Turkish Journal of Agriculture - Food Science and Technology, 12(s4): 2832-2839, 2024
DOI: https://doi.org/10.24925/turjaf.v12is4.2832-2839.7318

Turkish Journal of Agriculture - Food Science and Technology

Available online, ISSN: 2148-127X | www.agrifoodscience.com | Turkish Science and Technology Publishing (TURSTEP)

Impact of Foliar-Applied Essential Oils on Growth, Yield and Quality of Potato (*Solanum tuberosum* L.)

Arif Şanlı[1,a,*], Fatma Zehra Ok[1,b]

[1]*Department of Field Crops, Faculty of Agriculture, Isparta University of Applied Science, Isparta, Türkiye*
[*]*Corresponding author*

A R T I C L E I N F O

Research Article

Received : 11.11.2024
Accepted : 13.12.2024

Keywords:
Potato
Essential oil
Foliar application
Tuber yield
Quality

A B S T R A C T

In this study, effects of sage (*Salvia officinalis* L.), oregano (*Origanum onites* L.), rosemary (*Rosmarinus officinalis* L.), dill (*Anethum graveolens* L.), cumin (*Cuminum cyminum* L.), fennel (*Foeniculum vulgare* var. dulce L.) and Turkish pickling herb (*Echinophora tenuifolia* L. subsp. *sibthorpiana* (Guss.)) essential oils applied to plant leaves at different doses on potato growth, tuber yield and quality were investigated. Essential oils were applied to the upper parts of the plant by spraying at doses of 300, 600, 900 and 1200 ppm three times at 15-day intervals, starting 15 days after the completion of emergence. The number of tubers and tuber yield per plant, marketable and total tuber yield, chlorophyll content, starch content, reducing and total sugar content parameters were examined. The effects of essential oil applications on tuber yield and quality were found to be statistically significant, and this effect varied according to application doses. Compared to the control, essential oil applications increased the marketable tuber yield by approximately 38% (300 ppm rosemary essential oil) and the total tuber yield by up to 28% (600 ppm rosemary essential oil). However, rosemary and oregano oils caused phytotoxicity and reduced tuber yield when applied in high doses. Except for sage and oregano, other essential oils positively affected chlorophyll synthesis. Essential oil applications reduced the accumulation of reducing sugar, which negatively affects tuber quality, and the lowest reducing sugar contents were detected in tubers to which fennel and oregano essential oils were applied. In the study, it was understood that tuber yield in potatoes could be increased significantly with the applications of 300 and 600 ppm rosemary essential oil and 300 ppm cumin essential oil.

[a] *arifsanli@isparta.edu.tr* *https://orcid.org/0000-0002-5443-2082* | [b] *fhzehraok@gmail.com* *https://orcid.org/0000-0002-0199-572X*

Introduction

Potato (*Solanum tuberosum* L.), originating from South America and grown in many region of the world, is one of the most important non-grain food crops globally, with an approximate global production of 376 million tons among all agricultural products (Baruah and Mohanty, 2021). Potato ranks as the third most consumed staple food globally, coming after rice and wheat (Hussain, 2016). According to 2022 data in our country, potato production covered an area of 138.000 hectares with approximately 5.1 million tons produced, and a yield of 3.671 kg/da was achieved (Anonim, 2022). The rapid increase in potato demand and rising production costs over the past 25-30 years have driven all potato growers to enhance yield per unit area and profitability with low input usage. Agricultural producers encounter significant challenges from biotic and abiotic stressors exacerbated by climate change. Factors such as drought, salinity, weeds, pests, and diseases pose serious threats to potato growth and yield (Parajuli et al., 2019). In response, pesticides and non-organic fertilizers have become vital in mitigating their impacts and boosting yield per unit area (Sharma et al., 2019). However, this not only imposes a burden on farmers but also leads to increased environmental pollution in the long term, including soil degradation and groundwater contamination (Bijay-Singh and Craswell, 2021). Intensive research is being conducted on alternative approaches for long-term and sustainable agricultural production programs (Zulfiqar et al., 2020). A suggested strategy involves utilizing plant extracts, an innovative, eco-friendly, and sustainable method that leverages plant secondary metabolites to improve crop yield and quality (Mbuyisa et al., 2023).

Secondary metabolites are organic compounds produced by plants, particularly under stress conditions, and are integral to their defense mechanisms (Guo et al., 2024). Essential oils, which are complex blends of these secondary metabolites, are distinguished by their lipophilic nature and high volatility (de Sousa et al., 2023). While they act protectively against stress factors in the plants in which they are synthesized, they also exhibit various ecological functions for the external environment, such as serving as attractants, repellents, providing resistance to certain stress conditions, and stimulating certain chemical defense signals (Sharifi-Rad et al., 2017). Thanks to these properties, secondary metabolites act as reducing agents, hydrogen donors, singlet oxygen scavengers, and metal chelators (Anjitha et al., 2021). Secondary metabolites also have free radical scavenging functions, including clearing superoxide, alkoxyl, peroxyl, and nitric oxide radicals, and they exhibit insecticidal, antifungal, antibacterial, and antiviral activities (Parham et al., 2020).

This study aims to evaluate the effects of essential oil applications from sage (*Salvia officinalis* L.), oregano (*Origanum onites* L.), rosemary (*Rosmarinus officinalis* L.), dill (*Anethum graveolens* L.), cumin (*Cuminum cyminum* L.), fennel (*Foeniculum vulgare* var. dulce L.), and Turkish pickling herb (*Echinophora tenuifolia* L. subsp. *sibthorpiana* (Guss.)) on tuber yield and quality in potatoes.

Material and Methods

Experimental Site

The field experiment was carried out in Isparta,Türkiye (37º 50' 47" N, 30º 32' 12" E, 1035 m) on loamiy soil with a pH of 8.2, a total salt content of 0.025%, and a cation exchange capacity of 38%. It is rich in lime (25.5%), low in organic matter (1.58%), poor in available phosphorus (18.2 mg/kg P_2O_5), rich in potassium (188 mg/kg K_2O), and low in total nitrogen content (0.82%). In the research year, the total rainfall during the vegetation period (April–September) was 215 mm, which was higher than the long-term average of 173 mm. The average temperature for April to September was 20.2°C, close to the long-term average of 20.6°C. The relative humidity during the vegetation period, when the studies were conducted, was also similar to the long-term average, at 54.3% compared to 50.5%.

Essential oil Extraction

The herbs of sage (*S. officinalis* L.), oregano (*O. onites* L.), rosemary (*R. officinalis* L.), and Turkish pickling herb (*E. tenuifolia* L. subsp. *sibthorpiana* (Guss.)) and the fruits of dill (*A. graveolens* L.), cumin (*C. cyminum* L.), and fennel (*F. vulgare* var. dulce L.) were ground, then the essential oils were obtained by distilling them for 3 hours using a Clevenger-type hydro-distillation apparatus and stored in dark-colored glass storage bottles at +4°C (Marotti and Piccaglia, 1992). The components of the essential oils of the species were determined using a GC/MS (Gas Chromatography/Mass Spectrometry) device (QP-5050 GC/MS, with a quadrupole detector) at the Experimental and Observational Research and Application Center of Suleyman Demirel University (Stein, 1990). The operating conditions of the device were: Capillary column: CP-Wax 52 CB (50 m × 0.32 mm, 0.25 µm), Oven temperature program: increasing by 10°C per minute from 60°C to 220°C, and holding at 220°C for 10 minutes, Total run time: 60 minutes, Injector temperature: 240°C, Detector temperature: 250°C, Carrier gas: Helium (20 ml/min).

Table 1. Main components of the essential oils used in the study

S. officinalis L.	
Compounds	%
1.8-cineole	15.35
α-thujone	19.45
Camphor	37.75
Borneol	4.85
R. officinalis L.	
Compounds	%
β-pinene	6.85
1.8-cineole	66.45
Camphor	5.85
α-terpineol	6.1
A. graveolens L.	
Compounds	%
Dihydro carvone	4.35
(S)-(+)-carvon	68.4
D-limonen	21.25
α-phellandren	1.15
C. cyminum L.	
Compounds	%
γ-terpinene	4.75
Cuminal	24.05
2-caren-10-al	51.65
P-mentha-1.4-dien-7-ol	8.7
O. onites L.	
Compounds	%
γ-terpinene	10.87
Linalool	9.55
Thymol	16.65
Carvacrol	46.55
F. vulgare var. *dulce* L.	
Compounds	%
Limonene	1.93
Fenchone	6.22
p -allyl anisol	4.31
Trans-anethole	85.27
E. tenuifolia L. subsp. *Sibthorpiana*	
Compounds	%
γ-terpinene	1.97
Methyl eugenol	30.41
α-phellandrene	50.63
α-terpinene	11.02

Experimental design

The study was designed according to a factorial arrangement in a Randomized Block Design with 3 replications. Seed potatoes (cv. Agria) were planted in plots of 6.6 m in length with a 70 x 30 cm spacing in the first week of May. Four rows of potatoes were planted in each plot. Plots where no application was made and those treated with Tween-80 (0.1%) were evaluated as controls. No fungicide or insecticide application was made to the tubers before planting. Before planting, 10 kg/da of nitrogen, phosphorus, and potassium were applied (15-15-15 compose fertilizer), along with top dressing 10 kg/da of pure nitrogen (ammonium nitrate (33% nitrogen)). The water required by the plants was supplied through a drip irrigation system, with irrigation applied for 4 hours weekly. Immediately after planting (pre-emergence), selective herbicide (Senkor wp 70, 70 g/da dose, with 70% metribuzin) was applied to control weeds, and insecticide with the active ingredient imidacloprid was used for potato beetle control. Different concentrations (300, 600, 900, and 1200 ppm) of each essential oil were prepared using water, and Tween-80 (0.1%) was used as an emulsifier to ensure a homogeneous mixture of the essential oils in water. The essential oils were applied 3 times throughout the vegetation period at 4 different doses, taking into account the timing and frequency of fungicide applications for potatoes. The first applications were made 15 days after full emergence, and subsequent applications were made at 15-day intervals from the first application (El-Moughy, 2009). The essential oils were sprayed separately on each plot using a pulverizator at a standard application rate (40 L/da). Harvesting was done when the skin formation of the tubers was complete. Leaf chlorophyll content was measured 1 week after the final application using a Minolta SPAD-502 chlorophyll meter. Tuber numbers (number/plant) and tuber yield per plant (g/plant) were determined by randomly selecting 20 plants of each plot, and marketable (kg/da) and total tuber yield (kg/da) were determined by harvesting all the plants in the plot. The amount of starch (%), reducing sugar (mg/100 g fw) and total sugar (%) content in a potato was quantified following the Somogyi–Nelson method (Nelson, 1944) with some adjustments.

Statistical Analysis

The data obtained from the measurements and analyses were analyzed using the generalized linear model (GLM) procedure in the SAS (2009) statistical software, following the randomized block design. The analysis was performed using standard analysis of variance (ANOVA), and the differences between the means were determined using the LSD test.

Results

Tuber Number and Tuber Yield Per Plant

The effect of essential oil applications on the number of tubers per plant was statistically significant (Table 2). While Tween-80 and oregano essential oil applications had similar effects to the control, all other treatments showed a significant increase in the number of tubers per plant. The highest average number of tubers per plant was obtained from the Turkish pickling herb oil applications, which resulted in approximately a 20% increase compared to the control. The average number of tubers per plant increased up to the 600 ppm dose, but significantly decreased above 900 ppm (Table 3). The highest number of tubers per plant (8.70 tubers/plant) was obtained from rosemary essential oil application at the 600 ppm dose, followed by Turkish pickling herb oil (7.57-7.97 tubers/plant) at 300-900 ppm, cumin oil (7.80 tubers/plant) at 900 ppm, and rosemary oil (7.70 tubers/plant) at 300 ppm applications. High doses of rosemary and oregano oil led to a decrease in the number of tubers per plant compared to the control.

The effects of essential oils on tuber numbers varied depending on the application dose. In sage oil applications, there was no significant difference between doses, whereas in dill oil, the number of tubers per plant was higher with applications of 600 ppm and above, in oregano oil, with applications up to 900 ppm, and in fennel oil, with applications of 900 ppm and above (Table 3). Essential oil applications significantly affected the tuber yield (Table 2). The average tuber yield per plant in the control was 955 g/plant, while in the essential oil applications, it varied between 851-1235 g/plant. Oregano essential oil applications caused a decrease in the average tuber yield compared to the control. The effects of the application doses on tuber yield were statistically significant. No significant change occurred with applications up to 900 ppm, but at the 1200 ppm dose, the tuber yield significantly decreased (Table 3). In the study, the highest tuber yield was obtained from rosemary oil applications at 300 and 600 ppm doses (1153 g/plant and 1235 g/plant, respectively), 900 ppm Turkish pickling herb oil (1112 g/plant), and 300 ppm cumin oil (1227 g/plant). These treatments resulted in a 16-29% increase compared to the control. The effects of doses on tuber yield were similar for dill, oregano, and fennel essential oils, while cumin oil at 300 ppm, Turkish pickling herb oil at 900 ppm, rosemary and sage oils at 600 ppm showed higher yields compared to other doses (Table 3).

Marketable and total tuber yield

Essential oil applications significantly affected the marketable tuber yield. With the exception of Tween-80 and oregano essential oil applications, all other treatments increased the marketable tuber yield compared to the control (3366 kg/da). Cumin (3884 kg/da), rosemary (3821 kg/da), and Turkish pickling herb (3783 kg/da) essential oil applications resulted in higher average marketable tuber yields than the other treatments. The effects of the application doses on marketable tuber yield were also significant. The marketable tuber yield increased up to the 600 ppm dose, but significantly decreased at the 1200 ppm dose (Table 4).

Table 2. Analysis of variance table for the parameters studied in the research

Variation Resources	S.D.	Tuber number	Tuber yield	Marketable tuber yield	Total tuber yield	Chlorophyll content	Starch content	Total sugar content	Reducing sugar content
Block	2	ns	ns	ns	ns	ns	ns	ns	ns
Applications (A)	8	**	**	**	**	**	**	**	**
Doses (D)	3	**	**	**	**	ns	ns	**	**
A x D	24	**	**	**	**	*	**	**	**
Error	70								
General	107								
CV (%)		4.07	8.08	3.47	4.20	3.29	4.45	6.49	4.99

ns, non significant, ** significant at 0.01, * significant at 0.05

Table 3. Effects of essential oil applications on the tuber number and tuber yield per plant

Applications	Tuber number per plant (number/plant)					Tuber yield per plant (g/plant)				
	300	600	900	1200	Mean	300	600	900	1200	Mean
Sage	7.07g-ı	7.23e-h	6.87g-j	7.13e-h	7.08c	947e-j	1069b-e	986c-ı	952 dj	989 cd
Rosemary	7.70b-d	8.70a	7.40c-f	5.83n	7.41b	1153ab	1235a	1036b-g	877 hj	1076 ab
TPH	7.57b-e	7.73b-d	7.97b	7.37c-f	7.66a	1000c-h	1079b-d	1112a-c	951 dj	1036 a-c
Dill	6.67ı-l	7.30d-g	6.87gh	6.80g-k	6.91cd	934f-j	1036b-g	972d-j	989 cı	983 cd
Oregano	6.80h-k	6.37k-l	6.30lm	5.90mn	6.34e	908h-j	905h-j	851j	866 ıj	883 f
Cumin	7.40c-f	7.43c-f	7.80bc	6.80h-k	7.36b	1227a	1049b-f	1045b-f	1074 be	1099 a
Fennel	6.43j-l	6.50j-l	7.07g-ı	7.00g-ı	6.75d	998c-h	999c-h	1077b-d	977 dj	1013 b-d
Tween-80	6.23ln				6.23e	892h-j				892ef
Control	6.40kl				6.40e	955d-j				955de
Mean	6.92b	7.10a	6.99ab	6.61c		1002a	1025a	992a	955 b	
	Lsd int: 0.46					Lsdint:130				

Table 4. Effects of essential oil applications on the marketable and total tuber yield

Applications	Marketable tuber yield (kg/da)					Total tuber yield (kg/da)				
	300	600	900	1200	Mean	300	600	900	1200	Mean
Sage	3499k-m	4073b-d	3727f-ı	3455k-o	3688cd	3945g-j	4397cd	4020f-ı	3910 g-j	4068 cd
Rosemary	4663a	4143bc	3769f-ı	3008r	3821ab	4762ab	5035a	4258d-f	3572 k-l	4407 a
TPH	3756f-ı	3909d-f	4065b-d	3400l-p	3783a-c	4152d-g	4342c-e	4585bc	3948 g-ı	4257 b
Dill	3463k-n	3803e-h	3663h-j	3725ı-f	3664d	3895g-j	4347c-e	4093e-h	4088 e-h	4106 c
Oregano	3294n-q	3340k-q	3215p-q	3161qr	3253e	3820h-k	3735j-l	3585k-l	3510 l	3663 e
Cumin	4257ab	3855e-g	3627h-k	3798e-h	3884a	4887a	4395dc	4265d-f	4305 de	4463 a
Fennel	3576ı-k	3825e-h	3985c-e	3590ı-k	3744b-d	4112e-g	4157d-g	4407cd	4085 e-h	4190 bc
Tween-80	3252o-q				3252e	3748ıl				3748e
Control	3366m-p				3366e	3937gj				3937d
Mean	3647b	3730a	3630b	3417c		4140ab	4233a	4100b	3900 c	
	Lsdint:204					Lsdint:280				

TPH: Turkish pickling herb

The highest marketable tuber yield in the study was obtained from rosemary (4663 kg/da) and cumin (4257 kg/da) oil applications at the 300 ppm dose, with increases of 38% and 26%, respectively, compared to the control. Sage oil at 600 ppm, Turkish pickling and fennel oils at 600-900 ppm, and dill oil at 600-1200 ppm resulted in higher marketable tuber yields than other doses. The highest marketable tuber yield in rosemary and cumin oil applications was found at 300 ppm, and as the application dose increased, the marketable tuber yield significantly decreased (Table 4).

The average total tuber yield significantly decreased in plants treated with oregano essential oil and Tween-80, while there was no significant change in sage oil treatments. Other essential oil applications significantly increased the total tuber yield compared to the control (Table 4). The average total tuber yield increased up to the 600 ppm dose, but applications at higher doses resulted in a significant decrease in the total tuber yield. The highest total tuber yield in the study was obtained from rosemary (5035 kg/da and 4732 kg/da at 600 and 300 ppm, respectively) and cumin oil (4887 kg/da at 300 ppm), and these applications increased the total tuber yield by approximately 21-28% compared to the control (Table 4). In sage oil applications at 600 ppm, Turkish pickling herb and fennel oil applications at 600-900 ppm, dill oil at 600 ppm and above, and oregano oil at 900 ppm, the total tuber yield was higher than other doses. At the 1200 ppm dose of rosemary and oregano essential oil at doses higher than 900 ppm, the total tuber yield significantly decreased compared to the control (Table 4).

Chlorophyll Content

Essential oil applications affected the chlorophyll content statistically significantly, while the chlorophyll content of plants applied with Tween-80, sage and oregano essential oil was similar to the control, other essential oil applications significantly increased the leaf chlorophyll content compared to the control. The highest chlorophyll contents in the study were obtained from rosemary at 300 and 600 ppm doses, Turkish pickling herb at 600 and 900 ppm doses, dill at 600 ppm doses, cumin at 300-900 ppm doses and 900 ppm fennel essential oil applications. While there was no significant difference between the doses in terms of chlorophyll content in sage, Turkish pickling herb, dill and cumin oil applications, 300 and 600 ppm doses in rosemary oil and 900 and 1200 ppm doses in fennel oil increased the chlorophyll content more than the other doses (Table 5).

Starch Content

Essential oil applications significantly affected tuber starch ratio (Table 2), and starch ratio varied between 11.5-15.4% depending on the applications. While the average starch content of the tubers were similar to the control in Tween-80 and oregano essential oil applications, all other applications caused a significant decrease in starch content. There was no significant difference in starch content between the application doses. The highest starch content were obtained from the control and Tween-80 together with 600 ppm sage, 900 ppm rosemary, 300 ppm dill, 600 and 1200 ppm oregano and 300 and 900 ppm fennel essential oil applications.

Table 5. Effects of essential oil applications on the chlorophyll and starch content

Applications	Chlorophyll content (SPAD)					Starch content (%)				
	300	600	900	1200	Mean	300	600	900	1200	Mean
Sage	36.7h	38.8fh	38.0eh	37.7fh	37.8c	12.7j	15.0a-c	13.6f-j	13.4g-j	13.7d
Rosemary	41.8ab	42.4a	39.9bf	36.6h	40.0a	14.1d-h	13.8f-ı	15.4a	13.9e-ı	14.3c
TPH	39.4cg	40.3ae	41.0ac	39.0cg	39.9a	14.2c-g	14.1d-h	13.5f-j	13.1h-j	13.7d
Dill	38.5dh	40.7ad	39.8bf	39.7bf	39.7ab	15.2a-c	14.3b-g	13.1h-j	13.4g-j	14.0cd
Oregano	39.2cg	39.3cg	38.4eh	36.9gh	38.4bc	14.0e-ı	14.5a-f	14.0e-ı	15.3ab	14.5ac
Cumin	42.0ab	40.7ad	40.3ae	40.1be	40.8a	14.1d-h	13.0ı-j	13.0ı-j	13.9e-ı	13.5d
Fennel	38.3eh	38.1eh	41.1ac	39.7bf	39.3b	15.0a-d	11.5k	14.5a-f	13.9e-ı	13.7d
Tween-80	37.6gh				37.6cd	14.9a-e				14.9ab
Control	38.0eh				38.0c	15.2a-c				15.2a
Mean	39.4	40.0	39.8	38.8		14.4	14.0	14.1	14.1	
	Lsd_{int}:2.2					Lsd_{int}:1.03				

TPH: Turkish pickling herb

Table 6. Effects of essential oil applications on the total and reducing sugar content

Applications	Total sugar content (%)					Reducing sugar content (mg/100 gfw)				
	300	600	900	1200	Mean	300	600	900	1200	Mean
Sage	1.32ab	0.72kj	1.30b	0.88f-h	1.10a	409de	296lm	417 cd	318 k-m	360 e
Rosemary	0.96ef	0.90e-g	0.62lm	0.58l-n	0.77d	357f-h	351f-ı	327 h-l	326 h-l	340 f
TPH	0.53m-o	0.58l-n	0.72kj	0.80ı-j	0.66e	320ı-m	350f-j	435 b-d	364 fg	367 e
Dill	1.10c	1.40a	1.36ab	0.48o	1.08ab	379ef	438b-d	490 a	292 nm	400 e
Oregano	0.86g-ı	0.56m-o	0.67kl	0.26p	0.59e	339g-k	319j-m	336 g-k	290 nm	321 g
Cumin	1.08cd	0.99de	0.97ef	0.92e-g	0.99bc	452b	442bc	416 cd	366 fg	419 c
Fennel	0.78ıj	0.60lm	0.50no	1.28b	0.79d	291nm	298lm	263 n	376 f	307 g
Tween-80	0.96ef				0.96c	442bc				442b
Control	1.13c				1.13a	489a				489a
Mean	0.96a	0.87ab	0.91a	0.81b		386b	380b	402 a	363 c	
	Lsd_{int}:0.094					Lsd_{int}:31.1				

TPH: Turkish pickling herb

The highest starch content was obtained at doses of 300 ppm for dill essential oil, 600 ppm for sage essential oil, and 900 ppm for rosemary essential oil. In contrast, fennel essential oil at 300 and 900 ppm, and thyme essential oil at 600 and 1200 ppm showed higher starch content compared to other doses. (Table 5).

Total and Reducing Sugar Content

The effects of the applications on the total sugar content of the tuber were found to be statistically significant (Table 2). Except for the sage and dill essential oil, all other applications significantly reduced the average total sugar content compared to the control, the lowest average total sugar contents were obtained from toregano (0.59%) and Turkish pickling herb essential oil (0.66%) applications. The average total sugar content was determined to be lower in the applications made at 1200 ppm dose than in the other doses. Total sugar content varied between 0.26% and 1.40% depending on the essential oil applications, the highest total sugar rates were obtained from dill oil made at 600 and 900 ppm doses (1.40% and 1.36%, respectively) and sage oil applications made at 300 ppm dose (1.32%). The oregano essential oil applications made at 1200 ppm dose had the lowest total sugar content value with 0.26% (Table 6).

All applications significantly reduced the reducing sugar content compared to the control (489 mg/100g). The lowest average reducing sugar contents were obtained from fennel (307 g/100g) and cumin essential oil (321 mg/100g) applications in the same statistical group. Application doses significantly affected the reducing sugar content, while the average reducing sugar content was found to be higher in applications made at 900 ppm dose (402 mg/100g), reducing sugar content was significantly reduced in applications made at 1200 ppm dose (363 mg/100g) (Table 5). When all applications were considered, the reducing sugar content varied between 263-490 mg/100g, and the lowest reducing sugar content was determined in 300 and 900 ppm fennel and 1200 ppm oregano essential oil applications. The effects of essential oils on reducing sugar content depending on the doses were found to be statistically significant, with applications at 600 and 1200 ppm in sage, 300 ppm in Turkish pickling herb oil, and 1200 ppm in dill and cumin oils having lower reducing sugar content than other doses (Table 6).

Discussion

The use of essential oils as biostimulants is gaining attention due to the negative impacts of synthetic pesticides on human health and the environment. Plant extracts can boost growth and yield by influencing plant physiological processes positively (Zulfiqar et al., 2020). In agriculture, many compounds are known for their biostimulant effects on plant growth. Essential oils are a well-defined group of biostimulants, naturally derived from aromatic plants, and they exhibit various biological activities in living organisms (Bakkali et al., 2008). Therefore, this study aims to assess the growth and yield-enhancing effects of different essential oils.

Foliar applications of essential oils particularly *R. officinalis, E. tenuifolia* and *C. cyminum*, increased the number of tubers which is closely associated with factors such as number of main stems, stolon formation, and plant's nutritional status. Tuber formation, stolon length, the number of tubers per plant, and tuber size are characteristics in potatoes with high heritability (Abeytilakarathna, 2022). Additionally, factors such as internal hormone levels, aday-night temperature fluctuations (Hulscher et al., 2013), photoperiod (Bahram et al., 2020), drought, and irrigation regime (Aliche et al., 2020) significantly influence stolon formation and, consequently, tuber number. Gibberellins (GAs) are among the most influential growth regulators on stolon formation, promoting stolon elongation and inhibiting tuber formation by affecting starch hydrolyase activity or starch synthesis enzymes (Abeytilakarathna, 2022). Compounds present in high concentrations in *R. officinalis, C. cyminum* and *E. tenuifolia* essential oils such as 1,8-cineole, 2-caren-10-al, and α-phellandrene are synthesized via the MEP pathway, similar to GAs (Zebec et al., 2016). It is thus believed that these components may either exhibit hormone-like activity or influence hormone biosynthesis. The ability of essential oil applications to induce physiological changes in plants, such as alterations in phytohormone levels, has also been reported by Souri and Bakhtiarizade (2019).

Except for sage and oregano, essential oils applications from the leaves have increased tuber yield, with this increase being particularly higher in *R. officinalis, C. cyminum* and *E. tenuifolia* essential oils. In these applications, the higher number of tubers per plant and increased tuber yield explain the observed increase in total tuber yield. On the other hand, high doses of *R. officinalis* and *O. onites* essential oils likely caused phytotoxicity, leading to a reduction in tuber yield. Indeed, chlorophyll content in the leaves was also found to be lower in these applications. The reduction in chlorophyll content and tuber yield from a 1200 ppm rosemary and oregano essential oil spray may be due to decreased cell division or cell enlargement. Ethylene, a hormone involved in stress signaling, can limit plant growth when it accumulates in plant tissues (Marschner, 2011). In this study, the high-dose foliar spray of rosemary and oregano essential oils likely acted as a stressor or stress signaling molecule. On the other hand, increased leaf chlorophyll levels resulting from the foliar application of *C. cyminum*, *A. graveolens*, and *E. tenuifolia* essential oils may be linked to boosted gene activity related to photosynthesis, cell metabolism, and stress response. Furthermore, applying *Ascophyllum nodosum* and moringa leaf extract suppresses cysteine protease activity (Buit et al., 2019), which prevents chlorophyll breakdown and delays plant aging. It has been reported that foliar applications of cumin, clove, and dill essential oils extended the vegetation period in potato plants; morever, cumin and dill essential oil applications significantly increased tuber yield, while clove oil decreased yield (Ok and Şanlı, 2021). Moreover, the increase in tuber yield may have resulted from some components of the essential oils developing defense mechanisms against stress factors, while others exhibited hormone-like activity. Indeed, in addition to their protective roles, such as antioxidant activity, free radical scavenging, and UV light absorption, secondary metabolites are known to establish defense mechanisms against microorganisms in plants (Kennedy and Wightman, 2011). Beyond their medicinal and aromatic uses, essential oils have also been reported to possess antimicrobial and antioxidant properties by many researchers (Ntalli et al., 2010; Lang and Buchbauer, 2012).

Potato tuber yield is significantly reduced under challenging environmental conditions like drought, heat, and high salinity. Essential oils, complex organic compounds produced via plants' secondary metabolic pathways, serve crucial roles as signaling molecules in defending plants against various stresses such as pests, fungi, bacteria, and viruses (Tiku, 2018). Essential oils are believed to enhance potato plants' tolerance to environmental stresses, potentially increasing tuber yield. Under stress, reactive oxygen species (ROS) production rises in plants, and these ROS can damage cells and membranes, accelerating chlorophyll breakdown and aging. Essential oils, known for their antioxidant properties, help reduce ROS levels, potentially promoting growth, maintaining leaf greenness, and supporting developmental processes in potato plants. For example, Rguez et al. (2023) found that treating pathogen-infected tomato plants with *Tetraclinis articulata* EO boosted the activity of antioxidant enzymes, total polyphenol content, and antioxidant activity. Another possible reason for increased plant growth and tuber yield may be that essential oils improve nutrient uptake from the soil. Studies have shown that phenolic compounds can enhance nutrient absorption (Sánchez-Sánchez et al., 2002). A larger root surface area increases the rhizosphere area, improving uptake of nutrients like nitrogen, potassium, and iron (Marschner, 2011; Rose et al., 2014). In this study, foliar oil application may have promoted the release of protons, organic acids, and natural chelators or altered the redox potential in the lime-rich soil, facilitating nutrient absorption. Similarly, Soiri and Bakhtiarizade (2019) reported that rosemary oil foliar sprays increased nitrogen, iron, and zinc levels in tomato seedling leaves.

On the other hand, potato plants are susceptible to numerous phytopathogenic fungi throughout the growing season, which significantly restricts plant growth and yield. In this study, no synthetic fungicide treatments were applied against phytopathogens, leading to substantial development of fungal pathogens (such as powder mildew, Alternaria, Fusarium, etc.) in the plants. Another reason for the positive effects of essential oil applications on tuber yield and quality in potato plants is believed to be their ability to reduce fungal phytopathogen development. Plant essential oils are a promising source of antifungal compounds. Studies on plant pathogenic fungi have shown that certain essential oils possess antifungal properties that can inhibit fungal growth (Zaidi and Crow, 2005). This effectiveness is likely due to their diverse chemical compositions, the physical structure of their components, and the functional groups they contain, as well as possible synergistic interactions among their constituents (Bajpai et al., 2013). It has been reported that esseantial oils such as *Salvia officinalis*, *Rosmarinus officinalis*, *Origanum onites*, *Anethum graveolens*, *Cuminum cyminum*, and *Echinophora tenuifolia* exhibit antifungal activity against various phytopathogens, and their appropriate doses can be used as fungicides (Yilar et al., 2018; Kaur at al., 2021; Ok and Şanlı 2023; Şanlı and Ok, 2023).

In potatoes, tuber quality is closely related to plant health and nutritional status, and under conditions where the negative effects of biotic and abiotic stress factors are reduced, tuber quality is positively impacted. In the applications of *O. onites, E. tenuifolia, R. officinalis* and *F.*

vugare essential oils, the total sugar content was lower compared to other treatments. Similarly, all essential oil applications, especially those with fennel and oregano oils, resulted in a significant reduction in the reducing sugar content of the tubers. It is believed that this effect stems from certain active compounds in these essential oils that influence sucrose synthesis activity. Glucose produced through photosynthesis is converted into sucrose or reducing sugars through the activity of various enzymes, or it is converted into starch and stored in the tubers. The sucrose produced to be converted into storage material can, when needed, or for respiration, be converted back into reducing sugars. These transformations vary depending on numerous factors during the plant's physiological development. In addition to stress factors like temperature and humidity, the presence of diseases and pests can trigger the plant's defense mechanisms, causing it to generate energy by breaking down stored materials to cope with the negative conditions. The wide and significant variation in the total and reducing sugar content of the tubers depending on the treatments indicates that the applications are effective against stress factors that emerge during different stages of plant development. Foliar applications of essential oils reduced dry matter and starch accumulation. With these applications, promoting plant growth led to better development of the above-ground biomass. In plants with improved growth habitus, tuber yield increased due to higher photosynthetic activity, while dry matter and starch accumulation, indicators of quality, were lower.

Conclusion

Essential oils from medicinal plants are considered potential next-generation biostimulants and pesticides for controlling plant pathogens and pests, as well as for enhancing stress tolerance through various mechanisms, including the activation of plant defenses. In this study, the findings indicate that essential oils from *R. officinalis*, *C. cyminum*, and *E. teniufolia* exhibit significant biostimulant properties and enhancing potato plant growth and tuber yields. Foliar applications of *R. officinalis* at 300 and 600 ppm, and *C. cyminum* at 300 ppm have been shown to be a natural alternative for sustainable potato production. However, in order to reach a more definitive conclusion, detailed studies are needed to reveal the mode of action of essential oils and their biostimulant effects.

Declarations

This study was presented at the 7th International Anatolian Agriculture, Food, Environment and Biology Congress, (Kastamonu, TARGID 2024)

References

Abeytilakarathna, P.D. (2022). Factors Affect to Stolon Formation and Tuberization in Potato: A Review. Agricultural Reviews. 43(1): 91-97.

Aliche, E.B., Theeuwen, T.P.J.M., Oortwijn, M., Visser, R.G.F. and Linden, C.G.V.D. (2020). Carbon partitioning mechanisms in potato under drought stress. Plant Physiology and Biochemistry. 146: 211-219.

Anjitha, K.S., Sameena, P.P., Jos T. (2021). Puthur Functional aspects of plant secondary metabolites in metal stress tolerance and their importance in pharmacology. Plant Stress. 2, 100038.

Anonim (2022). Türkiye İstatistik Kurumu, Tedarik Sektörü Kayıtları, www.Tuik.Gov.Tr (Erişim Tarihi: 20.09.2024).

Bahram, D., Saleh, A., Bahman, P. and Reza, M. (2020). Combining ability analysis of tuber yield and related traits in potato. Genetika. 20(1): 215-228.

Bajpai V.K., Sharma A., Baek K.H. (2013). Antibacterial mode of action of Cudrania tricuspidata fruit essential oil, affecting membrane permeability and surface characteristics of food-borne pathogens. Food Control. 32:582–590.

Bakkali, F., Averbeck, S., Averbeck, D., Idaomar, M. (2008). Biological effects of essential oils–a review. Food Chem. Toxicol. 46 (2): 446–475.

Baruah, S.; Mohanty, S. (2021). Sustainable Intensification of Potato Cultivation in Asia. In Scaling-Up Solutions for Farmers: Technology, Partnerships and Convergence; Springer: Cham, Switzerland, 307–322.

Bijay-Singh, Craswell, E. (2021). Fertilizers and nitrate pollution of surface and ground water: an increasingly pervasive global problem. SN Applied Sciences, 3: 518.

Buet, A., Costa, M.L., Martínez, D.E., Guiamet, J.J. (2019). Chloroplast Protein Degradation in Senescing Leaves: Proteases and Lytic Compartments. Front. Plant Sci. 10, 747.

de Sousa, D.P., Damasceno, R.O.S., Amorati, R., Elshabrawy, H.A., de Castro, R.D., Bezerra, D.P., Nunes, V.R.V., Gomes, R.C., Lima, T.C. (2023). Essential Oils: Chemistry and Pharmacological Activities. Biomolecules, 13: 1144.

El-Mougy, N. (2009). Effect of some essential oils for limiting early blight (*Alternaria solani*) development in otato field, Journal of Plant Protection Research, 49(1), 57-62.

Guo, C., Wang, X., Wang, Q., Zhao, Z., Xie, B., Xu, L., Zhang, R. (2022). Plant defense mechanisms against ozone stress: Insights from secondary metabolism. Environmental and Experimental Botany, 217.

Hulscher, M.T., Delleman, J., Eising, J. and Bueren, E.T.L.V. (2013). The Inheritance of Traits, Potato Breeding. Aardappelwereld BV, The Hague, Netherlands, pp 40-63.

Hussain, T. (2016). Potatoes: Ensuring Food for the Future. Adv. Plants Agric. Res. 3: 178–182.

Kaur, V., Kaur, R., Bhardvaj, U., Kaur, H. (2021). Antifungal Potential of Dill (Anethum graveolens L.) Seed Essential Oil, its Extracts and Components Against Phytopathogenic Maize Fungi. Journal of Essential Oil Bearing Plants. 24(6): 1333-1348.

Kennedy DO, Wightman EL. (2011). Herbal extracts and phytochemicals: plant secondary metabolites and the enhancement of human brain function. Adv Nutr. 2(1): 32-50.

Lang, G., Buchbauer, G. (2012). A review on recent research results (2008–2010) on essential oils as antimicrobials and antifungals, A review. Flavour Fragr. J. 27: 13–39.

Marotti M, Piccaglia R. (1992). The influence of distillation conditions on the essential oil composition of three varieties of *Foeniculum vulgare* Mill. Journal of Essential Oil Res. 4.

Marschner, P. (2011). Mineral Nutrition of Higher Plants, third ed. Elsevier, London.

Mbuyisa, S.; Bertling, I.; Ngcobo, B.L. (2023). Foliar Application with Plant-Derived Extracts Enhances Growth, Physiological Parameters, and Yield of Potatoes (Solanum tuberosum L.). Biol. Life Sci. Forum. 27: 34.

Nelson, N.A. (1944). photometric adaptation of the Somogyi method for the determination of glucose. J. Biol. Chem.153: 375–380.

Ntalli, N. G, Ferrari, F, Giannakou, I., Menkissoglu-Spiroudi, U. (2010). Phytochemistry and Nematicidal Activity of the Essential Oils from 8 Greek Lamiaceae Aromatic Plants and 13 Terpene Components, J. Agric. Food Chem., 58: 7856–7863.

Ok, F.Z. and Şanlı, A. (2021). Effects of Pre-Harvest Application with Natural and Synthetic Sprout Inhibitors on Yield and Storage Quality of Potato (Solanum tuberosum L.). Journal of the Institute of Science and Technology, 11(Special Issue): 3546-3558.

Ok, F.Z., Şanlı, A. (2023). Antimicrobial Activity of Some Essential Oils Against Agricultural Phytopathogenic Fungi and Bacteria. III. International Congress of the Turkish Journal of Agriculture - Food Science and Technology, Malatya, Türkiye. 358–365.

Parajuli, R., Thoma, G., Matlock, M.D. (2019). Environmental Sustainability of Fruit and Vegetable Production Supply Chains in the Face of Climate Change: A Review. Sci. Total Environ. 650: 2863–2879.

Parham, S., Kharazi, A.Z., Bakhsheshi-Rad, H.R., Nur, H., Ismail, A.F., Sharif, S., RamaKrishna, S., Berto, F. (2020). Antioxidant, Antimicrobial and Antiviral Properties of Herbal Materials. Antioxidants. 21, 9(12): 1309.

Rguez, S., Sellami, I.H., Abid, G., Papetti, A., Hammami, M., Souissi, F., Chaouachi, M., Muhovski, Y., Djébali, N. (2023). Foliar pulverization of Tetraclinis articulata essential oil induces antioxidant status and defense genes expression in tomato plants against Botrytis cinerea infection. Electronic copy available at: https://ssrn.com/abstract=4093610.

Rose, M.T., Patti, A.F., Little, K.R., Brown, A.L. (2014). A meta-analysis and review of plant-growth response to humic substances: practical implications foragriculture. Adv. Agron. 124: 37–89.

Sánchez-Sánchez, A., Sánchez-Andreu, J., Juárez, M., Jordá, J., Bermúdez, D. (2002). Humic substances and amino acids improve effectiveness of chelate Fe EDDHA in lemon trees. Plant Nutr. 25: 2433–2442.

Sanli, A., Ok, F.Z. (2023). Chemical Composition and Antimicrobial Activity against Phytopathogenic Fungi of Essential Oils Obtained from Echinophora tenuifolia subsp. sibthorpiana Grown in Wild and Cultivated Conditions in Turkey. Molecules. 28: 585-593.

SAS Institute. (2009). INC SAS/STAT users’ guide release 7.0, Cary, NC, USA.

Sharifi-Rad J., Sureda, A., Tenore, G.C., Daglia, M., Sharifi-Rad, M., Valussi, M., Tundis, R., Sharifi-Rad, M., Loizzo, M.R., Ademiluyi, A.O., Sharifi-Rad, R., Ayatollahi, S.A., Iriti, M. (2017). Biological Activities of Essential Oils: From Plant Chemoecology to Traditional Healing Systems. Molecules. 22(1): 70.

Sharma, A., Kumar, V., Shahzad, B., Tanveer, M., Sidhu, G.P.S., Handa, N., Kohli, S.K., Yadav, P., Bali, A.S., Parihar, R.D. (2019). Worldwide Pesticide Usage and Its Impacts on Ecosystem. SN Appl. Sci. 1: 1446.

Souri, M.K. and Bakhtiarizade, M. (2019). Biostimulation effects of rosemary essential oil on growth and nutrient uptake of tomato seedlings. Scientia Horticulturae. 243: 472-476.

Stein SE. (1990). National Institute of Standards and Technology (NIST) Mass Spectral Database and Software, Version 3.02, Juen USA.

Tiku A.R. (2018). Antimicrobial compounds and their role in plant defense. In: Singh A., Singh I.K., editors. Molecular Aspects of Plant-Pathogen Interaction. Springer; Singapore pp. 283–307.

Yilar, M., Kadioğlu, İ., Telci, İ. (2018). Chemıcal Composıtıon And Antıfungal Actıvıty Of Salvıa Offıcınalıs (L.), S. Cryptantha (Montbret Et Aucher Ex Benth.), S. Tomentosa (Mıll.) Plant Essentıal Oıls And Extracts. Fresenius Environmental Bulletin. 27(3): 1695-1706.

Zaidi, M.A., Crow, S.A. (2005). Biologically active traditional medicinal herbs from Balochistan, Pakistan. J. Ethnopharmacol. 96:331–334.

Zebec, Z., Wilkes, J., Jervis, A.J., Scrutton, N.S., Takano, E., Breitling, R. (2016). Towards synthesis of monoterpenes and derivatives using synthetic biology. Current Opinion in Chemical Biology. 34:37-43.

Zulfiqar, F., Casadesús, A., Brockman, H., Munné-Bosch, S. (2020). An Overview of Plant-Based Natural Biostimulants for Sustainable Horticulture with a Particular Focus on Moringa Leaf Extracts. Plant Sci. 295: 110194.