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Mathematical approach used for the assessment of foliar application of biostimulant and fertilizers to coriander varieties (*Coriandrum sativum* L.)

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ABSTRACT

The biostimulants and fertilizers applied as foliar spray or directly to soil play a crucial role in enhancing the development and quality of coriander by supplying essential macro- and micro-nutrients. The ecological approach to reducing soil fertilizers prioritizes the utilization of foliar nutrients. The objective of this study was to investigate the impact of foliar applying products on the seed yield, essential oil content and composition of coriander cultivars in Central Bulgaria. The field trial was carried out on alluvial-meadow soil type in the region of Plovdiv, Central Bulgaria, in the period 2020–2022. The experiment was conducted using the approach of fractional parcels with four repetitions. Three foliar products were examined in the relevant rates: Energy 20–8–60 – 25 L ha^{-1}; Fulvin 40–22 – 80 L ha^{-1}; Isabion – 30 L ha^{-1}. The treated plants were compared to an untreated control. The tested products were applied in the end of the budding stage to five coriander varieties: Yantar, Moroccan, Mesten Drebnoploden, Thüringen and Marino. Results showed that the application of foliar products, compared to the control, led to an increase in seed yield by 4.2–9.6 % and essential oil content up to 11.8 %. Statistical analysis has demonstrated that the utilization of the Energy 20–8–60 has the most significant impact on the concentration of essential oils, while Isabion has the biggest influence on the quantity of seeds produced. The Isabion biostimulant increased the content of the main compound – β-linalool in the essential oil of Moroccan variety up to 8.9 % and Marino and Mesten Drebnoploden by 3.6 and 5.4 % respectively, compared to the control. The foliar application of Energy 20–8–60 fertilizer led to a decrease of β-linalool percentage in Marino, Moroccan, Mesten Drebnoploden and Thüringen. All studied varieties exhibited the presence of aldehyde 2E-tridecen-1-al under the impact of foliar fertilizers, whereas the untreated plants did not.

1. Introduction

The utilization of biostimulants and fertilizers plays a crucial and an inevitable role in enhancing agricultural food output. They are important for sustainable agriculture by enhancing plant growth and increasing crop productivity by optimizing nutrient uptake and efficiency (Hassanein et al., 2021; Ilieva and Vasileva, 2013; Kuri et al., 2017; Mohammadipour and Souri, 2019; Olowe et al., 2020; Polo and Mata, 2018; Pokluda et al., 2016; Rafiee et al., 2016; Roca, Pérez-Gálvez, 2021; Saa-Silva et al., 2013; Sánchez et al., 2005; Souri, 2016). The ecological strategy towards reduction of soil fertilizers accentuates the importance of using foliar nutrients (Tursun, 2022). Contemporary biologically active compounds are highly appealing due to their non-toxic and environmentally benign nature. Their application is not only economically viable, but also enhances the efficacy of the chemical fertilizers and boosts the crop yields.

Coriander (*Coriandrum sativum* L.) represents an extremely valuable essential oil crop on a global scale. It belongs to the Apiaceae (Umbelliferae) family and is one of the oldest medicinal plants that have been cultivated since centuries (Laribi et al., 2015; Nagre and Yadav, 2017). The most used part of coriander plants are their seeds, which contain essential oil and is widely used in the cosmetic, pharmaceutical and food industries (Gokduman and Telci, 2018; Huzar et al., 2018; Sourmaghi et al., 2015). Furthermore, coriander essential oils possess antibacterial, antioxidant, antidepressive, antifungal, anticancer, antimutagenic, and diuretic properties (Momin et al., 2012; Nguyen et al., 2020).

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Table 1
Description of the foliar treatment products.

Treatment option	Product	Producer	Chemical composition	Treatment dose
B1	Control			
B2	Mineral gel fertilizer – Grow energy 20–8–60+2 % MgO+ME+ amino acids and algae extract	Vakichim	N−20 %; P_2O_5 −8 %; K_2O−60 %; MgO- 2 %; SO_3−30 %; Fe−0.06 %; Mg−0.05 %; Zn- 0.035 %; Cu−0.065 %; B−0.04 %; Mo−0.002 %.	25 L ha^{-1}
B3	Fulvin liquid organic fertilizer 4–3–3 40–22	JISA	Organic substances - 40 %; fulvic acids - 22 %; C−23.2 %; N−4.5 %; P_2O_5.3 %, K_2O- 3 %	80 L ha^{-1}
B4	Isabion biostimulant	Syngenta	Free amino acids of animal origin and peptides	30 L ha^{-1}

The agricultural practices, agroecological and climatic conditions can influence productivity and essential oil composition of coriander varieties (Aqeel et al., 2023; Mazrou, 2019; Telci et al., 2006; Tursun, 2022). A number of experiments have confirmed the positive influence of different foliar products, such as growth regulators, biostimulants, retardants, bacterial products, vitamins, organic substances and anti-stress products) on elements of productivity, seed yield and essential oil content of coriander (Andrabi et al., 2019; Haokip et al., 2016; Massoud et al., 2016; Mounika et al., 2018; Mohammadipour and Souri, 2019; Nisarata et al., 2020; Parmar et al., 2018; Sahu et al., 2022; Serri et al., 2021; Singh et al., 2017; Yugandhar et al., 2017). Among the various foliar-applicable products the use of fulvic acid and amino acid had a significant effect on reproduction and growth characteristics of coriander. Amino acids stimulate growth and productivity of coriander plants (Hassanein et al., 2022; Rezakhani, Hadi, 2017; Wafaa et al., 2021) and have a positive effect on essential oil content and yield (Abd-Allah et al., 2021; Georgieva et al., 2022; Sowmya et al., 2023). The foliar application of seaweed extract and moringa extract showed positive effects on the β-linalool percentage and enhanced its content and concentration in coriander (Mazrou, 2019; Tursun, 2022).

However, there is a scarcity of research in Bulgaria regarding the impact of foliar products on coriander. Specifically, the effects of new foliar biostimulants, mineral and organic fertilizers such as Energy, Fulvin, and Isabion on the productivity and essential oil composition of coriander cultivars from various sources have not been studied.

The primary objective of this study is to investigate the impact of foliar application of biostimulant, mineral and organic fertilizers on the seed yield, essential oil percentage as well as essential oil components of five coriander varieties.

Table 2
Varieties and place of origin.

Option	Variety	Place of origin
A1	Yantar	Russia
A2	Morrocan	Italy
A3	Mesten Drebnoploden	Bulgaria
A4	Thüringen	Germany
A5	Marino	Nietherlands

2. Materials and methods

2.1. Field experiment

The field experiment was conducted in the period 2020–2022 in the region of Plovdiv, Bulgaria, on alluvial-meadow soil (Gyurov and Artinova, 2015), after a preceding crop winter wheat. The soil has following agrochemical parameters: Organic matter (Humus) – 1.37 %; pH 6.9; N – 16.24 mg/kg; P_2O_5 – 8.69 mg/100 g of soil; K_2O – 31.79 mg/100 g of soil.

The experiment was set by the method of fraction parcels in four repetitions for each variety, with size of the crop parcel – 15 m^2. Three foliar products were examined in the relevant doses: Energy 20–8–60 – 25 L ha^{-1}; Fulvin 40–22 – 80 L ha^{-1}; Isabion – 30 L ha^{-1}. The treated plants were compared to an untreated control (Their chemical structure and the treatment dose are presented in Table 1).

The tested foliar products were applied once in the crop stage end of budding to five coriander cultivars: Yantar, Moroccan, Mesten Drebnoploden, Thüringen and Marino (The examined varieties and their place of origin are shown in Table 2). The following characteristics were reported: seed yield, essential oil content and chemical composition.

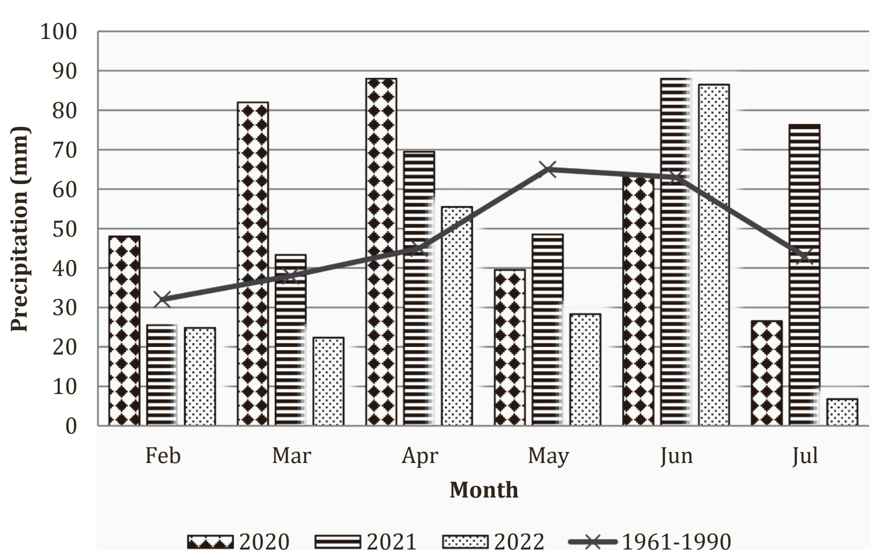

Fig. 1. Precipitation during the vegetation period of coriander, mm.

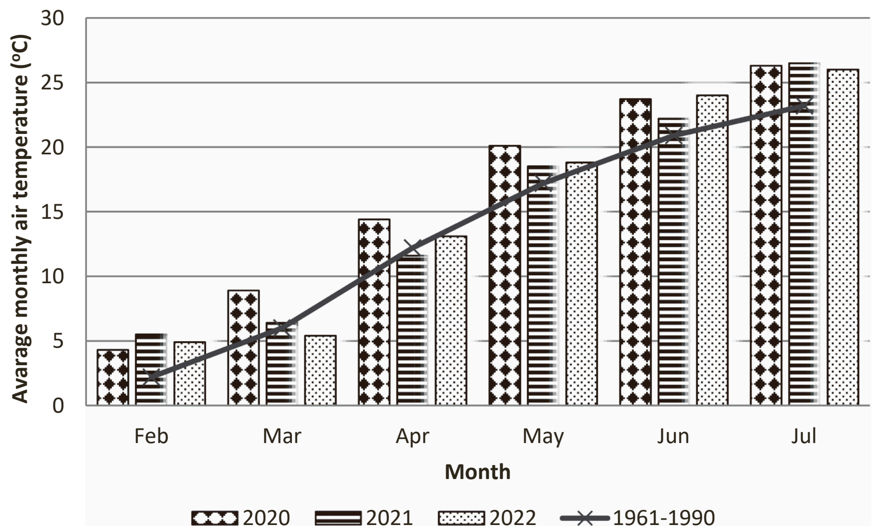

Fig. 2. Average monthly air temperature during the vegetation period of coriander, ^{0}C.

Table 3
Seed yield of coriander.

Year	Option	Seeds yield, t ha^{-1}				
		Yantar	Morrocan	Mesten Drebnoploden	Thüringen	Marino
2020	Control	1.45[c]	2.12[c]	2.03[d]	1.68[c]	1.62[c]
	Energy 20–8–60	1.49[b]	2.23[b]	2.17[bc]	1.78[b]	1.73[b]
	Fulvin 40–22	1.50[b]	2.24[b]	2.19[b]	1.77[b]	1.70[b]
	Isabion	1.58[a]	2.38[a]	2.25[a]	1.82[a]	1.78[a]
	LSD$_{5\,\%}$	0.04	0.10	0.03	0.02	0.04
2021	Control	1.53[d]	2.21[c]	2.14[d]	1.77[c]	1.71[d]
	Energy 20–8–60	1.59[bc]	2.35[b]	2.27[bc]	1.83[b]	1.81[c]
	Fulvin 40–22	1.62[b]	2.36[b]	2.29[b]	1.84[b]	1.83[b]
	Isabion	1.66[a]	2.51[a]	2.39[a]	1.95[a]	1.88[a]
	LSD$_{5\,\%}$	0.03	0.14	0.09	0.05	0.01
2022	Control	1.39[d]	2.08[c]	2.06[c]	1.60[c]	1.61[d]
	Energy 20–8–60	1.46[b]	2.22[b]	2.18[b]	1.63[b]	1.69[bc]
	Fulvin 40–22	1.48[bc]	2.23[b]	2.17[b]	1.63[b]	1.71[ab]
	Isabion	1.51[a]	2.29[a]	2.21[a]	1.72[a]	1.73[a]
	LSD$_{5\,\%}$	0.02	0.05	0.01	0.02	0.07
Average for the period	Control	1.45	2.14	2.08	1.68	1.65
	Energy 20–8–60	1.51	2.27	2.21	1.75	1.74
	Fulvin 40–22	1.53	2.27	2.22	1.75	1.75
	Isabion	1.58	2.32	2.28	1.83	1.80

* Means within columns followed by different lowercase letters are significantly different ($P<0.05$) according to the LSD test

The experiment was carried out following the adopted cultivation technology by the following practices: soil cultivation - ploughing of the stubble in August and ploughing at a depth of 20–22 cm in October, twice pre-sowing cultivation with harrowing, the last being at a depth of 5–6 cm. The fertilizer was applied at sowing of di-ammonium phosphate (P-N 48–18) at a rate of 200 kg ha^{-1}. Each experimental year, the sowing was carried out in the period of 20–25 February at spacing between the rows 12–15 cm and a seed rate of 250 germinating seeds per m^2 at a depth of 3–4 cm. Weeds were controlled by treatment with the herbicide Praxim (500 g L^{-1} metobromuron) – 2.50 L ha^{-1}, applied in BBCH 12–13 of coriander (2nd – 3rd true leaf unfolded) (Neshev et al., 2022). At "rosette" stage dressing with 100 kg ha^{-1} N was applied. Harvesting was done at full crop maturity. The seed yield was determined with standard grain moisture of 9 %.

2.2. Weather conditions

The major climatic factors determining the growth, development and productivity of coriander are temperature and precipitation, their combination and distribution throughout the vegetation season. The years of the study (2020–2022) differed significantly in the amount and distribution of rainfall during vegetation (Fig. 1). Its amount in the first experimental year was 347.7 mm, i.e. 55.7 mm higher than the amount measured for a long period of time. The amount of rainfall between February- July in the second experimental year was 351 mm or 59 mm higher than the values for the period 1961–1991, which determined 2021 year of the experiment as good for the studied varieties. The least amount of vegetation precipitation was reported in 2022 – only 224 mm, versus 292 mm measured for a long period of time. During the ripening stage (July) there was a substantial reduction in rainfall. This had an advantageous impact on the seed yield and on the essential oil content. Among the three years of study, the most favorable for the coriander

Table 4
Two-factor analysis of variance of seed yield.

Year	Source of variation	df	Mean Square (MS)	F	P-value	F crit
2020	Variety (A)	4	0.110	82.081	0.00*	2.758
	Foliar treatment products (B)	3	1.577	1173.268	0.00*	2.525
	Interaction (AxB)	12	0.003	2.139	0.00*	1.917
	Error	60	0.001			
2021	Variety (A)	4	0.138	120.244	0.00*	2.758
	Foliar treatment products (B)	3	1.690	1468.297	0.00*	2.525
	Interaction (AxB)	12	0.003	2.795	0.00*	1.917
	Error	60	0.001			
2022	Variety (A)	4	0.074	30.220	0.00*	2.758
	Foliar treatment products (B)	3	1.744	716.566	0.00*	2.525
	Interaction (AxB)	12	0.003	1.272	0.26 ns	1.917
	Error	60	0.002			

* Significant interaction at $P < 0.05$, ns – non-significant effect of the factor

Table 5
Essential oil content of coriander.

		Essential oil content, %				
Year	Option	Yantar	Morrocan	Mesten Drebnoploden	Thüringen	Marino
2020	Control	0.67^{d}	0.57^{c}	0.59^{c}	0.54^{c}	0.38^{d}
	Energy 20–8–60	0.75^{a}	0.63^{a}	0.65^{a}	0.58^{a}	0.42^{a}
	Fulvin 40–22	$0.73^{б}$	0.60^{b}	0.63^{b}	0.56^{b}	0.40^{b}
	Isabion	0.71^{bc}	0.62^{a}	0.62^{b}	0.56^{b}	0.39^{bc}
	LSD5 %	0.02	0.01	0.02	0.01	0.01
2021	Control	0.45^{c}	0.36^{b}	0.42^{a}	0.32^{b}	0.20^{b}
	Energy 20–8–60	0.49^{a}	0.39^{ab}	0.44^{a}	0.35^{ab}	0.22^{ab}
	Fulvin 40–22	0.47^{b}	0.38^{b}	0.43^{a}	0.34^{b}	0.21^{b}
	Isabion	0.46^{cb}	0.37^{b}	0.43^{a}	0.33^{b}	0.21^{b}
	LSD5 %	0.01	0.02	0.10	0.11	0.01
2022	Control	0.74^{c}	0.61^{c}	0.64^{c}	0.59^{c}	0.45^{c}
	Energy 20–8–60	0.83^{a}	0.68^{a}	0.71^{a}	0.64^{ab}	0.50^{a}
	Fulvin 40–22	0.78^{b}	0.63^{b}	0.67^{b}	0.63^{b}	0.47^{b}
	Isabion	0.77^{b}	0.64^{b}	0.69^{ab}	0.61^{b}	0.46^{b}
	LSD5 %	0.03	0.02	0.02	0.02	0.01
Average for the period	Control	0.62	0.51	0.55	0.48	0.34
	Energy 20–8–60	0.69	0.57	0.60	0.52	0.38
	Fulvin 40–22	0.66	0.54	0.58	0.51	0.36
	Isabion	0.65	0.54	0.58	0.50	0.35

* Means within columns followed by different lowercase letters are significantly different
($P<0.05$) according to the LSD test

Table 6
Two-factor analysis of variance of essential oil content.

Year	Source of variation	df	Mean Square (MS)	F	P-value	F crit
	Variety (A)	4	0.271	59.518	0.00*	2.525
2020	Foliar products (B)	3	0.022	4.780	0.00*	2.758
	Interaction (AxB)	12	0.006	1.246	0.27 ns	1.917
	Error	60	0.005			
2021	Variety (A)	4	0.157	126.414	0.00*	2.525
	Foliar products (B)	3	0.003	2.241	0.09ns	2.758
	Interaction (AxB)	12	0.0001	0.084	1.00ns	1.917
	Error	60	0.001			
2022	Variety (A)	4	0.199	69.861	0.00*	2.525
	Foliar products (B)	3	0.012	4.333	0.01*	2.758
	Interaction (AxB)	12	0.001	0.504	0.90 ns	1.917
	Error	60	0.003			

* Significant interaction at $P < 0.05$, ns – non-significant effect of the factorTable 3: Seed yield and essential oil content in coriander

seed yield was 2021 and referring to the essential oil content, 2022 proved to be the best.

Upon comparing the average monthly temperatures over the period of the study, it was seen that they were closely similar in all three years and were higher than the long-term measurements (Fig. 2). The temperature values, when combined with the reported vegetation precipitation, directly influenced the growth and development of the plants.

Table 7
The chemical composition of the essential oil (%) of coriander varieties on average for the period (2020–2022) through GC-MS.

Compound	RT*	Yantar				Morrocan				Mesten drebnoploden				Thüringen				Marino			
		Control	Energy 20–8-60	Fulvin 40–22	Isabion	Control	Energy 20–8-60	Fulvin 40–22	Isabion	Control	Energy 20–8-60	Fulvin 40–22	Isabion	Control	Energy 20–8-60	Fulvin 40–22	Isabion	Control	Energy 20–8-60	Fulvin 40–22	Isabion
Palmitic acid	5.81	1.755	1.091	1.206	0.947	0.414	0.613	1.046	0.538	0.413	1.258	1.147	0.423	0.880	0.760	0.096	0.818	0.583	0.736	0.465	0.384
α-Pinene	10.00	4.297	4.802	3.913	4.671	4.025	6.073	4.672	3.307	5.197	6.010	5.664	3.337	5.696	4.719	5.627	5.288	5.387	5.129	5.099	3.783
Camphene	10.53	0.486	0.704	0.520	0.693	0.404	0.660	0.494	0.421	0.559	0.550	0.577	0.360	0.538	0.551	0.587	0.562	0.585	0.502	0.578	0.420
β-Pinene	11.45	0.340	0.448	0.380	0.415	0.339	0.509	0.383	0.301	0.456	0.476	0.482	0.306	0.428	0.512	0.450	0.445	0.485	0.449	0.404	0.325
β-Myrcene	11.87	0.539	0.633	0.550	0.640	0.473	0.672	0.497	0.426	0.589	0.592	0.671	0.470	0.553	0.645	0.662	0.617	0.650	0.622	0.585	0.458
p-Cymene	13.00	2.854	1.612	1.833	1.613	3.127	2.041	2.419	1.464	1.670	2.092	1.878	2.024	2.144	2.119	2.106	2.252	2.147	2.707	1.868	2.008
Limonene	13.16	1.525	1.465	1.560	1.777	1.233	1.479	1.105	1.026	1.314	1.215	1.486	1.228	1.305	1.674	1.633	1.327	1.406	1.375	1.241	1.285
Eucalyptol	13.21	0.289	0.326	0.383	0.220	0.206	0.519	0.157	0.118	0.437	0.425	0.200	0.361	0.230	0.401	0.328	0.280	0.339	0.186	0.268	0.211
γ-Terpinene	14.50	6.619	7.297	6.156	7.024	5.812	9.403	5.180	5.089	8.415	7.256	7.926	6.274	7.631	7.376	7.933	7.713	8.011	7.846	7.107	6.645
Sabinene hydrate	14.96	0.121	0.204	0.140	0.097	0.153	0.316	0.131	0.156	0.145	0.190	0.252	0.166	0.136	0.166	0.109	0.120	0.146	0.040	0.144	0.134
Terpinolene	15.69	0.448	0.487	0.529	0.523	0.418	0.505	0.331	0.350	0.491	0.402	0.432	0.388	0.420	0.443	0.443	0.480	0.496	0.440	0.447	0.365
Camphor	17.03	4.207	4.213	4.840	4.246	4.014	3.438	3.566	3.848	3.885	3.603	3.957	3.747	3.417	4.238	3.574	3.539	3.549	4.521	3.794	3.436
β-Citronellal	17.36	0.075	0.089	0.066	0.059	0.050	0.053	0.041	0.049	0.036	0.083	0.062	0.079	0.053	0.088	0.068	0.057	0.061	0.040	0.072	0.080
Borneol	17.91	0.201	0.213	0.184	0.172	0.092	0.119	0.103	0.149	0.094	0.228	0.117	0.134	0.235	0.144	0.231	0.133	0.144	0.082	0.099	0.154
Terpinene−4-ol	18.34	0.271	0.172	0.159	0.216	0.279	0.345	0.278	0.365	0.290	0.221	0.308	0.310	0.153	0.285	0.400	0.220	0.279	0.315	0.265	0.373
α-Terpineol	18.64	0.497	0.366	0.445	0.408	0.438	0.455	0.463	0.520	0.445	0.505	0.436	0.511	0.401	0.474	0.576	0.464	0.476	0.448	0.478	0.390
Nerol	19.94	0.104	0.638	0.393	0.334	0.155	0.235	0.215	0.239	0.545	0.224	0.202	0.156	0.159	0.263	0.226	0.167	0.175	0.187	0.140	0.149
Decanol	21.52	0.196	0.756	0.218	0.177	0.593	0.185	0.436	0.180	0.852	0.141	0.968	0.292	0.171	0.763	0.829	0.290	0.286	0.836	0.295	0.726
Geranyl acetate	24.26	2.636	1.304	1.723	2.143	4.678	2.421	2.280	2.083	0.971	2.431	2.991	3.869	2.053	2.493	2.799	4.249	3.554	1.842	2.195	3.049
Myristic acid	38.14	0.425	0.234	0.145	0.164	0.127	0.105	0.142	0.093	0.251	0.382	0.308	0.100	0.268	0.160	0.687	0.114	0.092	0.222	0.065	0.083

*Retention time (min)

2.3. *Essential oil extraction*

Essential oil content was determined by the method of water-steam distillation done in Clevenger apparatus. Each plant option was set with samples weighing from 50 g to 200 g in 800 mL of water and air temperature 20 °C ± 2. The raw material - mature coriander seeds - was smashed before the thermal processing with the purpose of accelerating the process and revealing the essential oil receptacles. The distillation continued 2 hours, counted from the emergence of the first drop of essential oil (Clevenger, 1928).

2.4. *Gas chromatography – mass spectrometry analysis (GC–MS)*

The chemical compound composition of coriander essential oil was analysed at the research Centre in Plant Biotechnology- "ABI" - Agrobioinstitute - Sofia. The analysis of coriander essential oil was conducted using gas chromatography-mass spectrometry (GC-MS) with an Agilent 7890 A instrument fitted with an Agilent 5975 C mass spectrometer detector. An electron ionization energy of 70 eV was observed throughout a scan range of m/z 45–550. Compounds were separated by chromatography using a DB-5MS capillary column with the prescribed parameters: a 0.25 µm thickness, a 30 m length, and an internal diameter of 0.32 mm. The carrier gas used was helium, supplied at a flow rate of 1.0 mL per min. The temperature at the inlet was 250 ∘C. The temperature program for the GC oven was structured as follows: an initial temperature of 40 ∘C, maintained for 2 minutes, increased by 5 ∘C per minute to 300 ∘C, and then maintained at 300 ∘C for 10 min. A 1 % (v/v) solution of the sample in n-Hexane was produced and injected at a concentration of 1 microliter using a split ratio of 100:1. The compounds were determined by comparing the retention times and relative Kovats retention indices (RI) - obtained by injection of a mixture of n-Alkanes (C8-C20) under identical experimental conditions with those of standard substances and mass spectral data from the libraries of NIST'08 (National Institute of Standards and Technology, USA) and Adams Library.

In order to determine the essential oil structure, the preparation of the samples included the dissolution of 20,0 µL of essential oil into 380,0 µL of n-Hexane, respectively for each sample. Thus, the received solution was analyzed via gas chromatography with flame-ionization detector and mass spectrometer (GC-FID/MS).

2.5. *Statistical analysis*

A two-factor analysis of variance (ANOVA) was performed in order to establish the effect of the preparation on each coriander variety. Using the model of the two-way analysis of variance, the effect of the different preparations on the examined coriander varieties was studied.

A main task of the analysis of variance is to determine the individual or combined effect of a single or more factors on another indicator, as well as to estimate these effects.

Using different mathematical approaches, the following have been established:

– The influence of different preparations on the examined five coriander cultivars - via the two-factor analysis of variance (ANOVA);

3. Results and discussion

The foliar products applied in the present study influenced positively the values of the productive indicator Seed Yield (t ha^{-1}) concerning all tested cultivars. The Moroccan variety reacted most strongly to the application of the Isabion, resulting in an increase in yield from 261 kg ha^{-1} in the 2020–296 kg ha^{-1} in 2021 and further to 204 kg ha^{-1} in 2022, followed by the Mesten drebnoploden, which experienced yield increases of 217, 249, and 149 kg ha^{-1}, and the Thüringen, which demonstrated yields 127–183 kg ha^{-1} higher than the control. The Yantar variety exhibited the lowest response to the applied

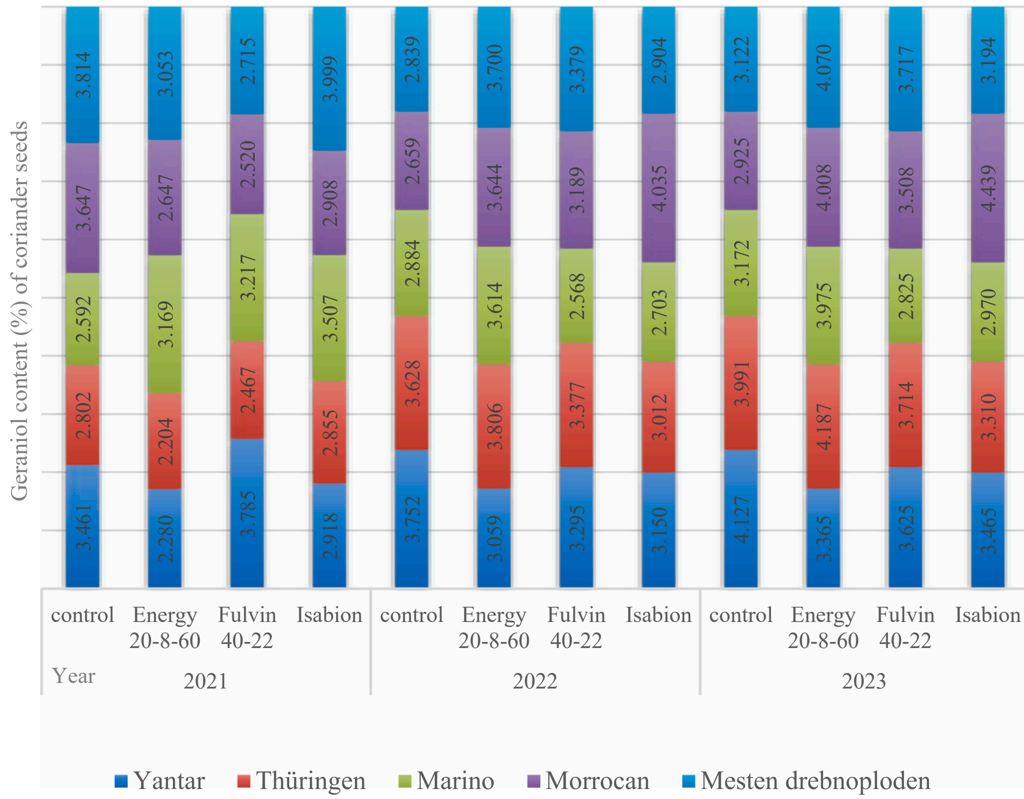

Fig. 3. Geraniol content (%) of coriander seeds essential oil through GC-MS.

Table 8
β-Linalool content of coriander seeds essential oil through GC-MS, %.

Year	Treatment\Sort	Yantar	Thüringen	Marino	Morrocan	Mesten drebnoploden
2020	control	62.95	60.28	61.86	61.62	60.35
	Energy 20–8–60	65.20	64.43	60.45	62.70	56.05
	Fulvin 40–22	61.68	62.04	56.70	63.01	58.35
	Isabion	58.98	63.70	59.36	62.09	69.96
2021	control	68.33	70.88	69.50	71.38	70.75
	Energy 20–8–60	69.23	66.82	66.33	67.07	70.55
	Fulvin 40–22	70.30	66.80	75.03	73.68	67.86
	Isabion	71.04	67.98	74.13	79.84	71.30
2022	control	66.16	65.97	66.45	68.2	67.82
	Energy 20–8–60	65.72	63.50	62.97	63.78	67.61
	Fulvin 40–22	69.03	63.48	72.53	71.65	64.65
	Isabion	68.14	64.78	71.54	77.82	68.43

biostumulator Isabion, with a yield increase ranging from 8.6 % to 9.1 % compared to the control over the course of three years. Applying the products Energy 20–8–60 – 25 L ha^{-1} and Fulvin 40–22 – 80 L ha^{-1} to the coriander varieties resulted in an increase in seed yield. Specifically, the Thüringen variety had a 1.8 % rise, while the Mesten drebnoploden showed a 7.9 % increase compared to the control (Table 3).

Compared to the control, the highest yield was registered for the treatment with the Isabion. Averagely for the experimental period (2020–2022), Isabion contributed to an increase in seed yield obtained by the studied varieties from 8.8 % (1.58 t ha^{-1}) to 9.9 % (2.32 t ha^{-1}), compared with the relevant control values –1.45 t ha^{-1} and 2.14 t ha^{-1}, in contrast the increase with the other products was from 3.7 % to 6.7 %.

The reported results were statistically significant. The two-factor analysis of variance showed strong statistical influence on seed yield with relation to the varieties and the foliar products, as well.

The interaction between both factors in 2020 and 2021 was statistically significant, and the same was non-significant in 2022 (Table 4).

The applied foliar products increase seed yield in coriander, which could reach up to 13.4 %, compared to the control, depending on the annual climatic factors. Other writers have corroborated the findings,

Table 9
2E-tridecene −1-al content of coriander seeds essential oil through GC-MS, %.

Year	Treatment\Sort	Yantar	Thüringen	Marino	Morrocan	Mesten drebnoploden
2020	control	nd	nd	nd	nd	nd
	Energy 20–8–60	0.15	0.19	0.62	0.04	0.14
	Fulvin 40–22	0.09	0.04	0.04	0.04	0.01
	Isabion	0.49	0.13	0.35	0.02	0.06
2021	control	nd	nd	nd	nd	nd
	Energy 20–8–60	0.10	0.19	0.20	0.05	0.27
	Fulvin 40–22	0.11	0.17	0.07	0.17	0.23
	Isabion	0.61	0.13	0.09	0.14	0.12
2022	control	nd	nd	nd	nd	nd
	Energy 20–8–60	0.11	0.21	0.22	0.06	0.29
	Fulvin 40–22	0.12	0.19	0.08	0.19	0.25
	Isabion	0.67	0.14	0.10	0.15	0.14

stating that the use of foliar treatments can lead to an increase in seed yield ranging from 4 % to 19 % compared to the control group (Georgieva et al., 2022; Sahu et al., 2022; Szempliński et al., 2018; Yugandhar et al., 2016, 2017; Vinogradov et al., 2018).

Seed quality in coriander varieties depends on the essential oil content. The values of this indicator are affected by the varying annual meteorological conditions and the foliar products as well (Table 5).

Unlike the other studied indicators, which exhibit higher values during years characterized by abundant and evenly distributed precipitation, the essential oil content is influenced by arid and hot weather conditions, as well as reduced precipitation during seed ripening (Zheljazkov et al., 2008; Georgieva et al., 2022).

In 2022, the essential oil content reached its highest value due to a temperature increase of 2.8 °C compared to the multi-year period. Additionally, the amount of precipitation decreased with 6.75 mm of rainfall compared to the usual 49 mm. The controlled variants have an essential oil content ranging from 0.59 % to 0.74 %. In the treated variants, the coriander varieties have a higher essential oil content, ranging from 0.63 % in the Thüringen and Moroccan varieties to 0.83 % in the Yantar variety. This represents an increase of 3.3–12.2 %.

Average for the period, the essential oil content in the control plants was from 0.34 % to 0.62 %, and in the treated options – from 0.35 % for the cultivar Marino to 0.69 % for the Yantar. Throughout the trial period, all treatments surpassed the control, with values ranging from 2.9 % to 11.8 %. Numerous authors have established that the application of foliar products leads to an increase in essential oil content (Hristova and Nenkova, 2012; Kolev et al., 2005; Mazrou, 2019; Prathibha et al., 2018; Rezakhani, Hadi, 2017).

It was statistically significant that the product Energy 20–8–60 affected essential oil content to the highest extent. These values were from 8.3 % for the Thüringen variety to 11.8 % for the Morrocan and Marino varieties. The application of Isabion and Fulvin to coriander plants increased the essential oil content from 2.9 % (Marino) to 6.5 % (Yantar). According to many authors, the essential oil content varies depending on the applied foliar products (Kurmi et al., 2020; Rahimi et al., 2009; Tursun, 2022).

The two-factor analysis of variance showed that with relation to the factor Variety, F value was greater than F crit. during the three experimental years. It was evident that this factor had a significant effect on essential oil content. Regarding the factor Foliar Products, in 2021 F value was less than F crit. It determined this factor as one that had a non-significant effect on essential oil content. In 2020 and 2022 the influence on this indicator was significant. The interaction of the factors on the indicator Essential Oil Content was non-significant during the experimental years (Table 6).

In total were identified 46 components in coriander essential oil, which represented between 98.8 % and 99.8 % of it. Table 7 displays the 20 most significant chemical constituents of the examined varieties together with their respective percentage makeup. A dominant essential oil component is the monoterpenoid. Geraniol is a monoterpenoid, which varied from 2.20 % to 4.44 % during the experimental period. Taking into account Mesten Drebnoploden variety, after its treatment with Isabion biostimulant in the three experimental years there were reported rises in geraniol concentration in comparison to the control options, as follows: in 2020 - from 3.81 % to 4.0 %, in 2021 - from 2.84 % to 2.90 % and in 2022 - from 3.12 % to 3.19 % (Fig. 3).

The main component of coriander essential oil is β-linalool, which content varied from 56.05 % to 79.84 % during the experimental period. Regarding Morrocan variety, when treated with the product Isabion and the organic preparat Fulvin, an increase in the β-linalool content during the three years of study was recorded. The β-linalool content in the treatment with Isabion was reported with 62.09 %, 79.84 %, and 71.05 %, and in the variant treated with Fulvin 40–22 - with 63.01 %, 73.68 % and 71.05 %, compared to the control values – 63.01 %, 71.38 % and 68.52 % in 2020, 2021 and 2022, correspondingly.

The biostimulant Isabion had a positive effect on β-linalool content for Mesten Drebnoploden variety, as β-linalool increase was with 15.9 % in 2020, 0.77 % in 2021 and 0.89 % in 2022, compared to the values of the control plants. As a result of the application of Fulvin 40–22 to Morrocan variety in 2020, 2021 and 2022, an increase in β-linalool concentrations with 2.26 %, 3.23 % and 3.70 %, correspondingly, compared to the controls was reported. Taking into account Yantar variety, after the application of foliar product Energy, β-linalool content grew with 1.4 % average for the period (Table 8). This corresponded to the results showing the β-linalool increase with 2.7 % after foliar treatment with amino acids-containing product (Humiforte) (Mohammad Reza Haj Seyed Hadia et al., 2022).

The presence of the aldehyde 2E-tridecenen-1-al was reported under the influence of the treatment with foliar biostimulant products in all tested varieties (concentrations from 0.038 % to 0.674 %), which was absent in the untreated plants (Table 9). It was found that the content of aldehydes in the essential oil of the varieties Yantar and Marino was significantly affected by treatment with Isabion, with a significant increase compared to the controls.

4. Conclusions

Overall, it can be inferred that the utilization of foliar biostimulant, mineral, and organic fertilizers to coriander varieties resulted in changes to agronomic indicators and the composition of essential oils. Coriander cultivars showed high responsiveness to the application of foliar fertilizers and biostimulators. Foliar spray of 25 L ha^{-1} Energy, 80 L ha^{-1} Fulvin and 30 L ha^{-1} Isabion enhanced seed yield by 4.2–9.6 % and essential oil content up to 11.8 % in all coriander varieties than control.

The Isabion biostimulant increased the content of the main compound - β-linalool in the essential oil of Morrocan variety by 8.9 % and Marino and Mesten Drebnoploden by 3.6 and 5.4 % respectively, compared to the control. The foliar application of Energy 20–8–60 fertilizer led to a decrease of β-linalool percentage in Marino, Morrocan, Mesten Drebnoploden and Thüringen varieties.

All studied varieties exhibited the presence of aldehyde 2E-tridecen-1-al under the impact of foliar fertilizers, whereas the untreated plants did not.

Submission declaration

The authors of the presented research "Mathematical approach used for the assessment of foliar application and biostimulant and fertilizers to coriander varieties (*Coriandrum sativum* L.)" confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

The authors confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed.

The authors confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property.

CRediT authorship contribution statement

Svetlana Manhart: Investigation. **Velika Kuneva:** Software, Formal analysis. **Manol Dallev:** Methodology. **Vanya Delibaltova:** Investigation. **Hristofor Kirchev:** Formal analysis, Conceptualization. **Emiliya Koycheva:** Writing – review & editing, Writing – original draft, Visualization.

Declaration of Competing Interest

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The authors do not have any financial interest or relationship related to the subject matter.

The authors do not have any patents or copyrights that are relevant to the work in the manuscript.

Data Availability

Data will be made available on request.

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