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Survey of Weed Flora Diversity as a Starting Point for the Development of a Weed Management Strategy for Medicinal Crops in Pančevo, Serbia

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Abstract

Similarly to conventional field crops, weeds often pose significant problems in the cultivation of medicinal plants. To date, no comprehensive documentation exists regarding weed infestation levels in these crops in Serbia. The objective of this study was to provide a valuable foundation for developing effective, site-specific weed management strategies in medicinal crop production. Weeds in five medicinal crops (lemon balm, fennel, peppermint, ribwort plantain, German chamomile), were surveyed based on the agro-phytosociological method between 2019 and 2024, and across 59 plots. A total of 109 weed species were recorded, belonging to 29 families and 88 genera. Among them, 75 were annuals and 34 perennials, including 93 broadleaved species, 10 grasses, and one parasitic species. All surveyed plots were heavily infested with perennial weeds such as *Elymus repens*, *Cirsium arvense*, *Convolvulus arvensis*, *Lepidium draba*, *Rumex crispus*, *Sorghum halepense*, *Taraxacum officinale*, etc. Also, several annual species were found in high abundance and frequency, including *Amaranthus retroflexus*, *Chenopodium album*, *Galium aparine*, *Lactuca serriola*, *Lamium amplexicaule*, *L. purpureum*, *Papaver rhoeas*, *Stellaria media*, *Veronica hederifolia*, *V. persica*, etc. The most important ecological factors influencing the composition of weed vegetation in investigated medicinal crops were temperature and light for fennel and peppermint plots, soil reaction for lemon balm and ribwort plantain plots, and nutrient content for German chamomile plots. A perspective for exploitation of these results is the development of effective weed control programs tailored to this specific cropping system. Weed control strategies should consider such information, targeting the control of the most frequent, abundant, and dominant species existing in a crops or locality.

Keywords: abundance; control strategy; diversity; frequency; medicinal crops; weed flora

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1. Introduction

Medicinal crops are most often grown on small areas around the world and as such are classified as minor crops. The areas cultivated in medicinal, aromatic, and spicy plants in Serbia vary from 2000 to 3000 ha per year (<0.15% arable lands), with 20–25 species being cultivated the most: chamomile, peppermint, fennel, lemon balm, ribwort plantain, thyme, marshmallow, parsley, marigold, dill, basil, oregano, etc. [1]. Medicinal crop production has an important and beneficial role in the economic, social, cultural, and ecological aspects of human communities worldwide. Those so-called minor crops in Serbia, which are typically cultivated on small farms averaging less than 0.3 ha per plot, can help smallholder farmers directly improve their livelihoods by generating income through trade and by contributing to health-related industries [2,3]. Also, the production of medicinal crops is a benefit for everyone, whether those herbs are used as food, in hygiene, personal care, in folk medicine, etc. [4].

As with conventional field crops, various constraints pose serious problems for the cultivation of medicinal crops, among which weeds are particularly significant. According to the definition adopted by the European Weed Research Society, "Weeds are any plant or vegetation, excluding fungi, that interferes with the objectives or requirements of people". Similarly, the Weed Science Society of America defines a weed as "a plant growing where it is not desired". Unlike plant pathogens and pests, weed species represent a permanent and major challenge in the cultivation of medicinal crops. It is generally estimated that weeds cause yield losses of about 10% in developed countries and up to 25% in less developed countries in conventional crop production [5]. Further, Kashem et al. [6] estimate that unmanaged weed growth during the early stages of crop establishment can reduce yields by 25% to 80%. Globally, it is estimated that approximately 1800 weed species are responsible for a 31.5% decline in crop production, causing annual economic losses of about USD 32 billion [7]. However, there are still limited studies on the diversity of weeds and their harmfulness in medicinal crop production systems [8–10]. The abundance and composition of weed species in medicinal crops, in addition to the type of crop and cultivation practices, largely depend on the soil type and quality, as well as on climatic and meteorological conditions in a given season [11–13].

The harmfulness of weeds in different crops is reflected in their ability to successfully compete with cultivated plants for natural resources such as light, nutrients, water, and space. Weeds negatively impact both the quantity and quality of crop yield, increase crop production costs due to the necessity of weed control measures, and can serve as hosts to numerous plant pests and diseases [14,15]. Globally, approximately 1570 weed species have been identified [16], with more recent estimates suggesting around 1800 species [7]. In Serbia, about 300 weed species have been confirmed in crop fields, while the total number of weed species, including those in non-crop areas, is estimated at around 1000 species [17]. However, there are still limited studies addressing the diversity of weeds and their harmfulness specifically in medicinal plant production systems [9,10]. Interestingly, weed-induced stress conditions may even enhance the synthesis of biologically active secondary metabolites in medicinal plants [18]. In addition, some weed species, such as *Adonis aestivalis*, *Aristolochia clematitis*, *Cirsium arvense*, *Carduus* spp., *Conium maculatum*, *Datura stramonium*, *Lolium temulentum*, and *Solanum nigrum*, can cause significant problems during mechanized harvesting, potentially contaminating the harvested agricultural or medicinal plants [19,20].

The reasons for weed control in medicinal crops are numerous: increasing crop productivity, enhancing product quality, reducing production costs, limiting the spread of other pests, improving animal health, supporting human activities, reducing impacts on transportation, and minimizing health risks. However, the primary reason for weed management in medicinal crops remains the prevention of yield and quality losses. A fundamental prerequisite for timely and effective weed control in medicinal crops is precise knowledge of weed species composition and their abundance in the fields. Detailed information on weed density, frequency, and community structure is essential for predicting potential yield losses and for defining cost-effective weed management thresholds [21].

Therefore, the aim of this research was to conduct a multi-year floristic survey across different years in order to provide reliable data on weed biodiversity and abundance in different fields, as a solid starting point for the development of an effective weed management strategy in medicinal crop plantations in Pančevo (a locality in a leading area of medicinal crop production in Serbia). The data obtained can now be used to identify major weed problems that require targeted research or the implementation of improved weed management practices.

2. Materials and Methods

Study area. The analysis of weed flora diversity in areas cultivated in selected medicinal crops, namely lemon balm (*Melissa officinalis* L.), fennel (*Foeniculum vulgare* Mill.), peppermint (*Mentha piperita* L.), ribwort plantain (*Plantago lanceolata* L.), and German chamomile (*Chamomilla recutita* L.), was conducted in a total of 59 fields between 2019 and 2024 on commercial farms of the Institute for Medicinal Plant Research "Dr Josif Pančić" located in Pančevo, South Banat, Republic of Serbia, Southeast Europe (44°52′20.0″ N, 20°42′04.7″ E).

Basic data on crop characteristics (i.e., life cycle, crop type, sowing time, seeding rate, and harvest period) are provided in Table 1. In these fields, medicinal crops are traditionally grown in crop rotation with small grain cereals.

Table 1. Overview of key cultivation practices for selected medicinal crops.

Crop	Lemon Balm	Fennel	Peppermint	Ribwort Plantain	German Chamomile
Life cycle	Perennial (5–6 years)	Perennial (5–10 years)	Perennial (1–3 years)	Perennial (1–3 years)	Annual
Crop type	Row crop	Row crop	Row crop	Row crop	Dense stand crop
Sowing/planting	Transplant seedlings: during autumn or early spring; 60–70 × 25–30 cm	Direct sowing: end of March to beginning of April; 60–70 × 20–30 cm	Planting stolon: mid-September to end of November or early spring; 60–70 × 70 cm	Direct sowing: end of March–beginning of April; 50–60 × 30 cm	Direct sowing: during September
Seeding rate (plants ha^{-1})	47.600–66.600	120–150.000	30.000	55.500–66.600	200.000
Harvest time	Twice per year: first harvest in July; second harvest in beginning of October	Second half of September	Twice per year: first harvest in July; second harvest in September/October	June (first year)–May (other years)	May

The soil type was chernozem, containing 2.3% humus and 0.19% total nitrogen, while the available phosphorus (P2O5) and potassium (K2O), extracted using ammonium lactate method, were 36 mg kg^{-1} and 362 mg kg^{-1}, respectively. Fertilizer was applied three times per growing season, adapted to soil nutrient status. The first fertilization was carried out following the deep autumn plowing using a solid NPK mineral fertilizer (NPK 15–15–15) at the rate of 0.6 t ha^{-1}. The subsequent two fertilizations were performed with calcium ammonium nitrate (KAN, 27% N) at the rate of 0.2 t ha^{-1}. The first KAN application was performed in early spring, after the development of two to four true leaves in all studied species. The timing of the second KAN application varied depending on the crop. In lemon balm and peppermint, the second application was carried out immediately after the first harvest to support regrowth and ensure sufficient nutrient availability for the subsequent growth cycle. In fennel and ribwort plantain, typically harvested once, the second application was made during peak vegetative growth, about 4–6 weeks after the initial fertilization and prior to flowering. In German chamomile, the second KAN application was timed at the beginning of the flowering stage to promote optimal flower development and essential oil yield.

Meteorological data, including average monthly temperatures and precipitation amounts for the period 2019–2024, were obtained from the local Meteorological Stations of the Republic of Serbia for the Pančevo locality (Table 2). According to these data, weather conditions varied notably between seasons and years. Generally, July or August were the warmest months, with average temperatures ranging from 23.7 to 26.9 °C, while January was typically the coldest month, with averages between 0.8 and 5.7 °C. In comparison to the thirty-year average, the average monthly temperatures were generally slightly higher (about 1–3 °C), except for the month of May, where the temperatures in most years were lower than the average. Precipitation patterns showed no consistent seasonal regularity throughout the study period. It was lower in some years and months, while in others, it was higher compared to the thirty-year average. However, the highest precipitation occurred in June 2020 (158.5 mm) or December 2021 (157.8 mm), depending on the year.

Table 2. Meteorological conditions in Pančevo during the period 2019–2024.

Month	Average Temperature (°C)						Precipitation (mm)					
	2019	**2020**	**2021**	**2022**	**2023**	**2024**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
January	0.8	2.0	4.3	2.4	5.7	3.6	81.8	22.1	68.6	45.7	79.3	50.6
February	5.6	7.6	6.5	6.9	4.9	10.6	33.7	55.9	34.4	22.2	62.9	9.6
March	11.4	9.1	7.2	7.1	10.1	11.5	11.5	48.0	49.3	10.5	37.6	51.1
April	14.2	14.3	10.6	12.3	11.3	15.6	76.8	8.9	50.7	80.1	79.0	38.8
May	15.6	16.6	17.4	20.3	17.5	18.2	142.3	70.9	93.4	32.2	92.8	132.9
June	24.2	20.9	24.3	24.8	21.7	24.1	138.7	158.5	34.2	43.3	75.6	77.2
July	24.3	23.7	26.6	25.9	26.0	26.6	43.0	37.6	63.1	63.9	46.8	114.4
August	26.2	24.9	24.0	25.0	24.7	26.9	39.7	89.6	38.2	89.7	87.7	0.8
September	20.2	21.1	19.4	18.0	22.2	19.8	26.1	22.1	9.4	98.0	71.2	87.9
October	16.1	14.3	11.7	15.5	17.6	14.3	13.3	93.3	73.4	13.1	13.0	38.2
November	12.4	7.2	8.9	9.3	9.5	6.0	54.3	12.6	122.8	64.9	107.4	70.9
December	6.0	5.6	4.1	7.0	7.0	3.7	55.3	34.8	157.8	76.1	33.3	105.7

Survey of weed diversity and abundance. The qualitative and quantitative evaluation of weed flora was conducted over 6 years each spring, following crop emergence and prior to any weed management measures, on chamomile (18 plots), ribwort plantain (11), peppermint (10), fennel (10), and lemon balm (10). Each plot measured approximately 0.50 ha. Plant species abundance and coverage were assessed using the 7-step Braun–Blanquet [22] scale, while weed frequency was calculated and expressed on a scale from I to V, where I indicates presence in 1–20% of plots, II in 21–40%, III in 41–60%, IV in 61–80%, and V in 81–100%. The vouchers of weed species were collected and are kept in the Laboratory of Botany and Laboratory of Weed Science at the Faculty of Agriculture, University of Belgrade. Species nomenclature was standardized according to Euro+Med PlantBase [23].

Data analysis. All plant species were classified by their life form according to Raunkiaer [24] as annuals (therophytes, T), biennials (thero-hemicryptophytes, TH), and perennials, with the latter group including geophytes (G), hemicryptophytes (H), chamaephytes (Ch), and phanerophytes (P). Diagnostic species (Dg) for each group were identified using JUICE 7.1 software, with the phi coefficient as a measure of fidelity [25,26]. Species with phi coefficient values greater than 0.15 were considered diagnostic. Species with a cover exceeding 25% and present in at least 50% of the total plots were considered dominant

(Dm) in each group, while species occurring in at least 50% of the total plots were classified as constant (C).

To assess the influence of environmental factors on the weed species composition across different communities, non-metric multidimensional scaling (NMDS) was applied using the JUICE 7.1 software, the R-project platform [27], and the vegan package [28]. Species cover was changed into percentages and transformed using the Hellinger transformation [29]. For ecological gradient analysis, ecological indicator values (EIVs) according to Pignatti [30] were used. Mean unweighted EIVs for light, continentality, temperature, nutrients, moisture, and soil reaction were used in NMDS as passively projected explanatory variables.

Diversity of weed communities in medicinal crops (lemon balm, fennel, peppermint, ribwort plantain, German chamomile) was estimated based on the following:

- Shannon diversity index (H):

$$H = -\sum_i \left(\frac{n_i}{N} \cdot ln\left(\frac{n_i}{N}\right)\right)$$

- Dominance index (D'):

$$D' = 1 - \frac{\sum_i n_i(n_i - 1)}{N(N-1)}$$

- Simpson index (D):

$$D = \frac{\sum_i n_i(n_i - 1)}{N(N-1)}$$

where:

- N is the total number of all individuals across all species;
- n_i represents the number of individuals of a specific species;
- $i = 1, 2, \ldots$

3. Results

3.1. Weed Flora

The presence of 109 distinct weed species were confirmed across 59 plots of five different medicinal crops, including 75 annuals and 34 perennials. The weed flora comprised 98 broadleaved species, 10 grasses, and one parasitic species. These species belonged to 29 families and 88 genera. Among the families, Asteraceae had the highest number of weed species (26), followed by Poaceae (10), Brassicaceae (7), Fabaceae (7), Polygonaceae (6), Apiaceae (4), Caryophyllaceae (4), Chenopodiaceae (4), Lamiaceae (4), Scrophulariaceae (4), Solonaceae (3), Boraginaceae (3), Geraniaceae (3), Plantaginaceae (3), Malvaceae (3), Amaranthaceae (2), Convolvulacae (2), Ranunculaceae (2), Rosaceae (2), and 10 families represented by a single species (Table 3).

Based on the three diversity indices (H, D', D) presented in Table 4, a high level of diversity in the weed community can be confirmed in all studied medicinal crops. That is, no single weed species was dominant in any crop.

Table 3. Survey of weed flora in studied medicinal crops.

Weed Species	Life Form	Medicinal Crops									
		Lemon Balm		Fennel		Peppermint		Ribwort Plantain		German Chamomile	
		Ab.	Fr.	Ab.	Fr.	Ab.	Fr.	Ab.	Fr.	Ab.	Fr.
Amaranthaceae											
Amaranthus blitoides S.Wat.	T	2–5	II			2–5	III	2	I		
Amaranthus retroflexus L.	T	3	I	2	II	2–7	IV	2	I		
Apiaceae											
Bifora radians M.B.	T							2	I		
Conium maculatum L.	T			1–2	IV						
Daucus carota L.	TH	3	I								
Foeniculum vulgare Mill.	H							2	I		
Asteraceae											
Achillea millefolium L.	G	2	I								
Ambrosia artemisiifoila L.	T	1–7	II	3	I	2–5	III	5–9	II		
Anthemis arvensis L.	T							3	II	2	I
Anthemis cotula L.	T							2	II	3–5	II
Arctium lappa L.	TH			1	III					2	I
Artemisia vulgaris L.	H			2–3	V	1–2	IV	2–3	IV		
Carduus acanthoides L.	TH	1–2	III	2	IV			1–5	III	2	II
Chamomilla recutita (L.) Rausch.	T	2–5	III	7	I	2–3	IV	2–7	III		
Cichorium intybus L.	H			1	I	1	I				
Cirsium arvense (L.) Scop.	G	2–5	III	2–3	III	1–2	IV	3–8	IV	2–8	IV
Crepis biennis L.	TH	2	II								
Cynara cardunculus L.	H			2	II						
Erigeron canadensis L.	T	2–5	II	1	II			2	II		
Helianthus annuus L.	T			1	II			1			
Lactuca serriola L.	T	1–2	II	2	III	1	III	3–7	IV	2–3	III
Lactuca viminea (L.) J.P.&C.P.	T	2	I	2	III	1	III	2	II	3	I
Picris hieracioides L.	TH	2	III	3	II	2	I			2	I
Senecio vernalis W. et K.	T	2	II								
Senecio vulgaris L.	T	1–2	III			1–2	III	2–3	III	2–3	V
Sonchus arvensis L.	G	2	II	2	III	1	IV	2	IV	2	II
Sonchus asper (L.) Hill.	TH	2	I								
Sonchus oleraceus (L.) Gou.	T	2	I			2	I			2	I
Erigeron annuus (L.) Desf.	T	2	III	3	II	2	III	3	II	2	I
Taraxacum officinale Weber.	H	2–3	V	3	IV	2	II	3	V	2	III
Tragopogon dubius Scop.	H										
Xanthium strumarium L.	T			2	I			1	I		
Boraginaceae											
Heliotropium europeum L.	T					2	II				
Lithospermum arvense L.	TH									2–3	II
Myosotis arvensis (L.) Hill.	T									7–8	I
Brassicaceae											
Brassica nigra L.	T							1	II		
Camelina microcarpa Andrz. ex DC	TH	3	II					3	II		
Capsella bursa-pastoris (L.) Medic.	T	2–8	III	3	II	2	I	2–7	II	2–5	V
Lepidium draba L.	G	2–3	IV			1–2	III	3–7	III	2–3	II
Roripa sylvestris (L.) Bess.	G	1	I								
Sinapis arvensis L.	T	2	I	2–5	III			1	I	2–7	V
Thlaspi arvense L.	T	2	I								
Caryophyllaceae											
Arenaria serpyllifolia L.	T							3	I		
Cerastium arvense L.	Ch	3	II			2	III			7	I
Silene alba (Mill.) Krause.	H	5	II	2	II						
Stellaria media (L.) Vill.	T	1–8	V			2	III	2–7	III	5–8	V

Table 3. *Cont.*

Weed Species	Life Form	Medicinal Crops									
		Lemon Balm		Fennel		Peppermint		Ribwort Plantain		German Chamomile	
		Ab.	Fr.	Ab.	Fr.	Ab.	Fr.	Ab.	Fr.	Ab.	Fr.
Chenopodiaceae											
Atriplex patula L.	T	2	I					2	I		
Chenopodium album L.	T	1–3	III	2	IV	2–7	IV	2–3	III	2–3	II
Chenopodium hybridum L.	T	3	III			1		2	I		
Chenopodium polyspermum L.	T					2	II				
Convolvulaceae											
Calystegia sepium (L.) R.Br.	G			1	III	2	III			2	I
Convolvulus arvensis L.	G	1–8	IV	2–7	V	2–3	III	2–5	IV	2–3	II
Cuscutaceae											
Cuscuta campestris Yunck.	T			3	I						
Euphorbiaceae											
Euphorbia virgata L.	G			1	I						
Fabaceae											
Lathyrus tuberosus L.	G	2	I	1	I	1–2	II	1–2	II		
Medicago lupulina L.	T	1	I								
Medicago sativa L.	H							2	II		
Trifolium repens L.	H	2	II								
Vicia cracca L.	G							2	II	3	I
Vicia hirsuta (L.) S.F.Gray.	T							1	II		
Vicia sativa L.	T	2	I			2	I	2	II		
Fumariaceae											
Fumaria officinalis L.	T			2	II	1–2	V			2	II
Geraniaceae											
Erodium cicutarium (L.) L'Herit.	T			2	III			3	IV	5	I
Geranium dissectum Jusl.	T	1	I							2	I
Geranium molle L.	TH							2	II		
Lamiaceae											
Lamium amplexicaule L.	T	2–7	III	2	III	3	IV	3–8	III	2–8	IV
Lamium purpureum L.	T	2–5	III	2–7	III	5	IV	2–9	III	2–8	IV
Melissa officinalis L.	G					2	I				
Stachys annua L.	T			2	I						
Linaceae											
Linum usitatissimum L.	T			2	I	1	I	1	I		
Malvaceae											
Abutilon theophrasti Medik.	T			2	I	2	I	2	I		
Hibiscus trionum L.	T	2	I	3–5	I	2–3	III	1	I		
Malva silvestris L.	TH							1	II		
Papaveraceae											
Papaver rhoeas L.	T	1	I	1–3	V	1–2	IV	3–9	V	2–8	V
Plantaginaceae											
Plantago lanceolata L.	H									2	I
Plantago major L.	H			3	II					3	I
Plantago media L.	H							2	II		
Poaceae											
Elymus repens (L.) Beauv.	G	2–7	IV	2–7	V	2	III	2–3	III	5	I
Avena fatua L.	T	2–3	III	3–5	III	2–3	IV	2–5	II	2–9	V
Bromus tectorum L.	T	2	I	3	III					2–8	III
Cynodon dactylon (L.) Pers.	G	3	I								
Dactilys glomerata L.	H							1–2	II		
Echinochloa grus-galli (L.) P.B.	T	2	I			2–7	II	2–3	III		
Hordeum murinum L.	T	2	II								

Table 3. *Cont.*

Weed Species	Life Form	Medicinal Crops									
		Lemon Balm		Fennel		Peppermint		Ribwort Plantain		German Chamomile	
		Ab.	Fr.	Ab.	Fr.	Ab.	Fr.	Ab.	Fr.	Ab.	Fr.
Setaria glauca (L.) P.B.	T					3	I	2	I		
Setaria viridis (L.) P.B.	T	2	II	2	I						
Sorghun halepense (L.) Pers.	G	1–3	IV	3	IV	3–7	III	3	II	8	I
Polygonaceae											
Bilderdykia convolvulus (L.) Dum.	T	2–3	III	2	I	2–7	IV	2–7	III	2–3	II
Polygonum aviculare L.	T	1–2	III	3	I	2–3	IV	1	III	2–3	II
Polygonum lapathifolium L.	T			2	I	2–8	IV				
Polygonum persicaria L.	T	2	II	3	II			2–3	III		
Rumex crispus L.	H	2–7	V	3–8	V	2–3	IV	2–5	V	2–7	V
Rumex obtusifolius L.	H			2–3	II	2	III			2	I
Portulacaceae											
Portulaca oleracea L.	T	5	I			3–5	II				
Ranunculaceae											
Consolida orientalis (Gaz.) Schr.	T	1	I	1–2	III	3	III	5	II	5	II
Consolida regalis S.F.Gray.	T	3	II			3	III	3	II	3–5	II
Resedaceae											
Reseda lutea L.	TH							1–2	III		
Rosaceae											
Potentilla anserina L.	H			2	II						
Rubus caesius L.	H					1–2	II	1	I		I
Rubiaceae											
Galium aparine L.	T			2–5	IV			2	II	5	III
Scrophulariaceae											
Kickxia elatine (L.) Dumort.	T			2	I						
Veronica hederifolia L.	T	3–8	III	2	III	8	III	2–5	III	3–9	V
Veronica persica Poir.	T	2–3	IV	2–3	V	2–8	IV	2–9	V	5–8	III
Veronica polita Fr.	T					2–5	III	2–5	I	5	I
Simaroubaceae											
Ailanthus altissima (Mill.) Swingle	P	2	I								
Solanaceae											
Datura stramonium L.	T					2–3	II	2	I		
Solanum dulcamara L.	nP	1	I								
Solanum nigrum L.	T	2–5	III	2–3	II	3–5	III	2	I		
Violaceae											
Viola arvensis Murr.	T					2–3	IV	3	II	2–5	IV

Ab—abundance, Fr—frequency, T—therophytes, TH—thero-hemicryptophytes, G—geophytes, H—hemicryptophytes, Ch—chamaephytes, P—phanerophytes, nP—nano-phanerophytes.

Table 4. Diversity indices of weed community in medicinal crops.

Crops	Shannon Diversity Index (*H*)	Dominance Index (*D*′)	Simpson Index (*D*)
Lemon balm	3.740	0.9721	0.02795
Fennel	3.716	0.9723	0.02775
Peppermint	3.504	0.9620	0.03802
Ribwort plantain	3.754	0.9701	0.02995
German Chamomile	3.376	0.9554	0.04164

The biological spectrum of life forms in the weed communities of medicinal crops was dominated by therophytes (T = 64), followed by thero-hemicryptophytes (TH = 11), hemicryptophytes (H = 17), and geophytes (G = 14), while chamaephytes (Ch) and phanerophytes (P) were represented by one and two species, respectively (Figure 1).

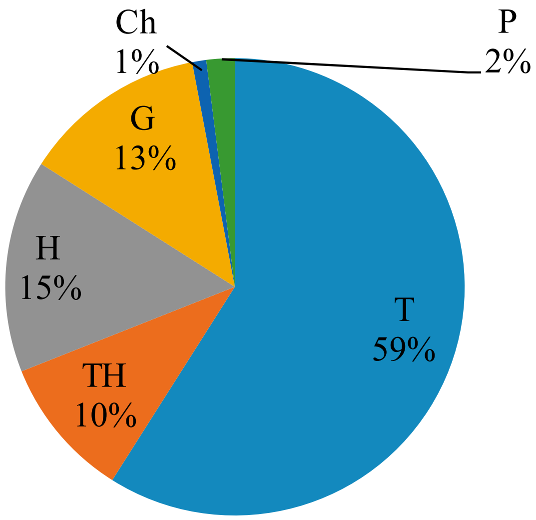

Figure 1. The participation of the life forms of weed flora in medicinal crops. T—therophytes, TH—thero-hemicryptophytes, G—geophytes, H—hemicryptophytes, Ch—chamaephytes, P—phanerophytes.

All surveyed plots of medicinal crops contained perennial weed species, including *Elymus repens*, *Artemisia vulgaris*, *Cirsium arvense*, *Convolvulus arvensis*, *Lepidium draba*, *Rumex crispus*, *Sonchus arvensis*, *Sorghum halepense*, and *Taraxacum officinale*, among others. These perennials are particularly problematic due to their persistence and difficulty of control. Most of these species reproduce vegetatively through underground organs such as rhizomes, roots and root shoots, complicating soil cultivation practices.

In addition to perennials, a significant number of annual weeds were present with high abundance and frequency, including *Amaranthus retroflexus* (abundance 2–7; frequency I–IV), *Chenopodium album* (ab. 1–7; fr. II–IV), *Galium aparine* (ab. 2–5; fr. II–IV), *Lactuca serriola* (ab. 1–7; fr. II–IV), *Lamium amplexicaule* (ab. 2–8; fr. III–IV), *L. purpureum* (ab. 2–9; fr. III–IV), *Papaver rhoeas* (ab. 1–9; fr. I–V), *Stellaria media* (ab. 1–8; fr. III–V), *Veronica hederifolia* (ab. 2–9; fr. III–V), *V. persica* (ab. 2–9; fr. III–V), etc. (Table 3).

In addition to typical weeds, volunteer medicinal crops frequently emerged as weeds within the plantation fields. For example, *Foeniculum vulgare* was often found in ribwort plantain plots, *Cynara cardunculus* appeared in fennel plots, and *Linum usitatissimum* was commonly present in fennel, peppermint, and ribwort plantain plots. Moreover, overall weed flora of medicinal crops showed a high abundance of alien invasive species, notably *Ambrosia artemisiifolia* (ab. 1–9) and *Ailanthus altissima* (ab. 2). The presence of weed species known for their high toxicity in vegetative and generative organs was also confirmed, including members of the Solanaceae (*Datura stramonim*, *Solanum nigrum*, *S. dulcamara*) and Apiaceae family (*Bifora radians*, *Conium maculatum*) (Table 3).

The total number of weed species recorded across studied medicinal crops was 109, while the mean number of weed species per specific medicinal crop ranged between 13 and 15, except in *Chamomilla recutita* plots, where significantly fewer weed species were observed (Figure 2).

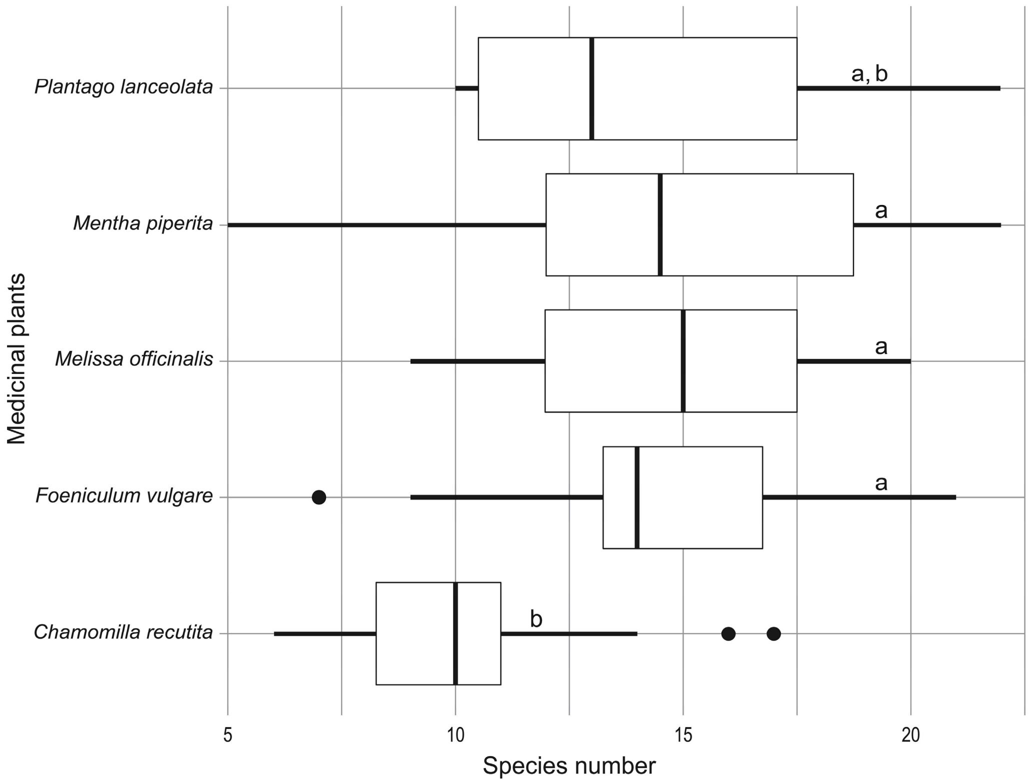

Figure 2. Box plots of numbers of weed species in different medicinal crops. Different letters next to the bars indicate statistically significant difference at $p < 0.05$.

3.2. Weed Vegetation Characteristics of Medicinal Crops

Division of weed vegetation according to medicinal crop grouped plots into five groups and diagnostic, constant, and dominant species with their fidelity values are shown (Figure 3).

Group 1: *Melissa officinalis* (Lemon balm) plots

Number of plots: 10

Diagnostic species: *Crepis biennis* 18.5, *Senecio vernalis* 18.5, *Trifolium repens* 18.5

Constant species: *Convolvulus arvensis* 28, *Lamium amplexicaule* 21, *Stellaria media* 25

Group 2: *Foeniculum vulgare* (Fennel) plots

Number of plots: 10

Diagnostic species: *Arctium lappa* 16.2, *Artemisia vulgaris* 16.0, *Conium maculatum* 26.8, *Cynara cardunculus* 18.5

Constant species: *Convolvulus arvensis* 24

Group 3: *Mentha piperita* (Peppermint) plots

Number of plots: 10

Diagnostic species: *Amaranthus blitoides* 19.9, *Amaranthus retroflexus* (C, Dm) 35.2, *Chenopodium polyspermum* 18.5, *Fumaria officinalis* 18.7, *Heliotropium europeum* 21.4

Constant species: *Amaranthus retroflexus* (Dg, Dm) 24, *Chenopodium album* (Dm) 24, *Lamium purpureum* 25

Dominant species: *Amaranthus retroflexus* (Dg, C) 30, *Chenopodium album* (C) 30

Group 4: *Plantago lanceolata* (Ribwort plantain) plots

Number of plots: 11

Diagnostic species: *Brassica nigra* 17.1, *Geranium molle* 17.6, *Medicago sativa* 17.6

Constant species: *Ambrosia artemisiifoila* 24, *Chamomilla recutita* (Dm) 24, *Cirsium arvense* (Dm) 35, *Lactuca serriola* (Dm) 31, *Lamium amplexicaule* 21, *Lamium purpureum* 24, *Lepidium draba* (Dm) 22

Dominant species: *Chamomilla recutita* (C) 36, *Cirsium arvense* (C) 27, *Lactuca serriola* (C) 27, *Lepidium draba* (C) 27

Group 5: *Chamomilla recutita* (German Chamomile) plots

Number of plots: 18

Diagnostic species: *Lithospermum arvense* 20.6, *Sinapis arvensis* (C) 27.3

Constant species: *Lamium amplexicaule* 26, *Lamium purpureum* (Dm) 31, *Sinapis arvensis* (Dg) 21, *Stellaria media* (Dm) 53

Dominant species: *Lamium purpureum* (C) 33, *Stellaria media* (C) 67

Vegetation in group 3 and 5 is dominated by annual weeds, while group 1, 2, and 4 represent perennial weed vegetation, but with many annuals because of management. Plant community of group 1 resembles association *Dauco-Picridetum*, of group 2 *Arctietum lappae*, and of group 4 to *Conyzo canadensis-Lactucetum serriolae*. Typical weed vegetation is found in *Mentha piperita* and *Chamomilla recutita* fields (groups 2 and 5) with several typical weeds: *Lamium amplexicaule*, *L. purpurea*, *Sinapis arvensis*, *Anthemis cotula*.

3.3. Weed Vegetation–Environment Relationships

The Non-metric Multidimensional Scaling (NMDS) ordination, based on species composition and ecological indicator values (Figure 3), revealed that the most important ecological factors influencing the diversity and variability of weed vegetation in investigated medicinal crops were temperature and light in *Foeniculum vulgare* and *Mentha piperita* plots, soil reaction in *Melissa officinalis* and *Plantago lanceolata* plots, and nutrient content in *Chamomilla recutita* plots. The first ordination axis was positively correlated with light (r = 0.99392; p = 0.001) and negatively with moisture (r = −0.87779; p = ns). The second NMDS axis was positively correlated with temperature (r = 0.95785; p = 0.001) and nutrients (r = 0.96740; p = ns), and negatively with soil reaction (r = −0.99685; p = 0.002).

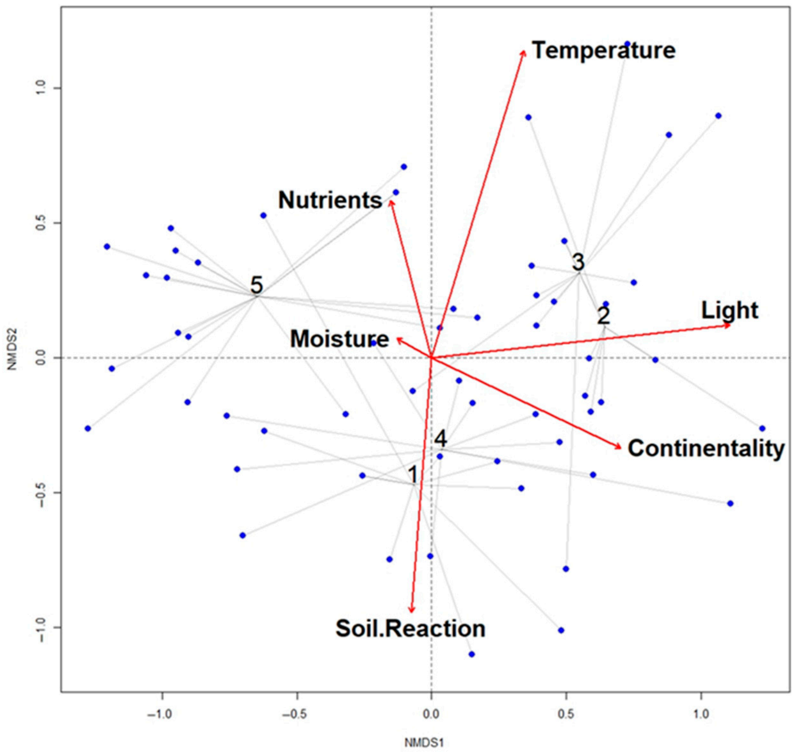

Figure 3. NMDS ordination analysis of weed vegetation in different medicinal crop plots. Group 1: *Melissa officinalis* (lemon balm) plots; Group 2: *Foeniculum vulgare* (fennel) plots; Group 3: *Mentha piperita* (peppermint) plots; Group 4: *Plantago lanceolata* (ribwort plantain) plots; Group 5: *Chamomilla recutita* (German chamomile) plots.

4. Discussion

The diversity, abundance, and frequency of weed flora in the surveyed medicinal crops (lemon balm, fennel, peppermint, ribwort plantain, German chamomile) are influenced by agro-ecological conditions, crop species, and cultivation practices. These findings are consistent with previous studies [4,9,12,13,31–33]. The high weed diversity recorded (109 weed species across 29 families and 87 genera) in a relatively small area, such as the Pančevo farm, suggests that the environmental conditions are favorable for weed flora development. However, this also indicates challenges in weed management practices [10,33].

Grouping of the surveyed plots by crop species revealed that specific diagnostic weed species developed in lemon balm and ribwort plantain plots. Annual weeds such as *Crepis biennis*, *Senecio vernalis*, and *Brassica nigra* were predominant in lemon balm plots, while *Geranium molle* was characteristic of ribwort plantain plots. Weed vegetation in lemon balm and ribwort plantain was primarily influenced by soil reaction, whereas the weed composition in German chamomile plots was more strongly affected by nutrient availability. The relatively small overall influence of soil properties on weed composition may be due to the artificial adaptation of soil conditions through fertilization, mechanical weed control, and herbicide use [34].

The absolute dominance of annual weed species (68.8% therophytes and 10% hemitherophytes) in studied medicinal crops, which are part of arable lands, further confirms that these areas are under continuous agricultural pressure [15]. If these annual weed species, particularly those with high abundance, are not controlled promptly and effectively, they can severely reduce both the yield and quality of medicinal crops [9,35]. Some annuals develop large canopies, such as *Abutilon theophrasti*, *Amaranthus retroflexus*, *Ambrosia artemisiifolia*, *Brassica nigra*, *Chenopodium* spp., *Datura stramonium*, and *Xanthium strumarium*, making them strong competitors for aboveground resources. Additionally, many weeds germinate and establish earlier (winter and early spring species), such as *Avena fatua*, *Bifora radians*, *Brassica nigra*, *Consolida* spp., *Capsella bursa-pastoris*, *Galium aparine*, *Lamium* spp., *Papaver rhoeas*, *Stellaria media*, *Veronica* spp., and *Viola arvensis*, giving them a competitive advantage for vital resources such as water, nutrients, and light.

Medicinal crops, such as lemon balm, fennel, peppermint, ribwort plantain, and German chamomile, generally exhibit lower competitiveness against weeds, especially during their early growth stages, which contributes to high levels of weed infestation [9]. This competition can prolong flowering and fruiting phases and significantly decrease final yields [36]. Some weeds, like *Stellaria media* (observed in medicinal crops with an abundance of 1–8 and a frequency of III–V), are particularly problematic due to their ephemeral life cycle and ability to produce multiple generations per year [37]. Although classified as an annual, *S. media* can also propagate vegetatively in the short term. It germinates throughout the year under favorable conditions and effectively competes with neighboring plants [38].

Perennial weed species also pose substantial management challenges. Perennials, such as *Artemisia vulgaris*, *Rumex crispus*, *Taraxacum officinale*, *Elymus repens*, *Cirsium arvense*, *Convolvulus arvensis*, *Lepidium draba*, *Sonchus arvensis*, and *Sorghum halepense*, were found with high frequency in the surveyed medicinal crops at Pančevo farm. The situation is more complex when their abundance is also significant, as seen with *Elymus repens* (abundance = 2–7), *Cirsium arvense* (ab. = 1–8), *Rumex crispus* (ab. = 2–8), *Sorghum halepense* (ab. = 1–8), and *Taraxacum officinale* (ab. = 2–3), all of which were present in every surveyed field with medicinal crops. According to Miller [39], the combined application of multiple weed control strategies is typically more effective for managing perennial weeds.

Since medicinal crops generally allow only limited herbicide use [35,40], repeated mechanical or other non-chemical measures are essential to deplete perennial weed populations [8] and reduce both the seed bank and vegetative reproductive structures in the soil.

Rhizomatous grasses, particularly *Elymus repens* and *Sorghum halepense*, present persistent control challenges [41]. Furthermore, species like *Cirsium arvense* (which forms clean oases) and *Convolvulus arvensis* and *Calystegia sepium* (which twine around crop plants), with their substantial aboveground biomass, are aggressive competitors and can significantly reduce yields if not controlled in a timely manner [42,43].

For sustainable and effective management of perennial weeds in medicinal crops, an integrated weed management (IWM) approach is recommended, combining cultural and chemical methods with a focus on prevention and early intervention. Agronomic practices such as tillage, mowing, and grazing can help suppress rhizome spread and seed production. When herbicides are used, targeting weeds at their early, most susceptible stages is crucial for effective control.

To further mitigate weed issues, it is important to ensure that the plots are thoroughly cleaned after harvest, removing any residual crop plants such as those found in this study, *Foeniculum vulgare*, *Cynara cardunculus*, and *Linum usitatissimum*, as these can emerge as volunteer crops in subsequent seasons and are often difficult to control chemically. Special attention should also be given to toxic weed species, such as *Bifora radians*, *Conium maculatum*, *Datura stramonium*, and *Solanum* spp., which contain various harmful alkaloids (atropine, coniine, conhydrine, gamma-coniceine, hyoscine, hyoscyamine, N-methylconiine, pseudotropine, pseudoconhydrine, scopolamine, solasonine, solamargine, etc.). These compounds can significantly compromise the quality and safety of medicinal crops [44–46].

Ultimately, knowledge of weed diversity, abundance, and frequency in medicinal crops provides a reliable framework for accurately assessing weed infestation and serves as a foundation for strategic weed management planning. Weed control measures should be tailored to the most frequent, abundant, and dominant species specific to each cropland or locality. So far, no comprehensive documentation exists regarding the relative importance and quantitative weed infestation levels in medicinal crop fields in Serbia. This study represents a valuable starting point for developing targeted weed management strategies for medicinal crop plantations in the region.

5. Conclusions

The diversity, abundance, and frequency of weed species in medicinal crops are influenced by multiple factors, including crop type and genotype, agro-ecological conditions, and applied weed management strategies. This study confirmed the presence of 109 weed species across five different medicinal crops, comprising 75 annuals and 34 perennials, with a predominance of broadleaved weeds. The recorded weed flora spanned 29 families and 88 genera. The most frequent and abundant species included annual weeds such as *Amaranthus retroflexus*, *Chenopodium album*, *Galium aparine*, *Lactuca serriola*, *Lamium amplexicaule*, *Lamium purpureum*, *Papaver rhoeas*, *Stellaria media*, *Veronica hederifolia*, and *Veronica persica*, as well as perennial weeds like *Elymus repens*, *Artemisia vulgaris*, *Cirsium arvense*, *Convolvulus arvensis*, *Lepidium draba*, *Rumex crispus*, *Sonchus arvensis*, *Sorghum halepense*, and *Taraxacum officinale*.

These findings provide a solid foundation for accurately assessing weed infestation levels in medicinal crop fields and highlight the need for species-specific and locally adapted weed management strategies. Considering the limited herbicide options available in medicinal crop production, integrating cultural, mechanical, and targeted chemical control measures is essential for sustainable weed management. The results of this study contribute to filling the existing knowledge gap regarding weed flora in medicinal crop plantations in Serbia and can serve as a valuable reference for the development of effective weed control programs tailored to this specific cropping system. Also, results of this study offer bases for future research on interactions (competition and allelopathy) between medicinal crops and weeds, weed seed bank dynamics, incorporation of remote sensing technologies for weed monitoring, and precision weed management. All these options should contribute to the development of IWM strategies for sustainable management in medicinal crops.

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Abbreviations

The following abbreviations are used in this manuscript:

KAN	calcium ammonium nitrate
T	therophytes
TH	thero-hemicryptophytes
G	geophytes
H	hemicryptophytes
Ch	chamaephytes
P	phanerophytes
Dg	diagnostic species
Dm	dominant species
C	constant species
NMDS	non-metric multidimensional scaling
EIVs	ecological indicator values

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