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Effect of Yeast and Planting Distances on Productivity and Volatile Oil of *Rosmarinus officinalis* L. Plant under Siwa Oasis Conditions

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A FIELD study was conducted on rosemary plants (*Rosmarinus officinalis*) in newly reclaimed sandy soil at Siwa Oasis in Egypt's Sahara. The goal was to find the best dry yeast extract concentration for spray, cultivation distance, and interaction to maximize yield. These issues have yet to be researched in the context of this region. The investigation was carried out using a split-plot design. The main plots were sprayed with four doses of dry yeast extract: 0, 8, 12, and 16g/L. The subplots involved cultivation at three different plant-to-plant spacings: 30, 50, and 70cm. Growth, yield, and essential oil characteristics were recorded as data points. Our findings showed that raising yeast extract concentrations increased development and production. Growing at a close distance of 30 cm yielded the most herb and essential oil production per hectare, although planting at a greater distance boosted fresh and dry weights per plant. The essential oil had high concentrations of α-pinene, 1,8-cineole, camphor, and borneol. To increase the producers' income under these environmental conditions, we recommend growing rosemary at a distance of 30 cm and spraying it with yeast extract at a dosage of 16g per liter.

Keywords: Planting distances, Rosemary, Yeast extract, Yield.

Introduction

Medicinal and aromatic plants, commonly referred to as herbal products, are raw materials utilized primarily for therapeutic, fragrant, and flavoring objectives. These plants are essential in many applications, such as beauty products, pharmaceuticals, dietary supplements, and other natural wellness commodities (Badr et al., 2014; Moustafa et al., 2015).

The Egyptian government aims to increase the productive land devoted to cultivating medicinal and aromatic plants on newly reclaimed desert lands. However, the productivity of these developed lands is frequently low. This is due to increased salinity, a lack of elements in the soil, and other stresses caused by the global greenhouse gas issue, which affect crop productivity. One of the most successfully cultivated plants is rosemary. Rosemary grows best in full sun, light, and well-drained soils. It can withstand irrigation water shortages. It is, to some extent, salt-tolerant, attributed to these plants' ability to store sodium in their leaves while maintaining turgor and osmotic adjustment. It is also resistant to a wide range of pests. So, those reclaimed lands are suitable for cultivating such a promising herb (Tounekti et al., 2008; Harrison et al., 2015; Abbaszadeh et al., 2020).

Rosemary, known scientifically as *Rosmarinus officinalis*, belongs to the Lamiaceae family. Leaves and essential oils are widely used in the culinary and medical industries. The therapeutic studies revealed that it could reduce cancer cells, relieve headaches, colic, indigestion, and flatulence, and aid women in maintaining regular menstrual cycles. Rosemary helps treat upper respiratory tract issues such as bronchitis, colds, and the flu. Because of its high concentration of essential oils, which can eliminate bacteria and viruses, it is used to treat rheumatoid arthritis joint pain and disinfect wounds. It is widely used to prevent food from spoiling, particularly meat. Owing to their distinct aroma, the leaves

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are excellent for helping flavor food. The plant, a trendy new ingredient used in beauty products, has been shown to have several positive effects on skin and hair (IUCN, 2005; Stankovic, 2020).

Secondary metabolites from medicinal and aromatic plants are highly valued in pharmaceutical manufacturing. The major compounds in rosemary essential oil are pinene, 1,8-cineole, camphor, and borneol. Pinene has numerous potential advantages. It has anti-inflammatory properties, improves discomfort and calmness, improves mental and breathing abilities, and may help to decrease the spread of infections and diseases. Cineole has antioxidant, anti-inflammatory, blood sugar regulation, anticancer, memory improvement, and antimicrobial effects. Borneol has anticancer and anti-inflammatory properties and can combat stress and tiredness (Mann et al., 1994; Badr et al., 2013).

The research on rosemary and other medicinal herbs belonging to the Lamiaceae family revealed that the agricultural practices used to grow these plants significantly influence the plant's overall productivity and active components. According to Peter (2012) and Toaima (2022, 2023), agronomic methodologies are the primary factor determining the amount and quality of crude herbal products. This is due to the influence of agricultural treatments on photosynthetic efficiency and metabolic byproducts. Foliar spray with an active dry yeast solution as a natural activator for growth and culture spaces between plants could be among these applications.

Active dry baker's yeast, also known as *Saccharomyces cerevisiae*, has been shown to increase the growth, yield, and chemically active constituents of medicinal herbs and spice plants farmed in the desert agroecosystem. Using yeast as a plant biofertilizer provides safe plant nutrition without adverse side effects. As a natural stimulator, the yeast extract contains phytohormones, vitamins, amino acids, and enzymes. It is generally agreed that baker's yeast is a risk-free and cost-effective biofertilizer. The researchers found that spraying with an active dry yeast solution resulted in increased vegetative growth, herb, and essential oil yields, as well as notable increases in the content of important constituents in the essential oil. This was compared to the control treatment, which did not give yeast extract and detected lower parameters (Ali, 2008; Toaima, 2014; Hamed, 2018).

The cultivation density between plants controls how much light each one takes in, how efficiently it utilizes radiation, and how much biomass each produces. It is of the utmost importance to attain the appropriate spaces for each plant, which vary quite a bit depending on the growing region's climatic conditions and the soil's nutritional level. Spacing between plants is one of the most critical factors contributing to enhanced productivity. It gives each plant an equal chance of surviving and maximizes the effectiveness of all other inputs. Transplanting seedlings nearby increases productivity per hectare. However, increasing the distance between them can increase the foliage weight per plant (Tadesse, 2019).

The major three exporters of rosemary oil are India, Spain, and France. Turkey, Morocco, and India are the primary three exporters of rosemary leaves, while Egypt's exports of rosemary products are still low. Newly reclaimed lands for the cultivation of rosemary and other medicinal crops can be found in Siwa Oasis, located in the Western Desert of Egypt (approximately 50 kilometers east of the border with Libya) in the Sahara Desert. Irrigation water resources are available based on groundwater from dug wells and naturally flowing springs. The gap in the study is the need for more information on producing a decent rosemary yield in this area. The cultivation of rosemary has just been made available to the local farmers there (El-Mahrouk et al., 2018; Hanafy et al., 2022; Toaima et al., 2022; Volza's Global Export Data).

This study aims to determine the optimal concentration of active dry yeast extract for spraying on plants as a natural growth promoter, the optimal culture distance, and the interaction between these factors on farmed rosemary to have a good harvest in this region.

Materials and Methods

The research was conducted in the Desert Research Center's Experimental Farm at Khamisa Village (29.21^{o} N and 25.40^{o} E), Siwa Oasis, for two seasons in 2021 and 2022.

The farm represents reclaimed sandy dunes. Its soil mechanical parameters were sand = 92.91%, silt = 5.21%, clay = 1.88%, and sandy texture. The soil chemical properties were pH= 7.50, organic matter= 0.51%, E.C.= 2624ppm, HCO_3^- = 3.61meq/L, Cl^- = 31.32meq/L, SO_4^{--} = 6.10meq/L, Ca^{++} = 8.61meq/L, Mg^{++} = 7.50meq/l, Na^+ = 0.22meq/L, and K^+ = 24.70meq/L. The source of irrigation was an underground water well. Irrigation water had the following chemical parameters: pH = 7.30, E.C. = 3296.00ppm, HCO_3^- = 1.32meq/L, Cl^- = 21.82meq/L, SO_4^{--} = 25.05meq/L, Ca^{++} = 7.80 meq/L, Mg^{++} = 9.67meq/L, Na^+ = 30.00meq/L, and K^+ = 0.72meq/L. Water and soil samples were analyzed, as mentioned by AOAC (2022).

The meteorological data for this region was as follows: the average high temperature ranges from 20°C in January to 38°C in July, with an average of about 30°C for the year. Each month's average low temperature runs from 4°C in January to 21°C in July. The highest temperature recorded was 50°C, and the lowest was 4.5°C. The mean relative humidity for a month is between 30 and 58%. It rarely rains (Egyptian Meteorological Authority).

The Ministry of Agriculture and Land Reclamation supplied rooted cuttings of rosemary seedlings (10-12cm in height). Before planting, 24m^3/hectare of compost manure was applied to the sandy soil during soil preparation. For both seasons, rosemary transplants were planted in March using a drip irrigation system with 75cm between each row. One plant was grown per hill. Chemical fertilization was applied to the experiment, as described by Abd El-Wahab (2002). All farm procedures were carried out using good agricultural practices (Abdalla et al., 2015). The trial involved twelve treatments, and its plan was a split plot.

The main plots were sprayed with four doses of active dry yeast extract: 0, 8, 12, and 16g/liter. Active dry yeast was purchased from the Egyptian Starch Yeast and Detergents Company. The chemical analysis of it showed protein = 45%, carbohydrates = 34%, amino acids = 10%, minerals = 8%, and lipids = 3%. According to El-Tohamy et al. (2008), an active dry yeast solution was prepared. The foliar spray was applied 45 and 90 days after planting and repeated after the first harvest. Sprays of distilled water served as a control. Subplots had cultivation between plants in a row at three different spacings: 30, 50, and 70 cm, corresponding to densities of 44444, 26667, and 19047 plants/hectare, respectively (Fig. 1).

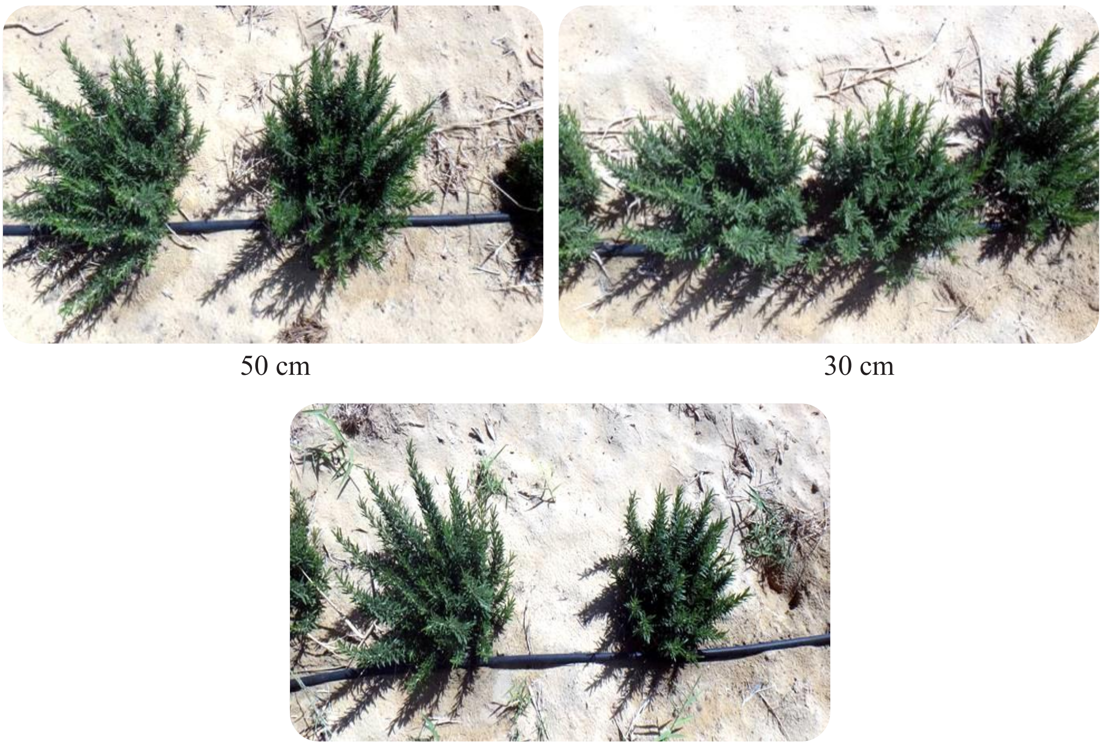

Fig. 1. Plant spacing was tested for rosemary in Siwa Oasis

The herb was harvested 10cm off the ground twice a year, in September and December, although some branches were left to promote regrowth. All the numbers were statistically evaluated with an ANOVA, and differences in means at the 0.05 level were compared using the least significant difference LSD test (Snedecor & Cochran, 1982). The data were analyzed using the statistical software SPSS.

The following information was collected during the harvest: growth and yield characteristics included plant height (cm), weight of fresh herb per plant (g), weight of dry herb per plant (g), yield of fresh herb per hectare (ton), and yield of dry herb per hectare (ton).

The percentage of essential oil contained in the air-dried herb after hydro-distillation was a measurable quality indicator (British Pharmacopoeia, 2002). Another quality factor is the essential oil yield per plant (ml), computed as oil percentage x weight of dry herb/100. Essential oil yield per hectare (l) was estimated as follows: yield of essential oil per plant × number of plants per hectare.

The essential oil of the second harvest was analyzed using a gas chromatography-mass spectrometer (GC/MS) in Egypt's Laboratory of Medicinal and Aromatic Plants at the National Research Center. Compounds were recognized using retention time comparisons with those of known standards and through mass spectral library and commercial spectra comparisons (Massada, 1976; Jennings & Shibamoto, 1980).

Results

Growth and yield attributes

Data presented in Tables 1-3 showed the influence of different treatments on vegetative growth parameters (plant height, weight of fresh herb per plant, and weight of dried herb per plant), and results regarding their effects on the yield of fresh and dried herb are offered in Tables 4, 5.

Notably, the effect of sprayed dry yeast extract on vegetative growth was improved by increasing its concentration. When the highest concentration, 16g per liter, was employed, the significant top values of plant height, weight of fresh herb per plant, and dry herb per plant were recorded. These values were 31.19cm, 78.04g, and 31.19g in the first harvest and 25.51cm, 200.80g, and 68.88g in the second harvest. The yield per hectare followed the same direction as 16g of active dry yeast per liter, resulting in the highest fresh and dry herb production per hectare. These parameters were 2.26 and 0.92 tons in the first cut and 5.72 and 1.98 tons in the second cut.

TABLE 1. Effect of yeast concentrations, planting spaces, and their interaction on plant height (cm) of *Rosmarinus officinalis* (mean values of the two successive seasons)

Yeast concentrations	1st cut				2nd cut			
	Planting spaces				Planting spaces			
	30cm	50cm	70cm	Mean	30cm	50cm	70cm	Mean
0g/L	19.90 f	22.28 f	25.14 g	22.44 a	19.03 f	19.89 f	23.10 gh	20.67 a
8g/L	22.98 f	23.03 fg	24.55 g	23.52 a	20.22 f	20.15 f	21.20 fg	20.52 a
12g/L	26.08 g	29.79 i	28.08 h	27.98 b	24.08 h	23.72 h	24.32 h	24.04 b
16g/L	29.17 hi	32.41 ij	32.00 ij	31.19 c	25.37 h	24.96 h	26.19 i	25.51 c
Mean	24.53 d	26.88 e	27.44 e		22.18 d	22.18 d	23.70 e	
LSD								
Yeast concentrations	1.83				1.39			
Planting spaces	1.58				1.20			
Interaction	3.16				2.40			

Means with the same letter are not significantly different at 0.05 level of probability

TABLE 2. Effect of yeast concentrations, planting spaces, and their interaction on the weight of fresh herb per plant (g) of *Rosmarinus officinalis* (mean values of the two successive seasons)

Yeast concentrations	1st cut				2nd cut			
	Planting spaces				Planting spaces			
	30 cm	50 cm	70 cm	Mean	30 cm	50 cm	70 cm	Mean
0g/L	30.17 h	43.68 i	59.71 j	44.52 a	72.16 h	90.50 ij	111.62 l	91.43 a
8g/L	42.52 hi	56.87 j	64.33 j	54.57 b	83.26 hi	102.80 kl	176.67 no	120.91 b
12g/L	58.56 j	70.65 k	76.53 k	68.58 c	97.31 jk	141.45 m	206.09 p	148.28 c
16g/L	67.79 jk	77.81 k	88.52 l	78.04 d	167.33 n	188.58 o	246.49 q	200.80 d
Mean	49.76 e	62.25 f	72.27 g		105.02 e	130.83 f	185.22 g	
LSD								
Yeast concentrations	7.39				7.98			
Planting spaces	6.40				6.91			
Interaction	12.79				13.81			

Means with the same letter are not significantly different at 0.05 level of probability

TABLE 3. Effect of yeast concentrations, planting spaces, and their interaction on the weight of dry herb per plant (g) of *Rosmarinus officinalis* (mean values of the two successive seasons)

Yeast concentrations	1st cut				2nd cut			
	Planting spaces				Planting spaces			
	30cm	50cm	70cm	Mean	30cm	50cm	70cm	Mean
0g/L	19.90 f	22.28 fgh	25.14 hi	22.44 a	19.33 h	33.00 i	40.94 jk	31.09 a
8g/L	22.98 fgh	23.03 fgh	24.55ghi	23.52 a	24.29 h	38.07 ij	58.10 l	40.15 b
12g/L	26.08 i	29.79 j	28.08 ij	27.98 b	37.83 ij	45.50 k	69.58 m	50.97 c
16g/L	29.17 j	32.41 j	32.00 j	31.19 c	58.26 l	68.54 m	79.83 n	68.88 d
Mean	24.53 d	26.88 e	27.44 e		34.93 e	46.28 f	62.11 g	
LSD								
Yeast concentrations	2.63				3.08			
Planting spaces	2.28				2.67			
Interaction	4.56				5.33			

Means with the same letter are not significantly different at 0.05 level of probability

TABLE 4. Effect of yeast concentrations, planting spaces, and their interaction on the yield of fresh herb per hectare (ton) of *Rosmarinus officinalis* (mean values of the two successive seasons)

Yeast concentrations	1st cut				2nd cut			
	Planting spaces				Planting spaces			
	30cm	50cm	70cm	Mean	30cm	50cm	70cm	Mean
0g/L	1.34 hi	1.17 h	1.14 h	1.22 a	3.21 i	2.41 gh	2.13 g	2.58 a
8g/L	1.89 j	1.52 hi	1.23 h	1.55 b	3.70 jk	2.74 h	3.37 ij	3.27 b
12g/L	2.60 k	1.88 j	1.46 hi	1.98 c	4.33 l	3.77 k	3.93 k	4.01 c
16g/L	3.01 k	2.08 j	1.69 ij	2.26 d	7.44 n	5.03 m	4.70 m	5.72 d
Mean	2.21 g	1.66 f	1.38 e		4.67 f	3.49 e	3.53 e	
LSD								
Yeast concentrations	0.26				0.22			
Planting spaces	0.23				0.19			
Interaction	0.45				0.37			

Means with the same letter are not significantly different at 0.05 level of probability

TABLE 5. Effect of yeast concentrations, planting spaces, and their interaction on the yield of dry herb per hectare (ton) of *Rosmarinus officinalis* (mean values of the two successive seasons)

Yeast concentrations	1st cut				2nd cut			
	Planting spaces				Planting spaces			
	30cm	50cm	70cm	Mean	30cm	50cm	70cm	Mean
0g/L	0.88 hi	0.59 f	0.48 f	0.65 a	0.86 gh	0.88 gh	0.78 g	0.84 a
8g/L	1.02 ij	0.61 f	0.47 f	0.70 a	1.08 ij	1.02 hi	1.11 ij	1.07 b
12g/L	1.16 jk	0.79 gh	0.54 f	0.83 b	1.68 mn	1.21 jk	1.33 k	1.41 c
16g/L	1.30 k	0.86 hi	0.61 f	0.92 b	2.59 o	1.83 n	1.52 lm	1.98 d
Mean	1.09 e	0.71 d	0.53 c		1.55 f	1.24 e	1.19 e	
LSD								
Yeast concentrations	0.10				0.10			
Planting spaces	0.10				0.09			
Interaction	0.17				0.17			

Means with the same letter are not significantly different at 0.05 level of probability.

In terms of the effect that planting spaces had on growth characteristics, it was found that increasing the distance between plants led to a considerable rise in the mean values measured for each plant. At a distance of 70cm, we found that the plant's height, the fresh herb's weight per plant, and the weight of the dry herb per plant all reached their maximums. These averages came in at 27.44cm, 72.27g, and 27.44g for the first cut and 23.70cm, 185.22g, and 62.11g for the second cut, respectively. The fresh and dry yield per hectare achieved from spacing the transplants only 30 cm apart was the highest. In the first harvest, these records stood at 2.21 and 1.09 tons; in the second harvest, they rose to 4.67 and 1.55 tons, respectively.

Concerning the effect of interaction within yeast concentrations and planting densities on growth characteristics, foliar spraying with an active dry yeast solution at a concentration of 16g per liter and cultivating plants at a spacing of 70cm considerably maximized fresh herb weight per plant and dry herb weight per plant. The first cut weights came in at 88.52g and 32.00g. There were no significant variations when comparing 30, 50, and 70 cm of cultivation with 16g per liter of spray regarding dry herb weight per plant. In the second harvest, these weights were 246.49 and 79.83g, as they recorded the most significant values. Contrary to the previous results, the heaviest fresh and dry yield per hectare was produced by spraying the plants with active dry yeast extract at 16g per liter and transplanting at the narrowest distance of 30cm. These values were 3.01 and 1.30 tons and 7.44 and 2.59 tons for the first and second cuts.

Essential oil attributes

Data in Tables 6-8 exhibited the influence of dry yeast concentration, planting spaces, and their interaction on essential oil parameters (essential oil percentage, oil yield per plant, and oil yield per hectare).

The essential oil accumulation was increased by increasing the concentration of active dry yeast. Spraying with yeast extract at 16g per liter led to the most significant increases in essential oil percentage, oil yield per plant, and oil yield per hectare. These determinations for the first harvest were 0.68%, 0.21mL, and 6.40L, and in the second harvest, they were 0.61%, 0.42mL, and 12.28L.

Planting space had a significant impact on essential oils as well. The minimal spacing of 30cm produced the most significant increase in essential oil percentage and yield per hectare. The means for the first cut were 0.68% and 7.56L, whereas the second cut was 0.57% and 9.33L. However, the essential oil output per plant followed a distinct pattern. There were no significant effects on oil yield per plant in the first cut, and cultivation at 70cm yielded the highest considerable value in the second cut (0.31mL).

TABLE 6. Effect of yeast concentrations, planting spaces, and their interaction on the essential oil percentage of *Rosmarinus officinalis* (mean values of the two successive seasons)

Yeast concentrations	1st cut				2nd cut			
	Planting spaces				Planting spaces			
	30cm	50cm	70cm	Mean	30cm	50cm	70cm	Mean
0g/L	0.63 ij	0.55 fh	0.51 f	0.56 a	0.50 j	0.47 i	0.43 h	0.47 a
8g/L	0.68 jk	0.60 hi	0.58 ghi	0.62 b	0.56 l	0.49 j	0.46 i	0.50 b
12g/L	0.69 jk	0.68 jk	0.64 ik	0.67 c	0.58 m	0.54 k	0.49 j	0.54 c
16g/L	0.71 k	0.68 jk	0.65 jk	0.68 c	0.65 o	0.61 n	0.57 l	0.61 d
Mean	0.68 e	0.63 d	0.60 d		0.57 g	0.53 f	0.49 e	
LSD								
Yeast concentrations	0.04				0.01			
Planting spaces	0.04				0.01			
Interaction	0.07				0.02			

Means with the same letter are not significantly different at 0.05 level of probability.

TABLE 7. Effect of yeast concentrations, planting spaces, and their interaction on the essential oil yield per plant (ml) of *Rosmarinus officinalis* (mean values of the two successive seasons)

Yeast concentrations	1st cut				2nd cut			
	Planting spaces				Planting spaces			
	30cm	50cm	70cm	Mean	30cm	50cm	70cm	Mean
0g/L	0.13 f	0.12 f	0.13 f	0.13 a	0.10 h	0.16 ij	0.18 jk	0.15 a
8g/L	0.16 gh	0.14 fg	0.14 fg	0.15 b	0.14 i	0.19 k	0.27 m	0.20 b
12g/L	0.18 hi	0.20 ij	0.18 hi	0.19 c	0.22 l	0.25 m	0.34 n	0.27 c
16g/L	0.21 j	0.22 j	0.21 j	0.21 d	0.38 o	0.42 p	0.46 q	0.42 d
Mean	0.17 e	0.17 e	0.17 e		0.21 e	0.26 f	0.31 g	
LSD								
Yeast concentrations	0.02				0.02			
Planting spaces	n.s.				0.02			
Interaction	0.03				0.03			

Means with the same letter are not significantly different at 0.05 level of probability.

TABLE 8. Effect of yeast concentrations, planting spaces, and their interaction on the essential oil yield per hectare (l) of *Rosmarinus officinalis* (mean values of the two successive seasons)

Yeast concentrations	1st cut				2nd cut			
	Planting spaces				Planting spaces			
	30cm	50cm	70cm	Mean	30cm	50cm	70cm	Mean
0g/L	5.78 k	3.20 hij	2.48 h	3.82 a	4.44 i	4.27 h	3.43 h	4.05 a
8g/L	7.11 l	3.73 ij	2.67 hi	4.50 b	6.22 j	5.07 i	5.14 i	5.48 b
12g/L	8.00 l	5.33 k	3.43 hi	5.59 c	9.78 l	6.67 j	6.48 j	7.64 c
16g/L	9.33 m	5.87 k	4.00 j	6.40 d	16.89 n	11.20 m	8.76 k	12.28 d
Mean	7.56 g	4.53 f	3.15 e		9.33 g	6.80 f	5.95 e	
LSD								
Yeast concentrations	0.68				0.58			
Planting spaces	0.58				0.50			
Interaction	1.17				1.00			

Means with the same letter are not significantly different at 0.05 level of probability.

Regarding the combination of the factors mentioned above, the significantly highest result for essential oil percentage (0.65%) was found in the second harvest by sprinkling yeast at 16g per liter and planting at a distance of 30cm. In the second harvest, the significantly highest value of essential oil yield per plant was given by applying yeast at 16g per liter and cultivating at 70cm spacing, and its value was 0.46mL. In contrast to the data on oil yield per plant, the highest means of oil yield per hectare were gained in both cuts when plants were sprayed with yeast at 16g per liter and cultivated in a dense space of 30cm. Their values were 9.33 and 16.89L for the first and second cuts, respectively.

Table 9 represents the influence of treatment interactions on essential oil composition. There were differences in chemical content between treatments. Total oxygenated compounds ranged from 64.88 to 75.71%, whereas total hydrocarbon compounds ranged from 24.29 to 34.94%. The primary ingredients of rosemary essential oils were α-pinene (12.34 to 20.46%), 1,8-cineole (15.01 to 21.16%), camphor (16.73 to 23.73%), and borneol (14.44 to 20.05%).

The highest concentration of α-pinene (20.46%) was found in the essential oil when yeast was sprayed at 12g per liter and the plants were grown at a distance of 70cm. The most 1,8-cineole (21.16%) was found in the oil of plants sprayed with yeast at a rate of 12g per liter and grown with 70cm between each plant. The best camphor percentage (23.73%) was seen when yeast was used at 8g per liter and plants were spaced 50 cm apart. The plants sprinkled with yeast at 12 g per litter and 50cm between plants had the highest concentration of borneol (20.5%).

Discussion

It was discovered that raising the concentration of the yeast solution resulted in improved growth characteristics and an increase in the yield of herbage and essential oil for the following reasons: Yeast involves a variety of amino acids, minerals, a group of B vitamins, and carbon dioxide, which form a medium around the plant that aids in photosynthesis. It produces the hormone cytokinin, which activates the process of cell division and results in the growth of a highly vegetative plant. Yeast improves plant resistance to pests, particularly fungal and bacterial infections. It boosts seedlings and increases their tolerance to environmental stresses (Bouizgarne & Arora, 2022).

These findings were consistent with previous research on rosemary in other fields in Egypt. Kassem (2013) reported that active dry yeast significantly boosted plant growth as measured by plant height, branch number per plant, and fresh and dry weights per plant. According to Sharaf et al. (2013), treating plants with active dry yeast resulted in much higher growth and yield than untreated plants. Khalil & Khalil (2015) studied the role of active dry yeast in water stress mitigation. The results showed that using active dry yeast reduced the influence of water stress on many growth and yield metrics, as well as essential oil percentage, yield, and composition.

The increased weights of fresh and dry herbs and essential oil yield per plant resulted from increased cultivation space. Wide spaces can boost metabolite synthesis due to decreased competition for water, nutrients, and light between plants. However, wider spacing promotes the growth of more woody stems than leaves, resulting in a lower essential oil percentage than closer spacing. Conversely, the maximum yield of fresh and dry herb and essential oil per hectare resulted from planting in the narrow space of 30 cm due to an increased number of plants per unit area and oil percent, positively affecting production (Toaima, 2022). These findings were consistent with the research on rosemary that Mishra et al. (2009), Zigene et al. (2012), and Tadesse (2019) concluded through dense cultivation of plants.

Regarding the interaction between the two factors of spraying with yeast extract and the distances, yeast spray with the highest concentration of 16g per liter and cultivation at a distance of 30cm gave the highest yield of fresh and dry herb per hectare and the highest production of volatile oil per hectare for the reasons mentioned above. It also increased essential oil ingredients over the control treatment, such as camphor, borneol, and bornyl acetate.

TABLE 9. Effect of the interaction between treatments on constituents (%) of the essential oil of *Rosmarinus officinalis*

Compounds	30cm + 0g/L yeast	30cm + 8g/L yeast	30cm + 12g/L yeast	30cm + 16g/L yeast	50cm + 0g/L yeast	50cm + 8g/L yeast	50 cm + 12g/L yeast	50cm + 16g/L yeast	70cm + 0g/L yeast	70cm + 8g/L yeast	70cm + 12g/L yeast	70cm + 16g/L yeast
Tricyclene	0.34	0.31	0.38	0.30	0.34	0.46	0.27	0.34	0.35	0.44	0.33	0.32
α-pinene	20.07	18.23	20.01	16.84	17.80	15.80	14.60	14.07	18.83	12.34	20.46	17.59
Camphene	5.69	5.26	6.13	5.06	5.67	7.12	4.56	5.49	5.74	6.52	5.53	5.27
Verbenene	1.64	4.98	1.78	1.53	-	0.93	1.30	1.66	1.64	0.98	1.75	1.64
β-pinene	0.39	0.37	0.43	0.36	0.37	0.79	0.49	0.38	0.38	0.80	0.37	0.46
α-Myrcene	-	-	-	-	-	-	-	0.49	-	0.28	-	0.19
Geraniol formate	0.23	0.22	0.20	0.18	0.19	-	-	-	0.19	-	-	-
2,4(10)-thujadien	-	-	-	-	1.54	-	-	-	-	-	-	-
3-Carene	1.21	1.13	1.23	1.06	1.08	0.32	0.87	1.22	1.13	0.36	1.14	1.10
α-Terpinene	0.31	0.26	0.31	0.24	0.27	-	0.19	0.37	0.24	-	0.23	0.24
Cymene	-	-	-	-	-	-	-	1.06	-	-	-	-
dl-Limonene	2.46	1.87	2.84	2.38	2.73	-	1.52	3.95	3.04	3.35		3.03
1,8-Cineole	19.42	18.13	19.57	18.88	18.87	18.72	18.91	16.33	19.20	15.01	21.16	18.99
Cyclohexene	0.21	-	-	-		-			-	0.20	1.69	
γ-Terpinene	-	-	0.14	-	-	-	-	-	0.11	0.16	0.12	-
2-Carene	-	0.21	-	-	-	-	-	-	-	-	-	-
Chrysanthenone	0.70	0.82	0.84	0.77	0.78	0.85	0.84	0.91	0.68	0.75	2.20	0.65
Tetracyclo	1.78	-	-	-	-	-	-	-	-	-	-	-
Linalool	1.83	1.91	1.90	2.24	2.11	0.82	2.64	4.72	2.16	2.15	-	2.39
Verbenol	0.18	0.23	0.18	0.23	0.22	0.18	0.24	-	0.18	0.42	0.17	0.21
Bicyclo[2.2.1] heptan-2-ol	-	-	-	-	-	-	-	-	-	0.11	-	-
Terpinen-4-ol	0.28	0.31	-	0.33		0.23	-	-	-	-	-	-
l-Verbenone	4.15	-	3.76	4.66	4.20	2.64	4.49	6.49	4.63	4.35	3.63	5.28
Caryophyllene	0.84	0.68	0.59	0.60	0.51	0.30	0.49	0.58	0.47	0.36	0.54	0.40
3-Pinanone	2.66	2.74	2.64	3.00	2.69	2.58	2.92	1.54	2.74	0.98	1.64	1.69
Isopinocamphone	-	-	-	-	-	-	-	1.20	-	2.31	1.05	1.07

TABLE 9. Cont.

Compounds	30cm + 0g/L yeast	30cm + 8g/L yeast	30cm + 12g/L yeast	30cm + 16g/L yeast	50cm + 0g/L yeast	50cm + 8g/L yeast	50 cm + 12g/L yeast	50cm + 16g/L yeast	70cm + 0g/L yeast	70cm + 8g/L yeast	70cm + 12g/L yeast	70cm + 16g/L yeast
α-Terpinolene	-	-	-	-	-	-	-	-	-	0.21	-	-
Squalene	-	-	-	-	-	-	-	-	-	0.20	-	-
Camphor	17.55	18.55	18.32	19.16	17.63	23.73	19.70	16.73	18.07	20.35	19.21	18.06
Borneol	14.82	16.85	14.44	17.16	17.59	16.79	20.05	15.37	15.75	16.04	14.47	16.48
α-Terpineol	0.37	0.38	0.38	0.40	0.45	0.19	0.59	1.33	-	0.80	0.30	-
5-Caranol	0.59	0.63	0.45	0.54	-	1.13	0.72	0.73	0.52	-	0.43	0.53
Bornyl acetate	2.28	3.02	2.47	3.00	2.81	4.03	2.87	2.77	2.27	3.97	2.62	2.53
Cyclohexanol	-	1.09	-	-	0.62	0.14	-	-	-	1.68	-	-
Carveol	-	-	0.75	0.93	1.08	1.78	1.22	1.26	0.93	2.62	0.69	0.95
Myrtenol	-	-	-	0.13	0.12	-	0.15	-	-	-	-	-
Pinocarvone	-	-	-	-	-	0.24	-	-	-	0.35	-	-
Isopulegol acetate	-	-	-	-	-	0.23	-	-	-	-	-	-
4-Terpineol	-	-	0.26	-	-	-	0.37	0.67	0.32	0.60	0.22	0.36
Isoborneol	-	-	-	-	-	-	-	0.34	-	0.57	-	-
Linalyl propionate	-	-	-	-	-	-	-	-	0.43	-	-	-
Cyclopentanol	-	-	-	-	-	-	-	-	-	0.17	-	-
Myrtenol	-	-	-	-	-	-	-	-	-	0.40	-	-
Dihydrocarvyl acetate	-	-	-	-	-	-	-	-	-	0.17	-	-
Linalyl propionate	-	-	-	-	-	-	-	-	-	-	-	0.57
Total identified compounds	100	98.18	100	99.98	99.67	100	100	100	100	100	99.95	100
Total hydrocarbon compounds	34.94	33.3	33.84	28.37	30.31	25.72	24.29	29.61	31.93	26.2	32.16	30.24
Total oxygenated compounds	65.06	64.88	66.16	71.61	69.36	74.28	75.71	70.39	68.07	73.8	67.79	69.76

The essential oil composition is an important component that determines the quality of rosemary (Guenther, 1961). Satyal et al. (2017) found five distinct chemotypes of rosemary oil: (1) α-pinene/1,8-cineole; (2) verbenone/α-pinene/camphor/1,8-cineole; (3) myrcene/1,8-cineole/camphor; (4) 1,8-cineole/camphor/α-pinene; and (5) α-pinene/β-pinene/camphene. Type 1 chemotype, dominated by α-pinene. Chemotype 2 is dominated by verbenone. The third chemotype is dominated by myrcene. The fourth chemotype is dominated by 1,8-cineole. The fifth chemotype is distinguished by almost equal levels of alpha-pinene, beta-pinene, and camphene. The essential oil isolated at Siwa Oasis complied with chemotype 4 since 1,8-cineole was the main constituent in the oil, which is medicinally valuable.

The effect of environmental conditions on volatile oil percentage was also noticeable, as the highest percentage was obtained in September (the first cut) when there was a rise in air temperature, while the oil percentage was lower in December when there was a decrease in temperature.

Finally, our work could be a plan for the climate problem facing rosemary cultivation, contributing to a drop in yield. As a result, planting at close spacing and spraying with a potent natural growth stimulator abundant in hormones and nutrients proved effective, thus advancing production.

Conclusion

Following the findings of this study, we advised farmers in Siwa Oasis to plant rosemary at a spacing of 30 cm in the row (a density of 44444 plants per hectare). They should also spray their plantations with 16 g per liter of active dry yeast solution. Spraying should begin between 45 and 90 days after transplantation and continue following each harvest. These agronomic practices will enable them to obtain the maximum possible fresh and dry yields and oil yields.

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تأثير الخميرة ومسافات الزراعة على الإنتاجية والزيت الطيار لنبات الحصالبان تحت ظروف واحة سيوة

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أجريت دراسة حقلية على نباتات الحصالبان في أرض رملية مستصلحة حديثا بواحة سيوة في صحراء مصر الكبرى. كان الهدف إيجاد أفضل تركيز مستخلص خميرة جافة للرش ومسافة الزراعة والتفاعل بينهم لتحقيق أعلى محصول. لم يتم بحث هذة النقاط من قبل في هذة المنطقة. نفذت التجربة بتصميم القطع المنشقة. تم رش القطع الرئيسية بأربع جرعات من مستخلص الخميرة الجافة صفر، 8، 12 و 16جم/ اللتر. اشتملت القطع الفرعية الزراعة على ثلاث مسافات مختلفة بين النبات والأخر 30، 50 و 70 سم. تم تسجيل صفات النمو، المحصول والزيت الطيار كبيانات. أظهرت النتائج أن زيادة تركيزات مستخلص الخميرة قد زاد من النمو والإنتاج. أدت الزراعة على مسافة ضيقة 30 سم إلى إنتاج أعلى محصول عشب وزيت طيار للهكتار، على الرغم من أن الزراعة على مسافة أكبر زادت من الأوزان الطازجة والجافة لكل نبات. احتوى الزيت الطيار على تركيزات عالية من الفا- بينين، -8,1 سينيول، كامفور و بورنيول. لزيادة دخل المنتجين تحت هذة الظروف البيئية، نوصى بزراعة الحصالبان على مسافة 30 سم ورشه بمستخلص الخميرة بتركيز 16 جم/اللتر.