The Pharma Innovation Journal 2023; 12(10): 1268-1271

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(10): 1268-1271

www.thepharmajournal.com
Received: 15-07-2023
Accepted: 18-08-2023

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Effect of irrigation and fertilizer levels on essential oil content and yield of Ajwain

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Abstract
An experiment was conducted during the late late *kharif* season of 2021-22 and 2022-23 at Main Horticultural Research and Extension Centre, University of Horticultural Sciences, Bagalkot, in order to study the effect of irrigation and fertilizer levels on the essential oil content and yield of ajwain. The experiment having split plot design, consists of three irrigation levels viz., Rainfed, 0.6 IW: CPE ratio and 0.8 IW: CPE ratio and three fertilizer levels viz., 75% RDF (75: 37.5: 37.5 $NP_2O_5K_2O$ kg ha^{-1}), 100% RDF (100: 50: 50 $NP_2O_5K_2O$ kg ha^{-1}) and 100% Organic (N equivalent FYM). The results indicated that, rainfed condition and organic fertilizer level can increase in the essential oil content and yield of ajwain. The highest essential oil content (3.22 and 3.23%) was obtained from the rainfed and organic level respectively. Whereas the highest essential oil yield (36.10 and 34.97 kg ha^{-1}) was recorded in irrigation at 0.8 IW: CPE ratio and 100% RDF treated ajwain and was on par with 75% RDF at same level of irrigation.

Keywords: Ajwain, *Trachyspermum ammi*, irrigation, fertilizer level, essential oil and essential oil yield

1. Introduction
Since the time of ancient and medieval eras, India has been famous for its spices and is regarded as the 'land of spices'. The history of Indian spices narrates a long tale of trading that has strengthened Indian civilization. Over time, Indian spice cultivation has increased by leaps and bounds, aiming to achieve the title of the largest producer, consumer, and exporter of spices in the world (Chattopadhyay *et al*., 2018) [1]. Out of the 109 spices recognized by the International Organization for Standardization (ISO), India cultivates more than 52–60 spice crops (Gidwani *et al*., 2022) [2], of which 20 are seed spices (Nath *et al*., 2023) [7], which includes major seed spices (Cumin, Coriander, Fenugreek and Fennel) as well as minor seed spices (Ajwain, Aniseed, Caraway, Celery, Dill and Nigella (Black cumin). Seed spices account for over 45 percent of the national spice acreage and make up more than 24 percent of the country's spice exports in terms of volume (Meena *et al*., 2019) [4].
Seed spices are predominantly grown in the semi-arid and arid zones of the country, which experience dry or wet cool weather conditions. Together, the states of Rajasthan and Gujarat, along with parts of Madhya Pradesh, can be referred to as the 'bowl of seed spices,' contributing to more than 80% of the country's annual production (Singh *et al*., 2015) [9].
There is a dearth of information regarding ajwain's nutrient and water requirement (Patel and Amin, 2017) [8] and very little investigation or research is being carried out on nutrient management in seed spices in the Rayalaseema region of Andhra Pradesh (Thanuja *et al*., 2020) [10]. One of the simplest methods to enhance ajwain crop productivity is to improve soil nutrient and fertility levels by providing a balanced and sufficient supply of major nutrients like nitrogen, phosphorus, and potassium, tailored to the plant's specific needs.

2. Materials and Methods
The experiment was conducted during the late *khaiff* season of 2021-22 and 2022-23 at Main Horticultural Research and Extension Centre, University of Horticultural Sciences, Bagalkot. The experimental site experiences semi-arid and the mean annual rainfall of the past 25 years at MHREC, Bagalkot was 537 mm, which was well distributed from May to October.
The soil type of the experimental site was loamy sand in texture, with the following characteristics: pH of 7.6, EC (Electrical Conductivity) of 0.11 dSm^{-1}, soil organic carbon content of 0.55%, available nitrogen (N) was 165 kg ha^{-1}, available phosphorus (P_2O_5) was

18.76 kg ha^{-1}, and a relatively high level of available potassium (K_2O) of 471 kg ha^{-1}.

The experiment was laid out in Split Plot Design and the treatment combination of Irrigation and fertilizer levels were replicated thrice.

2.1 Essential oil quality parameters

2.2 Essential oil content

The Clevenger apparatus is commonly used for the extraction of essential oil through hydro-distillation. The proportion of water to ajwain seeds for essential oil extraction using the Clevenger method may vary, but a typical ratio is often around 6:1 to 10:1, meaning 6 to 10 parts of water for every 1 part of ajwain seeds. Hundred grams of ajwain seed powder was taken and mixed with 600 ml of water in a flask and distilled for a period of two to four hours at the temperature range of typically around 90 °C to 100 °C, the essential oil was completely extracted from the seed sample from each treatment and each replication. The volume of oil collected was noted and expressed as percentage v/w on dry weight basis.

2.3 Essential oil yield (kg ha^{-1})

The essential oil yield was computed using essential oil content and seed yield per hectare and expressed as kilogram per hectare. The essential oil yield was computed using the following formula.

Essential oil yield (kg ha^{-1}) = Seed yield q ha^{-1} x Essential oil content

3. Results and Discussion

Table 1, 2 and Fig.1 provides an overview of the effects of different irrigation and fertilizer levels on essential oil content and yield, which is significantly influenced by the irrigation and fertilizer levels.

Among the irrigation levels, in the rainfed condition, a higher percentage of essential oil (3.22%) was produced compared to the other irrigation levels. However, the crop irrigated at 0.8 IW:CPE ratio yielded noticeably less oil content (3.05%). Among the fertilizer levels, the 100% organic treatment (3.23%) produced significantly higher essential oil content, which was on par with the crop fertilized with 75% RDF (3.21%).

Similar findings were also noticed by Kizil (2004) and Meena *et al.* (2012) [4]. Compared to the crop fertilized with 75% RDF (3.21%), the 100% organic treatment (3.23%) produced significantly higher essential oil content. Similar findings were also noticed by Naruka *et al.* (2012) [6], Kiran *et al.* (2020) [3].

Rainfed crop can experience stress, which may impact the quality and quantity of essential oil produced. The rise in essential oil content can be attributed primarily to stress condition. The rainfed environment was particularly conducive to the accumulation of essential oils, leading to a higher essential oil content in the seeds. FYM contains essential nutrients like nitrogen, phosphorus and potassium, as well as micronutrients. These nutrients are vital for plant growth and the production of secondary metabolites like essential oil.

Among the irrigation levels, in terms of essential oil yield, the 0.8 IW:CPE ratio outperformed the other irrigation levels (36.10 kg ha^{-1}), followed by irrigation at 0.6 IW:CPE ratio (31.86 kg ha^{-1}). However, rainfed situation resulted in significantly lower essential oil yield (25.92 kg ha^{-1}). Among the fertilizer levels, the 100% RDF supplemented crop (35.0 kg ha^{-1}) resulted in more essential oil yield but was on par with the crop given with 75% RDF (30.4 kg ha^{-1}). The 100% organic Nitrogen supplied with FYM, yielded the least essential oil yield (28.53 kg ha^{-1}).

Irrigation at 0.8 IW:CPE ratio irrigation with adequate nutrient availability can contribute to higher essential oil yield, was primarily due to higher seed yield. Irrigation at this specific ratio provided optimal moisture levels, which in turn enhanced the uptake of nutrients by the plants. This increased nutrient uptake likely played a role, either directly or indirectly, in the plant's metabolic processes, ultimately resulting in greater synthesis of essential oils. Consequently, this led to higher yield of essential oil. Moussavi-Nik *et al.* (2011) [5] and Vahidipour *et al.* (2013) [11] reported similar findings.

The interaction effect revealed a statistically significant difference in the essential oil content and yield based on irrigation and fertilizer levels. In the rainfed situation with organic treatment, there was a significantly higher oil content (3.39%) and was comparable with I_0F_2, I_1F_2 and I_2F_3. However, in terms of essential oil yield, the 0.8 IW:CPE ratio outperformed the other two irrigation scenarios (40.2 kg ha^{-1}) when applied to a crop with 100% RDF fertilizer. Meanwhile, it was equivalent to the yield obtained with a crop supplied with 75% RDF (34.6 kg ha^{-1}) and I_1F_2.

Table 1: Essential oil content of Ajwain as influenced by Irrigation levels and Fertilizer levels

Treatments	Essential oil content (%)											
	Irrigation levels (I)											
	2021				2022				Pooled			
Fertilizer levels (F)	I_0	I_1	I_2	Mean	I_0	I_1	I_2	Mean	I_0	I_1	I_2	Mean
F_1	3.26^{ab}	3.17^{a-c}	3.13^{a-c}	3.19^{a}	3.30^{ab}	3.21^{a-c}	3.20^{a-c}	3.24^{a}	3.28^{ab}	3.19^{ab}	3.16^{a-c}	3.21^{a}
F_2	2.98^{bc}	2.93^{bc}	2.83^{c}	2.91^{b}	3.02^{b-d}	2.96^{cd}	2.81^{d}	2.93^{b}	3.00^{bc}	2.95^{bc}	2.82^{c}	2.92^{b}
F_3	3.37^{a}	2.98^{bc}	3.15^{a-c}	3.17^{a}	3.41^{a}	3.27^{a-c}	3.21^{a-c}	3.30^{a}	3.39^{a}	3.12^{a-c}	3.18^{ab}	3.23^{a}
Mean	3.21^{a}	3.03^{b}	3.03^{b}		3.24^{a}	3.15^{ab}	3.07^{b}		3.22^{a}	3.09^{b}	3.05^{b}	
Source of variation	S.Em.±				S.Em.±				S.Em.±			
F	0.03				0.03				0.03			
I	0.07				0.06				0.06			
I at same F	0.11				0.10				0.10			
F at same or different I	0.10				0.09				0.09			

Legend: Main plot: Irrigation levels (I)	Sub plot: Fertilizer levels (F)
I_0: Rainfed	F_1: 75% RDF (75: 37.5: 37.5 $NP_2O_5K_2O$ kg ha^{-1})
I_1: 0.6 IW: CPE ratio	F_2: 100% RDF (100: 50: 50 $NP_2O_5K_2O$ kg ha^{-1})
I_2: 0.8 IW: CPE ratio	F_3: 100% Organic (N equivalent FYM)

Table 2: Essential oil yield of ajwain as influenced by Irrigation levels and Fertilizer levels

Treatments	Essential oil yield (kg ha^{-1})											
	Irrigation levels (I)											
	2021				2022				Pooled			
Fertilizer levels (F)	I_0	I_1	I_2	Mean	I_0	I_1	I_2	Mean	I_0	I_1	I_2	Mean
F_1	24.88^{d}	31.63^{bc}	35.63^{ab}	30.72^{ab}	25.73^{cd}	30.91^{bc}	33.55^{ab}	30.06^{ab}	25.31^{d}	31.27^{bc}	34.59^{ab}	30.39^{ab}
F_2	27.83^{cd}	36.50^{ab}	40.81^{a}	35.05^{a}	29.04^{b-d}	36.02^{ab}	39.61^{a}	34.89^{a}	28.43^{cd}	36.26^{ab}	40.21^{a}	34.97^{a}
F_3	24.86^{d}	27.29^{cd}	35.10^{ab}	29.08^{b}	23.18^{d}	28.83^{b-d}	31.93^{bc}	27.98^{b}	24.02^{d}	28.06^{cd}	33.51^{bc}	28.53^{b}
Mean	25.86^{c}	31.81^{b}	37.18^{a}		25.98^{c}	31.92^{b}	35.03^{a}		25.92^{c}	31.86^{b}	36.10^{a}	
Source of variation	S.Em.±				S.Em.±				S.Em.±			
F	0.92				0.77				0.40			
I	1.11				1.28				0.96			
I at same F	1.92				2.22				1.67			
F at same or different I	1.82				1.97				1.42			

Legend: Main plot: Irrigation levels (I)	Sub plot: Fertilizer levels (F)
I_0: Rainfed	F_1: 75% RDF (75: 37.5: 37.5 $NP_2O_5K_2O$ kg ha^{-1})
I_1: 0.6 IW: CPE ratio	F_2: 100% RDF (100: 50: 50 $NP_2O_5K_2O$ kg ha^{-1})
I_2: 0.8 IW: CPE ratio	F_3: 100% Organic (Nitrogen equivalent FYM)

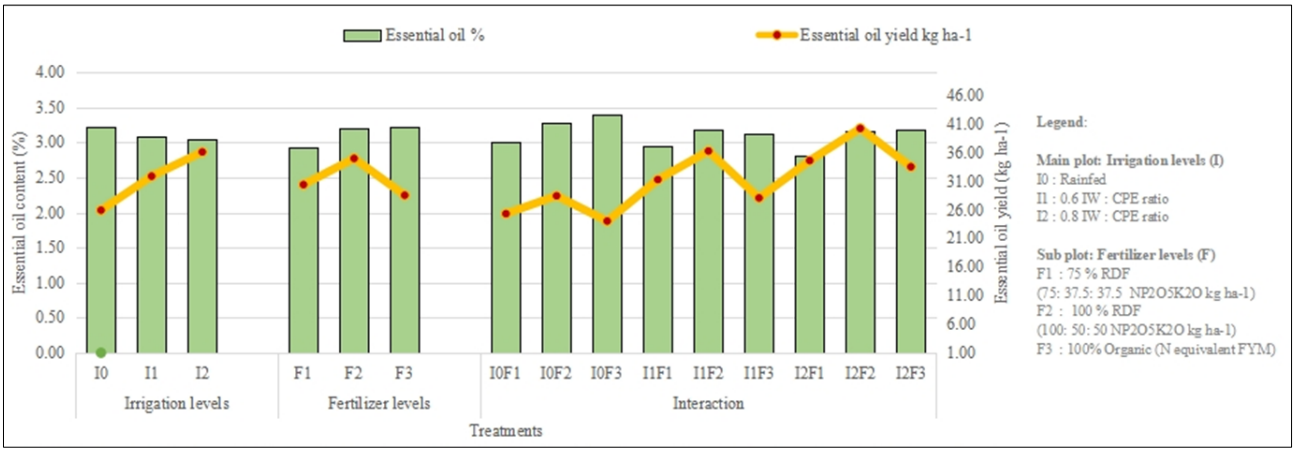

Fig 1: Essential oil content (%) and essential oil yield (kg ha^{-1}) of ajwain as influenced by irrigation and fertilizer levels

4. Conclusion

Cultivating ajwain as a rainfed crop with organic treatment has the potential to increase its oil content. Irrigation at 0.8 IW: CPE and application of 75% RDF is optimum for getting higher essential oil yield.

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