

PHYTOCHEMICAL DIVERSITY OF *DIGITALIS PURPUREA* L.: CORRELATING CHEMICAL PROFILES WITH ENVIRONMENTAL CONDITIONS

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ABSTRACT

Background: *Digitalis purpurea* Linn. (foxglove) is an important medicinal plant rich in cardiac glycosides and other bioactive phytochemicals. Environmental conditions, including weather and soil characteristics, can influence secondary-metabolite accumulation. This study compared cultivated and wild populations from Kashmir.

Materials and Methods: Leaf samples were collected from a cultivated population at Wadoora, Sopore, and a wild population from Drung, Tangmarg Reserve Forest. Methanolic extracts were prepared using Soxhlet extraction and evaluated for extraction yield, preliminary phytochemicals, and GC–MS composition. Soil characteristics and weather parameters, including temperature, rainfall, and relative climatic conditions, were also assessed for both collection sites.

Results: The wild population showed a higher extraction yield (14.7%) than the cultivated population (12.3%). GC–MS analysis identified 27 compounds in the wild population compared with 16 in the cultivated population. Digitoxigenin (21.6%) was the major constituent of the wild population, while α -tocopherol acetate (19.0%) predominated in the cultivated population. The wild site was characterized by higher elevation, cooler conditions, greater rainfall, and comparatively favorable soil organic carbon and nutrient status, which may have contributed to the greater phytochemical diversity observed.

Conclusion: The combined phytochemical, GC–MS, soil, and weather analyses demonstrate distinct chemical variation between cultivated and wild *D. purpurea* populations. The greater chemical diversity observed in the wild population may be associated with differences in climatic conditions and soil properties. These findings highlight the importance of environmental conditions in phytochemical accumulation and support the conservation and scientific cultivation of *D. purpurea* for sustainable medicinal use.

KEYWORDS: *Digitalis purpurea* Linn., Cultivated, Wild, Phytochemical profiling

1 INTRODUCTION

Medicinal plants constitute one of the most valuable resources for modern drug discovery and traditional healing systems (Ji *et al.*, 2025). They are primary sources of therapeutic agents used in approximately 80% of the global population's healthcare needs (Doughari, 2012, Ji *et al.* 2026). This widespread dependence on medicinal plants, coupled with their high market demand and economic value, has increased their collection and trade, providing important livelihood opportunities and financial returns to local communities (Peerzada *et al.*, 2022). Among such medicinally rich taxa, the genus *Digitalis* (family Plantaginaceae) is noteworthy for containing potent cardio-active glycosides. *Digitalis purpurea* Linn. commonly known as foxglove, is a biennial herb native to Western Europe but cultivated worldwide for ornamental and pharmacological purposes (Al-Oqab *et al.*, 2022). The plant's therapeutic value was first recognized in the 18th century when Withering (1785) described its efficacy in treating dropsy. Today, purified cardiac glycosides such as digitoxin and digoxin derived from *Digitalis* species remain reference molecules for managing congestive heart failure and atrial arrhythmias (Patel, 2016). Its leaves are the principal organ for glycoside extraction, containing compounds such as digoxin, digitoxin, gitalexin, gitoxin, and strophanthidin (Kreis, 2017). These compounds strengthen cardiac muscle contraction while regulating pulse rate and diuresis (Chevallier, 1996). However, metabolite composition in *Digitalis* species varies considerably with genetic background, environmental stress, altitude, and cultivation status (Zahid and Rizwani, 2016). Despite its medicinal importance, limited research has addressed phytochemical diversity of *Digitalis purpurea* Linn. populations in the Kashmir Himalaya. Most existing studies have focused on European accessions (Ravi *et al.* 2020; Gasic *et al.*, 2023) or on analytical technique development (Mahajan *et al.*, 2025). To the best of our knowledge comprehensive comparative information for Himalayan populations is limited. Therefore the present study was designed to estimate extraction yield of methanolic leaf extracts from cultivated and wild populations of *Digitalis purpurea* Linn. to identify qualitative differences in major phytochemical groups and to characterize volatile and semi-volatile constituents using GC–

MS. The resulting profile aims to guide germplasm selection for conservation and sustainable cultivation programs while enriching the scientific understanding of environmental effects on secondary-metabolite expression.

2 MATERIALS AND METHODS

2.1 Plant collection

Two populations of *Digitalis purpurea* Linn. were collected for comparative analysis. The cultivated population was obtained from the Regional-cum-Facilitation Centre North II, Faculty of Agriculture, Wadoora, Sopore, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir (SKUAST-K), while the wild population was collected from the Drung area of Tangmarg Reserve Forest in Tangmarg, Jammu and Kashmir, India (Plate 1,2). Herbarium specimens of the collected plants were submitted to the Centre for Biodiversity and Taxonomy (CBT), Department of Botany, University of Kashmir, Srinagar, for proper taxonomic identification. Following authentication, voucher specimen numbers (9640 and 9641) were assigned and the specimens were deposited in the Kashmir University Herbarium (KASH) for future reference.



Plate 1. Collection of *Digitalis purpurea* Linn. from Medicinal Plants Nursery of RCFC North II at Faculty of Agriculture, Wadoora, Sopore, SKUAST-K (Cultivated population)

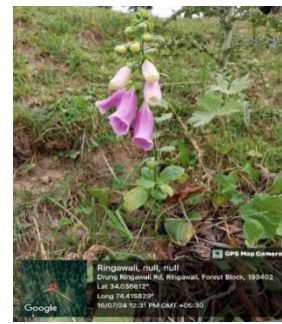


Plate 2. Collection of *Digitalis purpurea* Linn. from Drung area of Tangmarg Reserve Forest (Wild population)

Table 1. Geo-coordinates of the sample collection sites of *Digitalis purpurea* Linn.

Sl.no	Site of collection	Collection date	Latitude (N)	Longitude (E)	Altitude (mts.)
1	Cultivated population (Medicinal Plants Nursery of RCFC North II at Faculty of Agriculture, Wadoora, Sopore, SKUAST-K).	04-07-2024	34°34'00.98"	74°39'63.28"	1580
2	Wild population (Drung area of Tangmarg Reserve Forest)	16-07-2024	34°03'68.12"	74°41'58.29"	2500 to 3000

2.2 Extraction of phytochemicals

Fully matured, disease-free leaves were collected during the active growth period, washed with tap water to remove debris, surface-sterilized with 0.1 % HgCl₂, and air-dried in a well-ventilated room. Dried material was pulverized into fine powder using a mechanical grinder and stored in airtight containers until extraction. Subsequently ten grams of powdered leaves from each population were extracted in a Soxhlet apparatus using 200 mL of analytical-grade methanol for 4 h at 60–80 °C. Extracts were concentrated under reduced pressure using a rotary evaporator from Buchi and stored at 4 °C. The extraction yield (%) was calculated as:

$$\text{Percentage yield} = \frac{\text{Weight of dried extract (g)}}{\text{Weight of sample used (g)}} \times 100$$

(Duniya *et al.*, 2018)

2.3 Preliminary phytochemical screening

The extracts were subjected to qualitative tests to detect the presence of alkaloids, flavonoids, phenolic compounds, glycosides, tannins, steroids, and saponins, following different protocols as given below:

2.3.1 Test for alkaloids

Development of yellow color on mixing 5 mL of plant extract with 5 mL of Mayer's reagent (Potassium mercuric iodide) shows presence of alkaloids (Saxena and Gajendradkar, 2023).

2.3.2 Test for Flavonoids

2 ml extract was treated with 2ml of sodium hydroxide. Initially deep yellow colour will appear and then gradually become colourless by adding few drops of dilute hydrochloric acid which indicates the presence of flavonoids (Harborne, 1998).

2.3.3 Test for Saponins

1ml of extract mixed with 6 ml of distilled water, when shaken for 10 minutes, formation of foam indicates the presence of saponins (Nainwal, 2023).

2.3.4 Test for Phenols

2 ml of plant extract was treated with 2% ferric chloride solution formation of black colour indicates the presence of phenols (Shaikh and Patil, 2020).

2.3.5 Test for Steroids

2ml of extract was dissolved in 2ml of chloroform and an equal volume of concentrated sulphuric acid results in formation of bluish red, cherry red and purple colour in chloroform layer indicates presence of steroids (Shaikh and Patil, 2020).

2.3.6 Test for Terpenoids

2 mL of chloroform was added in 5mL of extract followed by 3mL of sulphuric acid poured gently on the side of the test tube. The formation of brown or red ring indicates the presence of terpenoids (Malik, 2017)

2.3.7 Test for Glycosides

0.5ml of extracts was dissolved in 2ml of glacial acetic acid containing 1 drop of ferric chloride. Then 2ml of concentrated sulphuric acid when added under layered. Brown colour will be formed which indicates the presence of deoxy-sugar which is the characteristic of cardiac glycoside (Ranaweera *et al.*, 2024)

2.4 GC–MS analysis

Methanolic extracts were analyzed on a Thermo Scientific GC–MS system equipped with an HP-5 MS column (30 m × 0.25 mm i.d., 0.25 µm film). Helium (99.999 %) was the carrier gas at 1.0 mL min⁻¹; injection was in split mode (10:1) at 250 °C. The oven temperature program started at 50 °C (2 min hold), ramped 10 °C min⁻¹ to 150 °C (2 min), then 5 °C min⁻¹ to 250 °C (5 min), and finally 10 °C min⁻¹ to 280 °C (5 min). Electron-ionisation mode (70 eV) was used with a scan range m/z 35–500. Compounds were identified by comparing retention times and mass spectra with entries in NIST Library v 20.1 (2020). Only matches ≥ 90 % were accepted for identification.

2.5 Soil and weather analysis

Soil samples were collected. from both the cultivated site at Wadoora, Sopore, and the wild site at Drung, Tangmarg Reserve Forest, following Gairola *et al.* (2012). Samples were air-dried, homogenized, and analyzed for pH, electrical conductivity (EC), soil organic carbon (SOC), available nitrogen, phosphorus, potassium, soil texture, bulk density, and porosity. Soil pH and EC were determined using a 1:5 soil-to-water suspension following Rayment (1992). SOC was estimated using the Walkley–Black wet oxidation method, while available N, P, and K were determined using the Mridaparishak (soil testing mini-laboratory) method. Soil texture was assessed based on sand, silt, and clay fractions. Bulk density was calculated from oven-dried soil mass and sample volume, while porosity was calculated from bulk density using a particle density of 2.65 g cm⁻³ Kousaret *et al.*, 2025), (Mir *et al.*, 2023), (Magrayet *et al.*, 2022), (Ahmad *et al.*, 2020) and (Jeelani, 2018). Meteorological parameters, including temperature, rainfall, and relative humidity, for 2024 were obtained from the India Meteorological Department (IMD), Srinagar. Soil and weather parameters were compared between the two populations to assess their possible influence on phytochemical variation and metabolite accumulation.

3. RESULTS

3.1 Extraction yield

The extraction yield of extracts differed noticeably between the two populations

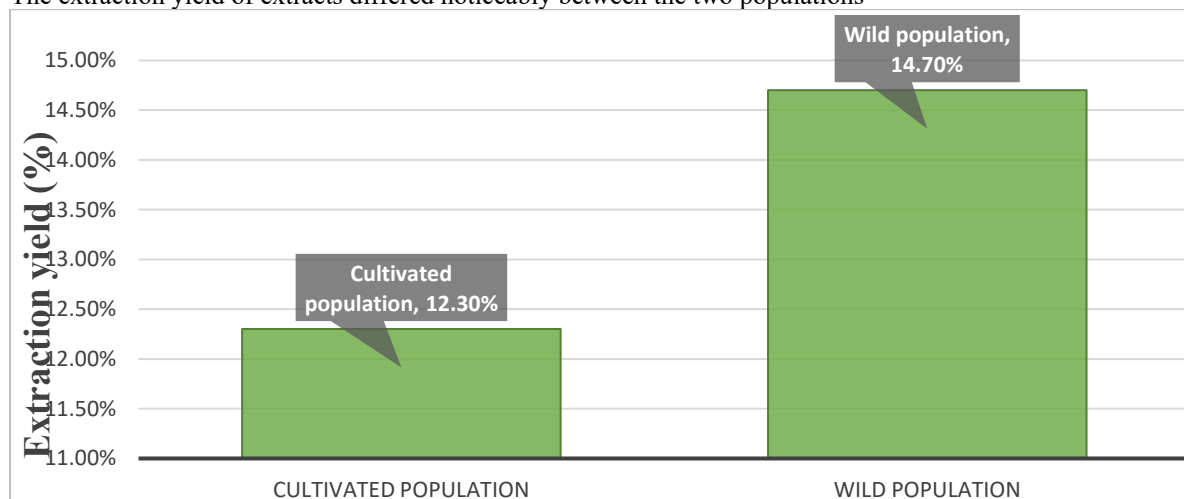


Fig 1. Comparative extraction yield of the extracts

The results of percentage yield reveals that highest quantity of extract was recovered from extract of wild population which gives 14.7%, while extracts of cultivated population was found to be 12.3%. This showed that, for the same extracting solvent, the wild population gives better degrees of extraction.

3.2 Qualitative Phytochemical profiling of Different Leaf Extracts of *Digitalis purpurea* L.

Qualitative phytochemical screening revealed differences in the phytochemical composition of cultivated and wild *Digitalis purpurea* L. leaf extracts. Flavonoids and glycosides were detected in the cultivated extract, whereas alkaloids and saponins were detected only in the wild extract. Phenols, steroids, and terpenoids were present in both cultivated and wild samples. These findings indicate variation in the phytochemical profiles of *D. purpurea* leaves depending on cultivation status.

3.3 GC–MS analysis

GC–MS analysis revealed a total of 43 distinct compounds across the cultivated and wild populations of *Digitalis purpurea* L. The cultivated population exhibited 16 identified constituents (Table 2), with α -tocopherol acetate (19.0%), phytol (16.2%), and 20,22-dihydrodigoxigenin (14.7%) representing the predominant compounds. In contrast, borane, trihexyl- (0.9%) and stearic acid (0.2%) were detected at comparatively low abundance. The wild population displayed a broader chemical profile, comprising 27 identified constituents (Table 3). Digitoxigenin (21.6%) was the major constituent, followed by lup-20(29)-en-3-one (15.6%) and β -D-glucopyranose (15.5%), whereas dicyclopentylethylphosphonate (0.15%) was detected as the least abundant constituent. Overall, the GC–MS profiles demonstrated distinct qualitative and quantitative differences in the volatile/semi-volatile chemical composition between cultivated and wild populations, suggesting that population origin and growing conditions may influence the accumulation and relative abundance of secondary metabolites in *D. purpurea*.

Table 2: GC–MS Profiling of Cultivated *Digitalis purpurea* L.

Sl. no	Name of the compound	Molecular formula	Area (%)	Reference
1.	Heptadecyloctanoate	C ₂₅ H ₅₀ O ₂	0.36	Bansal <i>et al.</i> , 2024 (0.30%)
2.	Stearic acid	C ₁₈ H ₃₆ O ₂	0.22	RehmanNengroo and Rauf, 2020 (0.96%)
3.	1-.beta.-D-Ribofuranosyl-3-[5-tetraazolyl]-1,2,4-triazole	C ₈ H ₁₁ N ₇ O ₄	1.08	Maheshwari and Vijayarengan, 2020 (2.75%)
4.	Smilagenin	C ₉ H ₁₇ B O ₃	1.35	Karakotiet <i>al.</i> , 2025 (5.49%)
5.	20, 22-dihydrodigoxigenin	C ₂₃ H ₃₆ O ₅	14.66	Ravi <i>et al.</i> , 2020 (14.66%)
6	Borane, trihexyl-	C ₁₈ H ₃₉ B	0.90	New finding
7.	9-Borabicyclo[3.3.1]nonane-9-(3-methoxycyclohexyl)oxy-	C ₁₅ H ₂₇ B O ₂	1.11	Shodeet <i>al.</i> , 2025
8.	Linoleic acid	C ₁₈ H ₃₂ O ₂	11.43	Karakotiet <i>al.</i> , 2025 (14.43%)
9.	n-Hexadecanoic acid	C ₁₆ H ₃₂ O ₂	13.89	Bansal <i>et al.</i> , 2024 (5.62%)
10.	beta-D- Glucosyloxyazoxymethane	C ₈ H ₁₆ N ₂ O ₇	10.93	Jan <i>et al.</i> , 2024 (0.81%)
11.	Phytol	C ₂₀ H ₄₀ O	16.24	Bansal <i>et al.</i> , 2024 (17.39%)
12.	Cyclododecyne	C ₁₂ H ₂₀	1.3	Anaduakaet <i>al.</i> , 2020 (19.33%)
13.	Terbinafine	C ₂₁ H ₂₅ N	5.18	New finding
14.	alpha.-Tocopheryl acetate	C ₃₁ H ₅₂ O ₃	19.00	Kadhimet <i>al.</i> , 2018 (8.96%)
15.	Diboroxane, triethyl[2-(pyridyl)amino]	C ₁₁ H ₂₀ B ₂ N ₂ O	1.29	Boladeet <i>al.</i> , 2018 (1.6%)

16.	Tris(tert-butyltrimethylsilyloxy) arsane	C ₁₈ H ₄₅ As O ₃ Si ₃	1.06	Jan <i>et al.</i> , 2024 (1.26%)
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Table 3: GC–MS Profiling of Wild *Digitalis purpurea* L.

Sl. no	Name of the compound	Molecular formula	Area (%)	Reference
1.	Catecholborane	C ₆ H ₅ B O ₂	1.59	Bhalla <i>et al.</i> , 2021 (0.6%)
2.	Decanal	C ₁₀ H ₂₀ O	0.46	Bansal <i>et al.</i> , 2024 (0.28%)
3.	Pyrazine, methoxy-4-oxide	C ₅ H ₆ N ₂ O ₂	0.18	Jan <i>et al.</i> , 2024 (1.98%)
4.	Oleic acid	C ₁₈ H ₃₄ O ₂	1.13	RehmanNengroo and Rauf, 2020 (1.04%)
5.	Digitoxigenin	C ₂₃ H ₃₄ O ₄	21.57	Karakotiet <i>al.</i> , 2025 (6.8%)
6.	7-[.beta.-d Ribofuranosyl]imidazo[4, 5-d][1,2,3]-triazin-4-one (2-azainosine)	C ₉ H ₁₁ N ₅ O ₅	0.34	Masoodiet <i>al.</i> , 2025 (2.96%)
7.	4-Aza-5 thiatricyclo[5.2.1.0(3,7)] decane, 4-(2-butenoyl) 10,10-dimethyl-5,5-dioxo	C ₁₄ H ₂₁ N O ₃ S	0.32	New finding
8.	Lup-20(29)-en-28-ol-3-one (Betulone)	C ₃₀ H ₄₈ O ₂	15.62	Orsiniet <i>al.</i> , 2015
9.	5-methyl-2-isopropylphenol	C ₁₀ H ₁₄ O	0.54	Bansal <i>et al.</i> , 2024 (0.55%)
10.	beta D glucopyranose	C ₆ H ₁₂ O ₆	15.55	Kadhimet <i>al.</i> , 2018 (16.43%)
11.	5,5,8-Trimethyl-nona 3,6,7-trien-2-one	C ₁₂ H ₁₈ O	0.18	El-Hadary, 2010 (0.20%)
12.	Z-8-Methyl-9 tetradecenoic acid	C ₁₅ H ₂₈ O ₂	0.40	Ukaet <i>al.</i> , 2022 (19.12%)
13.	Terbinafine	C ₂₁ H ₂₅ N	0.39	New finding
14.	n-Hexadecanoic acid	C ₁₆ H ₃₂ O ₂	1.66	Bansal <i>et al.</i> , 2024 (15.12%)
15.	20, 22-dihydrodigoxigenin	C ₂₃ H ₃₆ O ₅	6.05	Ravi <i>et al.</i> , 2020 (14.66%)
16.	cis-Calamenene	C ₁₅ H ₂₂	2.23	Kuaiteet <i>al.</i> , 2006 (13.1%)
17.	Dicyclopentylethylphosphonate	C ₁₂ H ₂₃ O ₃ P	0.15	New finding
18.	Docosanoic acid	C ₂₂ H ₄₄ O ₂	0.26	RehmanNengroo and Rauf, 2020 (0.42%)
19.	2-Pentene, 2-cyano-3-(diethylborylamino)	C ₁₀ H ₁₉ B N ₂	0.16	Zhang and Zhang, 2009

20.	beta.-D- Glucosyloxyazoxymethane	$C_8 H_{16} N_2 O_7$	4.86	Jan <i>et al.</i> , 2024 (0.81%)
21	Ethanethioic acid, S-[8 (diethylphosphono)octyl] ester	$C_{14} H_{29} O_4 P S$	0.60	Prasad <i>et al.</i> , 2023 (0.49%)
22	alpha.-Tocopheryl acetate	$C_{31} H_{52} O_3$	6.45	Kadhimet <i>et al.</i> , 2018 (8.96%)
22	7,10,10-Trimethyl-4-oxa 3,5 diazatricyclo[5.2.1.0(2,6)]deca-2,5-dien-3-one	$C_{10} H_{14} N_2 O_2$	0.21	New finding
23.	Gitogenin	$C_{27} H_{44} O_4$	14.89	Karakotiet <i>et al.</i> , 2025 (8.89%)
24	Undeca-3,4-diene-2,10- dione, 5,6,6-trimethyl-	$C_{14} H_{22} O_2$	0.32	Ernilasariet <i>et al.</i> , 2021 (7.02%)
25	Methyl palmitate	$C_{17} H_{34} O_2$	0.22	Bansal <i>et al.</i> , 2024 (0.45%)
26	Linoleic acid	$C_{18} H_{32} O_2$	3.43	Karakotiet <i>et al.</i> , 2025 (14.43%)
27	n-Decanoic acid	$C_{10} H_{20} O_2$	0.24	Kotteswari <i>et al.</i> , 2020

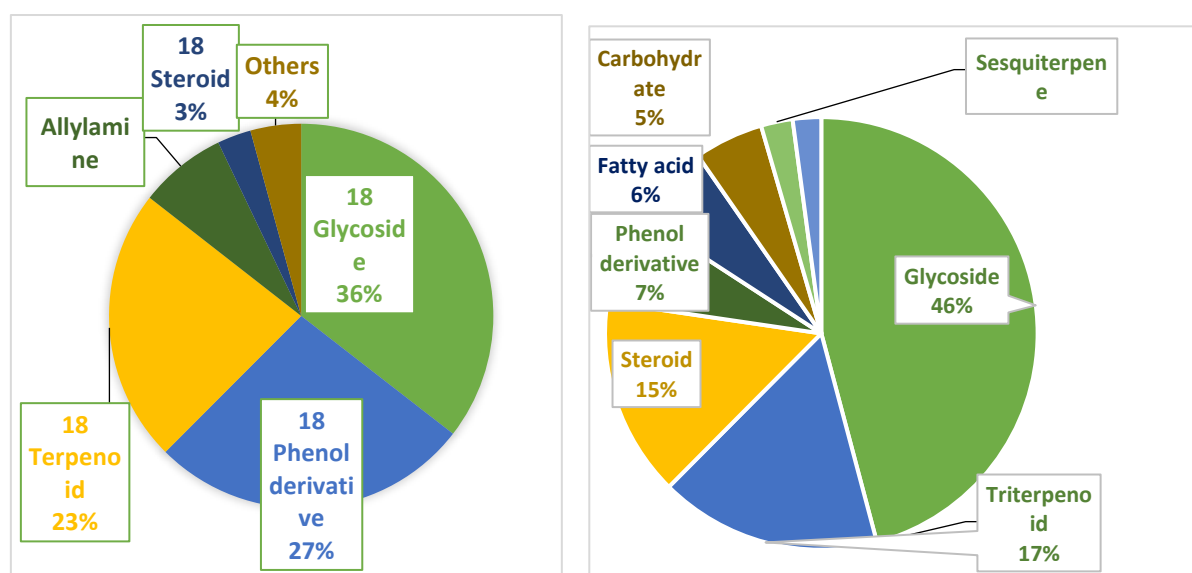


Fig 2: Comparative GC–MS phytochemical profiles of *Digitalis purpurea* L. from cultivated and wild populations.

Cultivated population

Wild population

3.4 Influence of Soil and Climatic Conditions on Phytochemical Diversity

Soil analysis revealed clear differences between the cultivated and wild populations of *Digitalis purpurea* L. The wild site showed higher soil organic carbon (4.02%), nitrogen (568.59 kg/ha), and phosphorus (100.8 kg/ha) than the cultivated site. Soil pH was 6.32 in the wild site compared with 6.5 in the cultivated site, while EC remained low at both locations (Table 5). Overall, the higher organic carbon and nutrient availability at the wild site may have contributed to the greater phytochemical diversity observed in the wild population.

The contrasting meteorological and ecological conditions between the two populations may have contributed to differences in the phytochemical profiles of *Digitalis purpurea* L. The wild population, occurring at a higher elevation (2500–3000 m), experienced comparatively cooler temperatures and greater rainfall than the cultivated population at Wadoora (1580 m). Higher elevation also increases exposure to UV radiation and other abiotic stresses, which can stimulate plant defense responses and enhance secondary-metabolite biosynthesis, particularly phenolics, terpenoids, and glycosides (Zidorn, 2010; Oner and Yesil, 2023). In addition, soil characteristics such as organic carbon, nutrient availability, pH, bulk density, and porosity can influence secondary metabolism through their effects on nutrient supply and soil–plant interactions (Clemensen et al., 2020). Thus, the greater phytochemical diversity observed in the wild population may reflect environmentally driven metabolic adaptation to its distinct climatic and edaphic conditions.

Table 4: Comparative Weather Parameters of Cultivated and Wild *Digitalis purpurea* L. Populations During year 2024

Sl.no	Weather parameter	RCFC North II Wadoora, Sopore (Cultivated population)	Drung ,Tangmarg Reserve Forest (Wild population)
1.	Temperature	Max	Min
		30-38°C	8°C
2.	Rainfall	170 mm	250 mm
3.	Relative humidity	Max	Min
		85-90%	50-52%
4.	Sunshine hour	6.5-8.3 hours	6-8 hours
5.	Evapotranspiration	90-150mm/month	60-90mm/month

Table 5: Comparative Soil Physicochemical Properties of Cultivated and Wild Populations of *Digitalis purpurea* L.

Sl. no	Soil parameters	Cultivated population	Wild population
1.	Soil Organic Carbon (%)	1.35	4.02
2.	pH	6.5	6.32
3.	Soil texture	Sandy loam to loam	Loam to silty loam
4.	Electrical conductivity (dS/m)	<0.5	<0.2
5.	Nitrogen (kg/ha)	455.8	568.59
6.	Phosphorous (kg/ha)	12.04 - 33.07	100.8
7.	Potassium (kg/ha)	77.57 - 195.8	100.8
8.	Bulk density	1.12-1.38g/cm ³	1.18-1.38g/cm ³
9.	Porosity (%)	38-56.9	47-50

4. DISCUSSION

The comparative phytochemical analysis revealed clear differences in the secondary metabolite profiles of cultivated and wild populations of *Digitalis purpurea* L., suggesting that population origin and environmental conditions may influence phytochemical accumulation. The absence of flavonoids in the cultivated population and alkaloids in the wild population indicates population-specific variation in secondary metabolism. Similar

site-dependent phytochemical differences have been reported in *Digitalis lanata* and *D. ferruginea* (Gasic et al., 2023). Controlled cultivation conditions may reduce environmental stress and influence the production of stress-responsive metabolites (Sanchez-Mata et al., 2009). The GC–MS analysis demonstrated substantial variation in the chemical profiles of cultivated and wild *Digitalis purpurea* L. populations, with the wild population showing greater chemical diversity (27 compounds) than the cultivated population (16 compounds). The predominance of digitoxigenin in the wild population is particularly noteworthy, as cardenolide-type constituents are characteristic bioactive metabolites of *Digitalis*. In contrast, the cultivated population was characterized mainly by α -tocopherol acetate and phytol. Such differences may be associated with variations in habitat, climatic conditions, soil properties, and environmental stress between the two populations. The broader chemical profile of the wild population may reflect adaptation to comparatively variable environmental conditions, which can stimulate the biosynthesis of secondary metabolites (Evans 1972). The differences in phytochemical profiles may be associated with contrasting altitude, climatic conditions, and soil properties between the two populations. Higher elevation and greater UV exposure can induce plant defense mechanisms and promote the biosynthesis of secondary metabolites such as phenolics and terpenoids (Zidorn, 2010; Oner and Yesil, 2023). In addition, differences in soil organic carbon and nutrient availability may influence secondary metabolism through nutrient and soil–plant interactions (Clemensen et al., 2020). Thus, the greater chemical diversity in the wild population may reflect environmentally driven metabolic adaptation.

5. CONCLUSION

The comparative phytochemical and GC–MS analyses reveal that *Digitalis purpurea* Linn. from wild habitats in Tangmarg accumulates a more complex and abundant array of bioactive compounds than cultivated plants from Wadoora. The major constituents such as digitoxigenin, α -tocopherol acetate, phytol, and 20, 22-dihydrodigitoxigenin reflect the species recognized cardiotonic and antioxidant properties. Environmental variables such as altitude, temperature, and soil organic content strongly influence the biosynthesis of these metabolites. This study provides essential baseline data for selecting elite chemotypes for large-scale propagation and for designing conservation and sustainable-harvest strategies. Further work integrating metabolomics, transcriptomics, and bioassay-guided fractionation is recommended to elucidate the full therapeutic potential of *Digitalis purpurea* Linn. in Himalayan ecosystems.

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