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Beyond the Nettles: Morphological and Chemical Divergence in Two Lamiaceae Weeds with Nutritional Potential

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Abstract
The Lamiaceae is a family of largely green and aromatic herbs that have conquered mild and temperate-climate regions. Among them, *Galeopsis tetrahit* and *Lamium purpureum* appear similar but show clear distinctions in genetics, ecology, and biochemical traits. *G. tetrahit* is a plant that inhabits a moist, nutrient-rich soil during the summer, while *L. purpureum* is a colder and more heavily disturbed area.
The aim of the study is to analyze the potential differences between these two species concerning their nutritional value.
Both literature and experimental data show that *G. tetrahit* has higher phenolic and flavonoid levels, explaining its stronger antioxidant activity in DPPH, ABTS, and FRAP tests.
These variations in the environment and biochemistry of organisms reflect different metabolic adaptations. Both species have a great supply of natural antioxidants and thus can be the sources of functional foods and dietary supplements to promote food diversification and human health.
Keywords: *Lamium purpureum, Galeopsis tetrahit,* bioactive compounds, adaptation, morphological differentiation

1. Introduction

The Lamiaceae family, often referred to as the mint group, consists of a wide range of fragrant and medicinal plants known for their impressive chemical variety and ecological flexibility.
Lamium purpureum is known to contain useful nutrients such as antioxidants, minerals, and small amounts of vitamins, which may help support general health when included in the diet [14]. *Galeopsis tetrahit* also shows strong nutritional potential, as its high content of phenolic and flavonoid compounds gives it notable antioxidant properties and possible benefits for human nutrition [9].
Members of this family produce a wide range of biologically active compounds such as phenolic acids, flavonoids, iridoids, and essential oils that contribute to their antioxidant and pharmacological potential [9]. Because of these bioactive molecules, Lamiaceae species are widely used in traditional medicine and food preservation, where natural antioxidants are sought as safer alternatives to synthetic additives [6].
These are plants that one can very often find growing on their own in nature, in open fields, and on lands that have been disturbed.
While they are only considered to be common wild herbs, they still carry some therapeutic value. *Lamium purpureum* is loaded with a variety of natural compounds such as hydroxycinnamic acids, flavonoids, and phenylethanoid glycosides, which are its protective agents.
These are the molecules that allow the plant to endure environmental stress and to reduce oxidative damage. Also, *Galeopsis tetrahit* produces iridoids

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and flavone glycosides, substances that have strong antioxidant and protective properties [3, 11].

Extracts made from *Lamium* species, especially those using butanol, can clean up free radicals almost as well as rutin or caffeic acid [3]. Tests with *Galeopsis tetrahit* show similar power. Methanolic extracts proved to be highly active in DPPH and ABTS experiments, showing that these plants contain many polyphenols with strong reducing properties [9].

According to Salehi et al. (2019), the plants from the genus Lamium are the source of a number of biologically active compounds of different groups, such as terpenoids, anthocyanins, and phytoecdysteroids, that, in combination, are the main factors behind the medicinal potential of these plants [14]. The content and variety of such substances seem to vary with the surroundings and the genetic differences of the species.

According to data reported in the literature, extracts obtained with polar solvents, such as methanol or butanol, show stronger antioxidant effects because they dissolve phenolic substances more efficiently [3]. The combined presence of different phenolic compounds may increase the overall protective activity of *Lamium* plants [14].

Similarly, *Galeopsis tetrahit* contains a range of phenolic and iridoid compounds with notable antioxidant and neuroprotective properties [11]. Comparative studies indicate that both *Galeopsis* and *Lamium* species are valuable sources of natural antioxidants, although the intensity of their biological effects can vary depending on the extraction solvent and habitat conditions [9].

Recent molecular studies on the genus *Galeopsis* revealed that tetraploid species, like *G. tetrahit*, through different hybridization and genome duplication events in each case, have originated. Such evolutionary mechanisms have increased their genetic and morphological variation; thus, the plants have been able to make use of a large variety of different habitats within temperate Europe [1].

Phytochemically, the genus *Galeopsis* is a rich source of tannins, flavonoids, saponins, and iridoids, bioactive compounds that are behind the antioxidant and anti-inflammatory activities of the plant extracts [8].

Comparative analyses of several European Lamiaceae species have shown that methanolic extracts from *Lamium* and *Galeopsis* demonstrate remarkable free-radical scavenging abilities and effectively prevent lipid peroxidation [8].

Using complementary assays (DPPH, ABTS and FRAP), polar extracts of *Lamium purpureum* consistently displayed strong antioxidant activity, a pattern explained by the high extractability and solubility of phenolic compounds in those fractions [5].

Bubueanu and colleagues (2013) reported similar results for butanoic extracts, which scavenged free radicals with efficacy comparable to natural standards such as rutin and caffeic acid. Because these preparations are rich in phenolics and flavonoids, their radical-scavenging effect increases with dose, supporting the potential use of *L. purpureum* extracts to mitigate oxidative stress in biological or food systems [5].

Collectively, these findings emphasize how evolutionary processes like polyploidy, combined with environmental influences, shape the chemical diversity of *Lamium* and *Galeopsis* species, strengthening their position as valuable natural sources of antioxidant agents with promising pharmacological and nutritional applications [1, 3].

In our field work we found these herbs growing everywhere, often where the soil was disturbed. Even as common weeds, they showed useful medicinal traits. From some samples, *Lamium purpureum* contains several phenolic types and flavonoids that help the plant resist stress. *Galeopsis tetrahit* yields iridoids and flavone derivatives that also act as antioxidants.

Lamium purpureum and *Galeopsis tetrahit* have been traditionally noted for their potential nutritional and medicinal uses. *L. purpureum* is sometimes consumed as an edible wild green rich in antioxidants, while *G. tetrahit* has been investigated for its bioactive compounds that may contribute to natural food preservation or health supplements [4, 14].

Since *Lamium purpureum* and *Galeopsis tetrahit* share similar ecological niches and are also close relatives from an evolutionary point of view, a comparison of their morphology, habitat, and chemical composition may reveal the influence of genetics and the environment in the production of secondary metabolites. Knowing such mechanisms at a deeper level may be the reason for new natural sources of antioxidants that could be used in medicine, nutrition, and environmental adaptation studies.

Therefore, the aim of this study is to compare the morphological, ecological, and chemical characteristics of *Lamium purpureum* and *Galeopsis tetrahit* and also to determinate their phenolic composition and antioxidant activity as a natural

field setting influence.

2. Materials and method

The research took into consideration the analysis of more than 100 scientifical publications and data from reliable databases in Europe and the U.S., from which the most relevant and up-to-date information was selected. The sources gave information concerning taxonomy, morphology, ecology, and phytochemical profiles of *Lamium purpureum* and *Galeopsis tetrahit*.

The cross-analysis was enhanced by the synthesis of data that came from botanical monographs, academic journals, and phytochemical databases. The data was arranged according to the principal research themes: taxonomy, morphology, ecology, and phytochemistry. Comparative tables were produced to highlight the similarities and differences of the two species, thus, giving more attention to the correlations between their ecological preferences and chemical composition. This comprehensive approach has facilitated the understanding of the influence of environmental factors on the bioactive profile of *Lamium purpureum* and *Galeopsis tetrahit*.

In the research, the differences between two species were highlighted mostly regarding their morphological traits and ecological habits. Besides that, the study delved into the unique characteristics of the stem, leaves, and flowers, along with the outdoor habitats where the plants typically grow and the seasons when they are most commonly seen. Apart from that, the chemical profile had some aspects of phenolic and flavonoid compounds quantified while antioxidant attributes were determined by very reputable methods that are mostly used in the field (DPPH, ABTS, and FRAP). The study through these means wanted to figure out how the environment could influence the chemical makeup of the plants.

3. Results and Discussion

The comparative assessment of *Galeopsis tetrahit* L. and *Lamium purpureum* L. are present in table 1 and highlights both their shared taxonomic placement within the Lamiaceae family and their divergent morphological, ecological, and genetic characteristics. Although both species are annual herbs widely distributed in temperate regions of Eurasia and North America, their evolutionary trajectories and ecological roles exhibit considerable differentiation [1, 14]. While *Galeopsis tetrahit* and *Lamium purpureum* both belong to the Lamiaceae family, their evolutionary stories diverge sharply. *G. tetrahit* is a tetraploid hybrid that developed through the natural crossing of *G. pubescens* and *G. speciosa*, whereas *L. purpureum* remains a diploid species with no known hybrid background [1, 14]. *Galeopsis tetrahit* typically presents as a vigorous, fast-growing annual that establishes readily in cultivated soils. It often attains greater biomass and successfully competes with neighboring plants, a habit that reflects its hybrid tetraploid origin. By contrast, *Lamium purpureum* is markedly smaller and more versatile; it commonly appears as a ruderal species in disturbed patches such as field margins, gardens or road verges. These divergent life-histories and behaviors are consistent with their different genetic backgrounds and help explain the contrasts in habit and ecological role between the two taxa.

Structurally, the species are easy to distinguish. *Galeopsis tetrahit* grows taller and has a course, robust aspect due to stiff, bristly hairs on stems and foliage, producing a rough tactile surface. *Lamium purpureum* remains low growing, its surfaces clothed in fine hairs and its leaves broadly cordate, which yields a softer appearance and feel [10, 14]. Both species bear purple bilabiate flowers typical of Lamiaceae, but they differ in floral construction: *G. tetrahit* develops a spiny calyx that shields developing nutlets, whereas *L. purpureum* has a smoother calyx and a proportionally longer corolla. These morphological contrasts reflect alternative adaptive strategies — one emphasizing mechanical defense and competitive stature, the other favoring rapid establishment and morphological plasticity in transient habitats.

Although both species are native to Eurasia, their ecological preferences diverge considerably. *G. tetrahit* thrives in moist, fertile soils and is most abundant in disturbed farmlands, while *L. purpureum* tolerates a wider range of habitats — from gardens to waste areas and no-till fields [10, 14].

Adaptability has allowed the latter species to spread more widely across the globe. By contrast, G. *tetrahit* is usually found only where soil and moisture conditions are just right, showing that it occupies a more specialized niche.

Table 1.Similarities of *Galeopsis tetrahit* and *Lamium purpureum*

Parameter	***Galeopsis tetrahit* L**	***Lamium purpureum* L.**
Taxonomy and general description	This annual herb belonging to the Lamiaceae is indigenous to Eurasia and widely naturalized across temperate zones of North America. Cytogenetic evidence indicates that it is a tetraploid species (2n = 32) of hybrid origin, derived from *Galeopsis pubescens* × *G. speciosa* [1]. Morphologically, the species is distinguished by its quadrangular stem, coarse bristly indumentum, and conspicuously swollen nodes [10].	This annual herbaceous weed, native to Europe and Asia, is a diploid species (2n = 18) commonly found in temperate regions and ruderal habitats [13, 14].
Morphological features	30–75 cm tall, erect stem with stiff hairs; opposite ovate leaves; pink to purple bilabiate flowers; calyx spiny with 5 pointed lobes enclosing 4 nutlets [10].	10–30 cm tall; weak square stem; purple bilabiate flowers with elongated corolla; leaves heart-shaped and covered with fine soft hairs [14].
Distribution and habitat	Prefers moist, nutrient-rich soils (pH 5–6); widespread in disturbed habitats (fields, roadsides, pastures) across Europe and temperate North America [10].	Common in Europe, Western Asia, and North America; thrives in waste places, gardens, and cultivated fields [14].
Growth and phenology	Summer annual; germination early spring; flowering July–September; long-day plant; no vegetative reproduction [10].	Winter/spring annual; germination fall to spring; flowers March–June [14].
Reproductive ecology	Reproduces by seed; largely self-fertile; ~380 seeds/plant; persistent soil seed bank [10].	Reproduces by seed; highly self-fertile; forms transient soil seed banks [14].
Ecological and agronomic significance	Competitive weed in cereals and oilseeds; yield losses 20–25%; contaminates grain; host for pathogens (*Phoma exigua*, *Erysiphe galeopsidis*) [10].	Ruderal species, minor weed; occasionally medicinal; nectar source for pollinators [14].
Control and management	Poor control with 2,4-D; responsive to MCPA, bromoxynil, dicamba, and metsulfuron; cultural methods include delayed seeding and crop rotation [10].	Controlled by standard broadleaf herbicides; thrives in no-till and moist soils [14].
Nuclear DNA content (flow cytometry)	0.950 ± 0.027 relative units [1]	The absence of data regarding nuclear DNA content indicates that no dedicated flow cytometry study has been conducted (or published) for *L. purpureum* or that such data are not openly accessible.

AFLP markers	47 total markers, 6 unique; error rate 4% [1]	No AFLP data reported in literature.
DNA methylation level	High [1]	No methylation data; presumed moderate methylation level in vegetative tissues (general for *Lamium* spp. [15].
Gene flow (genetic exchange)	Limited between different ploidy levels; frequent within the same ploidy level [1]	Not studied; wild populations show high pollen fertility (96–99%) in *Lamium purpureum* [2].
Origin and evolutionary status	Stable allopolyploid, independently formed relative to *G. bifida* [1].	Stable diploid species, no confirmed hybrid origin [14].

Unlike *L. purpureum*, which grows through the cooler months and blooms from early spring to early summer, *G. tetrahit* begins its life in spring and reaches its flowering stage later in the summer [10, 14]. Their contrasting growth rhythms help them use resources at different times of the year, reducing direct ecological overlap.

Both plants reproduce through seeds and are mainly self-fertile, yet their reproductive outputs differ. *G. tetrahit* produces around 380 seeds per plant, forming a long-lived seed bank, whereas *L. purpureum* creates only a short-term one [10, 14]. The former's persistence ensures its dominance in fields for years, while the latter tends to fluctuate annually depending on conditions. High pollen fertility in *L. purpureum* (up to 99%) further supports rapid recolonization of disturbed soils [2]. Agronomically, *G. tetrahit* is the more problematic weed, capable of reducing crop yields by 20–25% and serving as a host for fungal pathogens [10]. *L. purpureum* rarely reaches damaging levels and instead plays a beneficial ecological role as an early nectar source for pollinators [13, 14]. While *G. tetrahit* represents a true competitor in crop systems, *L. purpureum* functions more as a seasonal colonizer of open, nutrient-rich soils.

In figure 1 the results of the experiments emphasize that *Galeopsis tetrahit* L. is a very significant impact one in comparison with *Lamium purpureum* L. in terms of phenolic compounds accumulation. In the case of both plants, roots of *G. tetrahit* contained the phenolic compounds in an amount of more than 150 µg GAE/mL, while in roots of *L. purpureum* it was only about 95 µg GAE / mL. The difference in the phenolic content between the two species in the roots was also reflected in the aerial parts.

Table 2. Chemical differences between *Galeopsis tetrahit* and *Lamium purpureum*

Parameters	***Galeopsis tetrahit* L**	***Lamium purpureum* L.**
TPC (µg GAE/mL) roots	152.674 ± 12.412 [4]	95.6 ± 8.7 [14]
TPC (mg GAE/g) aerial parts	121.1 ± 10.4 [8] 17.5 ± 4.3 [8] 85.6 ± 5.9 [8] 81.5 ± 1.6 [8]	128.00 ± 0.001 [5] 89.23 ± 0.004 [5] 50.60 [5] 8.57 [5] 10.36 [3] 180 ± 14 [8]
TFC (mg QE/g) aerial parts	568.5 ± 24.2 [4]	39.80 ± 0.000 [5] 32.80 ± 0.001 [5] 37.90 [5] 24.20 [5] 3.52 [3]
TFC (µg QE/mL) leaves	568.543 ± 24.174 [4]	302.8 ± 17.9 [14]
TFC (µg QE/mL) roots	22.78 ± 0.663 [4]	15.2 ± 0.8 [14]
TAC DPPH Aerial parts (%)		50.57 – 87.95 [3]
TAC DPPH leaves (mg/mL)	0.458 ± 0.03 [4]	0.72 ± 0.04 [14]

TAC DPPH roots (mg/mL)	16.84 ± 0.97 [4]	2.64 ± 0.11 [14]
TAC ABTS leaves (mg/mL)	0.328 ± 0.003 [4]	0.49 ± 0.02 [14]
TAC ABTS roots (mg/mL)	4.77 ± 0.30 [4]	1.83 ± 0.12 [14]
TAC FRAP leaves (mM Fe^{2+} eq)	37.763 ± 2.52 [4]	21.34 ± 1.15 [14]
TAC FRAP roots (mM Fe^{2+} eq)	10.392 ± 0.40 [4]	6.82 ± 0.37 [14]

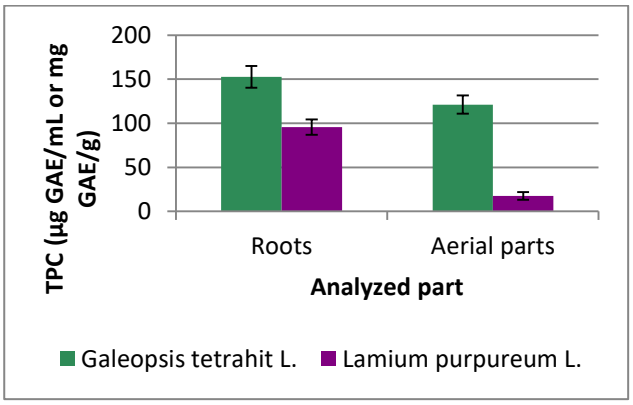

Figure 1. Total phenolic content
TPC=total phenolic content, µg GAE/mL= micrograms of gallic acid equivalents per milliliter, mg GAE/g= milligrams of gallic acid equivalents per gram

The figures point out that *Galeopsis* is more capable either to produce or accumulate phenolic compounds which from a long time have been known as antioxidants and protective agents in plants. These compounds play a role in the detoxification of reactive oxygen species and the strengthening of the plant's defense system against different abiotic stress factors. Hence, the high level of TPC in *G. tetrahit* can be regarded as a marker for its greater oxidative and ecological stress resistance as compared to *L. purpureum*.

The availability of phenolic compounds in *L. purpureum* may be limited due to differences in metabolic processes or gene expression related to the phenylpropanoid pathway. The differences in the Lamiaceae family species for the phenylpropanoid pathway genes are natural and they usually indicate the ecological roles and traits of the plants.

While determining the total flavonoid content, which are illustrated in Figure 2, Galeopsis *tetrahit* once again was the one that stood out with its values. In the aerial parts and leaves, the concentrations of its were extraordinarily high, going close to 568 mg QE/g, while *Lamium purpureum* disclosed quite low levels. Even in the roots, *G. tetrahit* kept on having a higher flavonoid presence.

Flavonoids are very important biologically active compounds which play an indispensable role in antioxidative protection, UV-screening and signaling processes. The big difference between the two species pointing out that *Galeopsis* possesses a more active flavonoid biosynthetic pathway which in turn may result in its overall stronger antioxidant profile.

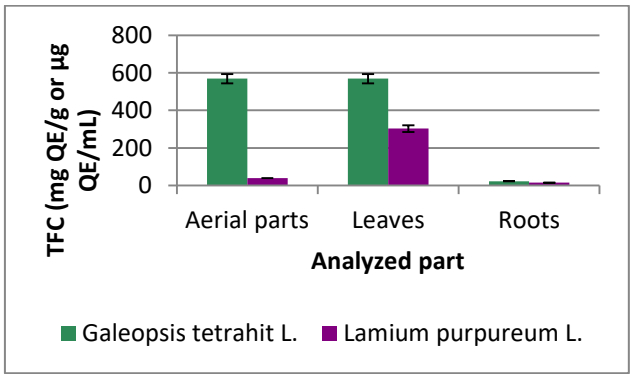

Figure 2. Total flavonoid content
TFC=total floavonoid content, mg QE/g= milligrams of quercetin equivalents per gram, µg QE/mL= micrograms of quercetin equivalents per milliliter

In the majority of plants, the top flavonoid levels can be found in leaves, the main source of photosynthesis, where contact with light and oxygen leads to oxidative stress. This model was also followed by the two species under investigation; however, the difference was much bigger in *G. tetrahit* thus it is more convincing that its metabolism is more capable of defensive compounds.

The antioxidant activity presented in figure 3 was determined by DPPH, ABTS, and FRAP assays is in line with the biochemical changes that were observed in phenolic and flavonoid contents. In all the methods, *Galeopsis tetrahit* was able to scavenge the radicals more effectively than *Lamium purpureum*. The strongest activities were found in the roots, especially in the DPPH and FRAP tests, which is an indication that root tissues could be a

main source of antioxidant compounds.

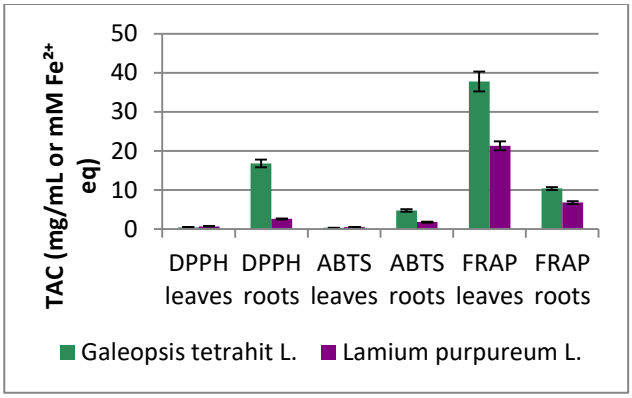

Figure 3. Total antioxidant capacity

T.A.C.=total antioxidant capacity, mg/ml=, milligrams per milliliter, mM Fe^{2+} eq= millimoles of ferrous ion equivalents per liter, DPPH leaves= the antioxidant activity of leaf extracts determined using the DPPH method, DPPH roots= the antioxidant activity of root extracts determined using the DPPH method, ABTS leaves= the antioxidant activity of leaf extracts determined using the ABTS method, ABTS roots= the antioxidant activity of root extracts determined using the ABTS method, FRAP leaves= the antioxidant activity of leaf extracts determined using the FRAP method, FRAP roots= the antioxidant activity of root extracts determinate using FRAP method.

The association between the amount of phenolics and flavonoids and the antioxidant performance is in agreement with the contribution of these metabolites to plant defense. The high TAC values recorded for *Galeopsis* may be indicative of the presence of more potent bioactive molecules to which the oxidative damage can be alleviated.

The analysis highlighted that both *Lamium purpureum* and *Galeopsis tetrahit* contain a rich profile of bioactive compounds that may enhance their nutritional and functional value. *G. tetrahit* showed higher levels of phenolics and flavonoids, which are linked to stronger antioxidant activity and potential health benefits when used as natural food ingredients. Although *L. purpureum* exhibited slightly lower antioxidant capacity, it remains a promising plant due to its balance of nutrients and the presence of compounds beneficial for human metabolism.

Besides, the results demonstrate that *Lamium purpureum* has been able to keep some antioxidant potential, although at a much lower level, thereby showing an interspecific variation effect instead of activity absence. Differences such as these are usually attributed to genetic, environmental, and physiological factors which have an impact on the accumulation of the active phytochemicals.

The biochemical profiles revealed in this research largely point to *Galeopsis tetrahit* L. having a secondary metabolism that is more fluctuating and able to react to changes than that of *Lamium purpureum* L. The fact that *G. tetrahit* was always superior in TPC, TFC, and TAC parameters indicates its potential as a source of natural antioxidants of great value.

The difference between species may be due to the different evolutionary adaptations of each species to its ecological niche. As an example, *Galeopsis*, which is generally recognized to grow in exposed or disturbed habitats, may require a powerful antioxidant defense system in order to endure oxidative stress and competition in such habitats. In a different way, *Lamium* might be giving more of its resources to reproductive and structural growth, thus lessening the production of secondary metabolites.

The differences here reflect the profound relationship that exists between plant chemistry, ecological behavior, and adaptation. From an ecological point of view, *Galeopsis tetrahit* could be a natural reservoir of antioxidant compounds that can be isolated for pharmaceutical or nutraceutical formulations, thus becoming a renewable source of value.

4. Conclusion

An examination of the two species *Galeopsis tetrahit* L. and *Lamium purpureum* L. has disclosed differences in their morphological, ecological, and biochemical characteristics, which indicate their varied evolutionary and adaptive strategies of the Lamiaceae family.

Geomorphologically and ecologically, *G. tetrahit* is a strong, summer annual plant species that has been naturally bred to grow in moisture and nutrient-rich soils and can be identified by its hairy covering and spiny calyx. On the other hand, *L. purpureum* is a tiny, early-flowering, spring annual originating from cold and freshly disturbed habitats. Different life cycles enable these species to live without competing directly and also to exhibit niche differentiation.

On the genetic level, *G. tetrahit* is a tetraploid hybrid (2n = 32) with a complicated evolutionary history, whereas *L. purpureum* is a diploid species (2n = 18) of a simpler origin. The polyploid nature of *G. tetrahit* may be one of the reasons that explain its greater morphological vigor and higher metabolic

capacity and thus can be a source of a potential explanation for the more significant bioactive compounds accumulation.

The chemical analyses are in line with the observed differences in secondary metabolite profiles. In this regard, *G. tetrahit* showed to be significantly more potent both in TPC and TFC of the phenolics isolated from the dry matter of the aerial parts and the roots, and in turn more active by antioxidative assays DPPH, ABTS, and FRAP. Therefore, these results unequivocally assign *G. tetrahit* to be the one equipped with a more dynamic and functionally versatile secondary metabolism, which is the main factor behind its intensified oxidative and abiotic stress resistance capacity. In contrast, *L. purpureum*, even being chemically less loaded, still preserves sufficient antioxidant activity to justify its existence as a small but stable and resilient species in nature.

The comparative study, in a broader sense, also reflects biochemical differences between the two taxa as a mirror of their genetic framework and ecological strategies. One may say that *Galeopsis tetrahit* is an upgrade of defensive metabolism band with higher ecological competitiveness, while *Lamium purpureum* represents the inherent feature of early growth and colonization as the main factors of its adaptive flexibility.

The two species behave quite differently on the molecular level: *G. tetrahit* might be considered to have an evolved defensive metabolism leading to higher ecological competitiveness, and *L. purpureum* to possess the inherent features of early growth and colonization as the major factors of its adaptive flexibility.

The figures provide evidence for very close relationships genetic background, environmental adaptation, and phytochemical profile in the two Lamiaceae species of the same genus. Phenolic and flavonoid contents in *G. tetrahit* are substantially elevated that the plant is a potential renewable source of potent antioxidants for pharmacological and nutraceutical applications, whereas *L. purpureum* will remain a fascinating model of plant adaptation in ruderal communities.

The findings suggest that both species could serve as valuable sources of plant-based antioxidants and nutrients with potential applications in functional foods or dietary supplements. Their chemical diversity supports the idea that wild Lamiaceae plants may contribute to developing healthier, more natural food alternatives. Promoting the use of *Galeopsis tetrahit* and *Lamium purpureum* in nutrition-related research could open new perspectives for sustainable and health-oriented food innovations.

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