agilent Poroshell 120 EC-C18 (1.9 μm, 2.1 mm×50 mm)
Column oven temp.	30°C
Injection volume	3 μL
Flow rate	0.3 mL/min
Mobile phase	A: Distilled water B: Acetonitrile
Gradient	0-4.5 min, 95% A→6.5-6.51 min, 50% A→9.0 min, 95% A
MS/MS condition	
Instrument	Shimadzu LCMS-8050 Triple quadrupole mass spectrometry
Ionization mode	ESI negative
Drying gas	10 L/min
Heating gas	10 L/min
Nebulizer gas	3 L/min
Interface temp.	350°C
DL temp.	100°C
Heat block temp.	400°C

LC, liquid chromatography; MS/MS, tandem mass spectrometry; ESI, electrospray ionization; DL, desolvation line; temp., temperature.

Table 3. Multiple reaction monitoring transition of six lignans

Compound	Retention time (min)	Quantifier ion (m/z)	Qualifier ion (m/z)
Seco	3.204	361.05→165.15	361.05→121.10
Mat	4.033	357.45→83.05	357.45→122.05
Lar	3.315	359.45→329.15	359.45→160.00
Pin	3.766	357.45→151.15	357.45→135.90
Syr	3.647	417.45→181.15	417.45→166.10
Med	4.026	387.45→99.00	387.45→193.00

Seco, secoisolariciresinol; Mat, matairesinol; Lar, lariciresinol; Pin, pinoresinol; Syr, syringaresinol; Med, medioresinol.

modification. Briefly, 25 μL of the sample extract was mixed with 500 μL of DPPH solution and incubated in the dark for 30 min. The absorbance was then measured at 520 nm using a spectrophotometer.

Catechin was used as the standard for both ABTS and DPPH radical scavenging activities, and the results were expressed as milligrams of catechin equivalent (CE) per mL of sample.

Statistical analysis

Data are presented as mean±standard deviation, derived from at least three independent experiments. Statistical analyses were conducted using one-way ANOVA in SAS software (version 9.0, SAS Institute), with significance set at $P<0.05$. Pearson correlation coefficients were calculated to assess the relationship between the total lignan content and antioxidant capacity across various sesame cultivars using SPSS software (version 24.0, SPSS Inc.).

RESULTS AND DISCUSSION

Lignan contents in the eight sesame varieties

Sesame seeds are well known for their rich lignan content, primarily composed of Sem, Sel, and Ses (each with their own health benefits). We have summarized the lignan content (detected in this study) of sesame seeds by variety in Table 4. The total lignan content varied significantly, ranging between 5.220 mg/g and 12.684 mg/g. Among the eight cultivars analyzed, Haniall exhibited the highest lignan concentration. The predominant lignan in sesame seeds was Sel (4.427-10.258 mg/g), followed by Ses (0.721-2.731 mg/g), while Seco and Med were either not detected or were present at levels below the limit of quantification.

The lignan with highest concentration across all the sesame varieties studied here, was Sel. This contrasts with most studies which indicate that Ses is typically present at higher concentrations than Sel (Kim et al., 2020a; Andargie et al., 2021) in sesame seeds. Lignan profiles (including those of Ses, Sem, and Sel) which vary widely among sesame varieties, are influenced by factors such as seed type, color, geographic origin, and cultivation conditions. Kim et al. (2014) found that the Sel content varied considerably, between 1.13 mg/g and 4.29 mg/g, depending on the cultivar. Similarly, Rangkadilok et al. (2010) reported that Sel levels in Thailand landraces sesame were higher than Ses whereas Sel was not detected

Table 4. Comparison of the lignan contents of sesame seeds from different cultivars

Cultivar	Lignan contents (mg/g)									
	Sem	Ses	Sel	Seco	Mat	Lar	Pin	Syr	Med	Total lignans
Sesame seed										
Ansan	0.028±0.003^{b}	2.654±0.136^{a}	9.246±0.489^{b}	ND	0.0012±0.0001^{c}	0.019±0.001^{b}	0.023±0.003^{a}	0.0003±0.0000^{b}	ND	11.971±0.626^{a}
Daheuk	0.033±0.000^{b}	0.721±0.003^{e}	4.427±0.015^{e}	Tr	0.0077±0.0002^{a}	0.008±0.000^{c}	0.024±0.002^{a}	0.0002±0.0000^{c}	ND	5.220±0.017^{d}
Goenbaek	0.029±0.001^{b}	1.600±0.090^{c}	7.651±0.436^{c}	Tr	0.0017±0.0000^{b}	0.007±0.000^{d}	0.006±0.000^{c}	0.0004±0.0000^{a}	ND	9.296±0.527^{c}
Kumok	0.038±0.003^{a}	2.374±0.076^{b}	7.402±0.178^{c}	Tr	0.0007±0.0000^{d}	0.004±0.000^{e}	0.006±0.000^{c}	0.0004±0.0000^{a}	ND	9.836±0.257^{bc}
Haniall	0.015±0.002^{d}	2.356±0.041^{b}	10.258±0.136^{a}	Tr	0.0079±0.0002^{a}	0.022±0.000^{a}	0.024±0.000^{a}	0.0004±0.0000^{a}	ND	12.684±0.179^{a}
Kangan	0.017±0.001^{cd}	2.731±0.111^{a}	7.683±0.280^{c}	Tr	0.0012±0.0000^{c}	0.009±0.000^{c}	0.011±0.001^{b}	0.0004±0.0000^{a}	ND	10.453±0.392^{b}
Kangyou	0.022±0.000^{c}	1.373±0.024^{d}	7.992±0.205^{c}	ND	0.0005±0.0000^{d}	0.002±0.000^{f}	0.006±0.000^{c}	0.0003±0.0000^{b}	ND	9.397±0.229^{c}
Nuri	0.021±0.003^{c}	2.411±0.011^{b}	6.745±0.022^{d}	ND	0.0003±0.0000^{d}	0.001±0.000^{g}	0.005±0.000^{c}	0.0003±0.0000^{b}	ND	9.185±0.014^{c}

Values are presented as mean±SD.
Different superscript letters (a-g) in the same column are significantly different (P<0.05) by Duncan's multiple range test.
Sem, sesamol; Ses, sesamin; Sel, sesamolin; Seco, secoisolariciresinol; Mat, matairesinol; Lar, lariciresinol; Pin, pinoresinol; Syr, syringaresinol; Med, medioresinol; ND, not detected; Tr, trace.

in breeding lines. Each sesame variety has a unique genetic makeup that can affect the biosynthetic pathways of Ses and Sel (Kancharla and Arumugam, 2020). Furthermore, soil type, rainfall and climate can also affect the Ses/Sel ratio (Zhang et al., 2019). For instance, Kumazaki et al. (2009) demonstrated that the accumulation of Ses and Sel is affected by various factors, including seeding time, day length, and soil temperature. Moreover, storage conditions which may vary depending on the sesame variety can affect the oxidative stability of lignan components and thus cause the observed relative changes in concentrations of compounds found in sesame seeds (Mujtaba et al., 2020). We surmise that the variations in the biosynthetic Ses/Sel ratio caused the sesame seeds to have higher Sel levels, compared to Ses levels.

The lignan profile can change depending on various factors such as sesame variety, harvesting, and processing methods. Here, the lignans Pin, Lar, Mat, Syr, and Ses were detected at lower concentrations than Sel and Sem. Liu et al. (2006) reported that lignans such as Pin, Lar, Mat, and Ses are contained in trace amounts in sesame compared to Sel and Sem. El-Beltagi et al. (2022) found that the chemical composition of sesame seeds changes depending on the temperature and roasting procedure used to produce the oil, which in turn affects the antioxidant activity of sesame oil.

Overall, our results show that among lignans found in sesame seed, Sel is contained in the highest concentrations, and its concentration varied depending on the sesame variety. Notably, the Haniall variety showed the highest total lignan content, indicating that it can be potentially used to develop sesame-based health products with improved benefits. In summary, this study details the lignan levels in the raw seeds of eight sesame varieties commonly cultivated in Korea. Further studies investigating how processing affects lignan composition and antioxidant properties are anticipated to facilitate a thorough assessment of the alterations in lignan profiles of different sesame varieties, before and after processing.

Polyphenol content and radical scavenging activities in the eight sesame varieties

The polyphenol contents in the methanol extracts of the eight varieties of sesame are shown in Table 5. The Ansan variety had the highest TPC (2.270 mg GAE/g), followed by the Goenbaek and Haniall varieties with 1.418 and 1.390 mg GAE/g, respectively. In contrast, the Daheuk variety exhibited the lowest TPC (1.009 mg GAE/g). The antioxidant activities of the eight sesame varieties were assessed using ABTS and DPPH radical scavenging assays (Table 5). The ABTS and DPPH radical scavenging activities varied across the varieties, ranging between 0.176 and 0.864 mg CE/g and between

Table 5. Total polyphenol contents and ABTS and DPPH radical scavenging activities of sesame seeds from different cultivars

Sample	Cultivar	Total polyphenol (mg GAE/g)	ABTS radical scavenging activity (mg CE/g)	DPPH radical scavenging activity (mg CE/g)
Sesame seed	Ansan	2.270±0.106^{a}	0.864±0.018^{a}	0.671±0.017^{a}
	Daheuk	1.009±0.073^{c}	0.176±0.010^{e}	0.367±0.002^{bc}
	Goenbaek	1.418±0.061^{b}	0.436±0.033^{b}	0.414±0.083^{b}
	Kumok	1.273±0.047^{bc}	0.274±0.016^{d}	0.219±0.007^{d}
	Haniall	1.390±0.103^{b}	0.361±0.009^{c}	0.257±0.012^{d}
	Kangan	1.186±0.007^{bc}	0.411±0.027^{b}	0.271±0.027^{cd}
	Kangyou	1.231±0.131^{bc}	0.302±0.022^{d}	0.276±0.049^{cd}
	Nuri	1.170±0.163^{bc}	0.264±0.025^{d}	0.247±0.012^{d}

Values are presented as mean±SD.
Different superscript letters (a–e) in the same column are significantly different (P<0.05) by Duncan's multiple range test.
GAE, gallic acid equivalent; CE, catechin equivalent; ABTS, 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid); DPPH, 2,2-diphenyl-1-picrylhydrazyl.

0.219 and 0.671 mg CE/g, respectively. The Ansan variety demonstrated the highest antioxidant activity in both assays. Conversely, the Daheuk variety showed a significantly lower ABTS radical scavenging activity. The Ansan variety had the highest DPPH radical scavenging activity, followed by the Goenbaek (0.414 mg CE/g) and Daheuk (0.367 mg CE/g) varieties. All other varieties showed lower activities, with values ranging between 0.219 mg CE/g and 0.276 mg CE/g, and no significant differences among them. In addition, the Ansan variety had the highest TPC, which indicated a higher antioxidant capacity. The content of phenolic compounds and antioxidant activity are positively correlated because polyphenols are essential for scavenging radicals in plants (Anesini et al., 2008; Ciulca et al., 2021). These compounds are particularly effective in donating hydrogen atoms or electrons, thereby neutralizing free radicals and reducing oxidative stress (Roy et al., 2010; Malenčić et al., 2012; Gulcin and Alwasel, 2023). A recent study showed significant differences in the total phenol content and antioxidant activity of different sesame varieties. Lin et al. (2017) reported that the polyphenol content of white sesame ranges between 370.5 mg GAE/100 g and 786.8 mg GAE/100 g. Dossou et al. (2024) reported that the total phenolic content of different varieties of sesame seeds ranged from 2.717 mg to 21.98 mg GAE/g, and Agidew et al. (2021) reported that the content of phenolic compounds in different varieties of sesame seeds ranges between 2.95 mg GAE/g and 6.95 mg GAE/g, which could be attributed to differences in geographical factors. Here, we confirmed that the Ansan variety has excellent antioxidant properties. This study is expected to be promising for cultivators of the Ansan variety because it extends the possibilities for its use in creating food which need to have excellent antioxidant properties. These results indicate the need to identify sesame seeds with excellent antioxidant potential as nutritional and functional foods.

Correlation between total lignans, polyphenols, and antioxidant activities

A Pearson correlation analysis was carried out to investigate the relationships between TPC, total lignan content, ABTS activity and DPPH radical scavenging activity of the sesame seeds, across the eight sesame varieties (Table 6). We found that, excepting total lignan content, the rest were strongly and positively correlated with each other. The TPC had the highest correlation with the ABTS radical scavenging activity (r=0.966, P<0.01). Additionally, we found that the TPC and DPPH radical scavenging activity were significantly correlated (r=0.850, P<0.01). Similarly, ABTS activity and DPPH radical scav-

Table 6. Pearson's correlation coefficients (r) of the relationships between (ABTS and DPPH) radical scavenging activities, total polyphenol, and total lignan contents of the sesame seeds from different cultivars

	Correlation coefficient			
	Total polyphenol	ABTS[1)]	DPPH[2)]	Total lignan
Total polyphenols	1			
ABTS	0.966**	1		
DPPH	0.850**	0.852**	1	
Total lignans	0.610	0.612	0.151	1

[1)]ABTS radical scavenging activity. [2)]DPPH radical scavenging activity.
All correlation coefficients were statistically significant at **P<0.01.
ABTS, 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid); DPPH, 2,2-diphenyl-1-picrylhydrazyl.

enging activity were significantly correlated (r=0.852, P< 0.01). In contrast, the total lignan content demonstrated a weak but positive correlation with the TPC and radical scavenging activities (ranging between r=0.151 and r= 0.612); however, these correlations were not significant.

The present study reveals a significant correlation between the TPC and the radical scavenging activities (specifically, the ABTS and DPPH radical scavenging activities) of sesame seeds. Polyphenols are renowned for their strong free radical scavenging properties, primarily due to specific structural features, such as hydroxyl groups, which facilitate electron donation and radical stabilization (Litwinienko and Ingold, 2007). Esmaeilzadeh Kenari et al. (2014) reported that the ABTS and DPPH scavenging activities of sesame cake extracts are highly correlated with its polyphenol content. Here, the correlation coefficient between lignans and radical scavenging activities was 0.612 in ABTS assay, whereas in DPPH assay it was 0.151, indicating that lignans are weakly correlated with the DPPH radical scavenging activity compared to ABTS radical scavenging activity. These differences may be attributed to variations in their ABTS and DPPH radical scavenging mechanisms and the structural properties of the lignans. The ABTS assay measures the antioxidant activity of compounds via, both, electron transfer and hydrogen atom transfer reactions of the cationic ABTS radical with the tested compound, while the DPPH assay relies on hydrogen atom transfer reactions (Schaich et al., 2015). Lignans may scavenge ABTS and DPPH radicals differently depending on the number of hydroxyl groups and electron-donating groups they contain (Abramovič et al., 2018; Moazzen et al., 2022; Zhang et al., 2024). Therefore, the correlation results—reflecting relation between the total phenol content and antioxidant activity of sesame seeds—may vary between ABTS and DPPH assays, due to the structural diversity of the comprising lignans. Interestingly, here, lignan content was significantly weakly correlated with the antioxidant activity of the sesame seed. Possibly, because, compared to polyphenols, lignans have reduced radical scavenging efficacy. Thus, although lignans such as Sem, Sel, and Pin possess health-promoting properties, they have a weaker direct impact on antioxidant activity of sesame seeds (Steffan et al., 2005; Suja et al., 2005). Dachtler et al. (2003) suggested that, rather than acting independently, lignans synergize the influence of other components, such as tocopherols, on the stability and antioxidant capacity of sesame oil. Thus, while lignans contribute to the overall antioxidant capacity of sesame seeds, their contribution may be less pronounced than that of polyphenols.

In conclusion, the enhanced antioxidant capacity of sesame seeds can be majorly attributed to their polyphenol content, as indicated by the significant positive correlation between their TPC and (ABTS and DPPH) radical scavenging activities. Meanwhile, rather than influencing independently, lignans synergize the effect of other sesame seed components on its antioxidant activity.

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AUTHOR DISCLOSURE STATEMENT

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Formal analysis: Yoonjeong K, JK. Investigation: Yoonjeong K, JK. Conceptualization: SK, MYK. Supervision: Younghwa K. Writing-original draft preparation: Yoonjeong K. Writing-review and editing: Younghwa K. All authors have read and agreed to the published version of the manuscript.

REFERENCES

Abramovič H, Grobin B, Poklar Ulrih N, Cigić B. Relevance and standardization of *in vitro* antioxidant assays: ABTS, DPPH, and Folin-Ciocalteu. J Chem. 2018. 2018:4608405. https://doi.org/10.1155/2018/4608405

Afroz M, Zihad S, Uddin SJ, Rouf R, Rahman MS, Islam MT, et al. A systematic review on antioxidant and antiinflammatory activity of Sesame (*Sesamum indicum* L.) oil and further confirmation of antiinflammatory activity by chemical profiling and molecular docking. Phytother Res. 2019. 33:2585-2608. https://doi.org/10.1002/ptr.6428

Agidew MG, Dubale AA, Atlabachew M, Abebe W. Fatty acid composition, total phenolic contents and antioxidant activity of white and black sesame seed varieties from different localities of Ethiopia. Chem Biol Technol Agric. 2021. 8:1-10.

Andargie M, Vinas M, Rathgeb A, Möller E, Karlovsky P. Lignans of sesame (*Sesamum indicum* L.): A comprehensive review. Molecules. 2021. 26:883. https://doi.org/10.3390/molecules 26040883

Anesini C, Ferraro GE, Filip R. Total polyphenol content and antioxidant capacity of commercially available tea (*Camellia sinensis*) in Argentina. J Agric Food Chem. 2008. 56:9225-9229. https://doi.org/10.1021/jf8022782

Blois MS. Antioxidant determinations by the use of a stable free radical. Nature. 1958. 181:1199-1200.

Cardoso CA, Oliveira GMM, Gouveia LAV, Moreira ASB, Rosa G. The effect of dietary intake of sesame (*Sesamum indicum* L.) derivatives related to the lipid profile and blood pressure: A systematic review. Crit Rev Food Sci Nutr. 2018. 58:116-125. https://doi.org/10.1080/10408398.2015.1137858

Chen Y, Lin H, Lin M, Lin P, Chen J. Effects of thermal preparation and *in vitro* digestion on lignan profiles and antioxidant activity in defatted-sesame meal. Food Chem Toxicol. 2019. 128:89-96. https://doi.org/10.1016/j.fct.2019.03.054

Cheng FC, Jinn TR, Hou RC, Tzen JT. Neuroprotective effects of sesamin and sesamolin on gerbil brain in cerebral ischemia. Int J Biomed Sci. 2006. 2:284-288.

Ciulca S, Roma G, Alexa E, Radulov I, Cocan I, Madosa E, et al. Variation of polyphenol content and antioxidant activity in some bilberry (*Vaccinium myrtillus* L.) populations from Romania. Agronomy. 2021. 11:2557. https://doi.org/10.3390/agronomy11122557

Cornwell T, Cohick W, Raskin I. Dietary phytoestrogens and health. Phytochemistry. 2004. 65:995-1016. https://doi.org/10.1016/j.phytochem.2004.03.005.

Dachtler M, van de Put FH, Stijn F, Beindorff CM, Fritsche J. Online LC-NMR-MS characterization of sesame oil extracts and assessment of their antioxidant activity. Eur J Lipid Sci Technol. 2003. 105:488-496.

dos Santos MG, Ribeiro RMP, de Albuquerque JRT, Lins HA, Júnior APB, Neto FB, et al. Production performance of sesame cultivars under different nitrogen rates in two crops in the Brazilian semi-arid region. Ind Crops Prod. 2018. 124:1-8.

Dossou SSK, Luo Z, Deng Q, Zhou R, Zhang Y, Li D, et al. Biochemical and molecular insights into variation in sesame seed antioxidant capability as revealed by metabolomics and transcriptomics analysis. Antioxidants. 2024. 13:514. https://doi.org/10.3390/antiox13050514

Dravie EE, Kortei NK, Essuman EK, Tettey CO, Boakye AA, Hunkpe G. Antioxidant, phytochemical and physicochemical properties of sesame seed (*Sesamum indicum* L). Sci Afr. 2020. 8:e00349. https://doi.org/10.1016/j.sciaf.2020.e00349

El-Beltagi HS, Maraei RW, El-Ansary AE, Rezk AA, Mansour AT, Aly AA. Characterizing the bioactive ingredients in sesame oil affected by multiple roasting methods. Foods. 2022. 11:2261. https://doi.org/10.3390/foods11152261

Esmaeilzadeh Kenari R, Mohsenzadeh F, Amiri ZR. Antioxidant activity and total phenolic compounds of Dezful sesame cake extracts obtained by classical and ultrasound-assisted extraction methods. Food Sci Nutr. 2014. 2:426-435. https://doi.org/10.1002/fsn3.118

Folin O, Denis W. On phosphotungstic-phosphomolybdic compounds as color reagents. J Biol Chem. 1912. 12:239-243. https://doi.org/10.1016/S0021-9258(18)88697-5

Ghafoorunissa, Hemalatha S, Rao MV. Sesame lignans enhance antioxidant activity of vitamin E in lipid peroxidation systems. Mol Cell Biochem. 2004. 262:195-202. https://doi.org/10.1023/b:mcbi.0000038235.01389.a9

Ghotbzadeh Kermani S, Saeidi G, Sabzalian MR, Gianinetti A. Drought stress influenced sesamin and sesamolin content and polyphenolic components in sesame (*Sesamum indicum* L.) populations with contrasting seed coat colors. Food Chem. 2019. 289:360-368. https://doi.org/10.1016/j.foodchem.2019.03.004

Gouveia Lde A, Cardoso CA, de Oliveira GM, Rosa G, Moreira AS. Effects of the intake of sesame seeds (*Sesamum indicum* L.) and derivatives on oxidative stress: A systematic review. J Med Food. 2016. 19:337-345. https://doi.org/10.1089/jmf.2015.0075

Gulcin İ, Alwasel SH. DPPH radical scavenging assay. Processes. 2023. 11:2248. https://doi.org/10.3390/pr11082248

Jayaraj P, Narasimhulu CA, Rajagopalan S, Parthasarathy S, Desikan R. Sesamol: a powerful functional food ingredient from sesame oil for cardioprotection. Food Funct. 2020. 11:1198-1210. https://doi.org/10.1039/c9fo01873e

Ji J, Liu Y, Shi L, Wang N, Wang X. Effect of roasting treatment on the chemical composition of sesame oil. LWT. 2019. 101:191-200. https://doi.org/10.1016/j.lwt.2018.11.008

Kancharla PK, Arumugam N. Variation of oil, sesamin, and sesamolin content in the germplasm of the ancient oilseed crop *Sesamum indicum* L. J Am Oil Chem Soc. 2020. 97:475-483. https://doi.org/10.1002/aocs.12346

Kim AY, Yun CI, Lee JG, Kim YJ. Determination and daily intake estimation of lignans in sesame seeds and sesame oil products in Korea. Foods. 2020a. 9:394. https://doi.org/10.3390/foods9040394

Kim JH, Seo WD, Lee SK, Lee YB, Park CH, Ryu HW, et al. Comparative assessment of compositional components, antioxidant effects, and lignan extractions from Korean white and black sesame (*Sesamum indicum* L.) seeds for different crop years. J Funct Foods. 2014. 7:495-505. https://doi.org/10.1016/j.jff.2014.01.006

Kim MY, Kim S, Kim JI, Oh E, Kim SW, Lee J, et al. Antioxidant and hepatoprotective effects of different varieties of sesame (*Sesamum indicum* L.) with variation in lignan content. J Korean Soc Food Sci Nutr. 2022a. 51:660-670. https://doi.org/10.3746/jkfn.2022.51.7.660

Kim S, Oh E, Kim JI, Lee MH, Pae SB, Ha TJ. A sesame variety 'KumOk' with high yield and disease resistance. Proceedings of the 2019 KSBS & SABRAO International Conference on Plant Breeding for Sustainable Development. 2019 Jul 2 – Jul 5. p 97.

Kim SU, Lee J, Oh E, Kim JI, Kim MY, Kim SW, et al. A white sesame variety 'Nuri' with phytophthora blight disease resistance. Korean J Breed Sci. 2022b. 54:51-56. https://doi.org/10.9787/KJBS.2022.54.1.51

Kim SU, Lee J, Oh E, Kim JI, Kim SW, Kim MY, et al. A Sesame variety 'Haniall'with non-shattering capsule and early maturity. Proceedings of the Current status and Future prospects of Plant Breeding Confronting the Era of Digital Agriculture. 2022c Jun 29 – Jul 1. p 459.

Kim SU, Lee J, Oh EY, Kim JI, Kim MY, Kim SW, et al. The white sesame variety 'Kangyou' with phytophthora blight and fusarium wilt disease resistance. Korean J Breed Sci. 2023. 55:367-372. https://doi.org/10.9787/KJBS.2023.55.4.367

Kim SU, Lee MH, Pae SB, Oh EY, Kim JI, Ha TJ. A sesame variety "Goenbaek" with phytophthora blight disease resistance and high yield. Korean J Breed Sci. 2018. 50:256-260. https://doi.org/10.9787/KJBS.2018.50.3.256

Kim SU, Lee MH, Pae SB, Oh EY, Kim JI, Ha TJ. A white sesame variety 'Nuri' with phytophthora blight disease resistance. Korean J Breed Sci. 2020b. 52:76-80. https://doi.org/10.9787/KJBS.2020.52.1.76

Kim Y, Kim HW, Sung J, Kim Y. Optimal extraction conditions and quantification of lignan phytoestrogens in cereal grains using targeted LC-MS/MS. Front Nutr. 2024. 11:1409309. https://doi.org/10.3389/fnut.2024.1409309

Kumazaki T, Yamada Y, Karaya S, Kawamura M, Hirano T, Yasumoto S, et al. Effects of day length and air and soil temperatures on sesamin and sesamolin contents of sesame seed. Plant Prod Sci. 2009. 12:481-491. https://doi.org/10.1626/pps.12.481

Lin X, Zhou L, Li T, Brennan C, Fu X, Liu RH. Phenolic content, antioxidant and antiproliferative activities of six varieties of white sesame seeds (*Sesamum indicum* L.). RSC Adv. 2017. 7:5751-5758. https://doi.org/10.1039/C6RA26596K

Litwinienko G, Ingold KU. Solvent effects on the rates and mechanisms of reaction of phenols with free radicals. Acc Chem Res. 2007. 40:222-230. https://doi.org/10.1021/ar0682029

Liu Z, Saarinen NM, Thompson LU. Sesamin is one of the major precursors of mammalian lignans in sesame seed (*Sesamum indicum*) as observed in vitro and in rats. J Nutr. 2006. 136:906-912. https://doi.org/10.1093/jn/136.4.906

Majdalawieh AF, Dalibalta S, Yousef SM. Effects of sesamin on

fatty acid and cholesterol metabolism, macrophage cholesterol homeostasis and serum lipid profile: A comprehensive review. Eur J Pharmacol. 2020. 885:173417. https://doi.org/10.1016/j.ejphar.2020.173417

Majdalawieh AF, Massri M, Nasrallah GK. A comprehensive review on the anti-cancer properties and mechanisms of action of sesamin, a lignan in sesame seeds (*Sesamum indicum*). Eur J Pharmacol. 2017. 815:512-521. https://doi.org/10.1016/j.ejphar.2017.10.020

Malenčić D, Cvejić J, Miladinović J. Polyphenol content and antioxidant properties of colored soybean seeds from central Europe. J Med Food. 2012. 15:89-95. https://doi.org/10.1089/jmf.2010.0329

Michailidis D, Angelis A, Aligiannis N, Mitakou S, Skaltsounis L. Recovery of sesamin, sesamolin, and minor lignans from sesame oil using solid support-free liquid-liquid extraction and chromatography techniques and evaluation of their enzymatic inhibition properties. Front Pharmacol. 2019. 10:723. https://doi.org/10.3389/fphar.2019.00723

Miyahara Y, Hibasami H, Katsuzaki H, Imai K, Komiya T. Sesamolin from sesame seed inhibits proliferation by inducing apoptosis in human lymphoid leukemia Molt 4B cells. Int J Mol Med. 2001. 7:369-371.

Moazzen A, Öztinen N, Ak-Sakalli E, Koşar M. Structure-antiradical activity relationships of 25 natural antioxidant phenolic compounds from different classes. Heliyon. 2022. 8:e10467. https://doi.org/10.1016/j.heliyon.2022.e10467

Mondal N, Bhat KV, Srivastava PS. Variation in fatty acid composition in indian germplasm of sesame. J Am Oil Chem Soc. 2010. 87:1263-1269. https://doi.org/10.1007/s11746-010-1615-9

Mujtaba MA, Muk Cho H, Masjuki HH, Kalam MA, Ong HC, Gul M, et al. Critical review on sesame seed oil and its methyl ester on cold flow and oxidation stability. Energy Rep. 2020. 6: 40-54. https://doi.org/10.1016/j.egyr.2019.11.160

Pathak N, Rai AK, Kumari R, Bhat KV. Value addition in sesame: A perspective on bioactive components for enhancing utility and profitability. Pharmacogn Rev. 2014. 8:147-155. https://doi.org/10.4103/0973-7847.134249

Pianjing P, Thiantanawat A, Rangkadilok N, Watcharasit P, Mahidol C, Satayavivad J. Estrogenic activities of sesame lignans and their metabolites on human breast cancer cells. J Agric Food Chem. 2011. 59:212-221. https://doi.org/10.1021/jf102006w

Rangkadilok N, Pholphana N, Mahidol C, Wongyai W, Saengsooksree K, Nookabkaew S, et al. Variation of sesamin, sesamolin and tocopherols in sesame (*Sesamum indicum* L.) seeds and oil products in Thailand. Food Chem. 2010. 122: 724-730. https://doi.org/10.1016/j.foodchem.2010.03.044

Re R, Pellegrini N, Proteggente A, Pannala A, Yang M, Rice-Evans C. Antioxidant activity applying an improved ABTS radical cation decolorization assay. Free Radic Biol Med. 1999. 26: 1231-1237. https://doi.org/10.1016/s0891-5849(98)00315-3

Rosalina R, Weerapreeyakul N. An insight into sesamolin: physicochemical properties, pharmacological activities, and future research prospects. Molecules. 2021. 26:5849. https://doi.org/10.3390/molecules26195849

Roy MK, Koide M, Rao TP, Okubo T, Ogasawara Y, Juneja LR. ORAC and DPPH assay comparison to assess antioxidant capacity of tea infusions: relationship between total polyphenol and individual catechin content. Int J Food Sci Nutr. 2010. 61:109-124. https://doi.org/10.3109/09637480903292601

Schaich KM, Tian X, Xie J. Reprint of "Hurdles and pitfalls in measuring antioxidant efficacy: A critical evaluation of ABTS, DPPH, and ORAC assays". J Funct Foods. 2015. 18:782-796. https://doi.org/10.1016/j.jff.2015.05.024

Shim KB, Hwang CD, Pae SB, Lee CK, Kim SU, Park CH, et al. A new white sesame variety 'Milsung' having dense capsule and high yield. Korean J Breed Sci. 2013. 45:138-141. https://doi.org/10.9787/KJBS.2013.45.2.138

Shim KB, Shin MN, Jeon WT, Han A. Effect of different sowing dates on the yield-related traits and seed yield of sesame. Korean J Crop Sci. 2021. 66:411-418. https://doi.org/10.7740/KJCS.2021.66.4.411

Srisayam M, Weerapreeyakul N, Kanokmedhakul K. Inhibition of two stages of melanin synthesis by sesamol, sesamin and sesamolin. Asian Pac J Trop Biomed. 2017. 7:886-895. https://doi.org/10.1016/j.apjtb.2017.09.013

Steffan B, Wätjen W, Michels G, Niering P, Wray V, Ebel R, et al. Polyphenols from plants used in traditional Indonesian medicine (Jamu): uptake and antioxidative effects in rat H4IIE hepatoma cells. J Pharm Pharmacol. 2005. 57:233-240. https://doi.org/10.1211/0022357055317

Suja KP, Jayalekshmy A, Arumughan C. Antioxidant activity of sesame cake extract. Food Chem. 2005. 91:213-219. https://doi.org/10.1016/j.foodchem.2003.09.001

Wang L, Dossou SSK, Wei X, Zhang Y, Li D, Yu J, et al. Transcriptome dynamics during black and white sesame (*Sesamum indicum* L.) seed development and identification of candidate genes associated with black pigmentation. Genes. 2020. 11:1399. https://doi.org/10.3390/genes11121399

Wei P, Zhao F, Wang Z, Wang Q, Chai X, Hou G, et al. Sesame (*Sesamum indicum* L.): A comprehensive review of nutritional value, phytochemical composition, health benefits, development of food, and industrial applications. Nutrients. 2022. 14:4079. https://doi.org/10.3390/nu14194079

Yin W, Washington M, Ma X, Yang X, Lu A, Shi R, et al. Consumer acceptability and sensory profiling of sesame oils obtained from different processes. Grain Oil Sci Technol. 2020. 3:39-48. https://doi.org/10.1016/j.gaost.2020.04.001

Zhang H, Miao H, Ju M. Potential for adaptation to climate change through genomic breeding in sesame. In: Kole C, editor. Genomic Designing of Climate-Smart Oilseed Crops. Springer. 2019. p 371-440.

Zhang M, Shuai XX, Wei Z, Dai TT, Wei CB, Li Y, et al. Characterization, antioxidant and antitumor activities of phenolic compounds from *Amomum villosum* Lour. Front Nutr. 2024. 11:1327164. https://doi.org/10.3389/fnut.2024.1327164