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Research Article

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The effects of foliar application of some micronutrient elements on the content and composition of the essential oil of Damask rose (*Rosa damascena* Mill.)

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ABSTRACT- The present study was conducted to investigate the effects of micronutrient elements (Fe, Cu, Zn and Mn) application on the content and composition of essential oil of Damask rose (*Rosa damascena* Mill.) flowers in southwestern Iran (Shahrekord) in 2019 and 2020. Four foliar fertilizers including Librel Fe-Lo, Librel Cu, Librel Zn and Librel Mn were applied as mineral fertilizers. Librel Fe-Lo contains 13.2% chelated iron, Librel Zn is a foliar fertilizer with 14% Zinc in chelated form, Librel Cu has 14% copper in chelated form, and Librel Mn is comprised of 13% Mn chelated with EDTA. Results obtained from gas chromatography/mass spectrometry (GC-MS) showed 36 essential oil components. The highest (0.11-0.14%) and lowest (0.03-0.05%) levels of essential oil content were obtained from combined Fe, Cu, Zn and Mn treatment and control treatment, respectively. Plants treated by the combinations of 40 ppm of micronutrients (Fe3Cu3Zn3Mn3 treatment) and control produced the greatest and lowest amounts in most essential oil components, respectively. The predominant components of the essential oil included oxygenated monoterpenes including beta-citronellol (22.5-28.1%), geraniol (15.1-23.1%), camphor (0.86-2.3%), citronellol (0.4-1.9%), trans-geraniol (0.5-2.1%), together with aliphatic hydrocarbons including nonadecane (11.1-13.3%), pentadecane (3.55-8.9%), and heneicosane (4.5-8.7%). Application higher than 40 ppm of micronutrients, most possibly due to toxicity, lowered both content and composition of essential oil.

INTRODUCTION

Aromatic and volatile products of plant secondary metabolism are used in the pharmaceutical, chemical, cosmetic, and food industries. In recent years, there has been an increasing interest in the use of natural substances due to concerns about the safety of some synthetic compounds, which have encouraged more detailed studies on originated substances (Saint Lari et al., 2016).

Damask rose (*Rosa damascena* Mill.) is a known aromatic plant. It is cultivated in Iran, Turkey, Bulgaria, India, South France, China, South Italy, Libya, South Russia, and Ukraine (Gorji Chakespari et al., 2017). Roses are constantly appreciated because of their inimitable aroma, popularity and visual appeal. In addition to the different Damask rose products (oil, water, concrete, absolute and gulkand), its dried petals are also used for health purposes (Liu et al., 2020; Khaleghi and Khadivi, 2020; Nayebi et al., 2017; Mahboubi, 2015; Hatamian et al., 2015). A large proportion of the essential oil of this plant is monoterpenoids such as geraniol and citronellol and an aromatic compound called phenyl ethyl alcohol with a pleasant odor (Mohammadinasab et al., 2019).

It has been reported that in the production of roses essential oil yield, applications of regulators increased essential oil yield as compared to the control (Aghaei et al., 2019; Bilal et al., 2020; Hamedi et al., 2020). It has also shown that plant growth regulators could enhance fresh flower yield and quality of Damask rose flowers (Thakur and Kumar, 2020). In addition, oil yields were significantly affected by irrigation water quantity and nitrogen levels (Ucar et al., 2016).

When nutrient deficiency cannot be corrected through soil application, foliar nutrition is adopted as an alternate method (Yadegari, 2017a, and 2017b). It has been shown that micronutrients such as Fe, Mn, Zn and Cu are necessary for plant intensification in much lower amounts for plant intensification than those of the primary nutrients (Bilal et al., 2020). There is ample research on the effectiveness of micronutrients on crop plants such as wheat (Aziz et al., 2019), *Borago officinalis*, *Calendula officinalis*, *Thymus vulgaris* and *Alyssum desertorum* (Yadegari, 2017a) and (*Melissa officinalis* L.) (Yadegari, 2017b). However few studies have been conducted on the combinational effect of iron, copper, zinc and manganese fertilizers in Damask rose.

Iron is one of the four essential nutrient elements needed by plants and is a key element in cytochrome

structure. In addition, plants treated with this micronutrient produce more yield (Schönherr et al., 2005).

Copper is another essential microelement in higher plants as it occurs as part of the prosthetic groups of several enzymes. It has been reported that foliar application with this element produces more essential oil in medicinal plants (Yadegari, 2017a, b; Kumar et al., 2016a).

Zinc is a building block of many proteins and an important chemical element in biological activity. Zn acts on enzymatic activation and cell division, so it has been shown that its deficiency causes cell damage, low protein and carbohydrate synthesis, impaired growth and development, and low crop yields (Alamer et al., 2020; Yadegari, 2017a, b; Cakmak et al., 2017; Figueiredo et al., 2017).

Manganese is involved in many biochemical functions, primarily acting as an activator of enzymes such as dehydrogenases and decarboxylases involved in respiration, amino acid and lignin synthesis, and hormone concentrations (Younis et al., 2013).

Foliar fertilization is particularly useful to meet the basic needs of plants for one or more micro- or macro-nutrients, especially trace minerals. It also helps correct deficiencies, strengthen weak or damaged crops, and enhance growth (Aziz et al., 2019).

The aim of this research was to determine the effects of foliar applications of iron, zinc, copper and manganese on essential oil content and composition in Damask rose to introduce the best combination of these micronutrients for better yield in this multipurpose plant.

MATERIALS AND METHODS

Plant Material and Fertilizers

This research was conducted on the accession of "Kashan" of Damask rose (*Rosa damascena* Mill.) which was planted in Shahrekord on 1 May 2016. Spaces between rows and plants were 2 m and 1 m respectively.

Four foliar fertilizers including Librel Fe-Lo, Librel Cu, Librel Zn and Librel Mn were applied and all of them are mineral fertilizers. Librel Fe-Lo contains 13.2% chelated iron, Librel Zn is a foliar fertilizer that contains 14% Zinc in chelated form, Librel Cu has 14% copper in chelated form and Librel Mn contains of 13% Mn chelated with EDTA (obtained from The Chemical Company of England and Germany). Theses fertilizers were sprayed at four concentrations (for example Fe_1, Fe_2, Fe_3, and Fe_4 were concentrations of Fe which had 0, 20, 40 and 60 ppm of Fe, respectively. The concentrations were similar in other micronutrients). The control plants had no any micronutrient foliar application.

Experimental Conditions

To determine the best combination of micronutrients to gain of the highest essential oil content and composition in the *R.damascena* Mill., a randomized complete block design was conducted in April-July 2019-2020 with three replications in the Shahrekord region of Chaharmahal-Bakhtiari Province, southwest of Iran. The soil (Typic calci xerocrepts) physical and chemical properties and climatic properties of the region are listed in Table 1 and Table 2 respectively. The top-soil of the experimental plot area was kept moist throughout the growing season when necessary. After the soil test, the required nutrients were added to the soil. Spraying of micronutrients was performed in three step before the blooming stage at intervals of four days. At the beginning of the blooming stage and before sunrise, the flowers of Damask rose plants were harvested from each treatment separately as discussed by Taheri et al. (2020).

Table 1. Physico-chemical properties of sample soil (0-30 cm) from Shahrekord region in two years

Characters	Year	
	2019	2020
N_{total} (%)	0.15	0.14
Organic matter (%)	0.66	0.59
pH	8.03	7.91
P ($mg \cdot kg^{-1}$)	15.31	14.71
K ($mg \cdot kg^{-1}$)	328	311
Ca ($mg \cdot kg^{-1}$)	4.74	4.91
Mn ($mg \cdot kg^{-1}$)	9.23	8.14
Fe ($mg \cdot kg^{-1}$)	3.12	2.81
Cu ($mg \cdot kg^{-1}$)	0.63	0.61
Zn ($mg \cdot kg^{-1}$)	0.72	0.69
EC ($dS \cdot m^{-1}$)	0.77	0.65
Texture	Clay loam	Clay loam

Preparation of Essential Oil Extraction

Essential oil content was determined by distilling flowers in the Clevenger apparatus. One thousand g of rose flowers was placed in 6 L Clevenger- type distillation apparatus and distilled for 5 h with 3 L of pure water. The quantities of rose oils obtained at the end of distillation, were measured as mL and % ratios (w/w) were determined by multiplying the oil content with oil density i.e., 0.858. The unit of the oil content is g/100 g (fresh weight). All the essential oil samples were dried over hydrous sodium sulphate and stored at 4°C until analyzed by gas chromatography (GC) and gas chromatography–mass spectrometry (GC–MS) analysis.

Ground GC analysis was done on an Agilent Technologies 7890 GC equipped with FID and an HP-5MS 5% capillary column. The carrier gas was helium at a flow of 0.8 mL/min. The initial column temperature was 60°C and programmed to increase at 4°C/min to 280°C. The split ratio was 40:1. The injector temperature was set at 300°C. The purity of helium gas was 99.99% and 0.1 mL of each sample was injected manually in the split mode.

Table 2. Climatic properties of Shahrekord region.

Average annual precipitation (mm)	Average of annual temperature (ºC)	Average maximum temperature (ºC)	Average minimum temperature (ºC)	Height (m)	Latitude and longitude
380	11.7	23.9	-1.8	2060	$32^0 19'$N-$50^0 51'$E

GC–MS analyses were carried out on a Thermo Finnigan Trace 2000 GC-MS system equipped with an HP-5MS capillary column (30 m×0.25 mm i.d., film thickness 0.25 μm). The oven temperature was held at 120°C for 5 min and then programmed to reach 280°C at a rate of 10°C/min. The detector temperature was 260°C and the injector temperature was 260°C. The compositions of the essential oil were identified by comparison of their retention indices relative to a series of *n*-alkanes (C7-C24), retention times and mass spectra with those of authentic samples in Wiley library (Adams, 2007; Shamspur and Mostafavi, 2010).

Data Analysis

All data were subjected to ANOVA and simple Pearson correlation indices using the statistical computer package SAS v.9 and treatment means separated using LSD's multiple range test at P <0.05 and P <0.01 levels.

RESULTS

The results obtained from GC-MS indicated the presence of 36 components in the essential oil of *R.damascena* and in this regard, significant differences in chemical compositions of rose essential oil were observed between treatments (Table 3). Although in some main treatments such as foliar application of Cu and Mn, no significant difference in chemical compositions of rose essential oil was found, however, in combined treatments there were differences in most compositions of essential oil and in this regard, the $Fe_3Cu_3Mn_3Zn_3$ treatment was the best treatment (Tables 4-9).

The main components in the essential oil of all plants treated by micronutrients included beta-citronellol, geraniol, nonadecane, camphor, citronellol, trans-geraniol, pentadecane and heneicosane. The highest amount of beta-citronellol (27.5-28.1%), geraniol (23.1-22.9%), nonadecane (13.3-12.9%), camphor (2.1-2.3%), citronellol (1.4-1.9%), trans-geraniol (1.8-2.1%), pentadecane (8.9-8.1%), and heneicosane (8.5-8.7%) in Damask rose obtained by 40 ppm of micronutrients foliar application in two cultivation seasons. The lowest amount of beta-citronellol (22.5-23.1%), geraniol (15.1-16.2%) and nonadecane (11.1-11.5%), camphor (0.9-1.1%), citronellol (0.4-0.7%), trans-geraniol (0.5-0.7%), pentadecane (3.55-4.1%), and heneicosane (4.5-5.1%) in Damask rose obtained from control plants in two cultivation seasons. Also. the highest (0.11-0.14%) and lowest (0.03-0.05%) levels of essential oil content were obtained with Fe, Cu, Zn and Mn micronutrient applications and control treatment, respectively (Tables 4-9).

Comparing the data from two years of experiment, there were positive correlations between essential oil content and main components and a high correlation was observed between essential oil content and beta-citronellol (Table 10). The application of concentrations of 20 ppm micronutrients improved most of the content and compositions of components but at-higher concentrations (i.e. 60 ppm), the content and compositions in all treated plants were decreased. The mean content (%) of many chemical compositions in Damask rose was lower than those of the control treatment when the plants were sprayed with concentrations of 60 ppm. It seems that the content and composition of essential oil were more affected by Zn and Fe compared to other micronutrients (Tables 4-9).

In this study, the effects of the micronutrients during two experimental years, and their interaction significantly (P≤0.01) influenced the essential oil content and composition of *R. damascena* (Table 3).

Table 3. Complex analysis of variance of variation of essential oil content and main compositions in *R.damascena* Mill. by different micronutrients

SOV[z]	df[y]	Geraniol	Citronellol	Nonadecane	Trans-geraniol	Camphor	Heneicosane	Pentadecane	β-citronellol	Essential oil
Year(Y)	1	12.7	0.008	7.2	7.7	1.4	2.7	1.1	7.8	0.003
R/Y	4	14.4	0.009	4.3	6.7	1.1	3.8	2.1	5.8	0.004
Copper (Cu)	3	112.1**	0.11**	5.1*	2.5^{ns}	1.9*	4.8*	1.3^{ns}	6.1*	0.00005^{ns}
Manganese (Mn)	3	55.2**	0.15**	4.4*	2.6^{ns}	1.6^{ns}	2.8^{ns}	1.1^{ns}	3.3^{ns}	0.00004^{ns}
Iron (Fe)	3	45.9*	0.004*	2.7^{ns}	2.8^{ns}	1.8^{ns}	2.9^{ns}	1.4^{ns}	2.8^{ns}	0.00005^{ns}
Zinc (Zn)	3	9.2^{ns}	0.0029*	2.9^{ns}	2.6^{ns}	1.5^{ns}	2.3^{ns}	1.9^{ns}	3.3^{ns}	0.00007^{ns}
Cu×Mn	9	544.2**	0.09**	4.4*	2.9*	1.1^{ns}	3.8*	2.8*	9.2**	0.00014*
Cu×Fe	9	22.4^{ns}	0.07**	8.9**	6.8**	1.4*	3.9*	5.4**	4.9*	0.0088**
Cu×Zn	9	234.86**	0.0021**	8.7**	3.1*	3.3**	7.8**	2.1*	4.52*	0.00011*
Mn×Fe	9	267.1**	0.003*	9.1**	7.9**	1.9*	7.7**	4.1**	11.9**	0.026**
Mn×Zn	9	29.1**	0.003*	10.7**	2.8*	4.9**	3.7*	4.9**	10.9**	0.000082*
Fe×Zn	9	77.4**	0.42**	3.8*	10.1**	3.9**	3.5*	3.2*	12.2**	0.000093*
Cu×Mn×Fe	27	19.1*	0.002*	1.91*	2.5*	1.4*	1.94*	7.8**	4.2*	0.00011*
Cu×Mn×Zn	27	59.6**	0.9**	14.6**	10.8**	6.1**	2.4*	1.9*	15.9**	0.071**
Cu×Fe×Zn	27	20.22*	0.92**	14.7**	2.4*	1.9*	10.2**	7.9**	14.4**	0.00008*
Fe×Zn×Mn	27	96.6**	0.94**	1.9*	15.6**	1.7*	2.1*	1.8*	3.7*	0.061**
Cu×Zn×Mn×Fe	81	14.9*	0.001*	1.7*	1.9*	1.1*	1.8*	1.9*	2.9*	0.00008*
T(Cu,Zn,Mn,Fe)×Y	255	2.9*	0.0004*	0.5*	0.5*	0.22*	0.3*	0.28*	0.7*	0.000011*
E	1020	11.95	0.002	1.5	1.3	0.88	1.1	1.4	1.9	0.00006
CV[x]		2.2	3.3	7.7	9.7	8.1	4.5	8.8	3.3	1.8

[z] SOV: source of variation, [y]df: degree of freedom, [x]CV: coefficient of variation, *, ** significant at P=0.05 and P=0.01 levels of probability respectively.

Table 4. Means of chemical composition (%) in Damask rose plants affected by 20 ppm concentration of micronutrients ((1st year).

No.	Compound	RI [z]	Fe	Zn	Cu	Mn	Fe×Zn	Cu×Fe	Mn×Fe	Cu×Zn	Mn×Zn	Cu×Mn	Cu×Fe×Zn	Fe×Zn×Mn	Cu×Mn×Fe	Cu×Mn×Zn	Cu×Zn×Mn×Fe
1	Linalool	1099	0.8±0.01[y]	0.4±0.02	0.3±0.03	0.02±0.02	0.02±0.08	0.4±0.02	0.9±0.02	0.4±0.01	0.5±0.01	0.1±0.02	0.2±0.02	0.1±0.02	0.04±0.02	0.03±0.02	0.1±0.02
2	Sic-rose oxide	1101	0.05±0.02	0.6±0.01	0.3±0.02	0.04±0.01	0.029±0.003	0.3±0.01	0.85±0.01	0.7±0.05	0.4±0.02	0.8±0.01	0.7±0.02	0.1±0.02	0.01±0.02	0.01±0.02	0.1±0.03
3	Rose oxide trans	1102	0.6±0.01	0.48±0.02	0.3±0.02	0.03±0.01	0.03±0.007	0.99±0.1	0.7±0.01	0.4±0.02	0.3±0.02	0.5±0.01	0.8±0.01	0.1±0.01	0.01±0.01	0.03±0.02	0.02±0.01
4	Benzene ethanol	1103	0.6±0.02	0.4±0.01	0.3±0.02	0.6±0.02	0.04±0.003	0.9±0.1	0.7±0.01	0.3±0.05	0.5±0.01	0.5±0.01	0.8±0.01	0.1±0.01	0.04±0.02	0.05±0.01	0.1±0.02
5	Trans-rose oxide	1104	0.06±0.02	0.55±0.03	0.44±0.01	0.42±0.01	0.5±0.08	1.1±0.1	0.1±0.01	0.1±0.03	0.2±0.02	0.6±0.01	0.7±0.02	0.8±0.03	0.02±0.01	0.03±0.01	0.4±0.01
6	**Camphor**	**1145**	**0.88±0.02**	**0.88±0.01**	**0.89±0.01**	**0.9±0.02**	**0.97±0.02**	**0.96±0.01**	**0.98±0.02**	**0.98±0.01**	**0.98±0.02**	**0.89±0.02**	**0.89±0.2**	**1.01±0.01**	**0.9±0.02**	**1.7±0.01**	**1.99±0.04**
7	**β-citronellol**	**1210**	**22.6±0.5**	**23.1±1.1**	**23.1±1.1**	**24.3±1.1**	**26.42±1.1**	**26.5±0.2**	**23.9±0.01**	**25.5±0.5**	**22.9±1.1**	**24.4±0.5**	**25.1±0.5**	**24.9±0.9**	**25.9±0.9**	**25.8±0.8**	**27.1±0.1**
8	**Citronellol**	**1228**	**0.6±0.02**	**0.55±0.01**	**0.79±0.2**	**0.73±0.02**	**0.8±0.01**	**0.7±0.1**	**1.1±0.01**	**0.9±0.05**	**1.1±0.1**	**0.7±0.1**	**0.9±0.01**	**0.77±0.01**	**0.55±0.01**	**1.2±0.01**	**1.3±0.2**
9	Z-citral	1238	0.8±0.02	0.7±0.03	0.5±0.03	0.6±0.02	0.4±0.03	1.3±0.01	1.1±0.09	0.8±0.03	0.5±0.03	0.6±0.03	0.6±0.01	0.9±0.02	0.6±0.02	0.5±0.01	0.4±0.02
10	**Trans-geraniol**	**1248**	**0.9±0.2**	**1.1±0.01**	**0.82±0.01**	**1.3±0.09**	**0.7±0.02**	**0.8±0.1**	**0.8±0.1**	**1.1±0.05**	**1.1±0.3**	**1.5±0.2**	**1.1±0.4**	**0.8±0.2**	**1.1±0.02**	**1.3±0.01**	**1.6±0.2**
11	**Geraniol**	**1252**	**16.1±0.02**	**15.5±0.5**	**14.9±0.2**	**16.1±0.04**	**15.5±0.9**	**17.9±0.1**	**16.9±0.1**	**17.9±0.3**	**18.9±0.02**	**18.8±0.5**	**18.8±0.3**	**19.2±0.5**	**20.7±0.7**	**21.9±0.7**	**22.9±0.5**
12	Citronellyl propionate	1271	0.8±0.01	0.7±0.04	0.1±0.02	0.66±0.01	0.8±0.04	1.2±0.02	0.99±0.01	0.8±0.02	0.7±0.01	0.54±0.01	0.6±0.02	0.1±0.01	0.4±0.02	0.7±0.01	0.5±0.03
13	E-citral	1302	0.8±0.01	0.05±0.01	0.1±0.02	0.91±0.01	0.9±0.04	0.6±0.01	0.1±0.02	0.8±0.02	0.9±0.03	0.5±0.01	0.5±0.02	0.5±0.02	0.4±0.04	0.8±0.01	0.1±0.02
14	Citronellol-acetate	1352	0.8±0.02	0.7±0.02	0.8±0.01	0.7±0.02	0.7±0.08	0.4±0.01	0.1±0.01	0.5±0.01	0.2±0.02	0.5±0.01	0.6±0.01	0.6±0.01	0.8±0.02	0.8±0.07	0.7±0.1
15	Methyl eugenol	1400	0.7±0.1	0.7±0.02	0.77±0.02	0.8±0.01	0.6±0.08	0.8±0.02	0.1±0.02	0.8±0.02	0.4±0.02	0.4±0.01	0.6±0.02	0.5±0.02	0.9±0.09	0.7±0.01	0.7±0.01
16	**Pentadecane**	**1500**	**4.7±0.01**	**3.9±0.001**	**3.88±0.04**	**4.6±0.02**	**5.1±0.01**	**5.1±0.09**	**4.9±0.01**	**5.3±0.01**	**4.9±0.02**	**4.9±0.01**	**4.9±0.01**	**5.9±0.2**	**7.3±0.2**	**8.5±0.2**	**8.5±0.2**
17	Phenol	1572	0.7±0.09	0.7±0.01	0.6±0.01	0.5±0.02	0.77±0.01	0.9±0.02	1.1±0.01	0.7±0.03	0.8±0.02	0.3±0.01	0.6±0.01	0.2±0.01	0.8±0.02	0.7±0.01	0.6±0.02
18	Lavandulyl acetate	1579	0.7±0.01	0.7±0.01	0.6±0.08	0.44±0.1	0.66±0.01	1.1±0.04	0.1±0.02	0.5±0.02	0.8±0.02	0.2±0.01	0.5±0.03	0.8±0.02	0.7±0.01	0.7±0.02	0.6±0.09
19	Benzene	1584	0.8±0.01	0.1±0.01	0.6±0.1	0.3±0.02	0.2±0.01	0.8±0.01	0.2±0.02	0.3±0.02	0.8±0.01	0.2±0.02	0.7±0.02	1.2±0.01	0.2±0.001	0.3±0.01	0.7±0.02
20	3,4-Dihydrocoumarin	1586	0.05±0.02	0.6±0.01	0.6±0.02	0.4±0.01	0.6±0.08	1.3±0.01	0.5±0.01	0.5±0.02	0.9±0.1	0.7±0.01	0.7±0.05	0.9±0.01	0.7±0.02	0.1±0.01	0.1±0.01
21	Germacrene D	1598	0.8±0.01	0.1±0.02	0.65±0.03	0.33±0.01	0.4±0.02	0.1±0.02	0.6±0.02	0.6±0.02	0.4±0.03	0.6±0.03	0.5±0.02	0.8±0.01	0.4±0.01	0.5±0.01	0.6±0.01
22	Hexadecane	1600	0.8±0.01	0.8±0.01	0.7±0.01	0.7±0.01	0.7±0.01	0.2±0.01	0.9±0.02	1.1±0.01	0.8±0.1	0.7±0.02	0.7±0.001	0.7±0.02	0.5±0.01	0.1±0.01	0.1±0.01
23	α-farnesene	1611	0.8±0.02	0.2±0.02	0.6±0.02	0.4±0.01	0.6±0.01	0.1±0.03	0.2±0.01	0.5±0.02	0.5±0.01	0.6±0.03	0.4±0.02	0.8±0.01	0.3±0.01	0.7±0.02	0.3±0.01
24	Delta 3-Carene	1623	0.5±0.01	0.6±0.01	0.44±0.01	0.5±0.01	0.43±0.03	1.1±0.01	0.9±0.02	1.3±0.03	0.8±0.02	0.8±0.02	0.4±0.01	0.6±0.01	0.8±0.02	0.7±0.001	0.5±0.01
25	8-Heptadecene	1633	0.8±0.02	0.6±0.01	0.14±0.01	0.7±0.01	0.66±0.01	0.9±0.02	1.1±0.01	0.7±0.02	0.7±0.01	0.6±0.03	0.8±0.01	0.1±0.01	0.4±0.01	0.2±0.01	0.4±0.03
26	N-Octadecane	1655	0.8±0.02	0.6±0.01	0.1±0.01	0.81±0.03	0.5±0.01	1.2±0.03	0.8±0.01	0.3±0.03	0.4±0.02	0.5±0.01	0.8±0.01	0.7±0.02	0.8±0.01	0.3±0.02	0.3±0.01
27	Heptadecene	1672	0.06±0.01	0.7±0.02	0.6±0.1	0.2±0.01	0.7±0.02	0.2±0.01	0.8±0.07	0.7±0.01	0.8±0.05	0.7±0.2	0.8±0.1	0.1±0.01	0.1±0.02	0.1±0.01	0.2±0.01
28	D-Nerolidol	1691	0.9±0.02	0.6±0.02	0.71±0.01	0.5±0.01	0.75±0.03	0.9±0.01	0.7±0.01	0.7±0.02	0.8±0.02	0.6±0.03	0.7±0.02	0.2±0.02	0.4±0.01	0.1±0.01	0.1±0.07
29	Farnesol 3	1709	0.6±0.01	0.1±0.01	0.3±0.01	0.6±0.01	0.62±0.01	0.95±0.02	0.2±0.02	0.8±0.01	0.4±0.02	0.1±0.01	0.1±0.02	0.2±0.01	0.3±0.01	0.2±0.01	0.1±0.01
30	Benzyl Benzoate	1759	0.8±0.01	0.5±0.01	0.4±0.02	0.42±0.01	0.77±0.03	0.95±0.02	0.1±0.01	0.1±0.01	0.1±0.06	0.2±0.01	0.7±0.01	0.1±0.001	0.8±0.02	0.2±0.02	0.4±0.01
31	Octadecane	1800	0.7±0.01	0.5±0.01	0.7±0.01	0.6±0.02	0.7±0.1	0.85±0.03	0.9±0.01	0.7±0.01	0.1±0.02	0.3±0.01	0.5±0.01	0.1±0.01	0.5±0.01	0.1±0.01	0.1±0.01
32	1-Heptadecene	1859	0.8±0.01	0.3±0.05	0.66±0.03	0.5±0.01	0.61±0.01	0.9±0.02	0.4±0.01	0.9±0.02	0.2±0.01	0.2±0.01	0.5±0.02	0.6±0.02	0.1±0.02	0.1±0.01	0.6±0.08
33	**Nonadecane**	**1900**	**11.1±0.4**	**11.2±0.4**	**11.5±0.5**	**11.7±0.02**	**11.2±0.02**	**11.2±0.2**	**11.4±0.3**	**11.4±0.4**	**11.3±0.3**	**11.3±0.6**	**11.1±0.8**	**12.1±0.5**	**11.9±0.9**	**12.5±0.2**	**13.1±0.5**
34	N-nonadecane	1901	0.5±0.01	0.5±0.01	0.5±0.02	0.2±0.01	0.62±0.01	1.8±0.02	0.9±0.02	0.7±0.02	0.6±0.01	0.4±0.01	0.1±0.01	0.8±0.01	0.1±0.01	0.1±0.01	0.1±0.01
35	Eicosane	2000	0.6±0.01	0.5±0.02	0.4±0.01	0.6±0.01	0.52±0.1	1.1±0.02	0.5±0.1	0.3±0.02	0.4±0.03	0.6±0.1	0.1±0.02	0.7±0.01	0.1±0.01	0.1±0.04	0.1±0.01
36	**Heneicosane**	**2109**	**5.2±0.1**	**5.9±0.05**	**7.2±0.1**	**7.7±0.02**	**7.1±0.18**	**7.5±0.2**	**7.5±0.1**	**7.2±0.3**	**7.3±0.1**	**7.9±0.3**	**5.9±0.1**	**7.5±0.2**	**7.4±0.3**	**7.5±0.5**	**8.1±0.2**
Total			79.8±1.71	76.11±2.5	76.29±1.9	80.81±1.5	82.62±1.1	93.1±1.9	83.02±1.5	87.28±1.2	81.78±1.8	83.73±1.8	82.19±2.5	85.58±1.4	86.97±1.5	89.35±1.1	93.61±2.3
Essential oil content (w/w%, g/100g fresh weight basis)			0.05±0.01	0.041±0.01	0.04±0.001	0.058±0.001	0.07±0.04	0.07±0.01	0.03±0.02	0.06±0.02	0.05±0.03	0.07±0.01	0.07±0.002	0.081±0.01	0.08±0.01	0.09±0.01	0.092±0.01

[z] RI: Retention Indices, as determined with FID and HP-5MS 5% capillary column using a series of the standards of C7-C30 saturated n-alkanes. [y] Values are means of triplicates ± standard deviation (p <0.05)

Table 5. Means of chemical composition (%) in Damask rose plants affected by 20 ppm concentration of micronutrients (2nd year)

No.	Compound	RI [z]	Fe	Zn	Cu	Mn	Fe×Zn	Cu×Fe	Mn×Fe	Cu×Zn	Mn×Zn	Cu×Mn	Cu×Fe×Zn	Fe×Zn×Mn	Cu×Mn×Fe	Cu×Mn×Zn	Cu×Zn×Mn×Fe
1	Linalool	1099	0.7±0.03[y]	0.42±0.02	0.4±0.01	0.1±0.03	0.1±0.01	0.5±0.01	0.8±0.01	0.5±0.02	0.6±0.02	0.2±0.01	0.3±0.01	0.2±0.01	0.1±0.01	0.1±0.01	0.2±0.01
2	Sic-rose oxide	1101	0.15±0.01	0.6±0.02	0.4±0.01	0.1±0.03	0.1±0.02	0.4±0.01	0.8±0.01	0.5±0.02	0.4±0.01	0.8±0.02	0.7±0.02	0.2±0.01	0.1±0.01	0.1±0.01	0.2±0.01
3	Rose oxide trans	1102	0.5±0.01	0.4±0.02	0.3±0.02	0.1±0.03	0.1±0.07	0.9±0.1	0.8±0.02	0.4±0.02	0.6±0.02	0.6±0.01	0.9±0.01	0.6±0.01	0.1±0.02	0.1±0.01	0.1±0.02
4	Benzene ethanol	1103	0.5±0.02	0.5±0.01	0.4±0.02	0.5±0.02	0.1±0.01	0.8±0.1	0.7±0.01	0.5±0.05	0.5±0.01	0.5±0.01	0.8±0.01	0.1±0.01	0.1±0.01	0.1±0.01	0.2±0.01
5	Trans-rose oxide	1104	0.16±0.01	0.6±0.03	0.4±0.02	0.4±0.01	0.5±0.02	0.8±0.09	0.3±0.01	0.4±0.03	0.4±0.02	0.7±0.02	0.9±0.01	0.9±0.02	0.3±0.01	0.1±0.02	0.5±0.01
6	**Camphor**	**1145**	**0.88±0.02**	**1.1±0.01**	**1.1±0.01**	**1.09±0.01**	**1.02±0.02**	**1.03±0.02**	**1.2±0.01**	**1.2±0.02**	**1.1±0.01**	**1.2±0.03**	**1.2±0.3**	**1.12±0.02**	**1.2±0.04**	**1.8±0.01**	**2.01±0.05**
7	**β-citronellol**	**1210**	**22.6±0.4**	**23.2±1.5**	**23.2±1.4**	**24.4±1.5**	**26.51±1.4**	**26.7±0.4**	**23.8±0.7**	**25.8±0.8**	**23.7±1.6**	**24.9±0.8**	**25.8±0.6**	**25.3±0.6**	**26.2±0.6**	**25.9±0.9**	**27.5±0.5**
8	**Citronellol**	**1228**	**0.71±0.02**	**0.8±0.01**	**0.79±0.2**	**0.75±0.03**	**0.83±0.02**	**0.77±0.02**	**0.9±0.02**	**0.92±0.1**	**1.2±0.2**	**0.9.2**	**0.92±0.1**	**0.81±0.01**	**0.83±0.1**	**1.21±0.1**	**1.34±0.2**
9	Z-citral	1238	0.9±0.02	0.8±0.01	0.6±0.02	0.5±0.03	0.5±0.02	0.9±0.02	0.8±0.01	0.9±0.03	0.6±0.01	0.7±0.02	0.7±0.02	0.9±0.01	0.6±0.02	0.5±0.02	0.5±0.01
10	**Trans-geraniol**	**1248**	**0.81±0.1**	**1.03±0.02**	**0.8±0.02**	**1.4±0.1**	**0.8±0.1**	**0.82±0.1**	**0.84±0.1**	**1.2±0.1**	**1.2±0.4**	**1.4±0.2**	**1.2±0.3**	**1.3±0.3**	**1.4±0.1**	**1.4±0.1**	**1.61±0.3**
11	**Geraniol**	**1252**	**16.5±0.1**	**16.3±0.7**	**16.3±0.3**	**16.3±0.1**	**16.5±0.3**	**17.5±0.3**	**16.8±0.2**	**17.8±0.4**	**18.8±0.1**	**18.9±0.7**	**18.9±0.5**	**19.5±0.7**	**20.9±0.8**	**22.1±0.9**	**23.1±0.4**
12	Citronellyl propionate	1271	0.8±0.01	0.7±0.01	0.1±0.02	0.6±0.01	0.9±0.04	1.1±0.01	0.9±0.01	0.9±0.02	0.7±0.01	0.7±0.02	0.6±0.02	0.3±0.01	0.5±0.01	0.7±0.01	0.6±0.02
13	E-citral	1302	0.8±0.02	0.1±0.01	0.2±0.02	0.9±0.02	0.9±0.04	0.7±0.01	0.3±0.01	0.8±0.01	0.9±0.03	0.5±0.01	0.5±0.02	0.5±0.02	0.4±0.04	0.8±0.01	0.1±0.02
14	Citronellol-acetate	1352	0.9±0.02	0.7±0.02	0.8±0.02	0.7±0.02	0.7±0.02	0.6±0.02	0.5±0.01	0.7±0.01	0.2±0.02	0.5±0.02	0.7±0.02	0.7±0.02	0.8±0.02	0.8±0.01	0.7±0.1
15	Methyl eugenol	1400	0.8±0.09	0.8±0.01	0.8±0.02	0.9±0.01	0.8±0.08	0.8±0.02	0.5±0.01	0.9±0.02	0.5±0.01	0.6±0.01	0.6±0.02	0.5±0.02	0.9±0.01	0.9±0.01	0.8±0.02
16	**Pentadecane**	**1500**	**4.55±0.1**	**4.1±0.1**	**4.1±0.1**	**4.62±0.1**	**5.2±0.1**	**5.2±0.1**	**4.8±0.1**	**5.2±0.1**	**5.1±0.1**	**5.1±0.1**	**4.92±0.1**	**5.8±0.3**	**7.2±0.3**	**8.4±0.3**	**8.8±0.3**
17	Phenol	1572	0.7±0.03	0.7±0.02	0.7±0.01	0.6±0.01	0.8±0.02	0.9±0.02	0.9±0.01	0.7±0.01	0.8±0.02	0.3±0.01	0.6±0.02	0.7±0.02	0.5±0.02	0.7±0.01	0.7±0.01
18	Lavandulyl acetate	1579	0.7±0.01	0.8±0.01	0.6±0.08	0.5±0.08	0.7±0.01	0.8±0.02	0.1±0.02	0.6±0.01	0.9±0.01	0.5±0.02	0.7±0.03	0.8±0.02	0.7±0.01	0.7±0.01	0.6±0.02
19	Benzene	1584	0.9±0.01	0.1±0.02	0.7±0.09	0.3±0.02	0.2±0.01	0.8±0.01	0.2±0.01	0.3±0.02	0.8±0.01	0.2±0.02	0.7±0.02	0.9±0.02	0.2±0.01	0.3±0.01	0.7±0.01
20	3,4-Dihydrocoumarin	1586	0.1±0.03	0.7±0.01	0.6±0.02	0.4±0.02	0.6±0.02	0.8±0.02	0.7±0.01	0.6±0.02	0.9±0.1	0.7±0.01	0.7±0.02	0.9±0.01	0.9±0.02	0.1±0.01	0.4±0.01
21	Germacrene D	1598	0.8±0.01	0.2±0.01	0.8±0.03	0.3±0.01	0.5±0.02	0.1±0.02	0.6±0.02	0.6±0.01	0.6±0.03	0.7±0.03	0.7±0.02	0.8±0.01	0.4±0.01	0.5±0.01	0.6±0.01
22	Hexadecane	1600	0.9±0.01	0.8±0.01	0.7±0.02	0.7±0.01	0.7±0.01	0.2±0.01	0.8±0.01	0.9±0.01	0.8±0.09	0.7±0.01	0.7±0.001	0.8±0.01	0.5±0.02	0.1±0.01	0.4±0.02
23	α-farnesene	1611	0.8±0.01	0.3±0.02	0.6±0.02	0.5±0.02	0.6±0.02	0.1±0.01	0.2±0.01	0.5±0.02	0.5±0.01	0.6±0.03	0.4±0.02	0.8±0.01	0.9±0.01	0.9±0.01	0.3±0.01
24	Delta 3-Carene	1623	0.5±0.01	0.6±0.02	0.4±0.01	0.5±0.01	0.5±0.03	0.9±0.01	0.9±0.02	0.89±0.03	0.9±0.02	0.8±0.02	0.5±0.02	0.6±0.01	0.8±0.02	0.7±0.001	0.5±0.01
25	8-Heptadecene	1633	0.9±0.02	0.6±0.01	0.2±0.02	0.8±0.01	0.7±0.01	0.9±0.02	0.9±0.02	0.7±0.03	0.7±0.01	0.7±0.02	0.8±0.01	0.2±0.02	0.4±0.02	0.2±0.01	0.6±0.02
26	N-Octadecane	1655	0.8±0.01	0.7±0.01	0.2±0.01	0.8±0.02	0.5±0.02	0.8±0.01	0.8±0.01	0.3±0.03	0.4±0.02	0.5±0.01	0.8±0.01	0.7±0.02	0.8±0.01	0.3±0.01	0.3±0.01
27	Heptadecene	1672	0.1±0.01	0.7±0.01	0.6±0.1	0.2±0.01	0.7±0.02	0.2±0.01	0.8±0.07	0.7±0.01	0.9±0.01	0.7±0.2	0.8±0.09	0.1±0.01	0.1±0.02	0.6±0.01	0.2±0.01
28	D-Nerolidol	1691	0.9±0.02	0.6±0.02	0.7±0.02	0.6±0.01	0.7±0.03	0.9±0.01	0.8±0.02	0.7±0.02	0.8±0.02	0.6±0.03	0.8±0.02	0.5±0.01	0.4±0.01	0.1±0.01	0.5±0.02
29	Farnesol 3	1709	0.6±0.02	0.3±0.01	0.3±0.01	0.6±0.02	0.6±0.02	0.9±0.01	0.2±0.02	0.8±0.01	0.4±0.02	0.2±0.02	0.5±0.02	0.2±0.01	0.3±0.02	0.2±0.01	0.1±0.01
30	Benzyl Benzoate	1759	0.8±0.01	0.5±0.02	0.5±0.02	0.4±0.01	0.8±0.03	0.9±0.02	0.4±0.01	0.3±0.01	0.4±0.01	0.2±0.01	0.7±0.01	0.1±0.001	0.8±0.02	0.8±0.02	0.6±0.01
31	Octadecane	1800	0.9±0.01	0.6±0.01	0.7±0.01	0.6±0.02	0.7±0.1	0.8±0.03	0.8±0.02	0.7±0.02	0.1±0.02	0.3±0.01	0.5±0.02	0.4±0.01	0.7±0.01	0.1±0.02	0.4±0.02
32	1-Heptadecene	1859	0.8±0.02	0.3±0.01	0.7±0.02	0.7±0.02	0.6±0.02	0.9±0.01	0.4±0.01	0.5±0.02	0.2±0.01	0.3±0.02	0.6±0.02	0.6±0.04	0.5±0.02	0.5±0.01	0.6±0.08
33	**Nonadecane**	**1900**	**11.62±0.3**	**11.5±0.5**	**11.6±0.6**	**11.8±0.1**	**11.5±0.1**	**11.5±0.4**	**11.6±0.5**	**11.7±0.6**	**11.6±0.4**	**11.8±0.6**	**11.6±0.9**	**12.2±0.6**	**11.9±0.5**	**12.4±0.4**	**13.3±0.3**
34	N-nonadecane	1901	0.5±0.01	0.6±0.01	0.5±0.02	0.3±0.01	0.6±0.01	1.9±0.02	0.8±0.02	0.7±0.02	0.6±0.01	0.4±0.01	0.4±0.02	0.9±0.01	0.4±0.01	0.1±0.01	0.5±0.01
35	Eicosane	2000	0.6±0.01	0.5±0.01	0.5±0.01	0.6±0.02	0.52±0.09	1.2±0.01	0.5±0.2	0.5±0.01	0.6±0.01	0.7±0.1	0.4±0.02	0.7±0.02	0.4±0.01	0.5±0.01	0.1±0.02
36	**Heneicosane**	**2109**	**5.2±0.3**	**5.8±0.1**	**6.6±0.4**	**7.5±0.1**	**7.3±0.3**	**7.3±0.4**	**7.6±0.3**	**7.4±0.4**	**7.5±0.2**	**7.92±0.4**	**7.2±0.2**	**7.52±0.3**	**7.5±0.5**	**7.3±0.6**	**8.4±0.4**
Total			81.38±1.8	77.87±3.3	78.89±2.2	82.06±1.4	85.38±1.5	93.32±2.1	84.74±1.7	88.71±1.5	84.9±2.2	87.02±2.4	89.74±2.6	89.15±1.8	90.73±1.9	92.11±1.4	98.06±2.7
Essential oil content (w/w%, g/100g fresh weight basis)			0.061±0.002	0.055±0.002	0.052±0.001	0.06±0.001	0.069±0.005	0.071±0.01	0.06±0.02	0.06±0.03	0.07±0.04	0.07±0.01	0.07±0.003	0.084±0.03	0.086±0.002	0.092±0.001	0.097±0.001

[z] RI: Retention Indices, as determined with FID and HP-5MS 5% capillary column using a series of the standards of C7-C30 saturated n-alkanes. [y] Values are means of triplicates ± standard deviation (p <0.05)

Table 6. Means of chemical composition (%) in Damask rose plants affected by 40 ppm concentration of micronutrients and control plants (1st year).

No.	Compound	RI [z]	Fe	Zn	Cu	Mn	Fe×Zn	Cu×Fe	Mn×Fe	Cu×Zn	Mn×Zn	Cu×Mn	Cu×Fe×Zn	Fe×Zn×Mn	Cu×Mn×Fe	Cu×Mn×Zn	Cu×Zn×Mn×Fe	Control
1	Linalool	1099	0.91±0.01[y]	0.42±0.01	0.41±0.01	0.03±0.01	0.021±0.08	0.44±0.1	0.92±0.01	0.41±0.02	0.6±0.01	0.2±0.01	0.3±0.01	0.1±0.01	0.05±0.01	0.04±0.01	0.12±0.01	0.1±0.02
2	Sic-rose oxide	1101	0.08±0.03	0.61±0.02	0.5±0.07	0.04±0.01	0.03±0.003	0.33±0.05	0.88±0.01	0.72±0.05	0.5±0.09	0.9±0.01	0.8±0.005	0.2±0.01	0.02±0.01	0.01±0.03	0.1±0.03	0.01±0.01
3	Rose oxide trans	1102	0.7±0.01	0.51±0.02	0.3±0.02	0.07±0.002	0.03±0.007	1.1±0.1	0.72±0.09	0.45±0.04	0.4±0.01	0.6±0.01	0.9±0.01	0.1±0.01	0.02±0.01	0.04±0.01	0.01±0.01	0.01±0.01
4	Benzene ethanol	1103	0.61±0.02	0.51±0.02	0.33±0.01	0.6±0.04	0.04±0.003	1.1±0.01	0.71±0.01	0.3±0.05	0.6±0.01	0.5±0.02	0.8±0.01	0.05±0.02	0.05±0.03	0.06±0.01	0.2±0.02	0.03±0.01
5	Trans-rose oxide	1104	0.08±0.01	0.61±0.03	0.59±0.01	0.42±0.01	0.51±0.08	1.2±0.1	0.2±0.002	0.12±0.04	0.1±0.01	0.7±0.01	0.7±0.004	0.8±0.03	0.03±0.01	0.04±0.009	0.5±0.007	0.05±0.01
6	**Camphor**	**1145**	**0.9±0.001**	**0.98±0.03**	**0.91±0.03**	**0.92±0.02**	**0.97±0.01**	**0.92±0.01**	**0.99±0.09**	**0.99±0.01**	**1.1±0.01**	**0.9±0.01**	**0.9±0.1**	**1.1±0.01**	**0.93±0.01**	**1.8±0.01**	**2.1±0.03**	**0.86±0.01**
7	**β-citronellol**	**1210**	**23.1±0.9**	**24.1±1.6**	**24.9±1.1**	**24.5±1.4**	**26.51±1.1**	**26.8±0.1**	**24.2±0.01**	**25.9±0.9**	**23.1±1.2**	**24.5±0.8**	**25.3±0.8**	**25.2±1.1**	**26.1±1.1**	**26.1±0.9**	**27.5±0.9**	**22.5±0.1**
8	**Citronellol**	**1228**	**0.7±0.02**	**0.76±0.01**	**0.88±0.1**	**0.8±0.02**	**0.91±0.01**	**0.2±0.1**	**1.3±0.02**	**1.1±0.07**	**1.2±0.3**	**0.8±0.1**	**0.91±0.01**	**0.8±0.02**	**0.6±0.03**	**1.3±0.01**	**1.4±0.1**	**0.4±0.001**
9	Z-citral	1238	0.9±0.01	0.73±0.03	0.5±0.03	0.66±0.01	0.44±0.03	1.5±0.04	1.1±0.08	0.8±0.05	0.5±0.01	0.6±0.03	0.6±0.01	0.9±0.02	0.7±0.03	0.5±0.01	0.4±0.03	0.6±0.01
10	**Trans-geraniol**	**1248**	**1.1±0.2**	**1.2±0.02**	**0.91±0.02**	**1.4±0.09**	**0.84±0.01**	**0.9±0.1**	**0.1±0.01**	**1.4±0.05**	**1.5±0.7**	**1.9±0.07**	**1.1±0.3**	**0.8±0.09**	**1.1±0.05**	**1.5±0.009**	**1.8±0.1**	**0.5±0.009**
11	**Geraniol**	**1252**	**17.2±0.02**	**16.7±0.2**	**15.3±0.1**	**16.4±0.05**	**16.05±1.1**	**18.1±0.5**	**17.1±0.2**	**18.1±0.4**	**19.1±0.01**	**20.1±0.9**	**19.1±0.4**	**19.5±0.9**	**21.5±0.8**	**22.2±0.84**	**23.1±0.9**	**15.1±0.01**
12	Citronellyl propionate	1271	0.9±0.02	0.82±0.04	0.11±0.02	0.66±0.01	0.8±0.04	1.2±0.02	1.1±0.01	0.7±0.01	0.8±0.01	0.59±0.003	0.6±0.01	0.1±0.08	0.4±0.03	0.8±0.01	0.51±0.03	0.5±0.01
13	E-citral	1302	0.81±0.01	0.08±0.02	0.13±0.04	0.92±0.01	0.91±0.04	0.6±0.01	0.11±0.1	0.8±0.01	0.9±0.02	0.5±0.001	0.5±0.02	0.6±0.02	0.4±0.04	0.9±0.009	0.08±0.01	0.6±0.02
14	Citronellol-acetate	1352	0.91±0.01	0.8±0.02	0.82±0.01	0.77±0.03	0.77±0.08	0.5±0.09	0.1±0.01	0.6±0.01	0.1±0.02	0.5±0.01	0.6±0.01	0.64±0.001	0.84±0.01	0.8±0.07	0.7±0.1	0.4±0.02
15	Methyl eugenol	1400	0.77±0.1	0.7±0.02	0.82±0.02	0.82±0.01	0.62±0.08	0.38±0.02	0.1±0.01	0.1±0.01	0.5±0.01	0.4±0.001	0.7±0.001	0.54±0.01	0.93±0.09	0.8±0.01	0.7±0.01	0.6±0.02
16	**Pentadecane**	**1500**	**5.1±0.02**	**4.2±0.003**	**4.98±0.02**	**4.74±0.01**	**5.5±0.02**	**5.1±0.09**	**5.1±0.02**	**5.4±0.01**	**5.1±0.04**	**5.1±0.01**	**5.1±0.02**	**6.1±0.1**	**7.5±0.1**	**8.6±0.1**	**8.9±0.1**	**3.55±0.01**
17	Phenol	1572	0.72±0.1	0.71±0.04	0.62±0.09	0.55±0.03	0.77±0.01	0.92±0.02	1.1±0.01	0.6±0.03	0.7±0.02	0.3±0.01	0.7±0.01	0.2±0.01	0.9±0.001	0.72±0.003	0.7±0.01	0.5±0.03
18	Lavandulyl acetate	1579	0.8±0.01	0.7±0.01	0.62±0.08	0.44±0.1	0.66±0.01	1.3±0.04	0.1±0.02	0.5±0.01	0.8±0.001	0.2±0.01	0.5±0.03	0.8±0.01	0.8±0.01	0.7±0.001	0.7±0.09	0.8±0.01
19	Benzene	1584	0.9±0.01	0.18±0.04	0.61±0.2	0.31±0.03	0.21±0.01	0.8±0.08	0.2±0.01	0.2±0.02	0.9±0.01	0.2±0.001	0.7±0.01	1.2±0.01	0.3±0.001	0.3±0.01	0.7±0.001	0.7±0.01
20	3,4Dihydrocoumarin	1586	0.07±0.01	0.7±0.01	0.65±0.02	0.44±0.01	0.61±0.08	1.4±0.02	0.7±0.01	0.5±0.01	0.9±0.01	0.8±0.01	0.7±0.05	0.9±0.01	0.7±0.001	0.1±0.01	0.09±0.01	0.01±0.02
21	Germacrene D	1598	0.9±0.01	0.18±0.02	0.65±0.01	0.33±0.01	0.42±0.02	0.1±0.02	0.61±0.02	0.61±0.02	0.5±0.03	0.6±0.03	0.6±0.02	0.8±0.02	0.5±0.01	0.6±0.01	0.6±0.03	0.4±0.01
22	Hexadecane	1600	0.9±0.02	0.82±0.02	0.71±0.01	0.72±0.03	0.7±0.01	0.2±0.07	1.1±0.009	1.2±0.01	0.98±0.01	0.8±0.01	0.7±0.001	0.9±0.01	0.5±0.002	0.1±0.01	0.1±0.01	0.8±0.009
23	α-farnesene	1611	0.81±0.02	0.25±0.02	0.61±0.02	0.44±0.01	0.65±0.01	0.2±0.03	0.2±0.01	0.5±0.02	0.6±0.01	0.6±0.03	0.4±0.001	0.8±0.01	0.4±0.01	0.7±0.001	0.4±0.01	0.7±0.03
24	Delta 3-Carene	1623	0.6±0.02	0.61±0.02	0.44±0.01	0.55±0.03	0.47±0.03	1.1±0.07	1.1±0.02	1.2±0.01	0.88±0.02	0.91±0.01	0.45±0.01	0.7±0.02	0.8±0.02	0.8±0.001	0.5±0.009	0.7±0.01
25	8-Heptadecene	1633	0.9±0.02	0.8±0.02	0.14±0.02	0.77±0.01	0.66±0.01	0.93±0.02	1.1±0.009	0.8±0.02	0.7±0.01	0.6±0.03	0.9±0.01	0.1±0.01	0.5±0.01	0.2±0.01	0.5±0.03	0.4±0.01
26	N-Octadecane	1655	0.82±0.01	0.81±0.01	0.1±0.01	0.81±0.03	0.52±0.01	1.3±0.03	0.8±0.01	0.3±0.01	0.5±0.01	0.6±0.01	0.8±0.01	0.8±0.02	0.8±0.01	0.3±0.001	0.3±0.09	0.6±0.01
27	Heptadecene	1672	0.1±0.01	0.97±0.02	0.67±0.1	0.2±0.06	0.7±0.02	0.2±0.02	0.9±0.07	0.8±0.01	0.9±0.05	0.7±0.04	0.9±0.1	0.1±0.01	0.2±0.01	0.1±0.01	0.2±0.08	0.7±0.1
28	D-Nerolidol	1691	0.93±0.01	0.82±0.01	0.71±0.01	0.55±0.01	0.78±0.03	0.92±0.01	0.8±0.01	0.7±0.01	0.8±0.01	0.7±0.03	0.7±0.001	0.2±0.01	0.4±0.01	0.1±0.001	0.1±0.07	0.1±0.01
29	Farnesol 3	1709	0.62±0.01	0.1±0.01	0.33±0.05	0.66±0.01	0.62±0.01	0.98±0.02	0.2±0.01	0.9±0.01	0.5±0.02	0.1±0.01	0.2±0.02	0.3±0.02	0.3±0.01	0.2±0.01	0.2±0.01	0.1±0.02
30	Benzyl Benzoate	1759	0.91±0.01	0.9±0.03	0.44±0.02	0.42±0.02	0.78±0.03	0.98±0.02	0.01±0.01	0.1±0.01	0.1±0.006	0.2±0.03	0.7±0.001	0.1±0.001	0.9±0.01	0.15±0.01	0.4±0.08	0.7±0.01
31	Octadecane	1800	0.71±0.02	0.6±0.02	0.71±0.02	0.61±0.02	0.72±0.1	0.88±0.01	0.91±0.01	0.8±0.01	0.1±0.01	0.4±0.01	0.6±0.001	0.1±0.01	0.6±0.01	0.06±0.01	0.05±0.03	0.1±0.01
32	1-Heptadecene	1859	0.91±0.02	0.38±0.07	0.71±0.03	0.58±0.01	0.63±0.01	0.97±0.02	0.4±0.02	0.9±0.01	0.1±0.01	0.2±0.01	0.5±0.01	0.7±0.01	0.1±0.01	0.07±0.001	0.6±0.008	0.7±0.01
33	**Nonadecane**	**1900**	**11.4±0.9**	**11.68±0.9**	**11.8±0.6**	**11.91±0.01**	**11.23±0.01**	**11.1±0.08**	**11.6±0.2**	**11.5±0.5**	**11.4±0.4**	**11.5±0.9**	**11.2±0.9**	**12.2±0.8**	**12.1±1.1**	**12.9±0.1**	**13.3±0.8**	**11.1±0.1**
34	N-nonadecane	1901	0.51±0.01	0.53±0.02	0.52±0.02	0.2±0.02	0.62±0.01	1.9±0.02	1.1±0.02	0.8±0.02	0.7±0.011	0.5±0.02	0.2±0.01	0.8±0.01	0.1±0.01	0.08±0.01	0.07±0.01	0.7±0.01
35	Eicosane	2000	0.61±0.07	0.61±0.02	0.44±0.02	0.6±0.01	0.55±0.1	1.1±0.02	0.5±0.06	0.3±0.01	0.4±0.021	0.6±0.2	0.1±0.01	0.8±0.01	0.08±0.01	0.07±0.08	0.06±0.03	0.1±0.01
36	**Heneicosane**	**2109**	**5.41±0.2**	**6.1±0.06**	**7.45±0.2**	**7.8±0.01**	**7.5±0.18**	**7.8±0.2**	**7.8±0.02**	**7.4±0.2**	**7.5±0.02**	**8.2±0.3**	**6.1±0.04**	**7.9±0.1**	**7.6±0.5**	**7.7±0.8**	**8.5±0.3**	**4.5±0.2**
Total			85.6±1.1	82.38±3.3	81.32±2.2	82.64±1.1	84.75±1.1	96.51±2.2	85.96±1.1	87.9±1.4	86.06±1.1	82.7±2.1	84.56±3.1	87.21±1.1	89.75±1.2	91.44±1.3	96.19±1.1	70.22±1.1
Essential oil content (w/w%, g/100g fresh weight basis)			0.051±0.01	0.044±0.01	0.04±0.001	0.06±0.001	0.072±0.04	0.09±0.01	0.055±0.02	0.063±0.02	0.061±0.03	0.078±0.01	0.08±0.002	0.089±0.01	0.097±0.01	0.1±0.01	0.11±0.01	0.03±0.01

[z] RI: Retention Indices, as determined with FID and HP-5MS 5% capillary column using a series of the standards of C7-C30 saturated n-alkanes. [y] Values are means of triplicates ± standard deviation (p <0.05)

Table 7. Means of chemical composition (%) in Damask rose plants affected by 40 ppm concentration of micronutrients and control plants (2nd year).

No.	Compound	RI [z]	Fe	Zn	Cu	Mn	Fe×Zn	Cu×Fe	Mn×Fe	Cu×Zn	Mn×Zn	Cu×Mn	Cu×Fe×Zn	Fe×Zn×Mn	Cu×Mn×Fe	Cu×Mn×Zn	Cu×Zn×Mn×Fe	Control
1	Linalool	1099	0.88±0.01[y]	0.33±0.02	0.33±0.02	0.02±0.02	0.1±0.01	0.6±0.1	0.8±0.01	0.5±0.01	0.7±0.02	0.1±0.02	0.4±0.02	0.3±0.02	0.1±0.02	0.1±0.02	0.2±0.03	0.2±0.02
2	Sic-rose oxide	1101	0.1±0.03	0.55±0.01	0.6±0.01	0.1±0.01	0.1±0.01	0.5±0.02	0.9±0.01	0.8±0.01	0.4±0.01	0.4±0.01	0.7±0.01	0.3±0.02	0.1±0.01	0.1±0.04	0.2±0.01	0.1±0.02
3	Rose oxide trans	1102	0.6±0.01	0.44±0.01	0.1±0.01	0.1±0.01	0.02±0.01	0.9±0.1	0.9±0.02	0.4±0.04	0.5±0.01	0.6±0.01	0.8±0.01	0.2±0.01	0.1±0.01	0.1±0.02	0.1±0.01	0.1±0.02
4	Benzene ethanol	1103	0.6±0.02	0.33±0.03	0.4±0.02	0.6±0.01	0.01±0.01	0.9±0.01	0.71±0.02	0.6±0.03	0.6±0.01	0.7±0.02	0.8±0.01	0.1±0.01	0.08±0.01	0.1±0.01	0.1±0.02	0.2±0.01
5	Trans-rose oxide	1104	0.1±0.01	0.55±0.01	0.47±0.01	0.5±0.01	0.6±0.01	0.8±0.1	0.5±0.002	0.6±0.04	0.5±0.02	0.7±0.01	0.5±0.01	0.7±0.01	0.1±0.01	0.2±0.01	0.6±0.01	0.1±0.01
6	**Camphor**	**1145**	**1.3±0.001**	**1.2±0.03**	**1.2±0.03**	**1.4±0.02**	**1.2±0.01**	**1.2±0.01**	**1.3±0.01**	**1.3±0.01**	**1.2±0.01**	**1.3±0.01**	**1.5±0.1**	**1.6±0.01**	**1.7±0.01**	**1.8±0.01**	**2.3±0.03**	**1.1±0.01**
7	**β-citronellol**	**1210**	**24.1±0.8**	**25.1±1.1**	**25.2±0.8**	**25.7±0.9**	**26.2±0.9**	**26.1±0.8**	**25.1±0.5**	**25.1±0.9**	**24.8±0.9**	**24.9±1.1**	**25.9±1.1**	**26.2±0.9**	**26.4±1.8**	**27.2±0.2**	**28.1±0.9**	**23.1±0.1**
8	**Citronellol**	**1228**	**0.8±0.07**	**0.9±0.02**	**0.98±0.01**	**0.99±0.01**	**1.1±0.02**	**1.1±0.01**	**1.4±0.01**	**1.5±0.01**	**1.6±0.1**	**0.8±0.02**	**1.4±0.02**	**1.5±0.1**	**1.6±0.2**	**1.5±0.3**	**1.9±0.1**	**0.7±0.01**
9	Z-citral	1238	0.8±0.01	0.8±0.01	0.4±0.01	0.55±0.01	0.5±0.01	0.7±0.01	0.8±0.03	0.6±0.05	0.5±0.02	0.8±0.01	0.8±0.04	0.8±0.02	0.9±0.01	0.4±0.02	0.5±0.02	0.3±0.01
10	**Trans-geraniol**	**1248**	**1.4±0.1**	**1.4±0.03**	**1.5±0.03**	**1.5±0.1**	**1.74±0.01**	**1.59±0.04**	**1.41±0.1**	**1.6±0.03**	**1.5±0.05**	**1.6±0.07**	**1.8±0.09**	**1.5±0.07**	**1.8±0.2**	**1.9±0.1**	**2.1±0.1**	**0.7±0.01**
11	**Geraniol**	**1252**	**17.2±0.03**	**17.5±0.4**	**17.1±0.2**	**17.5±0.07**	**18.1±0.9**	**17.9±0.09**	**17.6±0.3**	**18.5±0.09**	**19.2±0.04**	**19.1±0.08**	**18.9±0.5**	**19.8±1.1**	**21.1±0.9**	**20.9±1.1**	**22.9±0.9**	**16.2±0.01**
12	Citronellyl propionate	1271	0.9±0.02	0.77±0.02	0.2±0.01	0.7±0.01	0.8±0.04	0.9±0.01	0.9±0.02	0.7±0.01	0.5±0.01	0.7±0.01	0.6±0.01	0.4±0.01	0.1±0.03	0.7±0.01	0.5±0.02	0.7±0.01
13	E-citral	1302	0.7±0.01	0.05±0.01	0.2±0.01	0.8±0.01	0.8±0.01	0.4±0.01	0.1±0.1	0.6±0.01	0.5±0.01	0.5±0.001	0.4±0.02	0.5±0.02	0.4±0.01	0.6±0.01	0.1±0.01	0.8±0.02
14	Citronellol-acetate	1352	0.9±0.01	0.09±0.02	0.77±0.01	0.9±0.03	0.8±0.01	0.4±0.01	0.1±0.01	0.6±0.01	0.7±0.02	0.5±0.01	0.6±0.04	0.6±0.01	0.4±0.01	0.8±0.02	0.8±0.01	0.5±0.01
15	Methyl eugenol	1400	0.6±0.1	0.5±0.03	0.9±0.02	0.7±0.01	0.6±0.01	0.5±0.01	0.1±0.01	0.6±0.03	0.5±0.01	0.7±0.01	0.8±0.001	0.5±0.01	0.6±0.01	0.6±0.01	0.5±0.01	0.7±0.02
16	**Pentadecane**	**1500**	**5.5±0.1**	**5.4±0.1**	**5.4±0.1**	**5.5±0.01**	**5.7±0.05**	**6.3±0.06**	**5.4±0.06**	**6.1±0.09**	**6.2±0.1**	**6.3±0.1**	**5.9±0.1**	**6.2±0.2**	**7.6±0.2**	**7.5±0.4**	**8.1±0.3**	**4.1±0.1**
17	Phenol	1572	0.61±0.1	0.66±0.04	0.5±0.01	0.61±0.01	0.8±0.01	0.88±0.01	0.8±0.01	0.4±0.03	0.7±0.01	0.3±0.02	0.5±0.04	0.2±0.02	0.6±0.01	0.6±0.02	0.5±0.02	0.6±0.01
18	Lavandulyl acetate	1579	0.5±0.01	0.55±0.01	0.6±0.01	0.55±0.01	0.7±0.02	0.9±0.02	0.1±0.02	0.4±0.03	0.9±0.01	0.4±0.01	0.7±0.03	0.9±0.02	0.7±0.01	0.7±0.001	0.7±0.09	0.8±0.01
19	Benzene	1584	0.5±0.01	0.22±0.01	0.52±0.1	0.4±0.01	0.4±0.01	0.9±0.01	0.2±0.01	0.4±0.02	0.9±0.01	0.2±0.01	0.7±0.01	0.8±0.01	0.5±0.02	0.5±0.01	0.5±0.01	0.8±0.01
20	3,4-Dihydrocoumarin	1586	0.1±0.01	0.44±0.01	0.6±0.02	0.8±0.01	0.7±0.08	0.9±0.01	0.9±0.01	0.5±0.01	0.8±0.01	0.8±0.01	0.7±0.04	0.7±0.01	0.7±0.01	0.4±0.02	0.1±0.01	0.1±0.02
21	Germacrene D	1598	0.8±0.01	0.22±0.01	0.7±0.02	0.4±0.01	0.5±0.03	0.4±0.01	0.71±0.02	0.61±0.02	0.5±0.02	0.6±0.01	0.9±0.02	0.8±0.01	0.5±0.01	0.6±0.01	0.5±0.03	0.5±0.01
22	Hexadecane	1600	0.8±0.02	0.46±0.03	0.8±0.01	0.8±0.02	0.6±0.03	0.6±0.02	0.8±0.01	0.8±0.01	0.7±0.01	0.8±0.02	0.7±0.001	0.7±0.01	0.4±0.01	0.4±0.02	0.1±0.02	0.8±0.01
23	α-farnesene	1611	0.1±0.02	0.33±0.01	0.4±0.01	0.6±0.02	0.7±0.01	0.4±0.03	0.2±0.01	0.4±0.01	0.6±0.01	0.8±0.02	0.5±0.04	0.8±0.01	0.4±0.01	0.7±0.001	0.5±0.01	0.8±0.02
24	Delta 3-Carene	1623	0.4±0.02	0.55±0.01	0.5±0.01	0.5±0.03	0.5±0.02	0.9±0.02	0.9±0.02	0.8±0.02	0.9±0.02	0.8±0.01	0.6±0.01	0.7±0.01	0.6±0.02	0.4±0.01	0.5±0.01	0.7±0.01
25	8-Heptadecene	1633	0.5±0.02	0.09±0.02	0.2±0.01	0.7±0.01	0.6±0.01	0.9±0.01	0.9±0.01	0.8±0.02	0.7±0.02	0.6±0.03	0.6±0.01	0.5±0.01	0.5±0.02	0.4±0.01	0.8±0.03	0.7±0.01
26	N-Octadecane	1655	0.6±0.01	0.56±0.01	0.3±0.02	0.7±0.03	0.7±0.01	0.9±0.03	0.7±0.01	0.5±0.02	0.5±0.01	0.5±0.02	0.6±0.04	0.6±0.02	0.6±0.01	0.3±0.01	0.3±0.09	0.7±0.02
27	Heptadecene	1672	0.1±0.09	0.2±0.05	0.4±0.01	0.5±0.01	0.8±0.01	0.1±0.02	0.9±0.1	0.7±0.1	0.9±0.06	0.8±0.06	0.5±0.02	0.6±0.06	0.1±0.03	0.4±0.04	0.9±0.04	0.9±0.01
28	D-Nerolidol	1691	0.8±0.01	0.55±0.01	0.6±0.02	0.6±0.01	0.6±0.01	0.9±0.01	0.5±0.01	0.6±0.01	0.8±0.01	0.5±0.03	0.7±0.001	0.6±0.01	0.7±0.02	0.4±0.01	0.4±0.02	0.3±0.02
29	Farnesol 3	1709	0.6±0.01	0.2±0.01	0.4±0.06	0.8±0.01	0.5±0.01	0.9±0.01	0.2±0.02	0.6±0.02	0.4±0.03	0.1±0.01	0.5±0.04	0.3±0.02	0.3±0.01	0.2±0.01	0.2±0.01	0.4±0.02
30	Benzyl Benzoate	1759	0.6±0.01	0.8±0.02	0.6±0.01	0.3±0.02	0.9±0.02	0.8±0.01	0.3±0.01	0.1±0.01	0.1±0.01	0.5±0.03	0.7±0.001	0.5±0.01	0.7±0.02	0.4±0.02	0.4±0.01	0.7±0.01
31	Octadecane	1800	0.6±0.02	0.4±0.01	0.8±0.02	0.5±0.02	0.6±0.01	0.7±0.01	0.9±0.01	0.7±0.02	0.5±0.01	0.4±0.01	0.5±0.001	0.5±0.01	0.6±0.02	0.1±0.01	0.1±0.03	0.4±0.02
32	1-Heptadecene	1859	0.5±0.02	0.5±0.07	0.9±0.01	0.6±0.01	0.7±0.01	0.9±0.02	0.8±0.02	0.4±0.01	0.1±0.03	0.5±0.01	0.5±0.04	0.7±0.02	0.5±0.01	0.1±0.01	0.4±0.01	0.7±0.02
33	**Nonadecane**	**1900**	**11.6±0.3**	**11.9±0.4**	**11.7±0.3**	**11.8±0.3**	**11.5±0.2**	**11.6±0.09**	**12.1±0.2**	**11.9±0.2**	**12.1±0.2**	**12.2±0.2**	**12.5±0.3**	**12.6±0.2**	**12.5±0.3**	**12.3±0.4**	**12.9±0.3**	**11.5±0.1**
34	N-nonadecane	1901	0.3±0.01	0.49±0.01	0.4±0.01	0.3±0.02	0.8±0.02	0.9±0.01	0.6±0.02	0.6±0.01	0.5±0.011	0.5±0.02	0.5±0.01	0.6±0.01	0.4±0.02	0.1±0.01	0.1±0.01	0.5±0.02
35	Eicosane	2000	0.3±0.07	0.55±0.02	0.59±0.01	0.4±0.01	0.7±0.1	0.9±0.01	0.4±0.02	0.4±0.01	0.4±0.03	0.5±0.03	0.4±0.04	0.7±0.02	0.1±0.01	0.1±0.01	0.1±0.02	0.5±0.01
36	**Heneicosane**	**2109**	**5.5±0.1**	**6.2±0.2**	**7.2±0.1**	**7.6±0.1**	**6.4±0.1**	**5.8±0.3**	**6.9±0.3**	**7.1±0.1**	**7.2±0.1**	**7.2±0.2**	**6.7±0.2**	**7.8±0.4**	**7.7±0.5**	**7.8±0.5**	**8.7±0.4**	**5.1±0.2**
Total			82.29±1.8	81.78±1.5	83.03±1.8	87.22±2.5	88.07±1.5	91.97±1.8	87.83±2.5	88.81±2.6	90.1±2.5	88.7±1.9	91.8±2.5	92.8±2.2	92.88±3.5	91.4±2.2	97.7±1.8	76.9±1.5
Essential oil content (w/w%, g/100g fresh weight basis)			0.06±0.01	0.06±0.01	0.07±0.02	0.07±0.03	0.069±0.02	0.07±0.02	0.072±0.03	0.08±0.01	0.072±0.04	0.085±0.02	0.09±0.01	0.09±0.01	0.13±0.01	0.12±0.02	0.14±0.01	0.05±0.03

[z] RI: Retention Indices, as determined with FID and HP-5MS 5% capillary column using a series of the standards of C7-C30 saturated n-alkanes. [y] Values are means of triplicates ± standard deviation (p <0.05)

Table 8. Means of chemical composition (%) in Damask rose plants affected by 60 ppm concentration of micronutrients (1st year).

No.	Compound	RI[z]	Fe	Zn	Cu	Mn	Fe×Zn	Cu×Fe	Mn×Fe	Cu×Zn	Mn×Zn	Cu×Mn	Cu×Fe×Zn	Fe×Zn×Mn	Cu×Mn×Fe	Cu×Mn×Zn	Cu×Zn×Mn×Fe
1	Linalool	1099	0.6±0.02[y]	0.3±0.03	0.2±0.01	0.1±0.001	0.01±0.01	0.3±0.01	0.8±0.03	0.3±0.02	0.4±0.01	0.1±0.01	0.1±0.01	0.1±0.01	0.1±0.01	0.1±0.01	0.05±0.01
2	Sic-rose oxide	1101	0.1±0.02	0.5±0.01	0.2±0.01	0.02±0.002	0.02±0.001	0.2±0.02	0.8±0.03	0.6±0.01	0.4±0.01	0.5±0.01	0.6±0.02	0.1±0.01	0.1±0.01	0.1±0.01	0.05±0.01
3	Rose oxide trans	1102	0.4±0.02	0.4±0.02	0.2±0.01	0.1±0.01	0.02±0.001	0.9±0.1	0.6±0.01	0.4±0.02	0.2±0.01	0.4±0.02	0.8±0.02	0.2±0.01	0.1±0.01	0.01±0.01	0.01±0.01
4	Benzene ethanol	1103	0.6±0.02	0.4±0.02	0.3±0.02	0.5±0.02	0.03±0.001	0.8±0.05	0.6±0.03	0.4±0.05	0.4±0.01	0.4±0.01	0.6±0.01	0.1±0.01	0.1±0.01	0.01±0.01	0.1±0.01
5	Trans-rose oxide	1104	0.1±0.01	0.5±0.03	0.4±0.01	0.4±0.02	0.5±0.08	0.7±0.05	0.1±0.01	0.1±0.01	0.2±0.01	0.5±0.02	0.7±0.01	0.7±0.01	0.02±0.01	0.01±0.01	0.3±0.01
6	**Camphor**	**1145**	**0.86±0.01**	**0.86±0.02**	**0.86±0.01**	**0.86±0.02**	**0.87±0.03**	**0.82±0.02**	**0.9±0.03**	**0.95±0.02**	**0.94±0.03**	**0.85±0.02**	**0.87±0.2**	**0.98±0.01**	**0.88±0.02**	**1.2±0.01**	**1.1±0.05**
7	**β-citronellol**	**1210**	**22.5±0.5**	**22.9±1.1**	**22.9±1.1**	**24.1±1.1**	**25.2±1.1**	**25.3±0.2**	**23.5±0.01**	**25.1±0.5**	**22.5±1.1**	**24.2±0.5**	**24.8±0.5**	**24.5±0.9**	**24.5±0.9**	**24.2±0.8**	**23.2±0.2**
8	**Citronellol**	**1228**	**0.55±0.02**	**0.52±0.01**	**0.71±0.2**	**0.71±0.03**	**0.79±0.01**	**0.68±0.1**	**0.96±0.02**	**0.88±0.02**	**0.92±0.1**	**0.68±0.2**	**0.84±0.02**	**0.71±0.02**	**0.51±0.01**	**0.72±0.01**	**0.69±0.3**
9	Z-citral	1238	0.7±0.01	0.6±0.01	0.5±0.02	0.5±0.01	0.3±0.01	0.8±0.02	0.9±0.02	0.8±0.01	0.4±0.02	0.6±0.02	0.5±0.02	0.8±0.01	0.5±0.01	0.4±0.02	0.4±0.02
10	**Trans-geraniol**	**1248**	**0.82±0.2**	**0.9±0.01**	**0.8±0.01**	**1.1±0.1**	**0.65±0.1**	**0.7±0.1**	**0.8±0.1**	**0.95±0.05**	**0.91±0.3**	**1.1±0.1**	**0.95±0.2**	**0.75±0.1**	**0.95±0.1**	**1.1±0.01**	**1.2±0.3**
11	**Geraniol**	**1252**	**15.9±0.1**	**15.4±0.3**	**14.7±0.1**	**15.9±0.1**	**15.2±0.3**	**17.1±0.1**	**16.5±0.1**	**17.5±0.2**	**18.2±0.1**	**18.1±0.1**	**18.1±0.2**	**18.8±0.2**	**18.9±0.2**	**20.8±0.5**	**18.9±0.2**
12	Citronellyl propionate	1271	0.7±0.02	0.7±0.01	0.1±0.01	0.6±0.03	0.7±0.02	0.9±0.01	0.9±0.01	0.7±0.01	0.6±0.02	0.5±0.03	0.6±0.01	0.1±0.01	0.4±0.01	0.5±0.02	0.5±0.01
13	E-citral	1302	0.8±0.01	0.1±0.01	0.1±0.02	0.9±0.01	0.8±0.04	0.6±0.01	0.1±0.03	0.8±0.02	0.9±0.03	0.5±0.01	0.5±0.02	0.5±0.02	0.4±0.04	0.8±0.02	0.1±0.01
14	Citronellol-acetate	1352	0.8±0.01	0.7±0.03	0.5±0.01	0.7±0.02	0.7±0.02	0.4±0.02	0.1±0.01	0.5±0.02	0.2±0.01	0.4±0.03	0.5±0.01	0.5±0.02	0.8±0.01	0.7±0.07	0.6±0.1
15	Methyl eugenol	1400	0.6±0.1	0.6±0.02	0.7±0.01	0.7±0.03	0.5±0.02	0.8±0.02	0.1±0.02	0.8±0.02	0.4±0.02	0.4±0.01	0.6±0.01	0.5±0.02	0.4±0.09	0.6±0.01	0.6±0.01
16	**Pentadecane**	**1500**	**4.5±0.02**	**3.8±0.01**	**3.8±0.01**	**4.2±0.01**	**4.91±0.02**	**4.9±0.05**	**4.7±0.1**	**5.1±0.1**	**4.7±0.1**	**4.7±0.1**	**4.7±0.1**	**5.5±0.1**	**5.8±0.1**	**6.5±0.3**	**5.5±0.1**
17	Phenol	1572	0.6±0.02	0.7±0.01	0.6±0.01	0.5±0.01	0.7±0.02	0.9±0.01	0.9±0.03	0.7±0.01	0.7±0.02	0.2±0.03	0.5±0.01	0.1±0.01	0.8±0.01	0.7±0.02	0.6±0.02
18	Lavandulyl acetate	1579	0.7±0.01	0.6±0.01	0.6±0.04	0.4±0.02	0.6±0.01	0.8±0.04	0.1±0.02	0.5±0.02	0.8±0.01	0.2±0.01	0.5±0.01	0.8±0.02	0.6±0.01	0.7±0.02	0.6±0.01
19	Benzene	1584	0.7±0.02	0.1±0.03	0.5±0.1	0.3±0.02	0.1±0.01	0.8±0.01	0.2±0.03	0.4±0.02	0.8±0.01	0.2±0.02	0.6±0.02	0.9±0.02	0.2±0.001	0.2±0.02	0.6±0.01
20	3,4-Dihydrocoumarin	1586	0.1±0.02	0.6±0.01	0.6±0.02	0.4±0.01	0.6±0.02	0.9±0.02	0.4±0.01	0.5±0.03	0.7±0.1	0.5±0.03	0.7±0.01	0.9±0.01	0.7±0.01	0.1±0.01	0.1±0.01
21	Germacrene D	1598	0.8±0.02	0.2±0.02	0.6±0.02	0.3±0.02	0.4±0.01	0.1±0.02	0.6±0.02	0.6±0.02	0.4±0.01	0.6±0.03	0.5±0.02	0.7±0.01	0.4±0.01	0.5±0.01	0.6±0.01
22	Hexadecane	1600	0.8±0.01	0.8±0.03	0.7±0.01	0.7±0.01	0.6±0.01	0.2±0.01	0.8±0.03	0.95±0.01	0.8±0.1	0.6±0.01	0.7±0.02	0.7±0.01	0.4±0.01	0.1±0.02	0.2±0.02
23	α-farnesene	1611	0.7±0.02	0.3±0.02	0.5±0.02	0.4±0.01	0.6±0.02	0.1±0.01	0.2±0.01	0.5±0.03	0.4±0.01	0.6±0.03	0.3±0.02	0.7±0.01	0.3±0.02	0.6±0.02	0.3±0.01
24	Delta 3-Carene	1623	0.5±0.02	0.6±0.01	0.4±0.02	0.5±0.02	0.4±0.03	0.8±0.01	0.9±0.02	0.95±0.03	0.8±0.01	0.8±0.02	0.4±0.02	0.6±0.01	0.8±0.02	0.7±0.001	0.5±0.01
25	8-Heptadecene	1633	0.7±0.02	0.6±0.03	0.1±0.01	0.7±0.01	0.6±0.01	0.9±0.02	0.95±0.03	0.7±0.02	0.7±0.01	0.5±0.02	0.7±0.01	0.1±0.02	0.4±0.01	0.2±0.02	0.3±0.02
26	N-Octadecane	1655	0.8±0.01	0.7±0.01	0.1±0.01	0.8±0.02	0.5±0.02	0.9±0.01	0.8±0.01	0.3±0.02	0.3±0.02	0.5±0.01	0.8±0.02	0.6±0.02	0.7±0.02	0.2±0.02	0.3±0.01
27	Heptadecene	1672	0.1±0.01	0.7±0.02	0.6±0.02	0.2±0.01	0.7±0.02	0.2±0.01	0.8±0.03	0.6±0.01	0.8±0.01	0.7±0.2	0.8±0.1	0.1±0.02	0.1±0.02	0.1±0.01	0.2±0.01
28	D-Nerolidol	1691	0.8±0.02	0.8±0.03	0.7±0.01	0.4±0.01	0.7±0.02	0.9±0.01	0.7±0.01	0.7±0.02	0.8±0.02	0.5±0.02	0.6±0.02	0.2±0.02	0.4±0.01	0.1±0.02	0.1±0.02
29	Farnesol 3	1709	0.6±0.02	0.1±0.01	0.3±0.01	0.6±0.02	0.6±0.01	0.8±0.01	0.3±0.03	0.7±0.01	0.3±0.01	0.1±0.01	0.1±0.01	0.1±0.02	0.3±0.02	0.1±0.01	0.1±0.01
30	Benzyl Benzoate	1759	0.7±0.01	0.4±0.01	0.3±0.01	0.42±0.01	0.7±0.03	0.9±0.02	0.5±0.01	0.2±0.02	0.1±0.06	0.2±0.01	0.7±0.01	0.1±0.001	0.7±0.02	0.2±0.02	0.3±0.01
31	Octadecane	1800	0.7±0.01	0.5±0.02	0.7±0.01	0.5±0.01	0.7±0.1	0.8±0.03	0.9±0.01	0.7±0.01	0.1±0.02	0.2±0.02	0.4±0.01	0.1±0.01	0.5±0.01	0.1±0.02	0.1±0.02
32	1-Heptadecene	1859	0.6±0.02	0.4±0.05	0.7±0.03	0.5±0.01	0.5±0.02	0.9±0.01	0.4±0.02	0.8±0.02	0.1±0.02	0.2±0.01	0.4±0.01	0.5±0.01	0.1±0.01	0.1±0.01	0.5±0.02
33	**Nonadecane**	**1900**	**10.9±0.2**	**11.1±0.2**	**11.2±0.1**	**11.3±0.1**	**11.1±0.1**	**10.9±0.1**	**11.1±0.1**	**11.2±0.2**	**10.9±0.1**	**10.8±0.2**	**10.8±0.4**	**11.1±0.4**	**11.5±0.2**	**11.7±0.1**	**11.5±0.1**
34	N-nonadecane	1901	0.4±0.01	0.4±0.02	0.5±0.01	0.1±0.01	0.6±0.02	0.9±0.02	0.9±0.02	0.8±0.01	0.7±0.01	0.3±0.02	0.1±0.01	0.8±0.01	0.2±0.01	0.1±0.01	0.1±0.01
35	Eicosane	2000	0.6±0.02	0.5±0.02	0.5±0.01	0.6±0.01	0.4±0.1	0.8±0.02	0.5±0.2	0.3±0.02	0.4±0.01	0.6±0.1	0.1±0.01	0.6±0.01	0.1±0.01	0.05±0.01	0.1±0.02
36	**Heneicosane**	**2109**	**5.1±0.1**	**5.2±0.1**	**5.2±0.2**	**5.4±0.1**	**5.31±0.2**	**5.4±0.3**	**5.7±0.2**	**5.6±0.2**	**5.5±0.2**	**5.2±0.2**	**5.3±0.2**	**5.4±0.3**	**5.4±0.2**	**5.2±0.5**	**5.1±0.2**
Total			77.43±1.9	74.57±2.2	72.37±1.5	76.41±1.8	77.61±1.6	84.8±1.2	80.01±1.4	83.58±2.6	78.47±1.5	77.43±2.2	80.76±2.2	79.94±1.2	79.06±2.1	79.5±2.2	75.5±2.1
Essential oil content (w/w%, g/100g fresh weight basis)			0.05±0.01	0.04±0.01	0.042±0.001	0.05±0.001	0.06±0.04	0.06±0.01	0.04±0.01	0.05±0.01	0.051±0.02	0.052±0.02	0.053±0.001	0.053±0.01	0.052±0.01	0.051±0.01	0.05±0.001

[z] RI: Retention Indices, as determined with FID and HP-5MS 5% capillary column using a series of the standards of C7-C30 saturated n-alkanes. [y] Values are means of triplicates ± standard deviation (p <0.05)

Table 9. Means of chemical composition (%) in Damask rose plants affected by 60 ppm concentration of micronutrients (2nd year)

No.	Compound	RI [z]	Fe	Zn	Cu	Mn	Fe×Zn	Cu×Fe	Mn×Fe	Cu×Zn	Mn×Zn	Cu×Mn	Cu×Fe×Zn	Fe×Zn×Mn	Cu×Mn×Fe	Cu×Mn×Zn	Cu×Zn×Mn×Fe
1	Linalool	1099	0.7±0.01[y]	0.3±0.02	0.2±0.01	0.01±0.01	0.01±0.01	0.3±0.01	0.8±0.01	0.3±0.01	0.4±0.01	0.1±0.02	0.1±0.01	0.05±0.01	0.01±0.01	0.02±0.01	0.05±0.01
2	Sic-rose oxide	1101	0.1±0.01	0.6±0.02	0.3±0.01	0.01±0.01	0.01±0.003	0.2±0.02	0.8±0.02	0.6±0.01	0.3±0.01	0.8±0.01	0.6±0.02	0.05±0.01	0.01±0.01	0.01±0.01	0.05±0.01
3	Rose oxide trans	1102	0.6±0.01	0.4±0.02	0.2±0.02	0.01±0.01	0.02±0.001	0.9±0.05	0.6±0.01	0.3±0.01	0.2±0.01	0.5±0.01	0.7±0.02	0.05±0.01	0.01±0.01	0.02±0.01	0.01±0.01
4	Benzene ethanol	1103	0.6±0.01	0.4±0.01	0.2±0.01	0.5±0.02	0.04±0.001	0.8±0.1	0.7±0.01	0.2±0.01	0.4±0.01	0.5±0.01	0.7±0.01	0.1±0.01	0.01±0.01	0.02±0.01	0.05±0.01
5	Trans-rose oxide	1104	0.1±0.02	0.5±0.02	0.44±0.01	0.4±0.02	0.4±0.02	0.9±0.05	0.2±0.02	0.1±0.01	0.2±0.01	0.6±0.01	0.6±0.01	0.4±0.01	0.01±0.01	0.02±0.02	0.3±0.01
6	**Camphor**	**1145**	**1.3±0.01**	**1.3±0.02**	**1.1±0.02**	**0.92±0.01**	**0.98±0.01**	**1.2±0.01**	**1.2±0.01**	**1.2±0.02**	**1.2±0.02**	**1.1±0.03**	**1.2±0.2**	**1.01±0.02**	**1.2±0.04**	**1.2±0.02**	**1.1±0.03**
7	**β-citronellol**	**1210**	**22.5±0.6**	**22.9±0.9**	**23.1±0.9**	**24.1±0.9**	**25.5±0.9**	**26.1±0.1**	**23.5±0.01**	**24.2±0.2**	**22.5±1.1**	**24.2±0.4**	**24.1±0.4**	**23.5±0.5**	**23.7±0.6**	**23.5±0.5**	**23.3±0.2**
8	**Citronellol**	**1228**	**0.62±0.03**	**0.7±0.02**	**0.7±0.05**	**0.7±0.05**	**0.7±0.02**	**0.8±0.2**	**0.9±0.02**	**0.9±0.06**	**0.9±0.1**	**0.8±0.1**	**0.9±0.01**	**0.9±0.01**	**0.8±0.01**	**0.8±0.01**	**0.7±0.2**
9	Z-citral	1238	0.77±0.01	0.6±0.02	0.4±0.01	0.6±0.01	0.3±0.02	0.8±0.01	0.9±0.02	0.7±0.01	0.4±0.01	0.6±0.03	0.5±0.02	0.7±0.02	0.5±0.01	0.4±0.02	0.3±0.02
10	**Trans-geraniol**	**1248**	**0.8±0.2**	**0.9±0.01**	**0.8±0.01**	**1.1±0.09**	**0.8±0.02**	**0.9±0.05**	**0.8±0.1**	**0.9±0.06**	**0.95±0.1**	**1.1±0.04**	**0.95±0.08**	**0.95±0.1**	**0.9±0.02**	**0.86±0.03**	**0.95±0.3**
11	**Geraniol**	**1252**	**15.9±0.01**	**15.3±0.3**	**14.7±0.1**	**15.9±0.03**	**15.3±0.5**	**16.1±0.3**	**16.1±0.2**	**16.7±0.2**	**18.1±0.02**	**18.2±0.1**	**18.1±0.2**	**18.9±0.4**	**18.5±0.5**	**18.1±0.5**	**17.1±0.3**
12	Citronellyl propionate	1271	0.8±0.02	0.6±0.04	0.1±0.01	0.6±0.02	0.6±0.02	0.9±0.01	0.9±0.01	0.7±0.01	0.6±0.02	0.54±0.01	0.5±0.01	0.2±0.01	0.3±0.01	0.6±0.02	0.5±0.01
13	E-citral	1302	0.7±0.01	0.05±0.02	0.1±0.02	0.9±0.01	0.8±0.04	0.6±0.01	0.1±0.01	0.8±0.02	0.6±0.03	0.5±0.01	0.5±0.01	0.5±0.01	0.4±0.04	0.8±0.01	0.1±0.01
14	Citronellol-acetate	1352	0.8±0.01	0.7±0.02	0.7±0.02	0.7±0.01	0.7±0.02	0.4±0.01	0.1±0.01	0.5±0.02	0.2±0.02	0.5±0.01	0.5±0.01	0.6±0.01	0.7±0.01	0.8±0.07	0.6±0.1
15	Methyl eugenol	1400	0.6±0.1	0.6±0.02	0.7±0.02	0.7±0.01	0.6±0.02	0.7±0.01	0.1±0.01	0.7±0.02	0.3±0.01	0.4±0.01	0.4±0.01	0.3±0.02	0.9±0.01	0.6±0.02	0.6±0.01
16	**Pentadecane**	**1500**	**4.6±0.01**	**3.8±0.001**	**3.8±0.02**	**4.5±0.01**	**4.9±0.01**	**4.95±0.01**	**4.8±0.02**	**5.1±0.02**	**4.75±0.01**	**4.81±0.02**	**4.75±0.02**	**5.5±0.1**	**5.6±0.3**	**5.4±0.1**	**5.3±0.4**
17	Phenol	1572	0.7±0.01	0.6±0.02	0.6±0.02	0.5±0.01	0.7±0.02	0.9±0.01	0.9±0.02	0.7±0.01	0.7±0.02	0.3±0.01	0.6±0.01	0.1±0.02	0.7±0.01	0.6±0.02	0.6±0.03
18	Lavandulyl acetate	1579	0.6±0.01	0.7±0.01	0.6±0.01	0.4±0.1	0.6±0.01	0.9±0.04	0.1±0.02	0.4±0.02	0.8±0.01	0.2±0.01	0.4±0.01	0.8±0.02	0.7±0.01	0.6±0.01	0.5±0.01
19	Benzene	1584	0.8±0.02	0.2±0.02	0.5±0.05	0.3±0.02	0.2±0.01	0.8±0.02	0.2±0.01	0.3±0.01	0.7±0.01	0.2±0.02	0.7±0.02	0.8±0.01	0.12±0.01	0.2±0.01	0.7±0.01
20	3,4-Dihydrocoumarin	1586	0.05±0.02	0.6±0.01	0.6±0.02	0.4±0.02	0.6±0.01	0.8±0.01	0.4±0.01	0.4±0.02	0.7±0.05	0.7±0.01	0.7±0.01	0.9±0.02	0.6±0.02	0.1±0.02	0.1±0.01
21	Germacrene D	1598	0.6±0.01	0.2±0.02	0.6±0.03	0.3±0.01	0.4±0.01	0.1±0.02	0.6±0.01	0.6±0.01	0.4±0.03	0.6±0.03	0.4±0.01	0.8±0.01	0.4±0.02	0.4±0.01	0.5±0.01
22	Hexadecane	1600	0.8±0.02	0.8±0.02	0.6±0.02	0.7±0.01	0.7±0.01	0.2±0.02	0.8±0.02	0.9±0.01	0.7±0.05	0.7±0.02	0.7±0.001	0.6±0.02	0.5±0.01	0.1±0.02	0.1±0.02
23	α-farnesene	1611	0.6±0.02	0.2±0.02	0.6±0.02	0.3±0.02	0.6±0.02	0.1±0.03	0.2±0.02	0.5±0.01	0.4±0.02	0.6±0.03	0.3±0.02	0.8±0.02	0.2±0.01	0.6±0.02	0.2±0.01
24	Delta 3-Carene	1623	0.5±0.01	0.5±0.01	0.4±0.02	0.5±0.01	0.4±0.03	0.9±0.02	0.9±0.02	0.8±0.03	0.8±0.02	0.8±0.02	0.4±0.02	0.5±0.01	0.8±0.01	0.7±0.02	0.4±0.01
25	8-Heptadecene	1633	0.8±0.03	0.6±0.03	0.1±0.01	0.7±0.01	0.6±0.02	0.9±0.02	0.9±0.02	0.7±0.02	0.6±0.02	0.6±0.03	0.7±0.01	0.1±0.01	0.4±0.01	0.1±0.01	0.4±0.02
26	N-Octadecane	1655	0.6±0.02	0.6±0.01	0.1±0.02	0.7±0.02	0.5±0.01	0.9±0.02	0.8±0.01	0.2±0.01	0.4±0.02	0.5±0.01	0.8±0.02	0.5±0.01	0.6±0.01	0.3±0.01	0.2±0.01
27	Heptadecene	1672	0.1±0.01	0.6±0.02	0.5±0.1	0.2±0.01	0.7±0.01	0.2±0.01	0.7±0.01	0.7±0.01	0.7±0.01	0.7±0.2	0.7±0.1	0.1±0.01	0.1±0.04	0.1±0.01	0.1±0.02
28	D-Nerolidol	1691	0.9±0.03	0.6±0.01	0.6±0.02	0.4±0.02	0.7±0.03	0.9±0.02	0.7±0.01	0.6±0.02	0.7±0.02	0.6±0.03	0.7±0.01	0.2±0.02	0.4±0.01	0.1±0.01	0.1±0.02
29	Farnesol 3	1709	0.5±0.01	0.1±0.01	0.3±0.01	0.6±0.01	0.6±0.02	0.9±0.02	0.1±0.01	0.7±0.02	0.3±0.01	0.1±0.01	0.1±0.02	0.1±0.02	0.2±0.01	0.1±0.02	0.1±0.01
30	Benzyl Benzoate	1759	0.8±0.01	0.4±0.01	0.3±0.01	0.4±0.01	0.7±0.03	0.9±0.01	0.1±0.01	0.1±0.01	0.1±0.06	0.2±0.01	0.5±0.01	0.1±0.001	0.8±0.01	0.2±0.02	0.3±0.02
31	Octadecane	1800	0.6±0.02	0.5±0.01	0.7±0.01	0.6±0.01	0.7±0.1	0.8±0.03	0.8±0.01	0.5±0.01	0.1±0.01	0.3±0.01	0.5±0.02	0.1±0.01	0.4±0.01	0.1±0.01	0.1±0.01
32	1-Heptadecene	1859	0.8±0.01	0.2±0.03	0.6±0.02	0.5±0.01	0.6±0.02	0.8±0.01	0.4±0.02	0.8±0.01	0.1±0.01	0.2±0.01	0.4±0.02	0.6±0.01	0.1±0.01	0.1±0.02	0.5±0.01
33	**Nonadecane**	**1900**	**11.5±0.8**	**11.6±0.6**	**11.4±0.6**	**11.7±0.6**	**11.8±0.5**	**11.8±0.5**	**11.4±0.6**	**11.7±0.7**	**11.9±0.7**	**11.8±0.9**	**11.9±0.5**	**11.8±0.3**	**11.6±0.5**	**11.6±0.1**	**11.5±0.2**
34	N-nonadecane	1901	0.5±0.02	0.5±0.01	0.4±0.02	0.1±0.01	0.6±0.01	1.5±0.02	0.9±0.02	0.6±0.02	0.5±0.01	0.4±0.01	0.1±0.02	0.8±0.01	0.1±0.01	0.1±0.01	0.05±0.01
35	Eicosane	2000	0.5±0.01	0.4±0.01	0.4±0.02	0.6±0.02	0.5±0.06	1.1±0.01	0.4±0.02	0.3±0.01	0.4±0.02	0.6±0.1	0.1±0.02	0.6±0.02	0.1±0.01	0.1±0.01	0.1±0.01
36	**Heneicosane**	**2109**	**5.1±0.2**	**5.8±0.1**	**5.7±0.2**	**5.8±0.1**	**5.9±0.1**	**5.8±0.4**	**5.75±0.4**	**6.1±0.1**	**5.9±0.2**	**5.89±0.3**	**5.9±0.3**	**5.8±0.3**	**5.75±0.2**	**5.7±0.1**	**5.2±0.3**
Total			78.84±1.5	75.35±2.3	73.04±1.5	77.35±1.4	79.76±1.5	87.75±1.5	79.55±1.2	81.5±1.1	78.9±1.5	81.24±1.8	81.7±2.2	79.45±1.1	78.12±2.4	75.04±2.2	76.9±1.5
Essential oil content (w/w%, g/100g fresh weight basis)			0.05±0.01	0.05±0.01	0.045±0.001	0.055±0.001	0.06±0.045	0.06±0.02	0.05±0.03	0.05±0.02	0.06±0.03	0.06±0.02	0.06±0.001	0.07±0.01	0.06±0.01	0.06±0.01	0.05±0.01

[z] RI: Retention Indices, as determined with FID and HP-5MS 5% capillary column using a series of the standards of C7-C30 saturated n-alkanes. [y] Values are means of triplicates ± standard deviation (p <0.05)

Table 10. Results of simple correlation between essential oil content and main compositions in Damask rose plants under application of tested micronutrients in two year

Year	Pentadecane (9)	Camphor (8)	Citronellol (7)	Heneicosane (6)	Geraniol (5)	Trans-geraniol (4)	Nonadecane (3)	β-citronellol (2)	Essential oil (1)	
2019	-	-	-	-	-	-	-	-	1	1
	-	-	-	-	-	-	-	1	0.95**	2
	-	-	-	-	-	-	1	0.3	0.64*	3
	-	-	-	-	-	1	0.8**	0.52**	0.5**	4
	-	-	-	-	1	0.11	0.26	0.44**	0.29	5
	-	-	-	1	0.54**	0.39*	0.47**	0.64**	0.38*	6
	-	-	1	0.79**	0.78**	0.66**	0.3	0.6**	0.38*	7
	-	1	0.66**	0.69**	0.48**	0.66**	0.67**	0.72**	0.8**	8
	1	0.66**	0.86**	0.53**	0.81**	0.66**	0.79**	0.65**	0.45**	9
2020	-	-	-	-	-	-	-	-	1	1
	-	-	-	-	-	-	-	1	0.84**	2
	-	-	-	-	-	-	1	0.66**	0.66**	3
	-	-	-	-	-	1	0.62**	0.59**	0.51**	4
	-	-	-	-	1	0.3	0.29	0.55**	0.82**	5
	-	-	-	1	0.79**	0.42**	0.45**	0.71**	0.5**	6
	-	-	1	0.82**	0.68**	0.19	0.27	0.62**	0.4**	7
	-	1	0.7**	0.77**	.46**	0.66**	0.63**	0.7**	0.8**	8
	1	0.1	0.02	0.17	0.27	0.16	0.65**	0.25	0.45**	9

*, ** significant at $P = 0.05$ and $P = 0.01$ levels of probability, respectively.

DISCUSSION

In this research, the effectiveness of treatments was significant. Similar to this investigation, the results of a previous study by Bilal et al. (2020) depicted that applying micronutrient fertilizers enhanced the fresh flower yield of *R.damascena* in comparison with the control. Also, it has been shown micronutrients help to increase better and more absorption of nutrients by influencing enzyme activities (Marschner, 1995). As a result, these positive impacts of the micronutrients could lead to the improvement of photosynthetic rate, biomass production and yield component viz., number of flowers/plant, fresh flower weight, flower yield/plant, and flower diameter and finally increased the fresh flower yield (Hamedi et al., 2020).

In the current study it was found that the volatile oil of Damask rose content is in a yield ranging from 0.03% to 0.14% (w/w) (Tables 4-9). Similar results have also been reported by Ghavam et al. (2021) asserting that the volatile oils obtained from the *Rosa ×damascena* fresh flower petals, collected from the mountainous areas of the Kashan region in Iran, varied from 0.06% to 0.13%.

Additionally, findings of the previous studies (Baydar et al., 2016; Alizadeh and Fattahi, 2021; Ghavam et al., 2021) indicated that the content of volatile oil from *R.damascena* fresh petals varied from 0.01 % to 0.15 %. In the present investigation, maximum volatile oil contents were observed in the rose plants that received 40 ppm of Cu, Zn, Mn and Fe (0.14% w/w in the second experimental year). The main reasons for this enhancement in the volatile oil content by applying micronutrients can be related to the balance between absorption of the essential elements in the root environment, increasing the rate of photosynthesis, stimulating the vital enzymes, activating plant growth regulator production (PGR), and phytohormones as inducing signal for terpenes biosynthesis. It seems that combinational use of nutrients results in synergistic effects on the measured characters but upper than 40 ppm, the fertilizer becomes toxic (Aghaei et al., 2019; Khalvandi et al., 2019).

The findings of this research showed that by increasing essential oil content, the main compositions such as beta-citronellol and camphor in Damask rose plants treated with micronutrients in two years, increased (Table 10). Also, in the current study, 36 chemical components of the essential oils of Damask rose (*Rosa damascena*) were recognized. However, according to the information reported in some references more than 40 different compounds have been identified in the essential oils of roses, which are divided into 5 main groups according to their function including hydrocarbons, alcohols, esters, aromatic ethers and other compounds (aldehydes, rose oxides and norisoprenes) (Toluei et al., 2019; Akhavan and Zarezadeh Mehrizi, 2016). It has been shown that the percentage of the main compounds of essential oil, is the main factor determining the quality of the essential oil (Pal, 2013). The most common ingredients of the essential oil of *R.damascena* are citronellol, nonadecane, geraniol, pentadecane, and pentacosane (Toluei et al., 2019; Akhavan and Zarezadeh Mehrizi, 2016). It has been reported that among these compounds, monoterpene alcohols such as citronellol, trans geraniol, and hydrocarbons such as nonadecane and nonadecene improve the quality of the essential oil of *R.damascena* (Thakur et al., 2019; Yousefi and Jaimand, 2018; Baydar et al., 2016; Koksal et al., 2015). Also, it has been shown that citronellol, geraniol and 2-ethyl alcohol have the greatest effect on the aroma of the essential oil of *R.damascena* (Toluei et al., 2019).

According to the results of the present study, the availability of optimum amounts of micronutrients provided the necessary nutrients for producing higher content and composition of essential oil of Damask rose. A combination of the four micronutrients had a greater effect than a single micronutrient. Thus, the foliar application of 40 ppm Fe, Cu, Mn and Zn was the most effective treatment compared to other treatments. However, a combination of $Fe_3Cu_3Mn_3Zn_3$ treatment was more effective than other treatments.

The amount (percentage) of the main components in plants treated with 40 ppm of micronutrients was produced twice more than those of the control plants (Tables 4-9). The upper range of micronutrients (i.e. 60 ppm) decreased the content of the essential oil of Damask rose but the composition of the essential oil was similar in all treatments. Control plants made better amounts of many essential oil components of Damask rose than those treated plants with 60-ppm concentrations of Fe, Cu, Mn and Zn. In most treatments, the combination of $Fe_3Cu_3Mn_3Zn_3$ and $Fe_3Cu_3Mn_2Zn_3$ made the maximum amount of essential oil. However, $Fe_3Cu_3Mn_3Zn_3$ was the best combination (Tables 4-9).

In some essential oil compositions, control plants were similar to plants treated with $Fe_4Cu_4Mn_4Zn_2$, $Fe_4Cu_4Mn_4Zn_3$ and $Fe_4Cu_4Mn_4Zn_4$. It seems for toxicities of upper concentrations of Fe, Cu, Mn and Zn (i.e. 60 ppm), the content of components obtained at higher concentrations of micronutrients was similar to control plants. It was clear from the presented data that the highest levels of the four foliar fertilizers were more effective than the lower levels, and Librel Zn and Fe fertilizers were superior over other micronutrients. However, the highest essential oil percentage was found with $Fe_3Cu_3Mn_3Zn_3$ (Tables 4-9).

Similar to the results obtained in this study regarding Damask roses, the beneficial effect of micronutrients and production of higher essential oil content were reported by other researchers in Safflower (*Carthamus tinctorius*) (Galavi et al., 2012), pot marigold (*Calendula officinalis* L.), borage (*Borago officinalis*), alyssum (*Alyssum desertorum*) and thyme (*Thymus vulgaris*) (Yadegari, 2015, 2017a), lemon balm (*Melissa officinalis* L.) (Yadegari, 2017b), *Matricaria chamomilla* (Nasiri et al., 2010) and *Coriandrum sativum* (Said-Al Ahl and Omer, 2009).

Results of this research indicated that foliar application of micronutrients resulted in higher essential oil content in the flower of Damask rose plants than the control plants (Tables 7 and 8). In the present study, the effect of micronutrients on the essential oil content and composition was determined over two consecutive years. The essential oil yield increased with Fe, Cu, Zn

and Mn applications because of a significant rise in dry matter and the number of flowers (data not published). This is the first report on the effects of Fe, Cu, Zn and Mn on essential oil content/composition in Damask rose. It was revealed that Fe, Cu, Zn and Mn are beneficial for Damask rose plants with concentrations of 40 ppm or lower, and can result in more content of essential oil up to 40%. Fe, Cu, Zn and Mn have immediate impacts on the growth and development of plants. There are still many unanswered questions about the mechanism of Fe, Cu, Zn and Mn in enhancing yield and its components for Damask rose plants. One possibility is that the foliar applied Fe, Cu, Zn and Mn can affect dry matter accumulation and increase dry matter in flowers. because it has been shown that micronutrients can increase shoot dry weight and root dry weight (Younis et al., 2013).

It was determined in this study that control plants with no foliar treatment experienced better growth than the plants with a higher concentration of the micronutrients. Combinations of micronutrients with an optimum concentration (i.e. 40 ppm) had the best effect. However, combinations of micronutrients of a concentration higher than 40 ppm (i.e. 60 ppm) had more diminishing effects than single micronutrients. These results reflect the role of the simultaneous application of an optimum concentration of the four foliar fertilizers in improving the total essential oils in medicinal plants. Micronutrients of higher than 40 ppm concentration especially in three micronutrient- or in four micronutrient-combinations reduced the content and composition of the essential oil (Tables 4-9). Apparently, Fe, Cu, Mn and Zn boost the absorption and transition of essential nutrients and enhance metabolism and growth, thereby augmenting phytochemicals as shown by Alamer et al., (2020) and Kumar et al., (2016a and 2016b).

CONCLUSIONS

Rosa damascena plants treated with 40 ppm of iron, zinc, manganese and copper in the chelate formula, produced higher content and composition of the essential oil. It could be concluded from the results that iron, zinc, manganese and copper fertilization had significant effects on the measured characters as well as the chemical composition of the essential oil of Damask rose plants. Also, the combined application of micronutrient fertilizers had a more pronounced effect in comparison with the individual use of the micronutrients. This study provides some useful information about the impact of foliar application of micronutrients where soils have undesirable characteristics and chemical properties in particular.

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Conflict of Interest

The author declares that he has no conflict of interest.

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مقاله علمی- پژوهشی

اثرات محلول‌پاشی برخی عناصر ریزمغذی بر میزان و ترکیب اسانس گل محمدی (*Rosa damascena* Mill.)

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بتاسیترونلول
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چکیده - پژوهش حاضر برای بررسی تأثیر کاربرد عناصر ریزمغذی (آهن، مس، روی و منگنز) بر میزان و ترکیب اسانس گل محمدی (*Rosa damascena* Mill.) در جنوب غرب ایران (شهرکرد) در سال های ۱۳۹۸ و ۱۳۹۹ انجام شد. چهار کود برگی شامل لیبرل آهن، لیبرل روی، لیبرل مس و لیبرل منگنز به‌عنوان کود معدنی استفاده شد. کود لیبرل آهن حاوی ۱۳/۲٪ آهن کلات، کود لیبرل روی یک کود برگی با ۱۴٪ روی به شکل کلات، کود لیبرل مس دارای ۱۴٪ مس به صورت کلات، و کود لیبرل منگنز از ۱۳٪ منگنز کلات شده با EDTA تشکیل شده است. نتایج بدست آمده از کروماتوگرافی گازی متصل به طیف‌سنج جرمی، نشان‌دهنده وجود ۳۶ ترکیب در اسانس گیاهان گل محمدی بود. بیشترین (۰/۱۱-۰/۱۴ درصد) و کمترین (۰/۰۳-۰/۰۵ درصد) میزان اسانس به ترتیب از گیاهان تحت تیمار ترکیبی هر چهار عنصر ریزمغذی و گیاهان تحت تیمار شاهد بدست آمد. گیاهان تیمار شده با غلظت ۴۰ میلی‌گرم در لیتر (40 ppm) از عناصر ریزمغذی (تیمار Fe3Cu3Zn3Mn3) و گیاهان شاهد به ترتیب دارای بیشترین و کمترین مقادیر در اکثر اجزای اسانس بودند. مونوترپن‌های اکسیژنه شامل بتاسیترونلول (۲۲/۵-۲۸/۱ درصد)، ژرانیول (۱۵/۱- ۲۳/۱ درصد)، کامفور (۰/۸۶-۲/۳ درصد)، سیترونلول (۰/۴-۱/۹ درصد) و ترانس ژرانیول (۰/۵-۲/۱ درصد) و مونوترپن‌های حلقوی از جمله نونادکان (۱۱/۱-۱۳/۳ درصد)، پنتادکان (۳/۵۵- ۸/۹ درصد) و هنیکوزان (۴/۵- ۸/۷ درصد)؛ ترکیبات غالب اسانس گیاهان گل محمدی بودند. کاربرد بیش از ۴۰ میلی‌گرم در لیتر از ریزمغذی‌ها، به احتمال بسیار زیاد به‌دلیل سمیت، منجر به کاهش میزان و اجزای اسانس گردید.