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Growth-Promoting Bacteria and Salicylic Acid Improve Essential Oil, Flower Yield, And Compatible Osmolyte Content of Common Yarrow (*Achillea millefolium* L.) Under Drought Stress

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Drought is one of the major constraints on agricultural productivity in arid and semiarid regions. Coping with drought stress involves several adaptations and mitigation strategies such as the use of plant-growth promoting bacteria and salicylic acid, which was examined in this study under two levels of water regimes (well-watered as control and drought stress) in southwest Iran in 2018 and 2020 on common yarrow (*Achillea millefolium*). Catalase levels significantly increased in response to drought stress and salicylic acid application. Salicylic acid and combined application treatment of both bacteria also resulted in a significant increase in proline compared with the control. Different bacteria strains also resulted in a significant increase in peroxidase and superoxide dismutase when compared with the control. Drought stress, salicylic acid application, and different bacteria strains significantly reduced total protein. The use of salicylic acid and the combined application of both bacteria significantly increased the percentage of essential oil compared with the control. Moreover, 41 compounds were isolated, accounting for 92.08% of the essential oil, with more than 90.00% being volatile terpenes. The main components of yarrow essential oil were borneol (16.79%), flanderin (15.92%), cineole (14.32%), camphor (9.77%), and alpha-pinene (3.44%). In general, growth-promoting bacteria and salicylic acid application constitute an advantageous management practice for the commercial production of *Achillea millefolium*, increasing the nutraceutical and medicinal values of this species.

Keywords: proline, catalase, peroxidase, essential oil analysis, total protein

INTRODUCTION

Achillea millefolium, also known as yarrow or common yarrow, is a flowering plant of the Asteraceae family. It is native to temperate Northern Hemisphere regions such as Asia, Europe, and North America (Ebrahimpour and Eidizadeh 2009; Ghani et al. 2009). The dark blue essential oil of yarrow contains chemicals called proazulenes. This plant's most important active compounds are azulene chamazulene, δ-cadinol, isovaleric acid, salicylic acid, asparagine, sterols, and flavonoids (Jamshidi et al. 2010).

Water scarcity is one of the most significant factors limiting agricultural production worldwide, particularly in arid and semi-arid regions such as Iran. Drought occurs when a combination of physical and environmental factors causes plant stress, resulting in decreased growth. Because of the delay or lack of plant establishment, the plant is vulnerable to pests and diseases and morphological, physiological, and metabolism changes, resulting in decreased production quality and quantity (Ghodrat and Bahrani 2022). Drought stress decreases turgor pressure and cell development; for example, in yarrow, decreasing soil moisture decreases height, root weight, shoots, and several stems per plant (Sharifi Ashorabadi et al. 2009). Pouryousef (2015) investigated the effect of water stress on the yield, essential oil, and plant height of several medicinal plants. They discovered that while water stress reduced plant height and fresh and dry weight, it significantly increased the amount of essential oil produced during flowering.

In recent years, rhizosphere growth-promoting bacteria have been used as root-stimulating hormones and biocontrol agents due to their high potential in the production of plant hormones, their effect on plant growth and yield, and their reduction of damage caused by plant pathogens (Zahir et al. 2003).

A wealth of evidence supports the ability of rhizosphere bacteria to produce plant growth regulators and their impact on plant morphology, nutrition, and growth. Some of these regulators include auxin, cytokinin, and gibberellin. Previous studies have shown that the application of stimulants significantly increased plant growth, and a small amount of growth-promoting bacteria significantly increased essential oil content (Swamy and Seeta Ram Rao 2008; Bahrani and Pourreza 2012; Alipour et al. 2021). Many strains of fluorescent Pseudomonas, particularly *P. fluorescence* and *P. putida*, stimulate plant growth and increase crop yield (Vlassak et al. 1992). According to reports, the action of microorganisms induces a specific pathway for synthesizing secondary metabolites in medicinal plants. Pseudomonas' production of secondary metabolites emphasizes the importance of using them for industrial and health-related agricultural purposes (Omay et al. 1993).

The use of plant growth-promoting rhizobacteria and salicylic acid in drought stress conditions can lead to plant resistance and increase the oil content in the yarrow plant. Therefore, the main goal of this study was to investigate the possibility of drought resistance using growth-promoting bacteria and salicylic acid and the effect of these treatments on compatible osmolyte content, flower yield, and percentage of yarrow essential oil under drought stress.

MATERIALS AND METHODS

This research was conducted over two cropping years (2018–2020) at Gachsaran Agricultural and Natural Resources Research Station in Iran. This region has hot and dry weather conditions with a longitude of 50°50′ and latitude of 30°17′, minimum and maximum temperatures of 6°C and 47°C, respectively, with a relative humidity of 31% and an altitude of 710 m asl. Before the experiment, the soil was randomly sampled from a depth of 0 – 30 cm and the physicochemical properties of the soil were obtained.

Water regime is considered the main factor in two levels of well-watered as control and drought stress. To apply drought stress, information about the studied plant, planting date, growth rate, and meteorological parameters in a 15-yr statistical period were collected from the meteorological station of Gachsaran Research Center. Then, using CropWat, the required plant water and appropriate time of stress were determined (Suryadi et al. 2019). CropWat is a software released by the Food and Agriculture Organization of the United Nations (FAO) to facilitate the analysis of irrigation water needs and schedules. As input data, basic information such as climatological data, monthly rainfall data, plant data, and data on soil physical properties are required. The irrigation of all plots was carried out to the 4-leaf stage without stress. The moisture content of the soil before each irrigation was measured with a hygrometer of spectrum type (TDR model 150) made by Fondriest Environmental, Inc., USA.

Its sub-factors include foliar salicylic acid application at two levels of control (no foliar application) and foliar salicylic acid application (400 mg/L) by spraying the aerial part of the plants at the flowering stage. Control plants were sprayed with only distilled water (1 L) mixed with ethanol (10 mL). Foliar applications were applied on the 1st of May, the end of May, and the 3rd week of June. After applying plastic nylon to prevent the mixing of treatments, the foliar application was done in the first hours of the morning. Growth-promoting bacteria with Colony-Forming Unit (CFU) = 10^{-8} CFU/mL were used at four different control levels: no bacteria inoculation, Pseudomonas inoculation, Azotobacter inoculation, and both bacteria inoculations. To facilitate the inoculation of the seeds, some sugar dissolved in warm water (10 g of sugar per 100 g of water) was added for 1 h and then the seeds were dried under sunlight. The seeds were obtained from the National Forests and Rangelands Institute, Karaj, Iran. Seeds of *A. millefolium* have a low germination rate due to their dormancy. Therefore, GA3 treatment at 500 ppm levels was applied (Mirzaei et al. 2023).

Common yarrow seeds in 50-cm furrows were sown in 25-cm rows on the 4th of April of both years. Each plot had six planting lines with 5-m lengths in 30 cm and 10 cm inter-and between rows, respectively.

The flowering heads of *A. millefolium* plants were collected at harvest times. Fresh and dry weights of flowering heads (g plant^{-1} and ton ha^{-1}) were recorded.

To measure the percentage of essential oil, distillation was used using a Clevenger device (Darzi et al. 2009). To analyze and evaluate the constituents of the essential oil, about 100 µL of the essential oil was injected into the gas chromatography (GC) device and gas chromatograph-coupled to the mass spectrometer (GC-MS) with the following specifications: gas chromatograph connected to Agilent technologies mass spectrometer model A5975, HP-5M5 column with a length of 30 cm and a diameter of 0.25 mm, static phase layer thickness 0.25 µm, thermal programming of the column at 60 – 210°C with increasing temperature of 3°C per minute, and 210 – 240°C with increasing temperature of 20°C per min, injection chamber temperature: 280°C, ionization energy: 70 electron V, carrier gas: helium. The oil percentage was multiplied by seed yield per kg/ha and oil yield per kg/ha was obtained.

The activities of catalase, peroxidase, and superoxide dismutase were determined using the methods developed by Maehly and Chance (1954), MacAdam et al. (1992), and Gupta et al. (2002), respectively. The measurement of proline was performed according to Bates et al. (1973). The Kjeldahl method was applied to estimate total protein (content of leaf and seed) (Khanizadeh et al. 1995). Two-year data were combined and analyzed utilizing the SAS software (Ver. 9.1) and tests of significance were performed by standard deviation at the statistical level of 5%.

RESULTS

Proline

The analysis of variance results revealed that only the main effects of water regimes and salicylic acid were significant at the 1% probability level (Table 1). Mean comparison revealed that drought stress resulted in a significant increase in proline. Salicylic acid application significantly increased proline compared with the control. The highest proline level was obtained in the combined application treatment of Pseudomonas + Azotobacter application (Table 2).

Catalase

Only the main effects of water regimes, salicylic acid, and bacteria were significant in this trait at a 1% probability level (Table 1). Mean comparison also revealed that drought stress and salicylic acid application significantly increased catalase. Different bacterial strains significantly reduced catalase compared with the control. These strains resulted in the highest concentration of catalase obtained in the absence of bacteria treatment (Table 2).

Peroxidase

According to the analysis of variance results, only the main effects of water regimes and bacteria were significant at a 1% probability level. On this trait, the interaction of drought stress and salicylic acid, as well as the triple interaction of water regimes, salicylic acid, and bacteria, was significant at

Table 1. Combined analysis of variance of studied traits during 2018 – 2020.

Sources of variations (SOV)	Degree of freedom (df)	Proline enzyme (U/mg Protein. min)	Catalase enzyme (U/mg Protein. min)	peroxidase enzyme (U/mg Protein.min)	Superoxide dismutase (U/mg Protein.min)	Total protein (g/plant)	Flower yield (kg/ha)	Essential oil yield (kg/ha)
Year	1	50.173 ns	275.746**	816.033**	1.400 ns	69.890**	1956914779**	8731.390**
Year*Rep	2	11.142	1.574	5.515	0.079	3.715	4120.05	0.900
Water regimes (a)	1	942.740**	1929.313**	4821.278**	140.037**	1108.089**	7319245.38**	402.292**
Year * Water regimes	1	23.189 ns	21.314 ns	10.583 ns	0.287 ns	10.965 ns	3406008.4**	191.196**
Rep* Water regimes	2	0.431	5.251	9.011	0.192	2.156	300.97	0.065
Salicylic acid (b)	1	142.158 ns	463.299**	1.368 ns	0.0003 ns	10.464 ns	2255220.91**	144.207**
Bacteria (c)	3	445.366**	65.339**	505.620**	10.271**	62.973*	1684144.43**	96.190**
Year* salicylic acid	1	5.763 ns	10.603 ns	8.131 ns	0.049*	0.388 ns	925126.59**	100.737**
Year* Bacteria	3	39.809 ns	2.993 ns	96.829*	1.284 ns	9.596 ns	657110.86**	66.180*
b×a	1	112.323	0.003 ns	153.840**	0.528 ns	16.515 ns	15975.88 ns	4.018ns
a×c	3	9.823 ns	13.062 ns	43.223 ns	0.167 ns	8.372 ns	10725.4 ns	0.999ns
c×b	3	92.715 ns	13.439 ns	37.969 ns	0.325 ns	3.640 ns	42967.92 ns	3.072ns
Year*Water regimes*Salicylic acid	1	2.808 ns	2.106 ns	0.830 ns	0.091 ns	1.045 ns	15799.89 ns	4.318ns
Year*Water regimes* Bacteria	3	30.364 ns	0.938 ns	21.435 ns	0.1778 ns	4.304 ns	8950.86 ns	3.102ns
Year* Salicylic acid * Bacteria acid	3	37.141 ns	4.168 ns	20.744 ns	0.013 ns	1.017 ns	16768.51 ns	2.092ns
Water regimes * Salicylic acid * Bacteria	3	0.791 ns	3.594 ns	89.627**	0.953 ns	5.494 ns	71280.3**	1.468ns
Year* Water regimes * Salicylic acid * Bacteria	3	34.692 ns	2.722 ns	31.381 ns	0.204 ns	2.292 ns	49702.53**	5.003*
Coefficient of variation (CV)		42.301	6.077	7.457	17.794	7.407	11.030	1.400

**,* Significant at the level of 1% and 5% probability levels, respectively. ns: non-significant

Table 2. Mean comparison of results of the treatments on the studied traits.

Different Treatment Levels	Treatments	Proline (U/mg Protein.min)	Catalase (U/mg Protein.min)	Peroxidase (U/mg Protein.min)	Superoxide Dismutase (U/mg Protein.min)	Total Protein (g/plant)	Flower Yield (kg/ha)	Essential Oil Yield (kg/ha)
Drought stress	Water regimes	20.128 A	42.950 A	69.273 A	4.601 A	22.910 B	405.900 B	11.700 B
Well-watered		13.125 B	33.984 B	55.099 B	2.186 B	29.690 A	957.200 A	15.800 A
Mean		16.989	38.467	62.186	3.393	26.298	681.403	13.754
SD (0.05)		6.084	2.012	2.636	0.385	1.289	15.237	0.224
Foliar application	Salicylic acid	18.207 A	40.664 A	62.076 A	3.391 A	26.620 A	528.900 B	12.520 B
Non-foliar application		15.773 B	36.270 B	62.305 A	3.395 A	25.960 A	834.200 A	14.980 A
Mean		16.990	38.467	62.190	3.393	26.298	681.550	13.750
SD (0.05)		2.936	0.955	1.894	0.246	0.796	30.711	0.483
No inoculation	Bacteria	12.433 B	40.420 A	56.688 C	2.581 C	27.930 A	388.300 D	11.430 D
Pseudomonas inoculation		14.195 B	39.223 A	60.478 B	3.155 B	27.430 A	769.200 C	14.270 C
Azotobacter inoculation		20.469 A	37.349 B	64.340 A	3.833 A	25.070 B	565.100 B	13.110 B
Pseudomonas+ Azotobacter		20.862 A	36.877 B	67.231 A	4.004 A	24.750 B	1 002.900 A	16.190 A
Mean		16.989	38.467	62.184	3.393	26.295	681.375	13.754
SD (0.05)		5.487	1.785	3.541	0.461	1.487	57.4	0.903

a 1% probability level (Table 1). Mean comparison showed that drought stress significantly increased peroxidase. Different bacteria strains caused a significant increase in peroxidase compared with the control. Here, the highest amount of peroxidase was obtained in the combined application treatment of both bacteria (Table 2). The highest concentration of peroxidase was obtained in drought stress with no application of salicylic and bacteria, which showed a significant difference from other treatments in the triple interaction of these treatments (Fig. 1).

Superoxide Dismutase

Only the main effects of water regimes and bacteria were significant at a 1% probability level in both years. The results of the treatment interactions also revealed that only the interaction of salicylic acid with bacteria and the triple effect of all three treatments were significant (Table 1). Drought stress increased superoxide dismutase significantly. Different bacteria strains also caused a significant increase when compared with the control, with combined application treatment of both bacteria yielding the highest concentration of superoxide dismutase (Table 2).

Total Protein

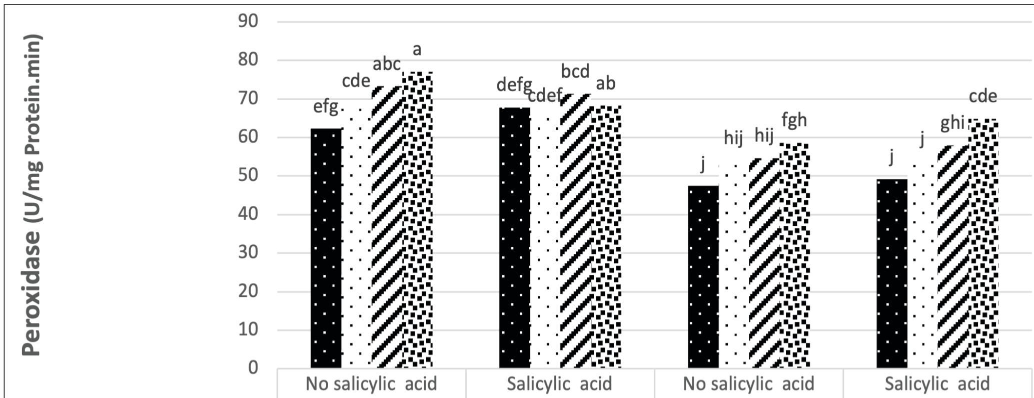
Only the main effect of water regimes at a 1% probability level and bacteria at a 5% probability level was significant for this trait (Table 1). Mean comparison revealed that drought stress and salicylic acid significantly reduced total protein. Different bacterial strains also resulted in a significant decrease in total protein compared with the control, with the control treatment yielding the highest amount and the combined treatment yielding the lowest (Table 2).

Flower Yield

The effects of water regimes, salicylic acid application, and bacteria, as well as their triple interaction, were significant at the 1% probability level. The water regimes-salicylic, water regimes-bacterial, and bacterial-salicylic interactions were significant at the 1% and 5% probability levels (Table 1). Mean comparison revealed that drought stress significantly reduced flower yield. Furthermore, the use of salicylic acid significantly decreased flower yield. Different strains of bacteria also significantly increased flower yield compared with the control, with the combined application of both bacteria resulting in the highest flower yield. Mean comparison of the interaction of salicylic acid and bacterial application revealed that the salicylic acid-bacterial application treatment produced the highest flower yield, which differed significantly from the other treatments (Table 2). Moreover, in drought stress conditions, the highest flower yield was obtained in both bacteria and the salicylic acid application (Fig. 2).

Essential Oil Yield

The main effects of year, water regimes, salicylic acid application, bacterium, dual interaction of year-water regimes, year-salicylic acid, year-bacterium, and interaction of all factors were significant at 1% probability level (Table 1). Mean comparison revealed that drought stress significantly reduced



	No salicylic acid	Salicylic acid	No salicylic acid	Salicylic acid
Control	62.329	67.783	47.44	49.199
Pseudomonas	68.885	65.106	54.096	53.859
Azotobacter	73.334	71.3375	54.676	58.014
Pseudomonas+Azotobacter	77.129	68.28	58.645	64.868

Control · Pseudomonas · Azotobacter · Pseudomonas+Azotobacter

Fig. 1. Comparison of the mean interactions of experimental treatments on peroxidase enzyme. Columns with common letters have no significant difference at the 5% probability level.

essential oil yield, which significantly increased with the use of salicylic acid. Different strains of bacteria significantly increased essential oil yield compared with the control group, with the combined application treatment of both bacteria yielding the highest essential oil yield. The interaction of water regimes treatments and salicylic acid revealed that the drought stress-salicylic acid application treatment produced the highest essential oil yield, which differed significantly from the other treatments. The triple interaction of the treatments revealed that the drought stress-salicylic acid-both bacteria treatments produced the highest essential oil yield, which differed significantly from the other treatments (Fig. 3).

Essential Oil Analysis Using the GC-MS Method

The percentage of essential oil extraction in yarrow was 0.29% by weight. Results were obtained using GC-MS to identify the major constituents of essential oils. The analysis of yarrow essential oil yielded 41 compounds, with more than 90% being volatile terpenes. The main constituents of yarrow essential oil were borneol (16.79%), flanderin (15.92%), cineole (14.32%), camphor (9.77%), and alpha-pinene (3.44%). Table 3 shows the compounds identified in yarrow essential oil and a small percentage of its compounds. Fig. 4 depicts the spectrum obtained from the analysis of yarrow essential oil.

DISCUSSION

Plants respond to drought-induced environmental stresses by changing some of their physiological and biochemical properties. One of these responses is proline accumulation. Proline is an effective potassium ion permeable channel regulator (Hong et al. 2000). Lutts et al. (1996) proposed four reasons for the increase in proline accumulation in the plant

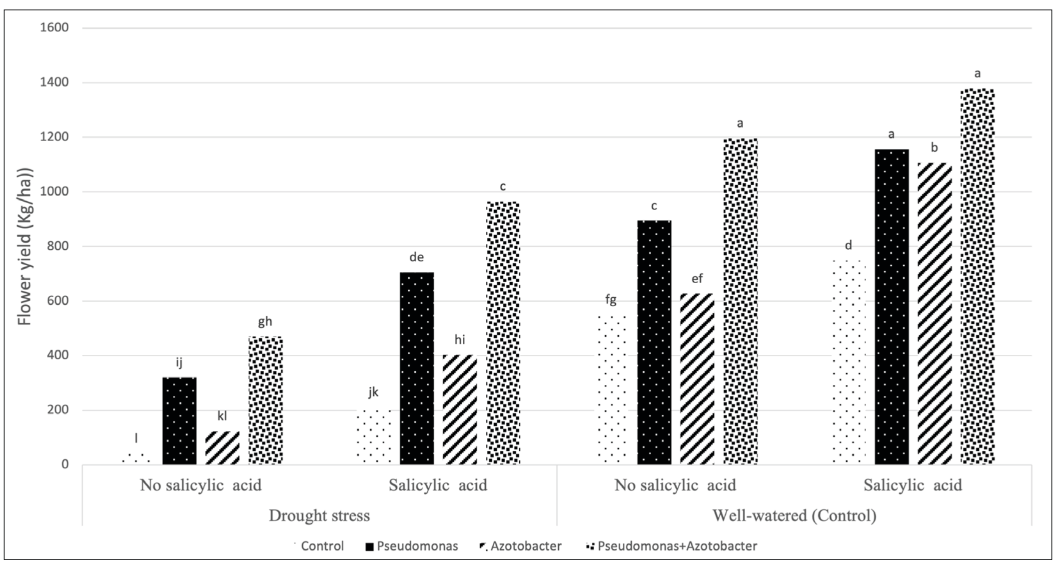


Fig. 2. Comparison of the average interaction effects of experimental treatments on flower yield. Columns with common letters have no significant difference at the 5% probability level.

response to stress: stimulating proline synthesis from glutamic acid, reducing proline export through the rinsing vessel, preventing proline oxidation during stress and degradation, and disrupting the protein synthesis process. Proline acts as an osmotic protector, stabilizing the photosystem II complex and preserving the structure of enzymes and proteins by protecting the plasma membrane from free radicals caused by light damage (Sarker et al. 2005). In this study, salicylic acid and a combination of Pseudomonas + Azotobacter application increased proline compared with the control. Proline and malondialdehyde levels increased as stress intensity increased (Gharibi et al. 2012).

Plants produce free radicals in response to osmotic stresses and employ various strategies to eliminate these toxic radicals, the most important of which is the production and accumulation of secondary metabolites. Drought stress could significantly increase the number of phenolic compounds and their antioxidant activity. As observed in this study, drought stress and salicylic acid application increased catalase, peroxidase, and superoxide dismutase enzymes. Different bacterial strains reduced catalase compared with the control. However, peroxidase and superoxide dismutase increased.

Salicylic acid plays an essential role in the response of plants to environmental stresses and protects the plant against many abiotic stresses (Hussein et al. 2007). It is also an endogenous guide molecule in plant resistance to environmental stress (Kaydan et al. 2006). Under adverse abiotic factors, salicylic acid accumulates in plant tissues and contributes to increased plant resistance to environmental stresses. It also increases plant resistance to incompatible biotic and abiotic stresses (Abdou et al. 2001). Several studies have confirmed the importance of salicylic acid in regulating the plant's response to abiotic

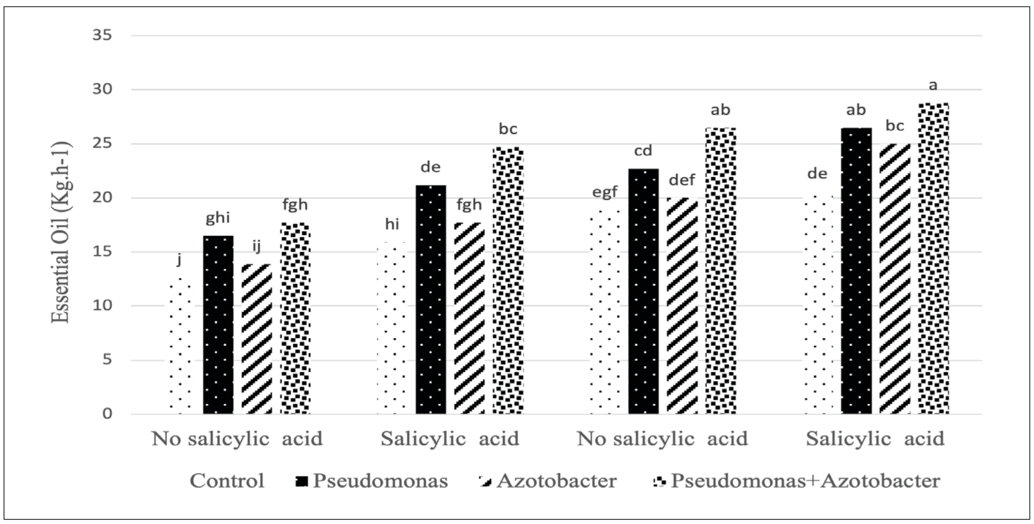


Fig. 3. Comparison of the mean interactions of experimental treatments on essential oil yield. Columns with common letters have no significant difference at the 5% probability level.

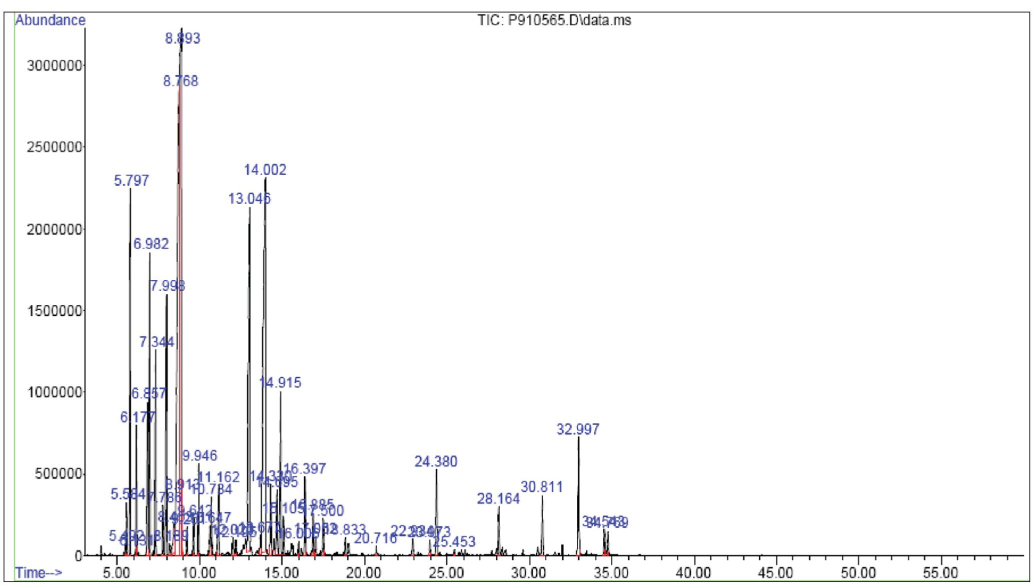


Fig. 4. Spectrum from the analysis of constituents of yarrow essential oil.

Table 3. Types of compounds, refractive index, and mass percentage of yarrow essential oil.

Row	Type of Compound	Mass Percentage	Refractive Index*	Row	Type of Compound	Mass Percentage	Refractive Index*
1	Fenchene	0.217	921	22	Menthenol	0.367	1 120
2	Camphene	0.621	925	23	Camphor	9.771	1 145
3	Sabinene	2.452	933	24	Pinocarvone	0.610	1 160
4	*a*-pinene	1.132	945	25	Borneol	16.769	1 168
5	Myrcene	1.330	947	26	Terpineneol	1.009	1 176
6	Tricyclene	1.980	972	27	Cryptone	1.322	1 185
7	*a*-Thujene	2.002	977	28	*a*-Terpineol	2.929	1 191
8	*β*-Pinene	3.442	990	29	Myrtenal	0.560	1 195
9	Phellandrene	0.748	1 005	30	*p*-Cymene	0.130	1 217
10	-3-Carene	2.986	1 011	31	Isobornyl formate	1.225	1 226
11	-Terpinene	0.213	1 016	32	Cumin aldehyde	0.401	1 237
12	trans-Carveol	0.936	1 023	33	Carvone	0.265	1 241
13	Phellandrene	15.924	1 032	34	Geraniol	0.574	1 252
14	1,8-Cineole	14.332	1 033	35	Bornyl acetate	0.317	1 283
15	(Z)- Ocimene	0.429	1 036	36	Hexyl tiglate	0.180	1 328
16	(E) Ocimene	0.406	1 046	37	Geranyl acetate	0.234	1 381
17	Terpinene	0.249	1 057	38	Gurjunene	0.217	1 406
18	cis-Sabinene hydrate	1.124	1 065	39	(E)-Caryophyllene	1.374	1 417
19	*p*-Mentha-2,4(8)-diene	0.366	1 085	40	Campholenal	0.208	1 124
20	Terpinolene	0.767	1 087	41	σ-Cadinene	0.790	1 511
21	Linalool	1.167	1 099				

* The refractive index of an essential oil is a unique number that designates how the oil responds and bends light. Essentially, it is a measurement that tests how the speed of light is altered when passing through the oil.

stresses such as drought, salinity, cold, and heat (Al-Hakimi 2008). In this study, there were also significant differences in almost all traits in the 2-yr duration of the experiment because of the difference in weather conditions.

There have been several studies done on the type of compounds and the percentage of yarrow essential oil extraction. Kazemizadeh et al. (2011) found a 1.8% yield of yarrow essential oil in flowers and a 1% yield of yarrow essential oil in leaves, with the main compounds being 1-cinnamol, 8-cinnamol, and trans-verbenone. Ghani et al. (2009) reported yarrow essential oil yields of 2.0% and 2.5% in the two habitats, respectively, with the main compounds being camphor, 1- and 8-cinnamol, camphene, α-pinene, myrsen, and *β*-pinene. According to Shafaghat (2009), the main constituents of essential oil are limonene, borneol acetate, and α-pinene. Azadbakht et al. (2001) also identified 1- and 8-cineole, borneol, and camphor in yarrow leaf and flower essential oils. In addition, 59.8% and 72.8% of essential oil monoterpenes and 22.2% and 12.2% of sesquiterpenes were found in leaves and flowers. In this study, the main constituents of yarrow essential oil were borneol, flanderin, cineole, camphor, and α-pinene. Ebrahimi et al. (2012) reported an essential oil yield of 0.36%, with camphor, cineole, and borneol as the essential oil components. The percentage of compounds extracted varies depending on the plant's genetic structure, weather conditions, essential oil extraction time, essential oil extraction method, and plant organ type (Ghani et al. 2009).

The positive effect of biofertilizers on yield, yield components, and other plant growth characteristics could be attributed to the uptake of nutrients due to the availability of soil minerals (Table 4).

Table 4. Physical and chemical properties of the field experiment.

Properties	Values	Properties	Values
Sand%	28.00	Mn (mg/k)	1.00
Silt%	29.00	P (mg/k)	6.70
Clay%	43.00	K (mg/k)	273.00
B.D (g/cm)	1.47	N %	0.11
Ec (ds/m)	0.80	Cu (mg/k)	0.95
pH	8.48	Fe (mg/k)	3.94
OC%	1.42	Zn (mg/k)	0.69

Biofertilizers help stabilize nitrogen in the soil and dissolve phosphorus and potassium. As observed in this study, different strains of bacteria increased flower yield compared with the control, and the combined application of both bacteria produced the highest flower yield. These fertilizers also promote root hair or lateral root formation by producing plant growth regulators (auxin, gibberellin, and cytokinin). Biofertilizers, particularly Azotobacter bacteria as plant growth stimulants and molecular nitrogen fixation, improve fertilizer efficiency by producing hormones and various growth stimulants such as auxin, pantothenic acid, and biotic acid through increased production of root hair and nutrient absorption (Khan et al. 2009). Using biofertilizers promotes root development and provides the conditions for nutrient absorption (Zahir et al. 2003; Rezvan Beidokhti et al. 2009).

CONCLUSION

The application of salicylic acid and different strains of bacteria used, especially in drought stress conditions, constitutes an advantageous management practice for the commercial production of yarrow (*Achillea millefolium*). Plants treated with salicylic acid and different strains of bacteria increased flower yield, which can enable producers to cultivate a greater number of plants per area and consequently generate better income. Concerning the synthesis of secondary metabolites, the application of salicylic acid and different strains of bacteria was the most effective in eliciting the production of essential oils and total phenols, with a consequent improvement of the antioxidant activity of the plant extract. The application of salicylic acid and different strains of bacteria resulted in a significant increase in the percentage of essential oil compared with the control, with the combined application of both bacteria producing the highest amount. Therefore, the use of these factors can be considered a useful strategy for plant water stress management.

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