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RESEARCH ARTICLE

Potential feed and food applications of invasive *Galinsoga quadriradiata:* insights from ethnobotanical, nutritional and HS–SPME–GC–MS investigations

Yixin Qin · Dipak Khadka · Zhongxin Duan · Jianbo Nie · Xingxing Chen · Fengke Lin · Binsheng Luo

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Abstract Invasive plants often pose challenges to ecosystem management, yet they can also serve as valuable resources when integrated with traditional knowledge. This study explores the sustainable applications of the invasive species *Galinsoga quadriradiata* through an innovative combination of ethnobotanical and chemical analyses. Ethnobotanical investigations revealed its utility as both a food source and animal feed, particularly for poultry. Nutritional profiling highlighted its exceptional nutrient density, including high levels of protein (17.70 ± 0.24 g/100 g dry weight), fiber (45.10 ± 0.10 g/100 g), potassium (2.17 ± < 0.01 g/100 g), and calcium (1.73 ± < 0.01 g/100 g), supporting its traditional uses. Furthermore, bioactive compounds such as flavonoids (0.46 ± < 0.01 g/100 g) and proanthocyanidins (0.146 g/100 g) underscore their potential health benefits. Metabolomic analysis via HS–SPME–GC–MS identified 238 volatile constituents, predominantly aldehydes (16.66%), alcohols (16.31%), and sesquiterpenes (13.01%), with 5,10-dioxatricyclo[7.1.0.04,64,64,6]decane (5.39%), 1-hexanol (3.54%), and 2-hexenal (3.26%) as the most abundant components. These volatiles provide mechanistic insights into the plant's attractiveness as food and feed while also suggesting ecological interactions. Our findings highlight *G. quadriradiata* as a promising candidate for sustainable feed and food production. By bridging ethnobotanical practices with scientific validation, this study establishes a robust framework for repurposing invasive species (*G. quadriradiata)* into valuable resources, promoting agricultural resilience, ecological sustainability, and biodiversity conservation.

Keywords Invasive species · Ecosystem management · Nutrition · Animal feed · Ethnobotany · *Galinsoga quadriradiata*

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Y. Qin · Z. Duan · J. Nie · X. Chen · B. Luo (✉)
Lushan Botanical Garden, Jiangxi Province and Chinese Academy of Sciences, Jiujiang, China
e-mail: luobins@lsbg.cn

D. Khadka
Guangdong Key Laboratory for Innovative Development and Utilization of Forest Plant Germplasm, College of Forestry and Landscape Architecture, South China Agricultural University, Guangzhou, China

F. Lin (✉)
School of Chemistry and Chemical Engineering, Tianjin University of Science and Technology, Tianjin, China
e-mail: fengkelin2023@email.tjut.edu.cn

Introduction

The *Galinsoga* genus, part of the Asteraceae family, comprises herbaceous plants native to Central and South America (Smith et al. 2020). Of the 15 recognized *Galinsoga* species (https://powo.science.kew.org/), two—*G. parviflora* and *G. quadriradiata*—are invasive in China (Shi et al. 2011). *G. quadriradiata*, originally from South America, has become a widely distributed invasive species in China, colonizing the southern regions and projected to expand into the northern zones (Yang et al. 2018; Zhang et al. 2022). This species poses significant ecological threats by competing with native flora and disrupting ecosystem functions (De Cauwer et al. 2021), necessitating effective management strategies.

Traditional management practices are effective but labor-intensive, including methods such as increasing crop planting depths, mulching, and manually uprooting weeds (Smith et al. 2020). Herbicidal options, including oxyfluorfen, flumioxazin, and linuron, demonstrate high efficacy (> 90%), but their long-term ecological sustainability remains a concern due to potential environmental impacts (Paula et al., 2022). These limitations highlight the need for integrated and environmentally sustainable strategies for managing invasive species. Local ecological knowledge (LEK) offers a promising, underutilized avenue for sustainable invasive species management. LEK encompasses traditional practices and insights that can guide localized planning and resource utilization (Luizza et al. 2013). Invasive species like *G. quadriradiata* may hold untapped ecological and economic potential, such as use as food or animal feed. Investigating these uses through nutritional and chemical profiling can help reframe invasive species as resources while mitigating their ecological impacts (Jönsson et al. 2023).

Lushan, a renowned biodiversity hotspot and tourist destination in Southern China, faces challenges from habitat destruction and invasive species proliferation due to human activities such as tourism and road construction (Hui et al. 2020). Our preliminary ethnobotanical investigations reveal that local communities have developed traditional practices for managing certain invasive species, such as utilizing *G. quadriradiata* as poultry feed, particularly for chickens. However, no comprehensive ethnobotanical research has been conducted specifically on *G. quadriradiata*. Moreover, integrating local ecological Knowledge (LEK) with scientific research for invasive species management remains underexplored in regions like Lushan and other parts of China.

This study conducted a comprehensive ethnobotanical study on invasive *G. quadriradiata* to investigate the LEK for ecologically sustainable management of this species. Additionally, metabolite compositions of *G. quadriradiata* were determined using nutritional and HS–SPME–GC–MS analysis to evaluate the related LEK from a chemical perspective. This integrated approach combines agroecology, local practices, and ecological sustainability, providing novel insights into invasive species management.

Materials and methods

Ethnobotanical study

This study used snowball sampling methods to select the key informants for informal interviews. From this, we reached 36 individuals between 50 and 80 years of age. We documented all the different uses of *G. quadriradiata* in the Lushan area and validated them with the secondary literature.

Plant materials

Whole plants of *G. quadriradiata* were collected from the three different sites of Lushan City of Jiangxi Province in August of 2024 with GPS coordinates recorded as follows: 1087 m (above sea level), 115.985274°E, 29.552131°N. Xingxing Chen identified the plant species at Lushan Botanical Garden, and a voucher specimen (EB240813002) was deposited in the herbarium of Lushan Botanical Garden. After collection, the material was air-dried in the shade, ground into powder, passed through a 40-mesh sieve, and then stored at − 20℃ until further nutritional and HS–SPME–GC–MS analysis.

Nutritional analysis

To clarify the nutritional composition of *G. quadriradiata,* we followed standard protocol consistent with the Standardized Technical Guidance report of the People's Republic of China and the International Organization for Standardization as described in 2021 similar to Duan et al. (2024) (Table 1).

Table 1 Determination of nutritional components in *Galinsoga quadriradiata*

	Test items	Methods	References
Macronutrients	Energy	GB/Z21922–2008	GB/Z 21922-2008 (2008)
	Protein	GB5009.5–2016	GB 5009.5-2016 (2016)
	Fat	GB5009.6–2016	GB 5009.6-2016 (2016)
	Dietary fiber	GB5009.88–2014	GB 5009.88-2014 (2014)
	Carbohydrate	GB5009.9–2016	GB 5009.9-2016 (2016)
	Trace elements	GB5009.268–2016	GB 5009.268-2016 (2016)
Vitamins	Vitamin B2	GB5009.85–2016	GB 5009.85-2016 (2016)
	Vitamin E	GB5009.82–2016	GB 5009.82-2016 (2016)
Total flavonoids	–	ISO 20759–2017	ISO 20759:2017, (2017)

HS–SPME–GC–MS analysis

The homogenized sample (200 ± 4 mg) was placed into a headspace vial (20 mL) for headspace solid-phase microextraction (HS-SPME). A final concentration of 10 mg/L of 2-octanol was added as an internal standard. During the HS-SPME process, the incubation temperature was set to 60 °C, with a preheating time of 15 min, an incubation time of 30 min, and a desorption time of 4 min. Following HS-SPME, the sample was analyzed by an Agilent 7890 gas chromatography (GC) coupled with a 5977B mass spectrometry (MS) (Agilent Technologies, Santa Clara, CA, USA). Volatile components were separated on a DB-WAX capillary column (30 m × 250 μm × 0.25 μm, Agilent Technologies). Helium at a constant flow rate of 1.0 mL/min was used as the carrier gas. The initial oven temperature was maintained at 40 °C for 4 min, then increased to 245 °C at a rate of 5 °C/min, and held for 5 min. The injection port, transfer line, ion source, and quadrupole temperatures were set to 250 °C, 250 °C, 230 °C, and 150 °C, respectively. Mass spectrometry was performed in electron impact (EI) mode with an ionization energy of − 70 eV. Data were acquired in scan mode over an *m/z* range of 20–400, with a solvent delay of 2.37 min. Data processing, including peak picking, baseline calibration, peak alignment, deconvolution, and integration, was performed using ChromaTOF 4.3X software (LECO Corporation, Saint Joseph, MI, USA) (Lin and Long 2023). The Kovats' retention index (KRI) of the volatile compounds was determined using a series of *n*-alkanes (C_9-C_{23}) as references. Volatile compounds were identified by matching their mass spectra with those in the NIST23 library, retaining compounds with a match similarity score above 700. Further verification was performed by comparing KRIs with values reported in online databases, including WebBook (https://webbook.nist.gov/chemistry/) and Flavornet (https://www.flavornet.org/). The relative abundance of annotated volatiles was expressed as a percentage of their peak area in the total ion chromatogram. Odor information for the volatile compounds was obtained from Flavornet and Flavor DB2 (https://cosylab.iiitd.edu.in/flavordb2/).

Data analysis

The ethnobotanical use of *Galinsoga quadriradiata* in animal feed was described, and the species' food and medicine uses were presented in a table. The mean and standard deviations of each nutritional parameter were calculated and shown in the tables using Microsoft Excel 2021. To determine the human food potential of *G. quadriradiata,* the obtained value of nutrition was compared with the U.S. Food and Drug Administration's daily intake values (https://www.fda.gov/). To validate the flavonoid and proanthocyanidin content of *G. quadriradiata*, we followed the methodology outlined by Ivey et al. (2017).

Results

Ethnobotanical investigations

G. quadriradiata, locally known as Be-Hua-Cao in Lushan, means "white-flowered herb." The plant is traditionally used as animal feed around Lushan. Normally, locals typically collect large quantities of *G. quadriradiata* from the edges of fields or mountains and bind them into bundles using nearby tough grasses or vines as reserve animal feed (Fig. 1). Some interviewees also mentioned using it as a wild vegetable, either boiled or stir-fried. According to our survey, both *G. quadriradiata* and *G. parviflora* are found in the area, but *G. quadriradiata* is more widespread. Locals consider them to be the same species, as they both have white flowers and very similar appearances. The practices used are reported to decrease over time due to the development of tourism around Lushan.

According to the literature, the species is also reported to be used for human consumption and medicinal purposes in other regions of China and different parts of the world (Table 2).

Nutritional composition of *G. quadriradiata*

Macronutrients

G. quadriradiata contains 942 ± 17.31 kJ (approximately 226 kcal) of energy per 100 g of dry weight, indicating a low energy density. Its nutritional composition per 100 g dry weight includes 17.70 ± 0.24 g of protein (30% of the Nutrient Reference Value, NRV), 7.24 ± 0.22 g of carbohydrates (2% NRV), 4.42 ± 0.04 g of fat (7% NRV), 45.15 ± 0.12 g of dietary fiber (38.13 ± 0.10 g insoluble fiber and 7.02 ± 0.02 g soluble fiber), and 6.49 g of starch. Our laboratory analysis, compared to FDA reference values, suggests that consuming 100 g of dry *G. quadriradiata* daily exceeds the recommended dietary intake for both protein and fiber (Table 3).

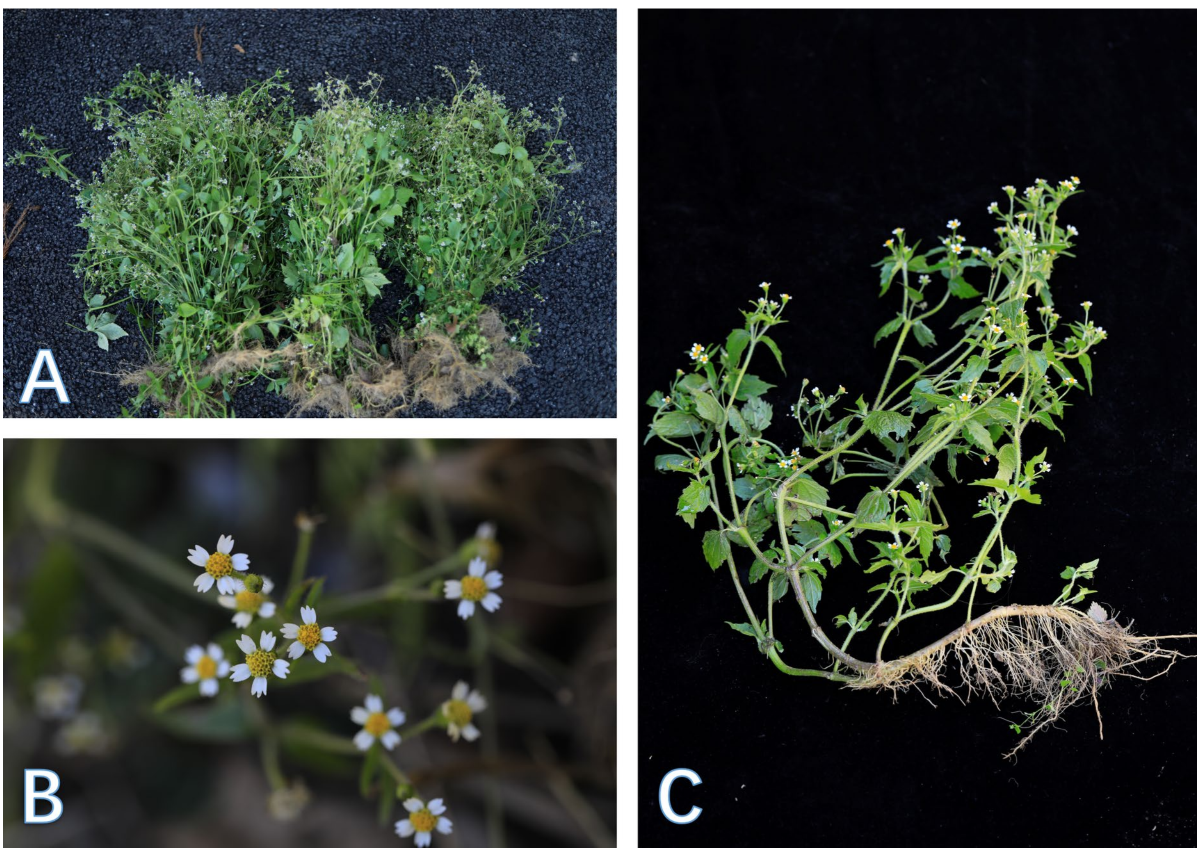

Fig. 1 The morphological characteristics of *Galinsoga quadriradiata* (**A**. The bundles of *G. quadriradiata*, **B**. The flowers of *G. quadriradiata*, **C**. The whole plant of *G. quadriradiata*)

Table 2 Uses of *Galinsoga quadriradiata* in food and medicine in different geographic areas in the world

Use categories	Uses	Geographic area	References
Food use	Stir-fried	China	Liu et al. (2023)
	Soups	Mexico	Damalas (2008)
	Salads	Colombia	Bautista-Cruz, et. al. (2011)
	Herbal teas	Southeast Asia	Giday M., et al. (2009)
	Vegetable	Africa	Yimer, A., Forsido, et al. (2023)
Medicinal use	Leaves are used in the treatment of wounds	Central Kenya	Njoroge & Bussmann (2006)
	The whole plant is used in the treatment of skin inflammations and wounds	Pakistan	Zareef et al. (2023)
	Leaves are used in the treatment of snakebite	Ethiopia	Giday et al. (2009)
	Whole plant is used in the treatment of skin problems	Poland	Bazylko et al. (2015a, b)
	Leaves are used to remove retained fetal membrane and/or placenta in animals	Southern Ethiopia	Tolossa et al. (2013)

Table 3 Comparison of the macronutrient values in *G. quadriradiata* (100 g dry weight, 226 kcal) with the recommended daily intake values when consumed daily (https://www.fda.gov/)

Macronutrients (unit)	*G. quadriradiata* (*mean* ± SD)	FDA recommended value
Protein (g)	17.70 ± 0.24	5.65
Carbohydrate (g)	7.24 ± 0.22	33.90
Fat (g)	4.4 ± 0.04	7.35
Fiber (g)	45.15 ± 0.12	2.83

Table 4 Comparison of the vitamin content in *Galinsoga quadriradiata* (100 g dry weight) with the recommended daily intake values for vitamins (Source: https://www.fda.gov/)

Vitamins (unit)	*G. quadriradiata*	FDA recommended
E (g)	< 0.01	0.02
B2 (g)	< 0.01	< 0.01

Vitamins

Regarding vitamins, only Vitamin B_2 and Vitamin E were detected in 100 g of dry *G. quadriradiata*. The content of Vitamin B_2 and Vitamin E were both < 0.01 g. Laboratory analysis comparing these values to FDA recommendations indicates that consuming 100 g of dry *G. quadriradiata* daily provides Vitamin E and B_2 levels below the recommended dietary intake (Table 4).

Table 5 Comparison of mineral content in 100 g dry weight of *Galinsoga quadriradiata* with recommended daily intake values (Source: https://www.fda.gov/)

Minerals (unit)	*G. quadriradiata*	FDA recommended
Calcium (g)	1.73 ± < 0.01	1.3
Potassium (g)	2.09 ± 0.01	4.7
Phosphorus (g)	0.38 ± < 0.01	1.25
Sodium (g)	0.01 ± < 0.01	2.3
Copper (g)	< 0.01	< 0.01
Zinc (g)	0.01 ± < 0.01	0.01
Iron (g)	0.15 ± 0.01	0.02

Minerals

In terms of minerals, 100 g of dry *G. quadriradiata* contains 0.14 ± < 0.01 g of Fe, 1.73 ± < 0.01 g of Ca, 2.17 ± < 0.01 g of K, < 0.01 g of Cu, 0.01 ± < 0.01 g of Zn, 0.37 ± < 0.01 g of P, and 0.01 ± < 0.01 g of Na. When compared to recommended daily intake values, consuming 100 g of this plant results in mineral levels below the FDA's recommended daily (Table 5). Similarly, in terms of heavy metals, 2.86 mg of lead and 0.811 mg of cadmium per kg of dry weight were detected**.**

Total flavonoid and proanthocyanidins

The total flavonoid content in 100 g of dry *G. quadriradiata* was 0.46 ± < 0.01 g (calculated as rutin), and the proanthocyanidin content was 0.15 g. Comparative analysis showed that the flavonoid content in 100 g of *G. quadriradiata* exceeds that of some of the best flavonoid-rich foods taken per day, such as tea, apples, and oranges, both raw and in juice form, which contain 0.38 g. However, the proanthocyanidin content in *G. quadriradiata* is approximately half that of the richest dietary sources of proanthocyanidins, including raw tea, apples, and strawberries, which contain 0.26 g per 100 g (Ivey et al. 2017).

Volatile profiling using HS–SPME–GC–MS

The volatile compounds of *G. quadriradiata* were analyzed for the first time using HS–SPME–GC–MS, resulting in the detection of 922 peaks, underscoring the chemical complexity of its volatile profile. The total ion chromatogram (TIC) profiles of six runs of the analyzed *G. quadriradiata* sample are shown in Figs. S1–S6. A total of 238 volatile molecules were identified, accounting for 81.10% of the total volatiles. These compounds were categorized into 16 chemical classes, with aldehydes being the most abundant (16.66%), followed by alcohols (16.31%), sesquiterpenes (13.01%), ketones (8.33%) and fatty acids (7.07%) (Fig. 2). Detailed information, including compound names and classes, for the 30 most abundant compounds is provided in Table 6. At the same time, a comprehensive list of all detected volatiles is available in Table S1 and the annotation of the major compounds is illustrated in a representative TIC

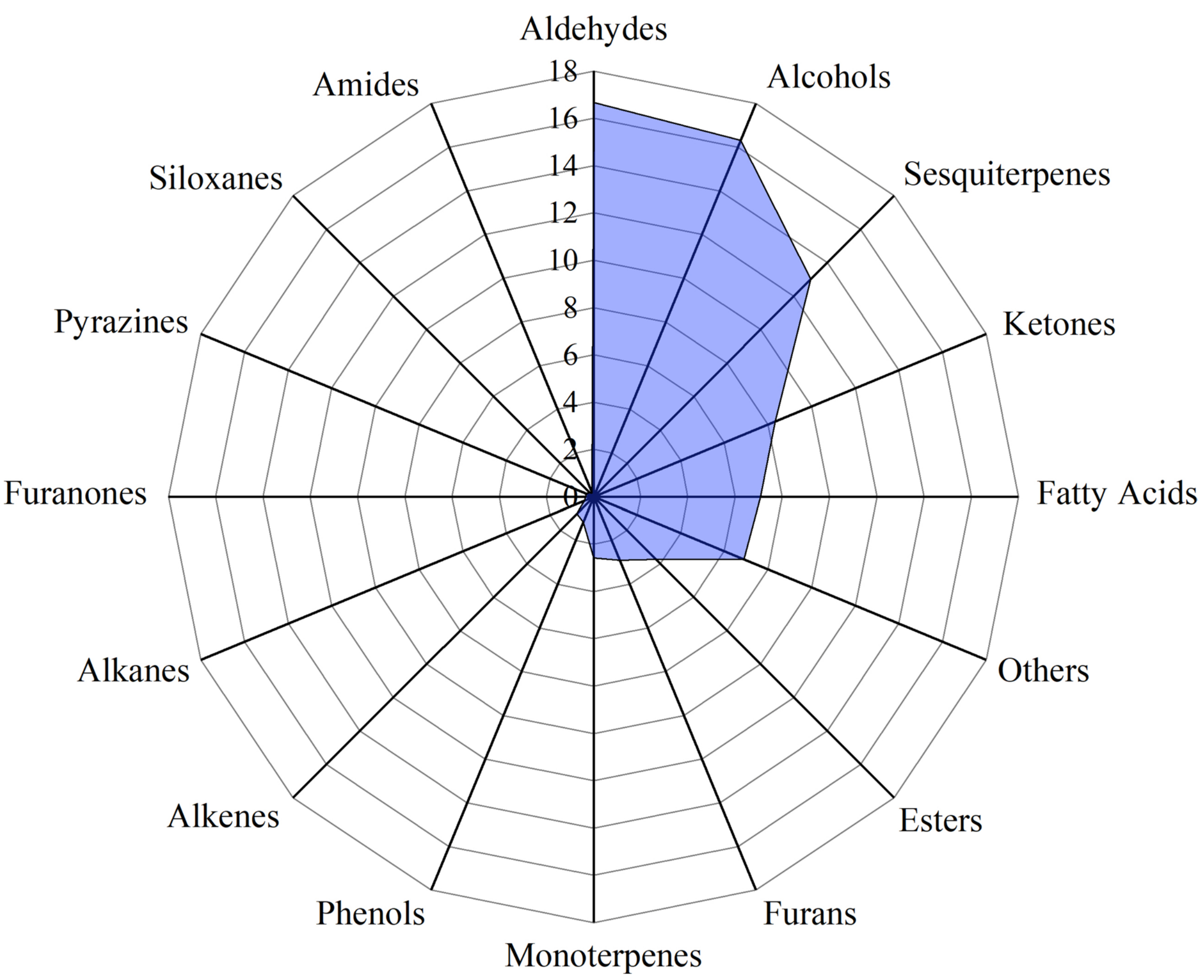

Fig. 2 The Constituents of volatile compounds in *Galinsoga quadriradiata*

Table 6 Main volatile compounds identified from *Galinsoga quadriradiata* using HS–SPME–GC–MS

No.[a]	Compound[b]	Class	KRI[c]	KRI[d]	Similarity[e]	RA[f] (%)
232	5,10-Dioxatricyclo[7.1.0.0(4,6)]decane	Others	1231		938	5.39
48	1-Hexanol	Alcohols	1346	1356	944	3.54
14	2-Hexenal	Aldehydes	1201	1216	902	3.26
17	Oct-7-enal	Aldehydes	1334		927	3.20
73	*α*-Copaene	Sesquiterpenes	1475	1475	927	2.97
138	Hexanoic acid	Fatty Acids	1832	1834	952	2.50
65	1,7-Octadien-3-ol	Alcohols	1691		902	2.40
75	3*H*-3a,7-Methanoazulene, 2,4,5,6,7,8-hexahydro-1,4,9,9-tetramethyl-, [3a*R*-(3a*α*,4*β*,7*α*)]-	Sesquiterpenes	1505	1532	852	2.36
49	3-Hexen-1-ol, (*Z*)-	Alcohols	1373	1373	844	2.27
25	Benzaldehyde	Aldehydes	1495	1495	749	2.21
132	Acetic acid	Fatty Acids	1430	1429	815	1.82
156	Bicyclo[2.2.1]heptan-2-ol, 1,7,7-trimethyl-, acetate, (1*S*-*endo*)-	Esters	1564		946	1.74
119	5-Hepten-2-one, 6-methyl-	Ketones	1323	1323	902	1.66
6	Hexanal	Aldehydes	1075	1077	940	1.63
36	Ethanol	Alcohols	935	935	951	1.63
90	(-)-*β*-bisabolene	Sesquiterpenes	1711	1736	898	1.55
129	*trans*-*β*-Ionone	Ketones	1927	1926	946	1.41
166	Furan, 2-pentyl-	Furans	1218	1215	960	1.31
114	Acetoin	Ketones	1268	1287	838	1.28
18	Nonanal	Aldehydes	1379	1380	768	1.14
193	Phenol	Phenols	1990	1992	768	1.13
56	1-Hexanol, 2-ethyl-	Alcohols	1479	1480	829	1.08
237	Triisobutyl phosphate	Others	1916		833	1.06
190	Bicyclo[2.2.1]heptan-2-ol, 1,7,7-trimethyl-, (1*S*-*endo*)-	Monoterpenes	1685	1675	957	1.02
59	7-Octen-1-ol	Alcohols	1598		957	0.96
81	Bicyclo[3.1.1]hept-2-ene, 2,6-dimethyl-6-(4-methyl-3-pentenyl)-	Sesquiterpenes	1572	1575	900	0.86
136	Butanoic acid, 2-methyl-	Fatty Acids	1653	1652	765	0.78
1	Butanal, 2-methyl-	Aldehydes	910	908	957	0.76
130	3-Buten-2-one, 4-(2,2,6-trimethyl-7-oxabicyclo[4.1.0]hept-1-yl)-	Ketones	1981	1967	856	0.76
57	6-Hepten-1-ol	Alcohols	1497		766	0.71

[a]The number was consistent with that in Table S1

[b]Compounds were identified by comparing their Kovats' retention index and mass spectra with those available in the NIST23 database

[c]Kovats' retention indexes (KRIs) on DB-WAS column, experimentally determined using a series of C_9–C_{23} *n*-alkanes as references

[d]Kovats' retention indexes (KRIs) on DB-WAS column, acquired in the NIST Chemistry WebBook database (https://webbook.nist.gov/chemistry/) and the Flavornet database (https://www.flavornet.org/)

[e]Match similarity values were determined by comparing the experimental mass spectra with those in the NIST23 database

[f]Relative abundance expressed as a percentage of their peak area in the total ion chromatogram

profile (Fig. S7). Among the individual components, the most abundant constituent was 5,10-dioxatricyclo[7.1.0.0(4,6)]decane, with a relative abundance of 5.39%, followed by 1-hexanol (3.54%), 2-hexenal (3.26%), oct-7-enal (3.20%), and *α*-copaene (2.97%). Many volatile constituents possess distinct odor properties. For instance, 1-hexanol has a sweet and alcohol-like scent, while hexanoic acid is characterized by a pungent, sour, and sweaty odor (Table S1).

Discussion

Traditional knowledge related to G. quadriradiata

Understanding the social aspects of invasive species management is important for effective intervention (García-Llorente et al. 2008). *G. quadriradiata* has high potential to be used in food systems and medicine, as indicated by the field survey in Lushan and the literature review. *G. quadriradiata's* traditional use in food and medicine is similar to the use of *G. parvifolia* (Sun & Shahrajabian 2023). We should align this traditional knowledge with the scientific data, which benefits invasive species management, including *G. quadriradiata.*

Potential uses as human food

G. quadriradiata can be used as a food source, supported by its nutritional composition. The energy content of *G. quadriradiata* is higher than that of many other vegetables, exceeding the threshold for low-calorie foods (< 600 kJ), making it suitable for individuals requiring a higher caloric intake (Ng et al. 2019). Its energy value surpasses that of *Brassica oleracea* (111.04 kJ), *Brassica capitata* (65.51 kJ), Chinese Lettuce (17.33 kJ), *Brassica pekinensis* (17.33 kJ), and *Allium sativum* (428.63 kJ) (Januškevičius et al. 2012). The average protein content in *G. quadriradiata* is also higher than that of common vegetables such as *Senna occidentalis* and *Manihot esculenta* (7.0 g/100 g), *Capitata oleracea* (1.0 g/100 g), and *Spinacia oleracea* (3.0 g/100 g) (Chip et al., 2010). Moreover, its fat content exceeds that of common vegetables like *Brassica oleracea* capitata, *Brassica oleracea*, *Lactuca sativa*, and *Spinacia oleracea*, while its carbohydrate content remains similar to these species (Hanif et al., 2006).

G. quadriradiata is also notably high in dietary fiber, surpassing vegetables and crops such as carrots, peas, spinach, coriander, leek, parsley, chard, and corn (Opazo-Navarrete et al. 2021). It contains significant amounts of Vitamin B_2, which is essential for the metabolism of fats, proteins, and carbohydrates into glucose. Additionally, the presence of Vitamin E, which exhibits antioxidant properties, plays a crucial role in immune function and cellular respiration (Suwannasom et al. 2020). Tocopherols (α, β, γ, δ) and tocotrienols (α, β, γ, δ) detected in the species further contribute to its antioxidant activity (NDA, 2016).

The mineral concentration was more than 1% of the plant's dry weight, which is considered to be higher than the typical mineral concentration in conventional and edible leafy vegetables (Damalas 2008). The Ca value is 173 g/kg, which is very high above the normal range (1–1.2 g/kg) and might be beneficial for bones. The Phosphorus value (3.68 g/kg) was above the normal range of 700–1000 mg/kg (Waziri et al. 2019). The value of K was above the normal range of ≥ 2 g/kg, which might be important for cardiovascular health (EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA, 2016). The level of zinc present in this species is below the FDA-recommended value. However, this value is above the other vegetables and the nutritional needs adopted by the Chinese Nutrition Society in 2013 (Mai et al. 2024). Heavy metal content was determined to be an important indicator for evaluating food safety (Mu et al. 2024). These metals are toxic even in low concentrations (Budi et al. 2024). Hence, we recommend using these species as food and feeding only from the non-polluted site. We also advise testing the limit of heavy metals before they are used.

Furthermore, *G. quadriradiata* contains good amounts of flavonoids and proanthocyanidins, which possess antioxidant and anti-inflammatory properties. These compounds can scavenge free radicals, reduce oxidative stress, and contribute positively to cardiovascular health.

Potential uses as an animal feed

The ethnobotanical finding demonstrates the use of *Galinsoga quadriradiata* in animal feed, which was supported by the nutritional analysis. It is suitable for chicken feed due to its nutritional content, including protein, fats, and carbohydrates (Ofori et al. 2019). The protein content is adequate for chicken feed as it provides essential building blocks for the chicken's body (Beski et al. 2015). Additionally, the soluble and insoluble dietary fibers in *G. quadriradiata* support chicken growth (Tejeda & Kim 2021). The levels of potassium (K), phosphorus (P), copper (Cu), zinc (Zn), and iron (Fe) are adequate for chicken feed (Ravindran 2013). The sodium (Na) content is too low (National Research Council & Subcommittee on Poultry Nutrition 1994) but can be supplemented with other added feeds.

To assess its suitability as a feed ingredient, the nutritional composition of *G. quadriradiata* was compared with the nutrient requirements of Cobb 500 broilers (https://www.cobb-vantress.com/resource/management-guides). Results indicate that 100 g of its dry matter contains appreciable levels of protein, fiber, and minerals, suggesting its potential for partial inclusion in poultry diets (Table 7).

Comparisons of volatile profiles of *G. quadriradiata* with other *Galinsoga* species

Although more than 15 species of *Galinsoga* have been identified worldwide (Li 2007), research on their volatile compounds has largely been confined to *G. parviflora*. A study analyzed the volatiles from the leaves of *G. parviflora* collected in Colombia using GC–MS, identifying 88 compounds, with (*Z*)-3-hexen-1-ol (21.7%), *β*-caryophyllene (12.4%), and 6-demethoxy-ageratochrome (14%) as the most abundant constituents (Pino et al. 2010). Recently, another study characterized 48 volatiles from the aerial parts of *G. parviflora*, with (*Z*)-*γ*-bisabolene (45.66%), (*E*)-caryophyllene (4.99%), and (*Z*)-bisabolol-11-ol (4.95%) as dominant components (Ripanda et al. 2023), indicating the chemical variability within the species. In contrast, the volatile compositions of other *Galinsoga* species remain underexplored. This study represents the first investigation of the volatiles of *G. quadriradiata*, an invasive species in China. A total of 238 volatile compounds were identified, spanning various chemical classes such as sesquiterpenes, ketones, and fatty acids. This number far exceeds the volatiles characterized in *G. parviflora* by Pino et al. (2010) and Ripanda et al. (2023). In addition, many volatiles from *G. quadriradiata* characterized in the current study were not previously reported in *G. parviflora*, including the main several components such as 5,10-dioxatricyclo[7.1.0.0(4,6)]decane, oct-7-enal and hexanoic acid. Collectively, our results highlight *G. quadriradiata* as a promising resource for further research on natural volatiles, with potential applications in various fields.

Aroma and Function in Feed Use

Our ethnobotanical study revealed that *G. quadriradiata* is commonly used as animal feed in Lushan City, Jiangxi Province, which reflects the local traditional botanical knowledge in resource utilization concerning invasive plants. Beyond traditional practices, the aroma of feed plays a significant role in influencing animals' intake preferences (Scherer et al. 2019; Janni 2020). To explore the volatiles of *G. quadriradiata* that might affect animal feed preference, we analyzed the volatile constituents of this species using HS–SPME–GC–MS. The analysis revealed a complex, volatile profile, identifying 238 compounds. Based on odor descriptions from databases such as FlavorDB2 and Flavornet, many volatiles possess distinct aromas. For example, *α*-copaene has a woody and spicy scent, while hexanoic acid possesses

Table 7 Potential of *Galinsoga quadriradiata* to be added in chicken feed comparison with Cobb 500 broilers requirements (Source: https://www.cobb vantress.com/resource/ management-guides)

Nutrients (unit)	*G. quadriradiata* (100 g)	Starter (455 g)	Grower 1 (2100 g)	Grower 2 (2100 g)	Finisher 1 (2100)	Comments on adding 100 g
Vitamin E (g)	< 0.01	0.04	0.11	0.11	0.11	Can be added
Vitamin B_2 (g)	< 0.01	< 0.01	0.02	0.02	0.01	Can be added
Calcium (g)	1.73 ± < 0.01	4.37	16.8	15.54	15.12	Can be added
Potassium (g)	2.09 ± 0.01	2.73–4.32	12.6–19.95	12.6–19.95	12.6–19.95	Can be added
Phosphorus (g)	0.38 ± < 0.01	2.64	8.4	7.77	7.56	Can be added
Sodium (g)	0.01 ± < 0.01	0.16–0.23	0.17–0.23	0.17–0.23	0.17–0.23	Can be added
Copper (g)	< 0.01	0.01	0.032	0.03	0.03	Can be added
Zinc (g)	0.01 ± < 0.01	0.05	0.21	0.21	0.21	Can be added
Iron (g)	0.15 ± 0.01	0.02	0.08	0.08	0.08	Caution
Protein (g)	17.70 ± 0.24	95.55–100.1	399–420	378–399	357–378	Can be added

fatty, sour, sweaty, and cheesy aroma. Several compounds with relatively high abundance, including 5,10-dioxatricyclo[7.1.0.0(4,6)]decane (5.35%), 1-hexanol (3.54%), 2-hexenal (3.26%), and oct-7-enal (3.20%), likely contribute to the overall aroma of *G. quadriradiata*, which may influence poultry preference for this species. However, further research is necessary to fully characterize the odors of 5,10-dioxatricyclo[7.1.0.0(4,6)] decane and oct-7-enal.

In addition to their sensory appeal, several identified volatiles exhibit significant antibacterial activity, potentially benefiting poultry health. Compounds such as α-copaene, 2-hexenal, and acetic acid have demonstrated efficacy against pathogens like *Escherichia coli* and *Salmonella enteritidis*, which pose risks to both poultry and human health (Lanciotti et al. 2003; Dziva and Stevens 2008; Chen et al. 2024). For instance, α-copaene, with a relative abundance of 2.97% in *G. quadriradiata* volatiles, has shown strong inhibitory effects against *E. coli*, with minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) values of 1 and 4 μL/mL, respectively (Chen et al. 2024). Similarly, acetic acid, detected in *G. quadriradiata* with a relative abundance of 1.82%, is a widely used feed additive that helps prevent *Salmonella enteritidis* infections in poultry (Attia et al. 2012). The presence of bioactive compounds with antimicrobial properties supports the scientific rationale for using *G. quadriradiata* as an animal feed. It not only supports animal health by preventing pathogen infections but also holds potential benefits for human health by reducing zoonotic risks. This dual role underscores the practical and scientific basis for selecting *G. quadriradiata* as a natural feed resource.

Safety concerns and alternative use

The amount of Pb, Cd, Cr, and Fe were above the permissible limits, indicating the sample was collected from polluted sites (Du et al. 2024). The permissible limit for Pb is 0.3 mg/kg, Cd is 0.05 mg/kg, Cr is 2.3 mg/kg (FAO/WHO, 2011), and Fe is 450 mg/kg (FAO. 2007). The higher concentration of these metals leads to different health complications in humans, such as ulcers and cancer in human (Manwani et al., 2022; Wilberforce & Nwabue 2013). In chicken, Pb and Cd exposure leads to growth depression and harm to different organs, such as the kidney and reproductive organs (Wolf & Cappai 2021). Hence, while using this species as feed/food should be used from the non-polluted site.

Limitations of the study

This study primarily focused on documenting the food and feed uses of *Galinsoga quadriradiata* and evaluating its nutritional profile. While these findings offer preliminary insights into the species' potential, some limitations remain. For instance, the analysis did not include common antinutritional compounds such as oxalates, phytates, and tannins, which could be relevant for a more comprehensive assessment. In addition, the nutritional evaluation was based on three biological replicates, which may not fully reflect the species' potential variability. Future research could consider incorporating a broader range of samples and examining antinutritional factors to further strengthen the evidence base.

Conclusion

Traditional knowledge plays a pivotal role in the management of plant resources, including invasive species. This study highlights the traditional utility of the invasive plant *Galinsoga quadriradiata*. Through a detailed ethnobotanical investigation, we identified its traditional uses as food and feed. Nutritional analyses further substantiated its potential by demonstrating its value as a nutrient-rich edible plant and a viable animal feed resource. The GC/MS study revealed its volatile compounds, offering insights into why it is palatable to animals and providing a mechanistic understanding of its feed potential from the perspective of volatile profiles. These findings collectively lay a foundation for the sustainable management of *G. quadriradiata*, contributing to the protection of agricultural ecosystems. Moreover, this approach offers a novel perspective for the effective management of other invasive plants by integrating ethnobotanical insights with scientific validation. Given that *G. quadriradiata* often thrives in disturbed environments, attention should be paid to the ecological characteristics and safety of collection sites, particularly regarding possible contamination by heavy metals or pesticides. Furthermore, while promoting its use as food or feed may support control efforts, such utilization strategies should be accompanied by proper ecological risk management to avoid unintentionally facilitating its further spread. Future research should expand on these findings to explore scalable applications and ecological implications, ensuring the sustainable utilization of invasive plant resources.

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Author contributions BL and FL conceptualized the study, supervised the research process, and provided critical revisions to the manuscript. DK and YQ conducted the ethnobotanical investigations, analyzed traditional knowledge, and interpreted its implications. FL led the GC–MS experiments and provided technical expertise in volatile compound analysis. ZD assisted in data collection and analysis, while JC contributed to experimental validation. JN guided the overall methodological framework and data integration. All authors read and approved the final manuscript.

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Data availability All data used is available in supplementary files.

Declarations

Conflict of interest The authors declare no conflict of interests.

References

Attia YA, Ellakany HF, Abd El-Hamid AE, Bovera F, Ghazaly SA (2012) Control of salmonella enteritidis infection in male layer chickens by acetic acid and/or prebiotics, probiotics and antibiotics. Arch Geflügelk 76(4):239–245

Bazylko A, Boruc K, Borzym J, Kiss AK (2015a) Aqueous and ethanolic extracts of *Galinsoga parviflora* and *Galinsoga ciliata*. Investigations of caffeic acid derivatives and flavonoids by HPTLC and HPLC—DAD—MS methods. Phytochem Lett 11:394–398

Bazylko A, Borzym J, Parzonko A (2015b) Determination of in vitro antioxidant and UV—protecting activity of aqueous and ethanolic extracts from *Galinsoga parviflora* and *Galinsoga quadriradiata* herb. J Photochem Photobiol B: Biol 149:189–195

Beski SS, Swick RA, Iji PA (2015) Specialized protein products in broiler chicken nutrition: a review. Anim Nutr 1(2):47–53

Budi HS, Catalan Opulencia MJ, Afra A, Abdelbasset WK, Abdullaev D, Majdi A, Taherian M, Ekrami HA, Mohammadi MJ (2024) Source, toxicity and carcinogenic health risk assessment of heavy metals. Rev Environ Health 39(1):77–90

De Cauwer B, Biesemans N, De Ryck S, Delanote L, Dewaele K, Willekens K, Vanden Nest T, Reheul D (2021) Effects of soil and crop management practices and pedo-hydrological conditions on the seedbank size of *Galinsoga* spp. in organic vegetable fields. Weed Res 61(1):55–67

Chen SY, Zheng H, Yang SP, Qi YG, Li W, Kang SN, Hu H, Hua Q, Wu YK, Liu ZJ (2024) Antimicrobial activity and mechanism of α - copaene against foodborne pathogenic bacteria and its application in beef soup. LWT 195:115848

Paula DF, Silva EM, Silva LB, Lima AD, Billu PB, Reis MR, Mendes KF (2022) Sustainable control of galinsoga parviflora with oxyfluorfen, flumioxazin, and linuron application in two soils cultivated with garlic. Sustainability 14(24):16637. https://doi.org/10.3390/su142416637

Bautista-Cruz A, Arnaud-Viñas MR, Martínez-Gutiérrez GA, Sánchez-Medina PS, Pérez-Pacheco R (2011) The traditional medicinal and food uses of four plants in Oaxaca. Mexico J Med Plants Res. 5(15):3404–3411

Damalas CA (2008) Distribution, biology, and agricultural importance of *Galinsoga parviflora* (Asteraceae). Weed Biol Manag 8(3):147–153

Du Y, Tian Z, Zhao Y, Wang X, Ma Z, Yu C (2024) Exploring the accumulation capacity of dominant plants based on soil heavy metals forms and assessing heavy metals contamination characteristics near gold tailings ponds. J Environ Manage 351:119838

Duan ZX, Mao K, Chen XX, Cui YM, Wu W, Nie JB, Cheng CS, Lin FK, Luo BS (2024) Ethnobotanical knowledge, nutritional composition, and aroma profile of vicia kulingiana bailey: an underutilized wild vegetable endemic to china. Foods 13(6):916. https://doi.org/10.3390/foods13060916

Dziva F, Stevens MP (2008) Colibacillosis in poultry: unravelling the molecular basis of virulence of avian pathogenic Escherichia coli in their natural hosts. Avian Pathol 37(4):355–366

Efsa ND (2016) Panel (EFSA Panel on dietetic products, nutrition and allergies) Scientific opinion on dietary reference values for iron. EFSA J 13:4254

FAO J (2007) Fao food standard programme codex alimentarius commission 13th session. Report of the Thirty-Eight Session of the Codex Com. on Food Hyg, Houston, United States of America, AliNorm

FAO/WHO (2011) Joint FAO/WHO food standards programme codex committee on contaminants in foods, food CF/5 INF/1. Fifth session, (The Hague, The Netherlands)

GB 5009.268–2016 (2016) Trace elements: national food safety standard- determination of mul-ti-elements in foods (method 2). National health and family planning commission of PRC china food and drug administration Beijing, China

GB 5009.5–2016 (2016). Protein: national food safety standard- determination of protein in foods (method 1). National health comission of PRC Beijing, China

GB 5009.6–2016 (2016) Fat: national food safety standard-determination of fat in foods (method 2). National health commission of PRC Beijing, China

GB 5009.82–2016 (2016) National food safety standard—determination of Vitamin A, Vitamin E and Vitamin D in foods (method 1). National health and family planning commission of PRC china food and drug administration Beijing, China

GB 5009.88–2014, 2014 Dietary fiber: national food safety standard- determination of dietary fibers in food. National health and family planning commission of PRC Beijing China

GB 5009.9–2016 (2016) Starch: national food safety standard-determination of starch in foods (method 2). National health and family planning commission of PRC; china food and drug administration Beijing, China

GB/Z 21922–2008 (2008) Energy: fundamental terminology and definition of nutritional component in foods. Ministry of health of prc; standardization administration of PRC Beijing, China

Giday M, Asfaw Z, Woldu Z (2009) Medicinal plants of the Meitin ethnic group of Ethiopia: an ethnobotanical study. J Ethnopharmacol 124(3):513–521

Hanif R, Iqbal, Z, Iqbal M, Hanif S, Rasheed M (2006) Use of vegetables as nutritional fod: role in human health. Journal of Agricultural and Biological Science, 1(1): 18–22.

Hui W, Ceming T, Wen X, Xuan W, Dahan A, Qiang F (2020) Vascular plants in the tourist area of Lushan National Nature Reserve, China: status, threats and conservation. Eco Mont J Protected Mountain Areas Res 12(1):60–63

Ivey KL, Jensen MK, Hodgson JM, Eliassen AH, Cassidy A, Rimm EB (2017) Association of flavonoid-rich foods and flavonoids with risk of all-cause mortality. Br J Nutr 117(10):1470–1477

Janni K (2020) Reflections on odor management for animal feeding operations. Atmosphere 11(5):453

Januškevičius A, Januškevičienė G, Andrulevičiūtė V (2012) Chemical composition and energetic values of selected vegetable species in Lithuanian supermarkets. Vet Med Zoot 58:8–12

Jönsson M, Merkel A, Fredriksson C, Karlsson EN, Wendin K (2023) Nutritional, physicochemical, and sensory characterization of four common Northern European seaweed species intended for food. Algal Res 75:103258

Lanciotti R, Belletti N, Patrignani F, Gianotti A, Gardini F, Guerzoni ME (2003) Application of hexanal,(E)-2-hexenal, and hexyl acetate to improve the safety of fresh-sliced apples. J Agric Food Chem 51(10):2958–2963

Li J (2007) Flora of China. Harv Pap Bot 13:301–302

Lin F, Long C (2023) GC-TOF-MS-based metabolomics correlated with bioactivity assays unveiled seasonal variations in leaf essential oils of two species in Garcinia L. Ind Crops Prod 194:116356

Liu J, Zhang Y, Wang H (2023) Rhizosphere and root fungal community of the invasive plant *Galinsoga quadriradiata*. J Plant Ecol 16(1):rtac055. https://doi.org/10.1093/jpe/rtac055

García-Llorente M, Martín-López B, González JA, Alcorlo P, Montes C (2008) Social perceptions of the impacts and benefits of invasive alien species: implications for management. Biol Cons 141(12):2969–2983

Luizza MW, Young H, Kuroiwa C, Evangelista P, Worede A, Bussmann R, Weimer A (2013) Local knowledge of plants and their uses among women in the bale mountains. Ethiopia 11:315–340

Mai W, Wang F, He S, Wen Y, Yu G, Zhang L, Dong H (2024) Zinc contents in foods and estimates of dietary intakes in Guangzhou, Guangdong Province. China Front Nutr 11:1364033. https://doi.org/10.3389/fnut.2024.1364033

S Manwani et al (2022) Heavy metal contamination in vegetables and their toxic effects on human health. Sustain Crop Prod: Recent Adv 181

Mu W, Kleter GA, Bouzembrak Y, Dupouy E, Frewer LJ, Radwan Al Natour FN, Marvin HJ (2024) Making food systems more resilient to food safety risks by including artificial intelligence, big data, and internet of things into food safety early warning and emerging risk identification tools. Compr Rev Food Sci Food Saf 23(1):e13296

Opazo-Navarrete M, Burgos-Díaz C, Soto-Cerda B, Barahona T, Anguita-Barrales F, Mosi-Roa Y (2021) Assessment of the nutritional value of traditional vegetables from southern chile as potential sources of natural ingredients. Plant Foods Hum Nutr (Dordr, Neth) 76(4):523–532. https://doi.org/10.1007/s11130-021-00935-2

Ng KW, Sangster J, Priestly J (2019) Assessing the availability, price, nutritional value and consumer views about foods and beverages from vending machines across university campuses in regional New South Wales. Australia Health Promot J Aust 30(1):76–82

Njoroge GN, Bussmann RW (2006) Herbal usage and informant consensus in ethnoveterinary management of cattle diseases among the Kikuyus (Central Kenya). J Ethnopharmacol 108(3):332–339

Ofori H, Amoah F, Arah I, Krampah EK (2019) Proximate analysis and metabolizable energy of animals. ARPN J Eng Appl Sci 14(5):1026–1032

Pino JA, Gaviria M, Quevedo-Vega J, García-Lesmes L, Quijano-Celis CE (2010) Essential oil of Galinsoga parviflora leaves from Colombia. Nat Prod Commun. https://doi.org/10.1177/1934578X1000501129

Ravindran V (2013) Animal availability and nutrition in developing countries. Poultry Dev Rev 2(11):60–63

Ripanda A, Luanda A, Sule KS, Mtabazi GS, Makangara JJ (2023) *Galinsoga parviflora* (Cav): a comprehensive review on ethnomedicinal, phytochemical and pharmacological studies. Heliyon 9(2):e13517

Scherer R, Gerlach K, Südekum KH (2019) Decision-making of goats when exposed to choice feeding: triggered by taste or smell? Appl Anim Behav Sci 210:46–51

Shi Z et al (2011) Asteraceae (Compositae). Flora of China 20–21:1–8

Smith TP, Marble C, Steed S, Boyd N (2020) Biology and management of *Galinsoga* (*Galinsoga quadriradiata*) in ornamental crop production : ENH1329/EP593, 10/2020. EDIS. https://doi.org/10.32473/edis-ep593-2020

National Research Council, Subcommittee on Poultry Nutrition (1994) Nutrient requirements of poultry: 1994. National Academies Press

Sun X, Shahrajabian MH (2023) Therapeutic potential of phenolic compounds in medicinal plants—Natural health products for human health. Molecules 28(4):1845

Suwannasom N, Kao I, Pruß A, Georgieva R, Bäumler H (2020) Riboflavin: the health benefits of a forgotten natural vitamin. Int J Mol Sci 21(3):950

Tejeda OJ, Kim WK (2021) Role of dietary fiber in poultry nutrition. Animals 11(2):461

Tolossa K, Debela E, Athanasiadou S, Tolera A, Ganga G, Houdijk JG (2013) Ethno—medicinal study of plants used for treatment of human and livestock ailments by traditional healers in South Omo, Southern Ethiopia. J Ethnobiol Ethnomed 9:1–15

ISO 20759:2017 (2017) Total flavonoids: traditional chinese medicine—artemisia argyi leaf (Annex C). International organization for standardization: Geneva, Switzerland

Waziri B, Duarte R, Naicker S (2019) Chronic kidney disease-mineral and bone disorder (CKD—MBD): current perspectives. Int J Nephrol Renovasc Dis 12:263–276. https://doi.org/10.2147/IJNRD.S191156

Wilberforce JO, Nwabue FI (2013) Heavy metals effect due to contamination of vegetables from Enyigba lead mine in Ebonyi State. Nigeria Environ Pollut 2(1):19

Wolf P, Cappai MG (2021) Levels of Pb and Cd in single feeding stuffs and compound feeds for poultry. Biol Trace Elem Res 199:1074–1079

Yang Y-B, Liu G, Shi X, Zhang W-G, Cai X-W, Ren Z-L, Nie H (2018) Where will invasive plants colonize in response to climate change: predicting the invasion of *Galinsoga quadriradiata* in China. Int J Environ Res 12:929–938

Yimer A, Forsido SF, Addis G, Ayelign A (2023) Potential and prospects of utilization, development, and conservation of wild edible plants of the meinit ethnic community in bench-maji zone. South–western Ethiopia East Afr J Sci 17(2):199–214

Zareef H, Gul MT, Qureshi R, Aati H, Munazir M (2023) Application of ethnobotanical indices to document the use of plants in traditional medicines in Rawalpindi district, Punjab - Pakistan. Ethnobot Res Appl 25:1–29

Zhang WG, Chen XY, Liu RL, Song XJ, Liu G, Zou JB, Qian ZQ, Zhu ZH, Cui LJ (2022) Realized niche shift associated with *Galinsoga quadriradiata* (Asteraceae) invasion in China. J Plant Ecol 15(3):538–548