Original Research Paper

Study of Plant Growth and Essential Oil of *Nepeta cataria* L. in Kazakhstan

[1]Svetlana Kabanova, [1]Valeriy Bortsov, [1]Pavel Shakhmatov, [2]Matvey Danchenko, [3]Sabina Scott, [1]Andrey Kabanov, [1]Yana Krekova and [1]Igor Kochegarov

[1]*Department of Forestry and Agroforestry, Kazakh Research Institute of Forestry and Agroforestry A.N. Bukeikhana, Kazakhstan*
[2]*Department of Biological Sciences, National Research Tomsk State University, Tomsk, Russia*
[3]*Department of Life Sciences, The Ohio State University, USA*

Article history
Received: 27-12-2022
Revised: 27-02-2023
Accepted: 26-04-2323

Corresponding Author:
Sabina Scott
Department of Life Sciences,
The Ohio State University,
USA
Email: scott.1818@osu.edu

Abstract: The genus *Nepeta* exhibits a wide spectrum of biological activity in medicine, agriculture, and the food industry. The purpose of the research is to develop the optimal agricultural technology for plantation cultivation of *Nepeta cataria* L. with the preservation of useful properties and to increase the content of essential oil in the conditions of Northern Kazakhstan. The objects of research are annual plants *N. cataria* L. growing on a plantation in the Akmola region. It has been reliably proven that the increase in the growth of *N. cataria* L., the biomass, and the yield is positively affected by the application of complex fertilizer $N_{100}P_{80}K_{120}$. The essential oil yield was 0.52% in the experiment without fertilizers and 0.57% in the experiment with fertilizers. The main components of the essential oil of *N. cataria* L. grown in the experimental plots (plot #1 and plot #2) were 4aα7α7aα-Nepetalactone (76.5612 and 79.3200%), β-caryophyllene (4.0001 and 4.0351%) and caryophyllene oxide (1.9789 and 2.5969%). The remaining components were contained in the essential oil in small quantities. The composition of the essential oil of plants from Kazakhstan was similar to the composition of the essential oil of plants from central Iran, Egypt, and Korea, because the main substance was nepetalactone. The conducted studies prove the success of growing catnip in the conditions of Northern Kazakhstan.

Keywords: *Nepeta cataria* L., Essential Oil, Yield, Plant Growth

Introduction

The purpose of the research is to develop the optimal agricultural technology for plantation cultivation of *N. cataria* L. with the preservation of useful properties and to increase the content of essential oil in the conditions of Northern Kazakhstan.

Currently, herbal treatment is of great importance worldwide and because of the profound research, there is a diverse collection of the centuries-old experience growing medicinal plants (Malik, 2014). The genus *Nepeta* exhibits a wide spectrum of biological activity in medicine, agriculture, and the food industry (Prescott *et al*., 2011; Tan *et al*., 2019). *Nepeta cataria* L. is used for making cheeses, sausages, alcoholic and non-alcoholic drinks as a condiment, it can be used as an ornamental plant (Aćimović *et al*., 2021). In the near future, flavonoids extracted from *N. cataria* L. can be used to treat human lung cancer (Fan *et al*., 2017). The essential oil of *N. cataria* L. consists of terpenoid hydrocarbons, which act as an antimicrobial, sedative, antipyretic, antiviral, and diuretic substance (Gilani *et al*., 2009). One of the useful properties of the essential oil of *Nepeta* species is its repellent and insecticidal activity (Reichert *et al*., 2019). It is assumed that the antibacterial activity of the essential oil of *Nepeta* species against a strain of *Escherichia coli* and *Staphylococcus aureus* depends on the presence of nepetalactone in the composition. The presence of β-caryophyllene and β-caryophyllene oxide gives the plant antitumor activity, affecting the growth of cancer cells (Fidyt *et al*., 2016).

N. cataria L. is the introduced species for the conditions of Northern Kazakhstan. Until now, its useful properties have not been used in the pharmaceutical industry of the Republic of Kazakhstan and for this reason, the plant is not grown on plantations of medicinal herbs. According to the literature data, it was revealed that there were no scientific studies of the growth, yield, phytomass, and composition of the essential oil of *N. cataria* L. in Kazakhstan, which indicates the relevance of our research.

Materials and Methods

The experiments were carried out on a site located in Northern Kazakhstan, Akmola region, Zerendi district. The climate of the region is sharply continental, with frequent droughts, dry winds, and dust storms. Winter is characterized by low temperatures, late spring frosts, and early autumn frosts, which are repeated annually, the average annual temperature is 0.8-2.6°C.

The objects of research are the two-year-old plants of *N. cataria* L. Seeds were sown in containers in April 2021 and kept at room temperature. Young plants were planted in the open ground on May 14, 2021, and covered with material that protected the plants from late spring frosts. Seedlings were planted with a row spacing of 50 cm in length and in between rows of 60 cm in length. Planting of seedlings was carried out on two experimental plots (Plot #1 and Plot #2) with approximately the same chemical composition of the soil. Before planting seedlings, complex fertilizer $N_{100}P_{80}K_{120}$ was applied to the soil of the experimental plot (Wieteska *et al*., 2018). Fertilizers were not applied to the soil of the control plot. On the experimental and control plots rectangular lots were developed in three repetitions, on which measurements were carried out. The width of each lot was 1.6 meters (3 rows with edges), the length 17.5 m, and the area of a squared lot = 28 м^2. There were 100 plants in each measurement of biometric indicators, which was followed by a 3-fold repetition. Measurements of plant height and root length were carried out with a ruler with an accuracy of 0.1 cm. To assess the yield, the entire phytomass of medicinal plants during the flowering period was collected on all lots capturing the area of 1 × 1 (m), which was weighed on a laboratory balance with an accuracy of ±5 g.

The obtained data were processed by statistical methods using the Tibco Statistica program. Cluster analysis was carried out between the main components of the essential oil of plants from Kazakhstan and other countries to determine the similarity in composition. The significance of the differences between the experimental plants was determined using an analysis of variance.

Essential oil from plants' phytomass was obtained by hydro distillation process from air-dry raw materials for 3 h, using a Clevenger laboratory installation. To study the composition of the essential oil, we used the method of Gas Chromatography-Mass Spectrometry (GC-MS) using an Agilent Technologies 7890 A gas chromatograph with an MSD 5975 C quadrupole mass spectrometer as a detector. The capillary column HP-5MS had a size of 30 m × 0.25 mm (0.25 µm film thickness). The temperature of the evaporator is 230°C. The gas chromatography column was kept at a temperature of 40°C for 10 min; with temperature programming up to 240°C with a temperature change rate of 2°C/min and then kept in isothermal mode for 20 min. Sample injection mode flow division 100:1. The sample volume is 0.2 µL. Conditions for recording mass spectra 70 eV, mass range m/z 10-360. Data processing was performed using MSD chem station software supplied by Agilent Technologies in combination with AMDIS 32 and NIST 2017.

Results

Soils used in these experiments are typical chernozem with an average content of humus (5.33% on experimental plots and 6.03% on control plots). Humus content in soils was 4.3-5.2% respectively), and the pH scale indicated soil alkalinity (pH respectively 8.07-8.48). There was an acute shortage of easily hydrolyzable nitrogen in the soil, which content was 39.60 mg/kg on experimental plots and 46.41 mg/kg on control plots. The maximum nitrogen content in the soil should be from 50-100 mg/kg. Weather conditions are shown in (Table 1).

In the year of sowing of the cottontail, the air temperature and precipitation were optimal for seedlings. The amount of precipitation at a sufficiently high air temperature had a favorable effect on the emergence of seedlings, survival, and growth of young plants. In the summer months (June, and July of 2021), precipitation fell within 30 mm, but the lack of moisture in plants was compensated by irrigation. The greatest amount of precipitation was observed in August of 2021. The average temperature of the first and second growing seasons was approximately the same (16.2 and 15.9°C, respectively). The average amount of precipitation in the first year of plant life was 7.7% higher than in the second year. Consequently, the weather conditions of the two growing seasons were favorable enough for the emergence and growth of young plants.

Table 1: Weather conditions during the growth period of *N. cataria* L.

Weather indicators	Year	May	June	July	August	September
Amount of precipitation (mm)	2021	20.0	31.0	30.0	53.0	34.0
	2022	9.0	52.0	52.0	24.0	18.0
Air temperature (°C)	2021	17.0	16.5	19.7	18.7	8.7
	2022	14.3	17.3	19.5	16.1	12.7

Table 2A: Average length of stems, roots, and leaves of *N. cataria* L.

	Average length (cm)					
	Stem		Root		Leaf	
Plot type	Average	V[a], %	Average	V[a], %	Average	V[a], %
Experimental plot	683.0±5.2	33.9	33.6±0.9	16.5	4.7±0.1	18.1
Control plot	610.0±6.3	34.6	28.5±1.6	18.5	4.7±0.2	17.2
Excess of plot over control, %	+10.7		+15.2		0	

a. Variation

Table 2B: Number of shoots, inflorescences, and yield of *N. cataria* L.

	Number of side shoots (pieces)		Number of inflorescences (pieces)		Yield (g/m^2)	
Plot type	Average	V[a], %	Average	V[a], %	Average	V[a], %
Experimental plot	34.9±0.3	18.2	20.8±0.9	28.4	201.3	10.3
Control plot	35.2±0.4	14.5	19.5±0.8	18.3	178.8	12.2
Excess of plot over control, %	-0.9		+6.3		+11.2	

a. Variation

Table 3A: Raw biomass of stem and root of *N. cataria* L.

	Raw biomass of one plant (g)			
	Stem		Root	
Naming	Average	Variation, %	Average	Variation, %
Experimental plot	189.5±2.8	36.7	28.5±5.2	37.3
Control plot	172.8±2.1	37.9	27.9±4.8	37.8
Excess of plot over control, %	+8.8		+2.1	

Table 3B: Dry biomass of stem and root of *N. cataria* L.

	Dry biomass of one plant (g)			
	Stem		Root	
Naming	Average	Variation, %	Average	Variation, %
Experimental plot	64.3±2.6	34.8	11.5±1.9	34.2
Control plot	58.8±3.3	35.6	10.1±1.7	36.6
Excess of plot over control, %	+8.5		+12.2	

Laboratory seed germination was high at 89.9%, along with field germination at 84.1%. It should be noted that the rate of germination of seeds was good, as well as the survival rate of plants in open ground, which amounted to more than 90%. A comparative analysis showed that when fertilizers were applied, the length of the aboveground (by 10.7%) and underground parts (by 15.2%) was greater in the experimental plants (Table 2A-B). The number of lateral shoots of experimental plants is less than that of the control plants, but this difference is insignificant. More abundant flowering was observed in experimental plants, in which the number of inflorescences was higher than in the control plants by 6.3%. The length of the stem is more variable compared to the length of the roots, having a coefficient of variation in the range of 33.9-34.6%, while the length of the roots varies according to the coefficient of variation from 16.5-18.5%. The grass yield index was the most uniform, which varied at a low level (10.3-12.2%).

Without fertilization, the growth yield of plants was 178.8 g/m^2, with fertilization 201.3 g/m^2. All quantitative indicators of plant growth and yield in the experiments are significantly different according to student's t-test: Fexs = 17.8> Ftab = 5.14, which confirms the effect of fertilizer application on increasing plant growth of N. cataria L.

Fertilizers had a greater effect on increasing the biomass of the stem; in the experimental plot, the mass of the stem exceeded that of the control plants by 8.8% in the raw form and 8.5% in the dry form (Table 3A-B). The weight of the roots of experimental plants in the dry state exceeded the same indicator of control plants by 12.2%, and in the raw state by 2.1%. The coefficient of variation of the crude and dry phytomass of the aboveground and underground parts varied at a high level (34.8-37.9%). This indicates the heterogeneity of the trait and the different phytomass of plants and that the use of fertilizer had a positive effect on the increase in the mass of medicinal raw materials.

The composition of *N. cataria* L. essential oil was determined. Light yellow essential oil with a pleasant smell of freshness with a yield of 0.57% in the experimental plot and 0.52% in the control plot. Eighty-nine essential oil components have been isolated and identified, of which 29.4% are monoterpenes and 27.1% are sesquiterpenes. Figure 1 and Table 4 show the components of *N. cataria* L. essential oil. In total, the presence of 93.2% of the components in the control and 96.9% in the experimental plants was determined. Five components were present in the essential oil in the amount of more than 1%.

The main components of the essential oil of *N. cataria* L. grown on the control plots and experimental plots were 4aα7α7aα-nepetalactone (76.5612 and 79.3200% respectively), β-caryophyllene (4.0001 and 4.0351%) and caryophyllene oxide (1.9789 and 2.5969%), in addition, more than 1% contained cis β-Ocimene, β-copaene-4α-ol. The percentage composition of the components in the experiment with the application of fertilizers was generally higher than in the experiments without fertilizers.

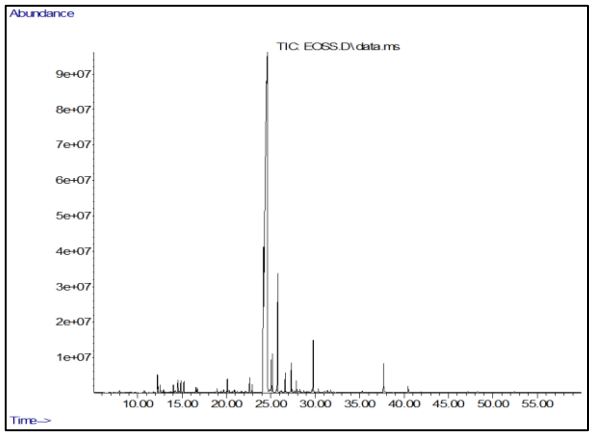

Fig. 1: The GC-MS spectrum for the composition of the essential oil of *N. cataria* L.

Table 4: The composition of the essential oil of *N. cataria* L. in Kazakhstan

RT, min	Time retention	Component	Content, % Experimental plot #1	Content, % Experimental plot #2
5.2611	783	Butanoic acid, 2-methyl-, methyl ester	0.0326	0.0426
6.8114	1073	1,3,6-octatriene, (E,E)-	0.0385	0.0463
7.9586	851	2-Hexenal	0.0978	0.1046
9.2213	850	Annulen	0.0321	0.0656
10.5561	868	Cyclohexene, 1,2-dimethyl-	0.0245	0.0121
10.7581	890	Cyclofenchene	0.0328	0.0500
10.9024	929	α-thujene	0.1089	0.1700
11.7683	933	3-hexenoic acid, methyl ester, (Z)-	0.0425	0.0138
12.2301	951	Camphene	0.0137	0.0148
14.1421	962	Benzaldehyde	0.0428	0.0316
12.2950	975	β-thujene	0.5900	0.6100
12.5475	976	β-pinene	0.1627	0.1792
12.8001	980	1-octen-3-ol	0.3270	0.2744
13.1247	991	β-myrcene	0.1032	0.1174
13.4999	994	3-octanol	0.2000	0.1100
13.6009	1003	3-carene	0.0981	0.1200
13.7308	1012	2,4-heptadienal, (E,E)-	0.0245	0.0383
14.0050	1019	α-terpinen	0.0641	0.0530
14.0339	1028	p-cymene	0.1257	0.2048
14.1710	1015	o-cymene	0.1452	0.1968
14.2647	1028	Cyclopentene, 3-isopropenyl-5,5-dimethyl-	0.0579	0.0384
14.3874	1032	Eucalyptol	0.1004	0.1574
14.5534	1036	Cyclohexanone, 2,2,6-trimethyl-	0.0032	0.0044
14.6977	1037	β-ocimene	0.2117	0.2591
14.8492	1038	cis-β-ocimene	1.3547	1.3646
15.2100	1045	Benzeneacetaldehyde	0.0428	0.0555
15.4986	1060	γ-Terpinene	0.3278	0.5571
16.1696	1089	Terpinolene	0.0185	0.0185
16.5159	1106	Cis-sabinene hydrate	0.0124	0.0233
16.5809	1103	Linalool	0.1652	0.1505
16.6819	1113	α-thujone	0.1021	0.1420
17.0859	1114	β-thujone	0.0325	0.0400
16.7324	1131	Allocimene	0.0987	0.0176
16.8118	1132	Cosmene	0.0300	0.0230
17.2375	1054	2-cyclopenten-1-one, 2,3,4,5-tetramethyl-	0.0821	0.0584

Table 4: Continue

18.6156	1144	(+)-2-bornanone	0.02740	0.0368
19.0774	1157	Isoborneol	0.01950	0.0197
19.3732	1171	Ectocarpene	0.02310	0.0237
19.4670	1182	Naphthalene	0.00390	0.0045
19.8999	1189	α-terpineol	0.04010	0.0466
20.0298	1192	Methyl salicylate	0.02970	0.0343
20.1092	1193	2-methoxy-5-methylphenol	0.39780	0.4119
20.6647	1244	Anisole	0.10080	0.1200
21.2347	1253	2-cyclohexen-1-one, 3-methyl-6-(1-methylethyl)-	0.05430	0.0636
21.3213	1257	1-cyclohexene-1-acetaldehyde, 2,6,6-trimethyl-	0.01450	0.0160
22.1078	1258	α-Ionene	0.09980	0.0892
22.2088	1286	Anethole	0.02550	0.0385
22.4902	1298	Thymol	0.79820	0.8100
22.6057	1299	Phenol, 2-methyl-5-(1-methylethyl)-	0.01650	0.0166
22.9015	1311	1H-Indene, 2,3-dihydro-1,1,5,6-tetramethyl-	0.01670	0.0136
23.0674	1317	2-Methoxy-4-vinylphenol	0.01440	0.0154
23.6930	1318	2H-1-Benzopyran, 3,4,4a,5,6,8a-hexahydro- 2, 5, 5, 8a-tetramethyl-, (2. alpha.,4a.alpha.,8a.alpha.)	0.06040	0.0560
24.8857	1355	Naphthalene, 1,2-dihydro-1,1,6-trimethyl-	0.00510	0.0058
25.3114	1372	Naphthalene, decahydro-2,6-dimethyl-	0.02120	0.0246
25.4340	1377	4aα,7α,7aα-nepetalactone	76.5612	79.3200
25.5062	1388	β-Bourbonene	0.18710	0.1496
25.6144	1440	trans- α-Bergamotene	0.04100	0.0321
25.7876	1413	Bicyclo[7.2.0]undec-4-ene, 4,11,11 -trimethyl-8-methylene-, [1R-(1R*,4Z,9S*)]-	0.03780	0.0247
25.9896	1413	Longifolene	0.06720	0.0700
26.3720	1419	β-Caryophyllene	4.00010	4.0500
26.6102	1436	β-Copaene-4α-ol	1.08570	1.1397
26.7039	1436	α-caryophyllene	0.71010	0.6027
26.7977	1439	Isogermacrene D	0.01960	0.0226
26.8483	1461	Alloaromadendrene	0.01820	0.0173
26.9926	1465	2,6,10-trimethyltridecane	0.05970	0.0479
27.3750	1477	γ-Muurolene	0.04250	0.0375
27.5409	1477	Eudesma-1,4(15),11-triene	0.05470	0.0487
27.6708	1486	trans-β-Ionone	0.10100	0.1201
27.7357	1498	trans muurola-4(14),5-diene	0.02430	0.0159
27.8728	1503	Azulene	0.03410	0.0254
28.0821	1513	Butylated hydroxytoluene	0.01830	0.0180
28.2985	1515	α-Farnesene	0.31580	0.3932
28.4645	1518	β-cyclogermacrane	0.14200	0.0983
28.6304	1528	δ-Cadinene	0.15740	0.1600
31.1630	1533	α-Muurolene	0.02000	0.0194
28.7170	1534	γ-Cadinene	0.04750	0.0371
28.7819	1538	α-Cadinene	0.01360	0.0179
29.2004	1538	Dihydroactinolide	0.03850	0.0325
29.6189	1544	α-Bisabolene	0.06990	0.0716
29.7705	1547	β -Bisabolene	0.04780	0.0535
29.9581	1561	β-Calacorene	0.01580	0.0097
30.1529	1570	3-Hexen-1-ol, benzoate, (Z)-	0.04780	0.0310
30.3621	1576	Spathulenol	0.15100	0.1326
30.5425	1581	Caryophyllene oxide	1.97890	2.5969
30.9682	1590	3-Cyclohexen-1-carboxaldehyde, 3,4-dimethyl-	0.12870	0.1393
31.0620	1649	τ-Cadinol	0.14030	0.1400
32.0721	1743	(1S,3aR,4R,8R,8aS)-1-isopropyl-3a-methyl -7-methylenedecahydro-4,8-epithioazulene	0.00900	0.0094
33.2122	1782	α-Muurolene-14-hydroxy	0.04420	0.0481
43.6671	1800	Octadecane	0.00980	0.0062
		Total	93.15620	96.9508

A comparative analysis of the component composition of the essential oil of *N. cataria* L. in different countries including Kazakhstan was carried out using cluster analysis (Table 5, Fig. 2).

Table 5: Component composition of *N. cataria* L. essential oil in different countries

Components	Kazakhstan	Egypt (Said-Al Ahl, 2018)	Germany (Patel *et al.*, 2007)	Iran (Zomorodian *et al.*, 2012)	Central Iran, (Safaei-Ghomi *et al.*, 2009)	France (Chalchat and Lamy 1997)	Iran Tehran (Saeidnia *et al.*, 2008)	Morocco (Zenasni *et al.*, 2008)	Korea (Kim *et al.*, 2006)	Pakistan (Suschke, *et al.*, 2007)	Italy (Aćimović, *et al.*, 2021)	Lithuania (Aćimović, *et al.*, 2021)	Poland (Aćimović, *et al.*, 2021)	Ukraine (Aćimović, *et al.*, 2021)	USA (Aćimović, *et al.*, 2021)
α-pinene		2.83	0.69	4.60		0.42		0.4		10.43					
Sabinene		0.62	0.75	0.15				0.2							
β-pinene	0.18		0.12	1.64	1.7	2.38		0.9	1.10	1.8					
cis-β-ocimene	1.36					0.82				2.74					
Linalool	0.15		0.38			0.5		0.4		1.28					
Citronellal		14.55	0.81										1.6		
Citronellol								0.2				6.9	14.0	9.4	5.6
Neroloxide			0.23			0.09									
Nerol/ citronellol			31.09			30.2	32.2						24.4	7.4	4.9
Neral (citral b)			3.71			3.17						0.7	6.6		
Neryl acetate						0.29									
Geraniol		11.73	19.57			25.9	4.31			6.8	55.3	5.5	23.5	22.4	
Geranial (citral a)			4.88			4.99			0.11		8.3	1.0	8.2	23.3	13.7
4aβ,7α,7aβ nepetalactone			0.59								0.4				
4aα,7α,7aα Nepetalactone (Z, E-nepetalactone)	79.32	35.15	20.37		87.1				90.9		4.4			6.1	
4aα,7α,7aβ nepetalactone			4.45	55.03	3.1			77.4							
4aα,7β,7aα nepetalactone		20.81		31.2	1.3										9.4
4aα,7α,7aβ Dihydrone-Petalactone (3,4α and (3,4 β)								5.0			6.2				9.2
α-citral							51.95			2.37					
β-caryophyllene	4.05		3.73	2.1	2.5	4.81		0.2	1.12	6.38		0.1	1.8		
α-caryophyllene	0.60		0.28												
Caryophyllene oxide	2.59	1.23	2.31	0.12		0.08					2.1	1.8	2.5	1.4	
iso-caryophyllene oxide															
β-farnesene			0.32		0.7				0.07	0.42					
Germacrene D									0.14						
Humuleneoxide			0.18							1.52					
α-Humulene	0.60	0.07		0.87		0.37			0.22			0.5			0.1
Thymol	0.81	0.34		0.57				1.3							
11-dodecenol				1.1						14.44					
Spathulenol	0.13			0.3											
β-bourbonene	0.15				0.4										
α-Thujene	0.17									1.69					
1,8-Cineole									1.49	0.21		0.4			
Citronellal		0.96				16.5						0.3			
Linalyl acetate						0.15		0.2		21.0					
Citronellyl acetate											6.0	13.4		11.4	
Geranyl acetate												54.8			48.3

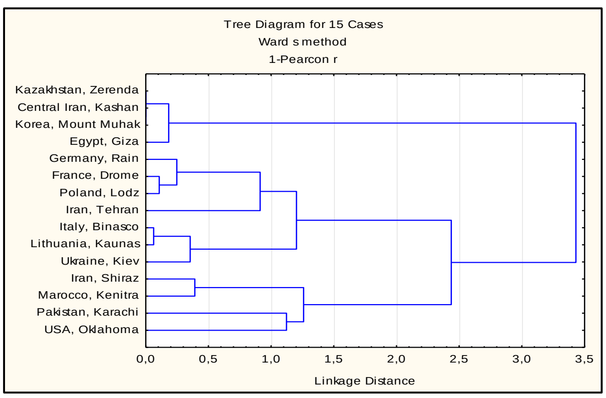

Fig. 2: Cluster analysis of *N. cataria* L. essential oil components from different countries

As a result of the cluster analysis of the components of *N. cataria* L. essential oil from different countries, it was revealed that all the studied samples were divided into 3 clusters. The essential oil from the plants of central Iran, Egypt, and Korea was closer in composition to the essential oil of plants from Kazakhstan. In plants from these countries, nepetalactone was the main component. The second cluster included plants from Germany (Nerol and 4a,7a,7a, nepetalactone (Z, E-nepetalactone), France (Nerol and Geraniol), Poland (Nerol and Geraniol), Iran (Tehran) (α-citral and Nerol), Italy (Geraniol), Latvia (Geranyl acetate) and Ukraine (Geraniol and Geranial). In this cluster, almost all countries, except Iran, are geographically located in Europe. In the essential oil of plants from these countries, the main components were Geraniol and Nerol. The third cluster includes plants growing in warmer climate countries Iran (Shiraz) (4aaa,7a,7aß nepetalactone), Pakistan (α-Pinene, 11-Dodecenol), USA (Oklahoma) (Geranyl acetate) and Morocco (4aaa,7a,7aß nepetalactone). Cluster analysis showed that the composition of the essential oil of plants from different countries is similar depending on the region of growth, most likely its composition is influenced by weather conditions.

Discussion

N. cataria L. prefers well-lit places and slightly drained alkaline soils (Manju *et al.*, 2019). It was experimentally found that for the germination of *Nepeta* seeds in conditions of Iran, the best soils are the ones with the light soil texture such as the sandy soils and the rate of seed germination on a certain soil texture depends on the origin of the seeds (Hakimzadeh *et al*., 2016).

The increase in the yield of medicinal raw materials of *Nepeta cataria* L. was influenced by mulching crops with flax straw, an additional positive effect was the reduction of weeds on the plantation (Duppong *et al*., 2004). It was found that with an increase in the level of water stress, the yield of green mass decreased and the content of essential oil, on the contrary, increased. The negative effect of water stress was reduced by spraying plants with salicylic acid which affected the growth of plants (Said-Al Ahl *et al*., 2016). Although soil salinization mainly affected the yield of *Nepeta cataria* L., small concentrations of soil salts increased the content of polyphenols, and flavonoids and stimulated antioxidant activity (Lungoci *et al*., 2022). To increase the yield of a plant of the genus *Nepeta*, it is necessary to develop not only optimal agrotechnical techniques but also plant breeding methodology (Srivastava *et al*., 2021).

The composition and main components of *Nepeta* essential oil are largely influenced by the soil and climatic conditions of the growing region, and its environmental and seasonal changes (Gomes *et al*., 2020). It is indicated that the low yield of essential oil may be due to the influence of changes in altitude and temperature conditions during the growth period of the plant (Srivastava *et al*., 2021). In Poland, to increase the essential oil yield, it is recommended to apply fertilizers of the NPK group: 100:80:120 kg/ha. Lack of nitrogen can negatively affect the metabolism of plants leading to a reduction in plant growth. It was found that under greenhouse conditions, the introduction of nitrogen at a concentration of 300 mg/L had an effect on the growth of *N. cataria* L., which increased the yield of essential oil (Wieteska *et al*., 2018).

An experiment with potassium humate as a soil conditioner was carried out on three species of *Nepeta*, including *N. cataria L*. All experimental plants were found to have an increase in their growth, yield, and essential oil and flavonoid content (Mohamed *et al*., 2018). This is consistent with our studies, in which *N. cataria* L. showed an increase in growth and productivity on slightly alkaline soils, where the height of two-year-old plants reached more than 60 cm. The use of complex NPK fertilizer increased almost all quantitative indicators of the growth and development of *N. cataria* L. The yield of experimental plants was 11.2% higher than that of control plants, which indicates the undoubted benefits of using fertilizers. According to our observations, *N. cataria* L. does not demand long-term agrotechnical care, it is easy to cultivate and it gives a large yield of its phytomass.

Nepetalactone and its derivatives are the most common essential oil components of most *Nepeta* species, including *N. cataria* L. (Zenasni *et al*., 2008; Safaei-Ghomi *et al*., 2009; Reichert *et al*., 2016; Ibrahim *et al*., 2017; Vukovic *et al*., 2016; Said-Al Ahl *et al*., 2016; 2018). This result is the same as in our studies in Kazakhstan when the composition of the essential oil contained more than 70% nonpetalactone with antibacterial activity. If we compare the content of essential oil in the experimental and control plants, it can be seen that the content of 4aa7a7aa-nonpetalactone was 3.5% higher in the experimental samples, and karyophyllene oxide by 23.8%. The yield of essential oil of plants at the experimental site was 8.8% higher, which indicates an improvement in the composition and an increase in the yield of essential oil when growing plants with fertilizer.

Antibacterial activity of *Nepeta cataria* L. essential oil can be associated not only with the main monoterpinoid component nepetalactone, but also with other monoterpenes, since in the composition of the essential oil of plants from different countries, the main components can be 1,8-cineol, α -pinene, geraniol, and others.

The components that are contained in the essential oil of plants from Kazakhstan more than 1% are β-caryophyllene, Caryophyllene oxide, cis β-Ocimene, β-copaene-4α-ol, the remaining components occupy an insignificant part (less than 1%). The absence of nepetalactone in the essential oil of *N. cataria* L. was revealed; the main components were citronellol, nerol, geraniol, and geranial (Saeidnia *et al*., 2008; Gomes *et al*., 2020), which were not found in our studies. The main components of the essential oil in *Nepeta* plants were β-caryophyllene and caryophyllene oxide (Suschke *et al*., 2007; Senatore *et al*., 2005), which were present in plants from Kazakhstan in a fairly large amount. The literature mentions only one studied species of the genus *Nepeta* growing in Kazakhstan, that is *Nepeta pannonica* L. The composition of the essential oil showed that the main component was 1,8-cineol, it contained less amount of nepetalactone two-fold (Kobaisy *et al*., 2005). In our studies of *N. cataria* L., 1,8-cineole was not present at all and nepetalactone was the leading component.

Conclusion

It has been reliably proven that the increase in the growth of *N. cataria* L., the phytomass, and the yield is positively affected by the application of complex fertilizer $N_{100}P_{80}K_{120}$. The growth yield on the fertilized plots increased by 12% compared to the control plot, and the raw and dry phytomass increased by 8.8 and 8.5%, respectively. Only the number of shoots decreased by 0.9% with the use of complex fertilizer, but this indicator does not play a major role in comparison to the increase in other biometric indicators of the plant that was observed in this study. The essential oil yield was 0.52% (control plots) and 0.57% (experimental plots). It was revealed that the main components of the essential oil of *N. cataria* L. grown on experimental plots and control plots were 4aα7α7aα-Nepetalactone (76.5612 and 79.3200%), β-caryophyllene (4.0001 and 4.0351%) and caryophyllene oxide (1.9789 and 2.5969%), respectively. The remaining components were contained in the essential oil in small quantities. In total, there were 5 components in the samples, which contained more than 1% of the essential oil. In the control, the content of essential oil components was less than in the experimental plot. The composition of the essential oil of plants from Kazakhstan was similar to the composition of the essential oil of plants from central Iran, Egypt, and Korea, because the main substance was nepetalactone. According to the literature data, catnip grows mainly in warmer temperate regions (Aćimović *et al*., 2021). But a sufficiently large yield of essential oil and the content of nepetalactone, compared to countries with a warmer climate, indicates the possibility of successful cultivation of catnip in the conditions of Northern Kazakhstan.

Acknowledgment

We thank the reserachers of Kazakh Research Institute of Forestry and Agroforestry A.N. Bukeikhana for their statistical input.

Funding Information

This research was funded by the science committee of the ministry of education and Science of the Republic of Kazakhstan (grant no. AP AP09259323) for 2022.

Author's Contributions

Svetlana Kabanova: Research project designed, participated in all experiments coordinated the data analysis, and contributed to the written of the manuscript.

Pavel Shakhmatov, Matvey Danchenko, Sabina Scott, Andrey Kabanov, Valeriy Bortsov, Igor Kochegarov, and Yana Krekova: Participated in all experiments and coordinated the data analysis and contributed to the written of the manuscript.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and that no ethical issues are involved.

References

Aćimović, M., Zeremski, T., Kiprovski, B., Brdar-Jokanović, M., Popović, V., Koren, A., & Sikora, V. (2021). *Nepeta cataria*-cultivation, chemical composition and biological activity. *Journal of Agronomy, Technology and Engineering Management (JATEM)*, *4*(4), 620-634. https://fiver.ifvcns.rs/handle/123456789/2344

Chalchat, J. C., & Lamy, J. (1997). Chemical composition of the essential oil isolated from wild catnip *Nepeta cataria L.* cv. Citriodora from the Drôme region of France. *Journal of Essential Oil Research*, *9*(5), 527-532. https://doi.org/10.1080/10412905.1997.9700770

Duppong, L. M., Delate, K., Liebman, M., Horton, R., Romero, F., Kraus, G., ... & Chowdbury, P. K. (2004). The effect of natural mulches on crop performance, weed suppression and biochemical constituents of catnip and St. John's wort. *Crop Science*, *44*(3), 861-869. https://doi.org/10.2135/cropsci2004.8610

Fan, J., Bao, Y., Meng, X., Wang, S., Li, T., Chang, X., ... & Bo, T. (2017). Mechanism of modulation through PI3K-AKT pathway about *Nepeta cataria* L.'s extract in non-small cell lung cancer. *Oncotarget*, *8*(19), 31395. https://doi.org/10.18632/oncotarget.15608

Fidyt, K., Fiedorowicz, A., Strządała, L., & Szumny, A. (2016). β-caryophyllene and β-caryophyllene oxide-natural compounds of anticancer and analgesic properties. *Cancer Medicine*, *5*(10), 3007-3017. https://doi.org/10.1002/cam4.816

Gilani, A. H., Shah, A. J., Zubair, A., Khalid, S., Kiani, J., Ahmed, A., ... & Ahmad, V. U. (2009). Chemical composition and mechanisms underlying the spasmolytic and bronchodilatory properties of the essential oil of *Nepeta cataria* L. *Journal of Ethnopharmacology*, *121*(3), 405-411. https://doi.org/10.1016/j.jep.2008.11.004

Gomes, E. N., Reichert, W., Vasilatis, A. A., Allen, K. A., Wu, Q., & Simon, J. E. (2020). Essential oil yield and aromatic profile of lemon catnip and lemon-scented catnip selections at different harvesting times. *Journal of Medicinally Active Plants*, *9*(1), 4. https://scholarworks.umass.edu/cgi/viewcontent.cgi?article=1140&context=jmap

Hakimzadeh, M. A., Hakimi, M. H., & Sodaeizadeh, H. (2016). Effects of seed source and soil texture on germination and survival of *Nepeta* asterotricha as a medicinal plant. *Journal of Rangeland Science*, *6*(3), 242-252. https://rangeland.borujerd.iau.ir/article_523966_da2e8f3a169dec854a52533f987ec7f9.pdf

Ibrahim, M. E., El-Sawi, S. A., & Ibrahim, F. M. (2017). *Nepeta cataria* L. one of the promising aromatic plants in Egypt: Seed germination, growth and essential oil production. *J Mater Environ Sci*, *8*, 1990-1995. https://www.jmaterenvironsci.com/Document/vol8/vol8_N6/211-JMES-2812-Ibrahim.pdf

Kim, J. H., Jung, D. H., & Park, H. K. (2006). The composition of essential oil from *Nepeta cataria* and its effect on microorganism. *Journal of Ecology and Environment*, *29*(4), 381-387. https://doi.org/10.5141/JEFB.2006.29.4.381

Kobaisy, M., Tellez, M. R., Dayan, F. E., Mamonov, L. K., Mukanova, G. S., Sitpaeva, G. T., & Gemejieva, N. G. (2005). Composition and phytotoxic activity of *Nepeta pannonica* L. essential oil. *Journal of Essential Oil Research*, *17*(6), 704-707. https://doi.org/10.1080/10412905.2005.9699037

Lungoci, C., Motrescu, I., Filipov, F., Jitareanu, C. D., Teliban, G. C., Ghitau, C. S., ... & Robu, T. (2022). The Impact of Salinity Stress on Antioxidant Response and Bioactive Compounds of *Nepeta cataria* L. *Agronomy*, *12*(3), 562. https://doi.org/10.3390/agronomy12030562

Malik, R. (2014). Cultivation of medicinal and aromatic crops as a means of diversification of agriculture in India. *Karnataka Journal of Agricultural Sciences*, *27*(1), 20-25. http://www.isec.ac.in/29%20Culti%20of%20Medi%20Crops%20&%20Arom%20Crop%20as%20a%20Means%20of%20Diver%20in%20Agri.pdf

Manju, M., Satish, S., & Sabaraya, A. R. (2019). A review on pharmacological activities of essential oil in *Nepeta cataria*. *Int J Pharma Chem Res*, *5*, 14-17. https://www.fimek.edu.rs/downloads/casopisi/jatem/issue/v4_4/3._Acimovic_et_al_2021_4(4)_620-634.pdf

Mohamed, H. F., Mahmoud, A. A., Alatawi, A., Hegazy, M. H., Astatkie, T., & Said-Al Ahl, H. A. (2018). Growth and essential oil responses of *Nepeta* species to potassium humate and harvest time. *Acta Physiologiae Plantarum*, *40*, 1-8. https://doi.org/10.1007/s11738-018-2778-5

Patel, D., Shukla, S., & Gupta, S. (2007). Apigenin and cancer chemoprevention: Progress, potential and promise. *International Journal of Oncology*, *30*(1), 233-245. https://pubmed.ncbi.nlm.nih.gov/17143534/

Prescott, T. A., Veitch, N. C., & Simmonds, M. S. (2011). Direct inhibition of calcineurin by caffeoyl phenylethanoid glycosides from Teucrium chamaedrys and *Nepeta cataria*. *Journal of Ethnopharmacology*, *137*(3), 1306-1310. https://doi.org/10.1016/j.jep.2011.07.063

Reichert, W., Ejercito, J., Guda, T., Dong, X., Wu, Q., Ray, A., & Simon, J. E. (2019). Repellency assessment of *Nepeta cataria* essential oils and isolated nepetalactones on Aedes aegypti. *Scientific Reports*, *9*(1), 1524. https://doi.org/10.1038/s41598-018-36814-1

Reichert, W., Park, H. C., Juliani, H. R., & Simon, J. E. (2016). 'CR9': A new highly aromatic catnip *Nepeta cataria* L. cultivar rich in Z, E-nepetalactone. *Hort Science*, *51*(5), 588-591. https://doi.org/10.21273/HORTSCI.51.5.588

Saeidnia, S., Gouhari, A., & Haji, A. A. (2008). Trypanocidal activity of oil of the young leaves of *Nepeta cataria* L. obtained by solvent extraction. file:///C:/Users/User/Downloads/822200804s08.pdf

Safaei-Ghomi, J., Djafari-Bidgoli, Z., & Batooli, H. (2009). Volatile constituents analysis of *Nepeta cataria* from central Iran. *Chemistry of Natural Compounds*, *45*, 913-915. https://doi.org/10.1007/s10600-010-9470-3

Said-Al Ahl, H. A., Sabra, A. S., & Hegazy, M. H. (2016). Salicylic acid improves growth and essential oil accumulation in two *Nepeta cataria* chemotypes under water stress conditions. *Ital. J. Agrometeorol*, *21*, 25-36.

Said-Al Ahl, H., Naguib, N. Y., & Hussein, M. S. (2018). Evaluation growth and essential oil content of catmint and lemon catnip plants as new cultivated medicinal plants in Egypt. *Annals of Agricultural Sciences*, *63*(2), 201-205. https://doi.org/10.1016/j.aoas.2018.11.005

Senatore, F., Arnold, N. A., & Piozzi, F. (2005). Composition of the essential oil of *Nepeta curviflora* Boiss. (Lamiaceae) from Lebanon. *Journal of Essential Oil Research*, *17*(3), 268-270. https://doi.org/10.1080/10412905.2005.9698898

Srivastava, A., Gupta, S., Singh, S., Verma, R. S., Srivastava, R. K., Gupta, A. K., & Lal, R. K. (2021). Genetic variability and elite line selection for high essential oil and nepetalactone content in catmint (*Nepeta cataria* L.). *American Journal of Plant Sciences*, *12*(7), 1135-1154. https://www.scirp.org/journal/paperinformation.aspx?paperid=110934

Suschke, U., Sporer, F., Schneele, J., Geiss, H. K., & Reichling, J. (2007). Antibacterial and cytotoxic activity of *Nepeta cataria* L., *N. cataria* var. citriodora (Beck.) Balb. and *Melissa officinalis* L. essential oils. *Natural Product Communications*, *2*(12), 1934578X0700201218. https://journals.sagepub.com/doi/pdf/10.1177/1934578X0700201218

Tan, J., Li, J., Ma, J., & Qiao, F. (2019). Hepatoprotective effect of essential oils of *Nepeta cataria* L. on acetaminophen induced liver dysfunction. *Bioscience Reports*, *39*(8). https://doi.org/10.1042/BSR20190697

Vukovic, N., Vukic, M., Djelic, G., Hutkova, J., & Kacaniova, M. (2016). Chemical composition and antibacterial activity of essential oils of various plant organs of wild growing *Nepeta cataria* from Serbia. *Journal of Essential Oil Bearing Plants*, *19*(6), 1404-1412. https://doi.org/10.1080/0972060X.2016.1211965

Wieteska, A., Jadczak, D., & Wesolowska, A. (2018). Comparison of the biological value of selected catnip plant (*Nepeta* sp.). *Asian J. Med. Plants*, *6*, 191-195. https://doi.org/10.15413/ajmp.2018.0135

DOI: 10.3844/ojbsci.2023.286.295

Zenasni, L., Bouidida, H., Hancali, A., Boudhane, A., Amzal, H., Idrissi, A., ... & Benjouad, A. (2008). The essentials oils and antimicrobial activity of four *Nepeta* species from Morocco. *Journal of Medicinal Plants Research*, *2*(5), 111-114. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=1e656d5dcb4e1cc26eb6733f137279d254fd079d

Zomorodian, K., Saharkhiz, M. J., Shariati, S., Pakshir, K., Rahimi, M. J., & Khashei, R. (2012). Chemical composition and antimicrobial activities of essential oils from *Nepeta cataria* L. against common causes of food-borne infections. *International Scholarly Research Notices*, *2012*. https://downloads.hindawi.com/archive/2012/591953.pdf