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EXPERIMENTAL PAPER

Impact of foliar application of copper sulphate and copper nanoparticles on some morpho-physiological traits and essential oil composition of peppermint (*Mentha piperita* L.)

ZAHRA NEMATI LAFMEJANI¹, ALI ASHRAF JAFARI*², PEJHMAN MORADI³, ALIREZA LADAN MOGHADAM⁴

¹Department of Horticulture
Islamic Azad University
Science and Research Branch
Tehran, Iran

²Research Institute of Forests and Rangelands
Agricultural Research Education and Extension Organization (AREEO)
Tehran, Iran

³Department of Horticulture
Islamic Azad University
Saveh Branch
Saveh, Iran

⁴Department of Horticulture
Islamic Azad University
Garmsar Branch
Garmsar, Iran

* corresponding author: aajafari@rifr-ac.ir

Summary

Introduction: Peppermint (*Mentha piperita* L.), a member of *Lamiaceae* family, is an important medicinal plant that has many useful properties. Copper is an essential micronutrient for normal plant growth and metabolism.

Objective: The aim of this study was to examine the effects of copper sulphate and copper nanoparticles

on morpho-physiological traits and essential oil composition of peppermint.

Methods: Seven treatments of copper sulphate and copper nanoparticles in three concentrations (0.5, 1.0 and 1.5 g/l) and control were applied in foliar application three times of the interval of 15 days up to flowering stages of peppermint in Karaj, Iran in 2015.

Results: Copper nanoparticles (1.0 g/l) increased chlorophyll content and essential oil percentage of 35% and 20% higher than control, respectively. The copper sulfate (0.5 g/l) increased dry matter yield up to 58% higher than control. The effects of treatments were significant on 17 out of 34 compositions. Copper nanoparticles (1.0 g/l) increased menthol, menthone and menthofuran content up to 15, 25 and 65% higher than in control, respectively.

Conclusions: Foliar application of copper sulfate (0.5 g/l) and copper nanoparticles (1.0 g/l) in flowering stage were suggested for increase of dry matter production, essential oil content and composition, respectively.

Key words: : *essential oil, leaf pigments, yield, foliar spray, copper nanoparticles, Mentha piperita*

INTRODUCTION

Peppermint (*Mentha piperita* L.) belongs the family *Lamiaceae*, is one of the most important medicinal plants that used in food, sanitary and cosmetic industries. The main constituent is menthol, used in oral hygiene products, pharmaceuticals, cosmetics, and foods. Menthol also has high antifungal and antibacterial potentials, thus becoming one of the most demanded substances by the scents and essences industry [1]. Menthol stimulates cold receptors in the respiratory tract, which inhibits cough and improves nasal airflow [2].

Peppermint is cultivated in the temperate, Mediterranean and subtropical regions of the world [3, 4]. This plant is a perennial with 50–60 cm tall. The square stems are usually reddish-purple and smooth. The leaves are short, oblong-ovate and serrate. The flowers are purple-pinkish and appear in summer months. The plant has runners above and below ground [5]. It is tetraploid ($2n=4x=72$), sterile natural hybrid of *M. aquatica* L. ($2n=96$) and *M. spicata* L. ($2n=48$) [6].

The essential oil of peppermint occurs between 1 and 2.5% in the dried leaves which is mostly made up from menthol (50%), menthone (10 to 30%), menthyl esters (up to 10%) and further monoterpene derivatives (pulegone, piperitone, and menthofurane) [7].

A balanced fertilization program with macro- and micronutrients in plant nutrition is very important in the production of high yield and quality products of medicinal plants [8]. For adequate plant growth and production, micronutrients are needed in small quantities; however, their deficiencies cause a great disturbance in physiological and metabolic processes

in the plant [9]. Plants normally take up nutrients from soils through their roots, although nutrients can be supplied to plants as fertilizers by foliar sprays. Foliar feeding is a relatively controversial technique of feeding plants by applying liquid fertilizer directly to their leaves [10].

Nanotechnology is one of the main advancements in the science technology of the last decade. Nanoparticles are considered as molecular or atomic aggregates between 1 and 100 nm [11]. Nanoparticles have potential applications as crop fertilizers because of their physical and chemical attributes [12]. The use of nanoparticle fertilizer leads to an increased efficiency of the elements, reduces the toxicity of the soil, at least reaches the negative effects caused by the consumption of excessive consumption of fertilizers and reduce the frequency of application of fertilizers [13]. With production of nanoparticle fertilizers, this nanocompounds rapidly and completely absorbed by plants and fix its nutrients shortages and growing needs [14]. Khater [15] in his assess of the effects of magnetite nanoparticles on growth and essential oil composition of *M. piperita* showed that magnetite nanoparticles significantly increased peppermint growth and the essential oil composition [15].

Copper is an essential micronutrient for normal plant growth and metabolism. In plants, Cu plays a vital role in various metabolic processes, namely cell wall metabolism, also acts as structural element in regulatory proteins, photosynthetic electron transport and mitochondrial respiration, biosynthesis of plant hormones, and as cofactor for a variety of enzymes [16, 17]. Changes membrane integrity and permeability [18] as well as affects the uptake of other nutrient elements [19]. However, an excess of this metal may inhibit plant growth and development [20].

The effects of metal application on yield and essential oil production of medicinal plants were extensively studied [21, 22]. However, the effects of copper nanoparticles on growth and essential oil production of medicinal plants are poorly understood. Thus, the aim of this study was to examine the effects of both copper sulphate and copper nanoparticles on growth and essential oils content of peppermint (*M. piperita*) in field conditions.

MATERIAL AND METHODS

The study was conducted in research farm of Jihad Daneshgahi, Karaj, Iran in 2015. Karaj region has a semi-dry, continental climate. The soil of the field was silty loam with pH 7.9, contains total N (0.08%), total P₂O₅ (36.2 ppm) and total K₂O (49.8 ppm) and Fe (5.74 ppm) with an EC of 0.93 (dS/m) (tab. 1).

plot was counted and the chlorophyll a, b, and total were measured on new leaves using spectrophotometer.

For extraction and measuring of essential oil, herb collected at full flowering stage, then 80 g of dried material grinded to measuring of essential oil by Kelvenger Instrument. Each samples (aerial parts) separated, triturated and steam-hydro distilled for 2 hours. The essential oil extraction was carried out according to method of Hungarian pharmacopoeia [23].

Essential oil yield was calculated by percentage content of essential oil percentage × aerial biomass yield as g/plot. The essential oil compositions were detected using GC/MS [24].

The data of morpho-physiological traits in three replications and essential oil composition in two replications were statistically analyzed using Minitab software and the mean values for each treatment were compared

Table 1.

The chemical and physical properties of the soil in research farm

Soil texture	Clay [%]	Silt [%]	Sand [%]	Lime [%]	N [%]	C [%]	K [ppm]	P [ppm]	EC [ds/m]	pH	Fe [ppm]	Zn [ppm]	S [ppm]	Mn [ppm]	Cu [ppm]
Silty loam	16	22	62	8.5	0.08	0.82	49.8	36.2	0.93	7.9	5.74	0.60	6.3	11.2	0.7

Field was established using tiller propagation of peppermint in May 2015 in a density of 16 plants/m² with an interspace of 25 cm. A randomized complete block design experiment was conducted in three replications. Treatments were copper fertilizer as copper sulphate and copper nanoparticles each in three concentration levels (0.5, 1 and 1.5 g/l) and control (no fertilizer). The fertilizer treatments were sprayed on plant as foliar three times in the interval of 15 days up to flowering stages. Then an area of 1×1 m² in center of each plot was selected for data sampling. The aerial part of plants were harvested in full flowering stage, weighed and dried under shadow and open air flow and weighed as aerial biomass yield. The stem number of each

using the Duncan's test at the $p < 0.05$ confidence level. The Excel software was used for drawn histograms of treatments comparison.

Ethical approval: The conducted research is not related to either human or animal use.

RESULTS AND DISCUSSION

Morpho-physiological traits and essential oil content

Results of analysis of variance showed significant differences between treatments for all of traits ($p < 0.01$)

Table 2.

Analysis of variance and mean of squares of some morphological, physiological traits and essential oil production of *Mentha piperita*

SOV	DF	MS							
		Chlorophyll			Fresh weight	Dry weight	Stem number	Oil [%]	Oil yield
		a	b	Total					
Treatments	6	0.652**	0.132**	1.39**	498.8**	39961**	714.2**	0.251**	0.487**
Replication	2	0.010	0.011	0.042	214.7	1160	5.9	0.051	0.002
Error	12	0.047	0.012	0.095	44.8	634	14.0	0.019	0.011
CV		7.45	7.50	7.05	2.99	87.80	4.83	4.71	12.93

*, **: significant at $p=0.05$ and 0.01 levels, respectively

(tab. 2), indicating foliar application of copper sulphate and copper nanoparticles had significantly affected chlorophyll a, b and total chlorophyll, dry matter yield, essential oil percentage, stem length and essential oil yield. Mean comparison between treatments were made using Duncan's ($p < 0.05$) and the results presented in figure 1. Results showed that copper nanoparticles fertilizer 0.5, 1.0 and 1.5 g/l significantly increased all forms of chlorophyll content of 25, 35 and 45% and essential oil percentage 10, 20 and 23% higher than that for control, respectively. The higher values of chlorophyll a, b and total chlorophyll content always were obtained in higher copper nanoparticles concentration (1.5 g/l), (fig. 1). For yield and morphological traits, the copper sulfate (0.5 g/l) significantly increased stem number and aerial dry yields and essential oil yield of 25, 58 and 61% higher than that for control. The excess of copper sulfate (1 and 1.5 g/l) inhibit plant growth and development compared to control (Fig. 1). Similar to our study, Zheljzakov *et al.* [25] in application of 20, 60 and 150 mg/l of copper sulfate in morphological traits of basil found that the lower level of micronutrient had significantly enhanced the yield and morphological traits [25]. In contrast, application higher concentration of copper sulfate 150 mg/l resulted in phytotoxicity symptoms and retarded plant growth. In our experiment, the low concentrations of copper stimulate growth, biomass and essential oil yield of peppermint while high concentrations it can cause some toxic effects. The positive effect of micronutrient on aerial dry matter yield may be due to increased biosynthesis of auxin, increased chlorophyll concentration, increase activities of ribulose biphosphate carboxylase and phosphoenolpyruvate carboxylase, reduce sodium accumulation in plant tissues, and increase efficiency of the absorption of micro and macronutrient in presence of low concentrations of these nutrient. In contrast, if heavy metal use more than the need of plant, it can affect the balance of nutrients and may disruption of physiological and biochemical processes and ultimately reduce the yield of the plant dry matter [26, 27].

Results showed that copper nanoparticles fertilizer significantly increased chlorophyll content. The effect of concentration on nanoparticles was linear on leaf pigments and the higher values of chlorophylls were obtained in Cu nanoparticles (1.5 g/l). In contrast, by increasing copper sulphate concentration chlorophyll content were reduced and lower values were obtained in higher concentration (1.5 g/l). Such negative effect of heavy metal leads to reducing leaf area and leaf size, leaf production and

eventually leaf loss. In general, higher heavy metals reduce the rate of cell division and prolongation and ultimately lead to a decrease in the final size of the leaf [28, 29]. Similar, result of lower essential oil percentage was found using higher concentration of copper sulphate (1.5 g/l), it may related to reduction of photosynthesis and leaf area and thus reduce the energy needed for the biosynthesis of essential oils [25, 30].

Essential oil yield was calculated by essential oil content \times aerial biomass yield. The copper sulfate (0.5 g/l) significantly increased essential oil yield of 61% higher than that for control. The excess of this micronutrient may reduce essential oil yield (Fig. 1). Considering the fact that in this study, although the influence of copper nanoparticles (1.5 g/l) were positive on essential oil percentage, but for dry matter yield and essential oil yields the best, concentration was copper sulfate (0.5 g/l). The results were in agreement with Preeti Paud *et al.* [27] and Dudareva *et al.* [30]. They suggested any deficiency and excess of copper may lead to disruption the plant physiological processes and can cause depletion and thus reduced essential oil yield [27, 30].

The use of nano fertilizer has many benefits. It leads to increased nutrient utilization, reduction of soil toxicity, minimizing negative effects of over-fertilization. Using nano fertilizer, the time and speed of release of the nutrients are matched with nutritional requirements of the plant. Therefore, the plant is able to absorb the highest amount of nutrients and consequently, reducing the leaching of the elements and increasing dry matter yield [31].

Our finding indicated the positive effect of lower concentration of copper sulfate than copper nanoparticles fertilizer on dry matter yield. Similarly, Stampoulis *et al.* [32] reported that application of copper in the amount of 1000 mg/l nanoparticles decreased dry matter weight of 14-day-old *Cucurbita pepo* seedling by 90% as compared to control [32]. Similarly, Shah and Belozerovala [33] reported that copper nanoparticles mixed with soil (130 and 600 mg/kg) significantly increased the growth of lettuce seedlings, by 40 and 91%, respectively [33]. However, at higher concentrations (1000 mg/l), the copper nanoparticles had toxicity and growth inhibition of seedlings of beans, wheat, yellow zucchini [34] and *Cucurbita pepo* [35].

Correlation between morpho-physiological traits and essential oil

The results of correlation analysis between the traits

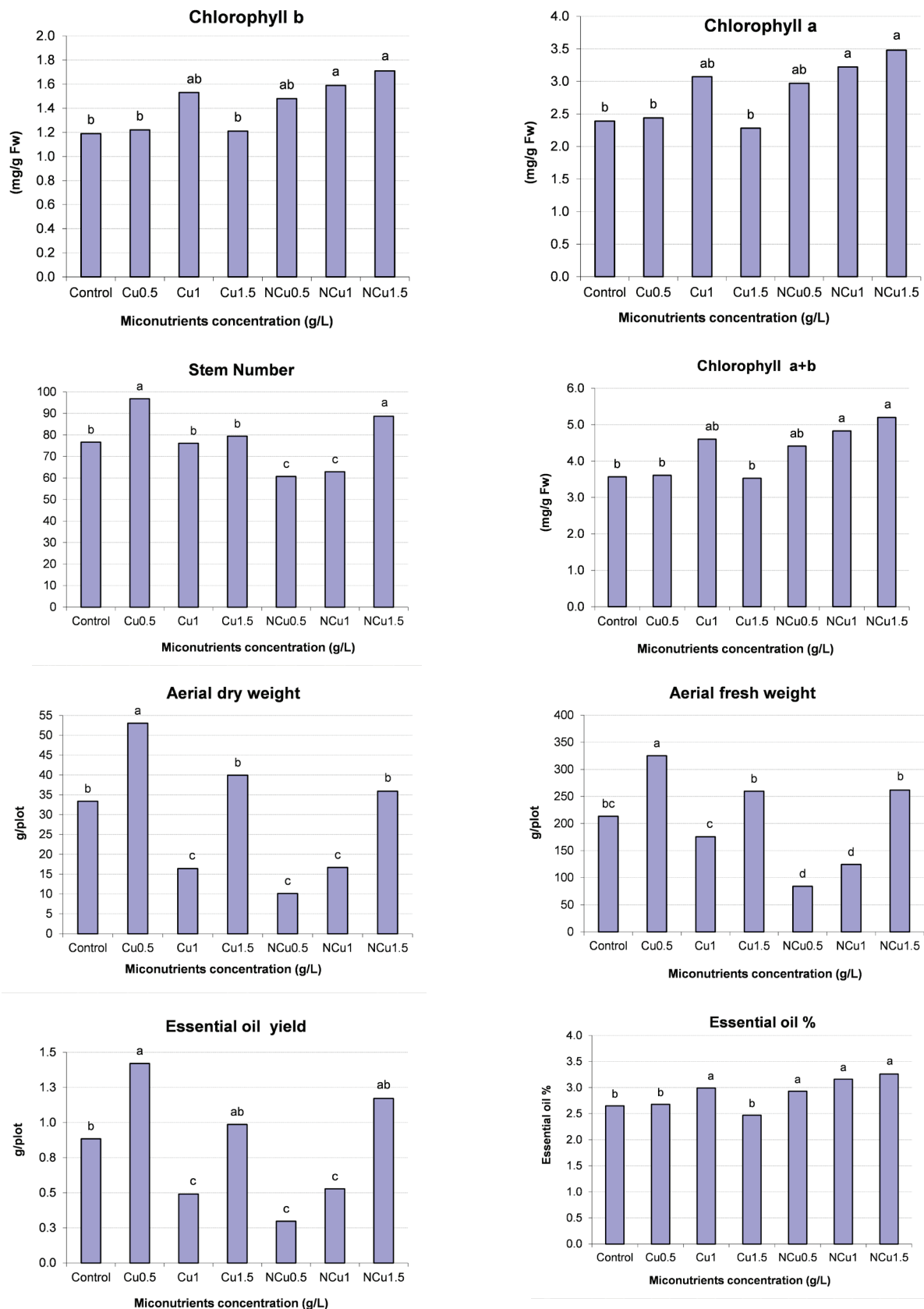


Figure 1.

Means of morphological, physiological traits and essential oil production of *Mentha piperita* in different levels of copper sulphate and copper nanoparticles fertilizer. Means of column followed by same letters have no significant differences based on Duncan test

showed that chlorophyll a, b and total had positively strong correlations ($r = 0.99$) with each other and all these traits had positively significant correlation with essential oil content ($r = 0.97$) (tab. 3). There

higher than copper sulphates on menthol, menthone and menthofuran. In contrast, effects on copper sulfate were higher than copper nanoparticles for β -caryophyllen, menthyl acetate and piperitone.

Table 3.

Phenotypic correlation coefficients between essential oil yield and morphological traits in of *Mentha piperita*

Traits	Chlorophyll a	Chlorophyll b	Chlorophyll total	Fresh weight	Dry weight	Stem number	Oil [%]
Chlorophyll b	0.98**						
Chlorophyll ab	0.98**	0.98**					
Fresh weight	-0.51	-0.55	-0.53				
Dry weight	-0.55	-0.57	-0.55	0.96**			
Stem number	-0.30	-0.33	-0.31	0.94**	0.90**		
Oil [%]	0.98**	0.97**	0.97**	-0.44	-0.50	-0.26	
Oil yield	-0.36	-0.38	-0.37	0.94**	0.97**	0.93**	-0.31

* significant at 0.05 probability level, ** significant at 0.01 probability level

was a positive and significant correlation between stem length and fresh and dry matter yield, and all these three traits showed positive and significant correlations with essential oil yield ($r = 0.94$).

Essential oil composition

In total, 34 essential oils were identified in the essential oil composition of peppermint. The highest composition with average values of 17.82% was obtained for menthol followed by piperitone, menthone, menthyl acetate, β -caryophyllen and menthofuran with average values of 6.51, 6.45, 6.14, 5.46 and 4.26%, respectively.

Result of analysis of variance showed that copper micronutrient treatments had significant effects on 17 composition out of 34 ($p < 0.01$) (tab. 4). Copper nanoparticles fertilizer (0.5 g/l) was effective on increasing the concentration of camphene, α -phellandrene and limonene. Similarly, copper nanoparticles fertilizer (1.0 g/l) had increased menthol, menthone and menthofuran content up to 15, 25 and 65% higher than that for control, respectively. The excess of copper nanoparticles (1.5 g/l) decreased the mentioned oil compositions (tab. 4).

The copper sulphate (0.5 g/l) had significantly increased 1-octanol-3-ol, myrtenal, dihydrocarvone, pulegone and the higher concentration of copper sulphate (1.5 g/l) had increased piperitone and menthyl acetate up to 33% and 58% higher than control. In contrast, for linalool and carvone the highest concentration were obtained in control (tab. 4).

In general, the effect of copper nanoparticles was

Principal component analysis of essential oil composition

Principal component analysis (PCA) is used to determine the relative importance of variables in forming the factor. The results of PCA analysis showed that the first five components accounted for 93% of the total variation. In the first component myrtenal, β -bourbonene, myrcene, β -caryophyllen and pulegone in positive sign, and menthone, menthol, α -terpinene and menthofuran in negative sign accounted for 29% of variation. In the second component, limonene, 1-octanol-3-ol and β -pinene in positive sign and sabinene, germacren D, isomenthone, borneol, carvacrol, α -humulen, eucalyptol and isopulegole in negative signs were identified as the important traits having 21% of total variation (tab. 5).

Distribution of six micro nutrient treatments relationships with 34 essential oil components vectors for the first two principal components is presented in figure 2. As shown in figure 2, in the first axes menthone, menthol, α -terpinene and menthofuran grouped with each other and they were associated with copper nanoparticles (fig. 2) and in contrast, myrtenal, β -bourbonene, myrcene, β -caryophyllen and pulegone were associated with soleplate copper (right hand side). This result indicated that association of treatments based on the first two component scores were in agreement with table 3.

Table 4.Means of the essential oil components of *Mentha piperita* in different concentration of copper (Cu) and Cu-based nanoparticles

Oil component	Cu 0.5	Cu 1	Cu 1.5	NCu 0.5	NCu 1	NCu 1.5	control	F test	Mean
α -Pinene	2.15	2.40	1.90	1.35	1.55	1.90	2.05		1.90
Camphene	1.75 b	1.85 a	1.15 b	2.80 a	1.95 a	1.20 b	1.45 b	*	1.74
Sabinene	1.65	1.55	2.35	1.85	1.65	2.15	2.00		1.89
β -Pinene	2.45	2.24	1.65	2.30	3.00	1.70	2.65		2.28
1-Octanol-3-ol	2.30 a	1.80 a	2.05 a	1.90 a	2.25 a	1.00 b	1.55 b	*	1.84
Myrcene	1.65	1.95	1.60	1.40	1.40	1.30	1.80		1.59
α -Phellandrene	2.55a	2.35 a	2.30a	3.05a	2.40a	1.40b	2.55a	*	2.37
α -Terpinene	1.90	2.00	1.65	2.00	2.95	2.85	2.25		2.23
Para-cymene	1.65	2.30	2.05	1.60	2.30	1.90	2.00		1.97
Eucalyptol	1.20	1.15	1.60	1.85	1.75	2.20	1.95		1.67
Limonene	2.30ab	2.85 a	2.40ab	2.70 a	2.55 a	1.60 b	2.85 a	*	2.46
1,8-Cineole	2.20ab	1.90b	2.65a	1.85b	2.85 a	1.90 b	1.90 b	*	2.18
β -Ocymene	1.65	1.30	1.25	1.70	1.40	1.50	1.50		1.47
γ -Terpinene	1.90	1.80	1.20	1.15	1.05	1.40	2.30		1.54
Linalool	2.60bc	2.95ab	2.60bc	2.00c	1.90c	2.90ab	3.20a	*	2.59
Isopulegole	1.80	1.40	2.15	1.60	1.90	2.15	1.95		1.85
Menthone	5.80d	6.40c	5.20d	6.60bc	7.45b	7.80a	5.90d	**	6.45
Isomenthone	1.85	1.80	2.15	2.25	1.19	2.10	2.05		1.91
Menthofuran	2.85c	5.00b	2.25c	4.90b	5.60a	6.25a	3.00c	**	4.26
Neomenthol	1.90	1.95	2.15	2.50	1.75	1.60	1.95		1.97
Menthol	17.00bc	18.10ab	16.20c	18.00ab	19.40a	19.05a	17.00bc	**	17.82
Myrtenal	2.25a	2.35a	1.70ab	1.25b	1.15b	1.55b	1.55b	*	1.69
Dihydrocarvone	1.80a	1.25b	0.95b	1.10b	1.50ab	1.50ab	1.15b	*	1.32
Carvone	1.85b	1.65b	1.30b	1.85b	1.85b	1.50b	2.95a	*	1.85
Pulegone	3.00a	2.85a	3.00a	2.15b	1.90b	1.95b	2.75ab	*	2.51
Piperitone	6.95b	6.60b	7.25a	6.80b	6.40b	6.10b	5.45c	*	6.51
Borneol	1.15	1.30	1.65	1.70	1.05	1.45	1.65		1.42
Menthyl acetate	6.80a	6.10b	7.45a	6.05b	5.85b	6.00b	4.70c	**	6.14
Carvacrol	1.75	1.60	2.05	2.20	1.65	1.90	2.15		1.90
β -Bourbonene	2.07	1.80	1.75	1.40	1.45	1.65	1.86		1.71
β -Caryophyllen	6.60a	5.00 b	7.10 a	5.10 b	4.40 b	3.55 c	6.50 a	**	5.46
α -Humulen	1.25	1.70	1.85	1.70	0.95	1.55	1.75		1.54
Dihydrocarvyl acetate	1.10bc	1.15b	1.85a	1.20b	1.55b	1.70a	0.90c	*	1.35
Germacren D	1.80	1.75	1.90	1.90	1.50	2.42	1.70		1.85

* Significant at the 0.05 probability level;

** Significant at the 0.01 probability level

Means of rows followed by same letters have no significant differences based on Duncan test.

Table 5.

Matrix of coefficients Eigen vectors and variance proportion from the first five principal component axes of 34 components of essential oil of *Mentha piperita*

Variable	PC1	PC2	PC3	PC4	PC5
Myrtenal	0.20	0.09	0.24	-0.05	0.25
β -Bourbonene	0.22	0.04	0.25	0.02	0.09
Myrcene	0.25	0.14	0.13	0.09	-0.07
β -Caryophyllene	0.28	-0.01	-0.05	-0.08	-0.14
Pulegone	0.31	0.03	0.10	-0.07	0.00
Menthone	-0.30	0.02	0.05	0.09	0.09
Menthol	-0.29	0.09	0.03	0.07	0.07
α -Terpinene	-0.29	0.04	0.10	0.11	-0.11
Menthofuran	-0.28	0.03	0.03	0.08	0.14
Limonene	0.16	0.20	-0.18	0.10	-0.18
1-Octanol-3-ol	0.09	0.24	-0.15	-0.23	-0.05
β -Pinene	-0.05	0.31	-0.10	0.14	-0.16
Sabinene	0.02	-0.34	0.01	-0.07	-0.19
Germacren D	-0.08	-0.30	0.11	0.01	0.27
Isomenthone	0.14	-0.29	-0.08	0.09	0.18
Borneol	0.11	-0.28	-0.17	0.12	-0.07
Carvacrol	0.08	-0.25	-0.24	0.13	-0.09
α -Humulen	0.18	-0.25	-0.04	0.08	0.00
Eucalyptol	-0.18	-0.23	-0.07	0.17	-0.16
Isopulegole	-0.07	-0.23	0.11	-0.09	-0.25
Linalool	0.15	-0.11	0.28	0.20	-0.03
α -Pinene	0.18	0.06	0.32	0.04	0.06
Neomenthol	0.15	-0.05	-0.35	-0.03	0.07
α -Phellandrene	0.14	0.16	-0.32	0.04	0.00
Camphene	-0.04	0.16	-0.32	0.06	0.21
γ -Terpinene	0.19	0.06	0.18	0.28	0.01
Carvone	0.07	0.08	-0.05	0.35	-0.20
Menthyl acetate	0.07	-0.06	0.01	-0.40	0.16
Piperitone	0.08	0.01	-0.10	-0.37	0.20
1,8-Cineole	-0.06	0.10	-0.01	-0.31	-0.31
Dihydrocarvyl acetate	-0.14	-0.18	0.06	-0.31	-0.11
Para-cymene	-0.05	0.12	0.17	-0.06	-0.35
Dihydrocarvone	-0.11	0.17	0.18	-0.01	0.25
β -Ocymene	-0.04	0.01	-0.18	0.18	0.33
Eigenvalue	9.77	7.24	5.91	5.42	3.13
Proportion	0.29	0.21	0.17	0.16	0.09
Cumulative	0.29	0.50	0.67	0.83	0.93

The bold and underline coefficients have significant correlation with the relevant axes

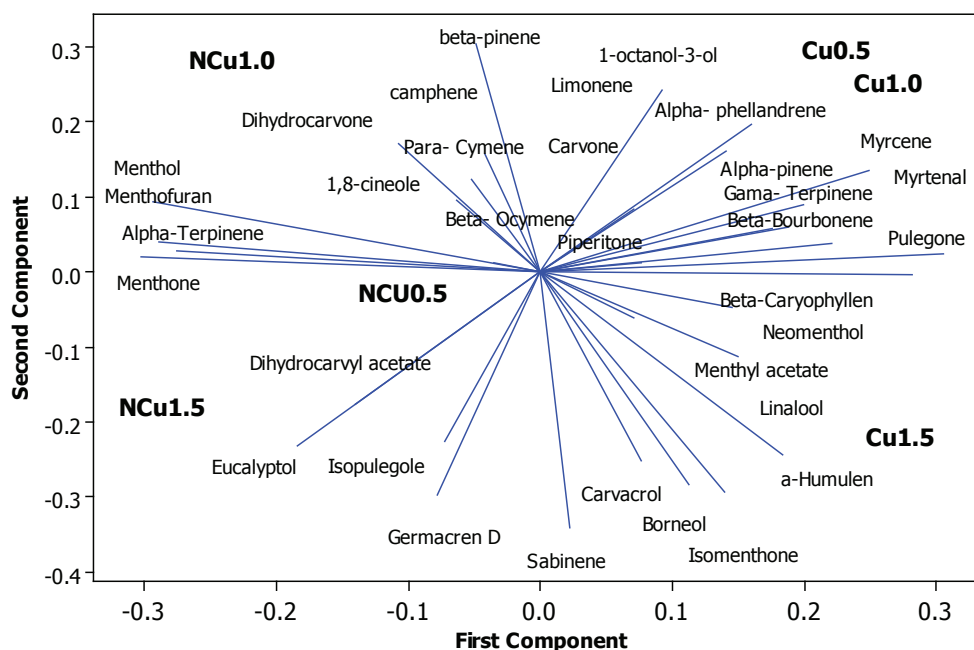


Figure 2.

Scatter plot of 6 treatments and 34 essential oil components vectors for first two PCA

Conflict of interest: Authors declare no conflict of interest.

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Wpływ dolistnego podawania siarczanu miedzi i nanocząstek miedzi na cechy morfologiczne i fizjologiczne oraz na skład olejku eterycznego z mięty pieprzowej (*Mentha piperita* L.)

ZAHRA NEMATI LAFMEJANI¹, ALI ASHRAF JAFARI^{*2}, PEJHMAN MORADI³, ALIREZA LADAN MOGHADAM⁴

¹Department of Horticulture
Islamic Azad University
Science and Research Branch
Tehran, Iran

²Research Institute of Forests and Rangelands
Agricultural Research Education and Extension Organization (AREEO)
Tehran, Iran

³Department of Horticulture
Islamic Azad University
Saveh Branch
Saveh, Iran

⁴Department of Horticulture
Islamic Azad University
Garmsar Branch
Garmsar, Iran

*autor, do którego należy kierować korespondencję: aajafari@rifr-ac.ir

Streszczenie

Wstęp: Mięta pieprzowa (*Mentha piperita* L.) z rodziny *Lamiaceae* jest ważną rośliną leczniczą o wielu zastosowaniach. Miedź jest ważnym mikroelementem niezbędnym do prawidłowego wzrostu i metabolizmu roślin.

Cel: Celem pracy było zbadanie wpływu siarczanu miedzi i nanocząstek miedzi na cechy morfologiczne i fizjologiczne oraz na skład olejku eterycznego mięty pieprzowej.

Metody: Siarczan miedzi i nanocząstki miedzi podawano dolistnie trzykrotnie w odstępie 15 dni aż do fazy kwitnienia. Hodowano także grupę kontrolną w trzech stężeniach (0,5, 1,0 i 1,5 g/l). Badanie przeprowadzono w Karaj w Iranie.

Wyniki: Nanocząstki miedzi (1,0 g/l) spowodowały wzrost zawartości chlorofilu i olejku eterycznego (w %), odpowiednio o 35 i 20% w stosunku do grupy kontrolnej. Siarczan miedzi (0,5 g/l) zwiększał suchą masę surowca o 58% w porównaniu z grupą kontrolną. Wpływ nawożenia był istotny statystycznie w przypadku 17 związków spośród 34 składników olejku. Nanocząstki miedzi (1,0 g/l) zwiększyły zawartość mentolu, mentonu i mentofuranu odpowiednio do 15, 25 i 65% w porównaniu z grupą kontrolną.

Wnioski: Podanie dolistne siarczanu miedzi (0,5 g/l) i nanocząstek miedzi (1,0 g/l) w stadium kwitnienia może powodować zwiększenie produkcji suchej masy surowca oraz wpływać na zawartość i skład olejku eterycznego.

Słowa kluczowe: *olejek eteryczny, barwniki liściowe, plon, spryskiwanie liści, nanocząstki miedzi, Mentha piperita*