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GS Thanuja
College of Horticulture, Dr. YSRHU, Anantharajupeta, Andhra Pradesh, India

B Sreenivasulu
College of Horticulture, Dr. YSRHU, Anantharajupeta, Andhra Pradesh, India

KM Yuvaraj
College of Horticulture, Dr. YSRHU, Anantharajupeta, Andhra Pradesh, India

K Giridhar
AICRP on Spices, Dr. YSRHU Lam, Guntur, Andhra Pradesh, India

U Umakrishna
College of Horticulture, Dr. YSRHU, V.R. Gudem, Andhra Pradesh, India

P Latha
Institute of Frontier Technology, RARS, ANGRAU, Tirupati, Andhra Pradesh, India

Corresponding Author:
GS Thanuja
College of Horticulture, Dr. YSRHU, Anantharajupeta, Andhra Pradesh, India

Effect of organic manures, plant growth promoting rhizobacteria and micronutrients on growth, grain yield and quality of Ajwain (*Trachyspermum ammi* L.)

GS Thanuja, B Sreenivasulu, KM Yuvaraj, K Giridhar, U Umakrishna and P Latha

Abstract
The present experiment entitled "Effect of organic manures, plant growth promoting rhizobacteria and micronutrients on growth, grain yield and quality of Ajwain (*Trachyspermum ammi* L.)" was carried out to study the individual and interaction effect of organic manures, PGPR and micronutrients on vegetative growth, yield and quality of Ajwain seed. Farm yard manure and vermicompost were used as organic source at 50% and 75% recommended dose of nitrogen (RDN). PGPRs namely *Azospirillum lipoferium*, *Bacillus megathurium* and *Frateuria aurantia* were used for seed priming. Micronutrients namely, $ZnSO_4$ and Fe_2SO_4 were applied as foliar spray The result revealed that sole application of vermicompost and FYM showed significantly effect on par on growth, grain yield, quality aspects of Ajwain. Among the PGPRs and micronutirents, seed priming with *Azospirillum lipoferium* and foliar application of zinc were found significantly superior in augmenting higher plant growth, yield and quality. Application of 50% of RDN through vermicompost and seed priming with *Azospirillum* along with foliar application of zinc was statistically on par with application of 50% of RDN through FYM and seed priming with *Azospirillum* along with foliar application of zinc in promoting growth, dry matter content per plant, grain yield, essential oil, fixed oil and thymol content of Ajwain.

Keywords: Ajwain, organic manure, PGPR, micronutrients, thymol, fixed oil

Introduction
Ajwain (*Trachyspermum ammi* L. Sprague) with 2n=18 belonging to the family of Apiaceae is also known as Ajwain Caraway, Bishops weed or Carom. It is a cross-pollinated, aromatic and annual herbaceous plant. The seed of which possesses stimulant, antispasmodic and carminative properties and used traditionally as an important remedial agent for flatulence, abdominal tumors, diarrhoea and bronchial problems etc. Ajwain is famous for its brownish essential oil. Apparently, it owes its characteristic odour and taste due to presence of an essential oil (2-5%). Usually, thymol is the main Ajwain essential oil constituent and may be yielded from 35% to 60%. Thymol is a strong germicide, antispasmodic and fungicide, used for gastro intestinal ailments, lack of appetite and bronchial problems.

In India, during the year 2017-18, the area under the Ajwain crop was 35,000 ha and the production was 24,000 MT with a productivity of 703.70 kg ha^{-1} (Anon., 2018) [2]. India is the largest producer and exporter of the Ajwain seeds in the world. In Andhra Pradesh, Ajwain is cultivated in about 8,000 ha in Kurnool district mainly in Aluru, Aspari, Adoni and Kallur mandals. Ajwain has been one of the jewels in the crown of the district with 'Kurnool Ajwain' having a nation-wide market. Kurnool ajwain market yard is one of the biggest in the country supplying nearly 50,000 quintals to the entire country. Owing to low productivity of Ajwain, its cultivation is still confined to marginal lands with poor fertility (Meena *et al*., 2015) [5]. A little attention has been paid by the research workers to develop proper agro techniques for successful cultivation of such an important crop. Being a cash crop, Ajwain is getting importance amongst the farmers of Rayalaseema region of Andhra Pradesh, as against the traditional crop, farmers are therefore in want of diversification of cropping pattern through the short duration seed species like Ajwain, Coriander, Fennel, Cumin etc.

Very limited research work on nutrient management in seed spices is done in Rayalaseema region of Andhra Pradesh. The promising research on effect of nutrient levels on Ajwain is a major limitation in one hand however, on the other hand this will open new vistas of wide scope to check the performance of organically grown Ajwain with plant growth promoting

rhizobacteria and micronutrient sprays and restructuring of nutrient doses for getting economic yields with sustainable soil health. Keeping these points in view, the present study was conducted to study the interaction effect of organic manures, PGPR and micronutrients on vegetative growth, yield and quality of Ajwain

Material and Methods

The study was carried out at College of Horticulture, Anantharajupeta, Y.S.R. Kadapa District, Andhra Pradesh during 2017-18 and 2018-19. LTa-26, variety of Ajwain, released by Dr. Y.S.R.H.U was used for the study. The experiment consisted of 25 treatments, laid out in Factorial RBD with single control design and replicated thrice. Farm yard manure and vermicompost were used as organic source at 50% and 75% recommended dose of nitrogen (RDN).PGPRs namely *Azospirillum lipoferium*, *Bacillus megathurium* and *Frateuria aurantia* were used for seed priming. Micronutrients namely, $ZnSO_4$ and Fe_2SO_4 were applied as foliar spray@0.5% before flowering, 50% flowering and during grain formation stages. All the morphological, growth, yield and quality parameters were recorded.

Results

Growth parameters

Data presented in Table (1) showed that there was a significant difference in plant height, number of leaves and dry matter production of Ajwain for different treatments of sole application of organic manures, PGPR and micronutrients during both the years of experimentation. Maximum plant height (98.07 cm), number of leaves (69.09), dry matter production (50.03 g plant^{-1}) was recorded in the treatment received 50% of RDN through vermicompost which was on par with the treatment received 50% of RDN through FYM. Sole application of PGPR could also bring significant variation in plant height, number of leaves and dry matter production. Significantly highest plant height (96.93 cm), highest number of leaves (68.23) and highest dry matter production (49.26 g plant^{-1}) were recorded by seed priming with *Azospirillum* at harvest. Further, sole application of foliar spray of micronutrients could bring significant variation in dry matter production. Significantly highest plant height (95.84 cm), number of leaves (67.20) and dry matter production (48.52 g plant^{-1}) at harvest were recorded with spraying of zinc at 0.5 per cent.

Table 1: Plant height, No. of leaves and Drymatter of Ajwain as influenced by organic manures, plant growth promoting rhizobacteria and micronutrients

	Plant height			No.of leaves			Drymatter (g plant^{-1})		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Organic manures (A)									
A_1	97.37	97.10	97.24	71.48	65.59	68.54	50.39	48.70	49.54
A_2	89.99	89.34	89.66	64.35	60.78	62.56	48.58	42.62	45.60
A_3	98.20	97.94	98.07	71.88	66.29	69.09	50.76	49.30	50.03
A_4	90.88	90.28	90.58	65.13	61.34	63.23	48.90	43.06	45.98
SEm±	2.27	2.01	2.14	1.07	0.87	0.99	0.48	0.62	0.75
CD (P=0.05)	6.76	6.12	6.44	3.17	2.62	2.90	1.35	1.77	2.15
Plant Growth Promoting Rhizobacteria (B)									
B_1	97.20	96.66	96.93	70.88	65.57	68.23	50.35	48.17	49.26
B_2	91.13	90.71	90.92	65.30	61.20	63.25	48.90	43.65	46.27
B_3	94.01	93.62	93.81	68.44	63.73	66.09	49.73	45.93	47.83
SEm±	0.88	0.67	0.78	0.65	0.59	0.62	0.21	0.52	0.48
CD (P=0.05)	2.59	2.08	2.34	2.04	1.76	1.90	0.57	1.45	1.38
Micronutrients (C)									
C_1	96.09	95.59	95.84	69.72	64.68	67.20	50.10	46.94	48.52
C_2	92.13	91.74	91.93	66.70	62.32	64.51	49.22	44.89	47.06
SEm±	1.08	0.95	1.02	0.75	0.59	0.68	0.23	0.63	0.47
CD (P=0.05)	3.19	2.86	3.03	2.24	1.76	2.00	0.76	1.82	1.34

Treatment details		
A-Organic manures	**B- Plant Growth Promoting Rhizobacteria**	**C-Micronutrients**
A_1: 50% of RDN through FYM	B_1: Azospirillum	C_1: Zn @ 0.5%
A_2: 75% of RDN through FYM	B_2: Phosphorus Solubilising Bacteria (PSB)	C_2: Fe @ 0.5%
A_3: 50% of RDN through VC	B_3: Potash Mobilizing Bacteria (KMB)	
A_4: 75%of RDN through VC		

	Plant height			Number of leaves			Dry matter (g plant^{-1})		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
A x B x C (Organic manures x PGPR x Micronutrients)									
$A_1B_1C_1$	104.40	103.86	104.13	75.66	69.26	72.46	51.35	50.45	50.90
$A_1B_1C_2$	97.06	96.98	97.02	72.88	65.22	69.05	50.75	49.13	49.94
$A_1B_2C_1$	96.99	96.84	96.92	71.33	64.32	67.83	50.48	48.79	49.64
$A_1B_2C_2$	92.47	92.14	92.31	66.44	62.84	64.64	49.12	46.22	47.67
$A_1B_3C_1$	98.28	97.98	98.13	74.33	67.24	70.79	51.09	49.96	50.53
$A_1B_3C_2$	95.03	94.82	94.93	68.22	64.68	66.45	49.55	47.62	48.59
$A_2B_1C_1$	95.02	94.79	94.91	68.00	64.10	66.05	49.41	47.11	48.26
$A_2B_1C_2$	90.70	89.67	90.19	65.33	61.48	63.41	48.95	43.60	46.28
$A_2B_2C_1$	87.87	87.68	87.78	62.22	59.04	60.63	48.40	40.19	44.30
$A_2B_2C_2$	86.26	85.14	85.70	61.77	58.28	60.03	47.14	38.16	42.65

$A_2B_3C_1$	90.95	89.96	90.46	66.11	62.28	64.20	49.04	45.67	47.36
$A_2B_3C_2$	89.11	88.78	88.95	62.66	59.48	61.07	48.55	40.97	44.76
$A_3B_1C_1$	105.83	104.08	104.96	76.77	72.68	74.73	52.16	51.24	51.70
$A_3B_1C_2$	97.64	96.84	97.24	73.44	65.80	69.62	51.09	49.85	50.47
$A_3B_2C_1$	95.71	94.92	95.32	68.66	63.42	66.04	50.43	48.79	49.61
$A_3B_2C_2$	92.78	92.64	92.71	66.44	62.56	64.50	49.29	46.72	48.01
$A_3B_3C_1$	101.43	103.01	102.22	75.22	68.64	71.93	51.17	50.24	50.71
$A_3B_3C_2$	95.81	96.14	95.98	70.77	64.64	67.71	50.44	48.96	49.70
$A_4B_1C_1$	95.31	95.82	95.57	68.55	62.92	65.74	50.01	48.05	49.03
$A_4B_1C_2$	91.63	91.25	91.44	66.44	63.12	64.78	49.09	45.94	47.52
$A_4B_2C_1$	90.35	89.06	89.71	63.55	60.28	61.92	48.59	41.46	45.03
$A_4B_2C_2$	86.58	87.24	86.91	62.00	58.82	60.41	47.74	38.86	43.30
$A_4B_3C_1$	90.97	89.04	90.01	66.22	61.96	64.09	49.06	41.34	45.20
$A_4B_3C_2$	90.46	89.24	89.85	63.99	60.94	62.47	48.90	42.70	45.80
SEm±	1.27	0.36	0.85	0.48	1.15	0.89	0.28	0.31	0.33
CD (P=0.05)	3.76	1.01	2.47	1.36	3.50	2.76	0.89	0.91	0.95
Controlvz Rest	82.85	83.56	83.21	59.55	55.14	57.35	43.39	37.12	40.26
SEm± (Control)	7.61	7.75	7.88	2.77	2.56	2.66	1.18	1.07	1.13
CD (P=0.5) (Control)	22.76	23.18	22.97	8.23	7.64	7.94	3.52	3.19	3.37
CV%	13.96	13.24	13.60	6.97	6.15	6.56	4.35	4.13	4.94

It was also evident from the Table (1) that combined effect of organic manures, PGPR and micronutrient produced significant influence on phenotypical growth of Ajwain. Maximum plant height (104.96cm), number of leaves (74.73) and maximum dry matter production (51.70 g plant^{-1}) was recorded with application of 50% of RDN through vermicompost +seed priming with *Azospirillum*+ foliar spray of Zn at 0.5% which was on par with 50% of RDN through FYM + seed priming with *Azospirillum*+ foliar spray of Zn at 0.5%.

Adequate supply of vermicompost early in the crop season resulted in greater availability of nutrients particularly in crop root zone. Increased availability of nutrients in the root zone coupled with higher metabolic activity at the cellular level might have enhanced the nutrient uptake and accumulation in the vegetative parts, which inturn resulted in higher plant height, number of leaves, fresh weight and dry mater content (Atiyeh *et al*., 2002) [3].

From the table it was evident that supplementation of organic manures (VC/FYM), PGPR *(Azospirillum)* and micronutrient (Zn) either sole or in combinations could promote plant height and increased production of leaves in Ajwain. The reason for the changes might be due to cell multiplication and cell enlargement and cell differentiation, which could have resulted in increasing the height and number of leaves in the plant. The favourable effect of combination between organic manures, PGPR, and micronutrients may be attributed to the effect of the beneficial bacteria on availability of the nutrients, vital enzymes and hormonal stimulating effects on plant growth or increase of photosynthetic activity. Moreover, biofertilizers have several possible modes of action on plant growth on nitrogen fixation which contributed to the plant, hormonal effects, which alter the plant metabolism and thereby increasing the height and number of leaves. The above results are in accordance with findings of Abdel *et al*. (2016) [1] in Fennel and Mehta *et al*. (2007) in Ajwain

It is evident that the increased dry matter production could be attributed to better vegetative growth that was observed in attributes like plant height, number of primary and secondary branches and number of leaves *etc* contributing in production of more fresh weight. Effect of PGPR on dry weight of plant was due to increased uptake and the growth rate improvement. (Mahfouz and Eldin, 2007). Micronutrient (Zn) plays an important role in many physiological processes and cellular formation within the plants.

Yield characters

The results of the study (Table 2 and 3) clearly indicated that application of organic manure, plant growth promoting rhizobacteria and foliar application of micronutrients significantly increased the yield of Ajwain. Significantly highest number of umbels per plant (213.98), seed yield per plant (11.29 g), biological yield (4346.31 Kg ha^{-1}) seed yield per hectare (1239.00 Kg ha^{-1}) and test weight of seeds (1.10 g) was recorded with sole application of 50% RDN through VC which was on par with 50% RDN through FYM. Seed priming with *Azospirillum* recorded significantly higher number of umbels per plant (207.13), seed yield per plant (10.99 g), high biological yield (4158.21 Kgha^{-1}), seed yield per hectare (1211.0 Kg ha^{-1}) and high test weight of seed (1.05). In case of micronutrients application, foliar spray of Zn at 0.5% produced significantly higher number of umbels per plant (202.21), higher seed yield per plant (10.74 g), biological yield (4018.58 Kg ha^{-1}), higher seed yield (1181.32 Kg ha^{-1}) and higher test weight of seed (1.02 g)

Table 2: Number of umbels per plant, Seed yield per plant and Biological yield of Ajwain as influenced by organic manures, plant growth promoting rhizobacteria and micronutrients

	Number of umbels per plant			Seed yield per plant			Biological yield		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Organic manures (A)									
A_1	214.43	209.62	212.02	11.29	11.01	11.15	4367.47	4222.01	4294.74
A_2	178.48	170.83	174.65	9.68	9.17	9.43	3257.85	3149.23	3203.54
A_3	216.61	211.36	213.98	11.38	11.20	11.29	4417.23	4275.40	4346.31
A_4	185.44	178.44	181.94	9.89	9.53	9.71	3478.30	3329.98	3404.14
SEm±	5.60	3.75	4.52	0.25	0.23	0.27	28.58	27.51	28.82
CD (P=0.05)	15.93	11.12	13.47	0.72	0.61	0.74	81.27	82.43	86.35
Plant Growth Promoting Rhizobacteria (B)									
B_1	209.79	204.47	207.13	11.14	10.85	10.99	4235.13	4081.29	4158.21
B_2	186.17	179.66	182.92	9.91	9.55	9.73	3513.23	3383.43	3448.33
B_3	200.25	193.55	196.90	10.63	10.28	10.46	3892.27	3767.75	3830.01
SEm±	2.95	2.06	2.42	0.22	0.15	0.17	24.75	25.12	27.16
CD (P=0.05)	8.80	6.08	7.12	0.62	0.48	0.50	70.39	75.22	81.45
Micronutrients (C)									
C_1	205.24	199.19	202.21	10.91	10.58	10.74	4092.04	3945.11	4018.58
C_2	192.24	185.93	189.09	10.21	9.87	10.04	3668.38	3543.20	3605.79
SEm±	3.76	3.32	3.51	0.18	0.22	0.24	20.21	20.72	21.71
CD (P=0.05)	11.26	9.86	10.47	0.51	0.62	0.68	57.47	62.13	65.08

Treatment details		
A-Organic manures	**B- Plant Growth Promoting Rhizobacteria**	**C-Micronutrients**
A_1: 50% of RDN through FYM	B_1: Azospirillum	C_1: Zn @ 0.5%
A_2: 75% of RDN through FYM	B_2: Phosphorus Solubilising Bacteria (PSB)	C_2: Fe @ 0.5%
A_3: 50% of RDN through VC	B_3: Potash Mobilizing Bacteria (KMB)	
A_4: 75%of RDN through VC		

	Number of umbels per plant			Seed yield per plant			Biological yield		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
A x B x C (Organic manures x PGPR x Micronutrients)									
$A_1B_1C_1$	224.22	220.66	222.44	12.21	11.71	11.96	4886.48	4644.13	4765.31
$A_1B_1C_2$	215.88	211.65	213.77	11.38	11.10	11.24	4473.39	4355.77	4414.58
$A_1B_2C_1$	215.70	210.47	213.09	11.03	10.98	11.01	4433.26	4341.75	4387.51
$A_1B_2C_2$	202.22	197.53	199.88	10.56	10.25	10.41	3735.56	3581.28	3658.42
$A_1B_3C_1$	222.66	217.86	220.26	11.77	11.46	11.62	4625.74	4526.44	4576.09
$A_1B_3C_2$	205.88	199.56	202.72	10.77	10.54	10.66	4050.38	3882.71	3966.55
$A_2B_1C_1$	203.33	195.37	199.35	10.61	10.43	10.52	3946.73	3808.19	3877.46
$A_2B_1C_2$	185.77	178.23	182.00	9.93	9.36	9.65	3381.71	3239.74	3310.73
$A_2B_2C_1$	169.27	159.24	164.26	9.47	8.67	9.07	3158.9	2886.64	3022.77
$A_2B_2C_2$	152.90	147.78	150.34	8.33	8.01	8.17	2410.4	2605.98	2508.19
$A_2B_3C_1$	187.22	180.22	183.72	10.14	9.58	9.86	3466.4	3334.69	3400.55
$A_2B_3C_2$	172.40	164.11	168.26	9.60	8.97	9.29	3182.95	3020.15	3101.55
$A_3B_1C_1$	228.76	224.65	226.71	12.43	12.13	12.28	4936.29	4730.97	4833.63
$A_3B_1C_2$	219.44	215.34	217.39	11.54	11.36	11.45	4548.17	4450.5	4499.34
$A_3B_2C_1$	210.11	205.46	207.79	10.93	10.82	10.88	4182.23	4011.53	4096.88
$A_3B_2C_2$	203.33	195.22	199.28	10.59	10.37	10.48	3851.47	3668.84	3760.16
$A_3B_3C_1$	224.11	219.38	221.75	11.79	11.58	11.69	4671.15	4584.59	4627.87
$A_3B_3C_2$	213.88	208.11	211.00	11.02	10.94	10.98	4314.04	4205.97	4260.01
$A_4B_1C_1$	209.11	202.67	205.89	10.79	10.65	10.72	4071.06	3956.86	4013.96
$A_4B_1C_2$	191.84	187.22	189.53	10.20	10.06	10.13	3637.19	3464.18	3550.69
$A_4B_2C_1$	178.08	168.90	173.49	9.61	9.03	9.32	3246.98	3130.77	3188.88
$A_4B_2C_2$	157.77	152.67	155.22	8.74	8.25	8.50	3087.06	2840.62	2963.84
$A_4B_3C_1$	190.31	185.38	187.85	10.16	9.88	10.02	3479.26	3384.81	3432.04
$A_4B_3C_2$	185.55	173.78	179.67	9.81	9.28	9.55	3348.27	3202.64	3275.46
SEm±	1.54	1.38	1.56	0.18	0.17	0.19	38.43	39.11	40.22
CD (P=0.05)	4.61	4.12	4.57	0.56	0.50	0.53	115.24	117.22	120.54
Controlvz Rest	152.91	145.24	149.08	7.93	7.64	7.79	3017.79	2874.44	2946.12
SEm± (Control)	14.56	10.87	12.72	0.65	0.69	0.63	70.39	61.56	68.52
CD (P=0.5) (Control)	41.39	32.56	36.98	1.86	1.75	1.82	211.16	184.66	205.48
CV%	12.07	10.13	11.10	10.23`	5.20	5.20	3.15	4.20	3.68

The three way interaction of organic manures, PGPR and micronutrients could exert significant influence on yield and its attributing characters. Significantly highest number of umbels per plant (226.71), maximum seed yield per plant (12.28 g), biological yield (4833.63 Kg ha^{-1}), seed yield per hectare (1336.43 Kg ha^{-1}) and test weight of seed (1.18 g) was observed by combined application of 50% of RDN through vermicompost along with seed priming with *Azospirillum* and

foliar application of zinc which was statistically on par with application of 50% of RDN through FYM along with seed priming with *Azospirillum* and foliar application of zinc.

Table 3: Seed yield and Test weight of seed of Ajwain as influenced by organic manures, plant growth promoting rhizobacteria and micronutrients

	Seed yield (Kg ha^{-1})			Test weight of seed (g)		
	2017-18	**2018-19**	**Pooled**	**2017-18**	**2018-19**	**Pooled**
Organic manures (A)						
A_1	1229.34	1214.06	1221.70	1.11	1.05	1.08
A_2	1055.37	1014.98	1035.17	0.90	0.82	0.86
A_3	1246.36	1231.65	1239.00	1.13	1.07	1.10
A_4	1090.65	1069.96	1080.31	0.94	0.86	0.90
Sem±	15.21	12.11	13.56	0.05	0.03	0.05
CD (P=0.05)	43.25	36.24	40.58	0.12	0.11	0.13
Plant Growth Promoting Rhizobacteria (B)						
B_1	1218.38	1203.71	1211.04	1.08	1.02	1.05
B_2	1087.67	1049.24	1068.45	0.95	0.87	0.91
B_3	1160.24	1145.05	1152.64	1.02	0.95	0.98
Sem±	13.17	12.77	14.24	0.01	0.01	0.02
CD (P=0.05)	37.46	38.16	42.63	0.03	0.05	0.06
Micronutrients ©						
C_1	1191.87	1170.77	1181.32	1.05	0.99	1.02
C_2	1118.98	1094.56	1106.77	0.98	0.90	0.94
Sem±	10.20	11.27	10.89	0.01	0.01	0.02
CD (P=0.05)	30.59	33.71	32.14	0.03	0.03	0.06

Treatment details		
A-Organic manures	**B- Plant Growth Promoting Rhizobacteria**	**C-Micronutrients**
A_1: 50% of RDN through FYM	B_1: Azospirillum	C_1: Zn @ 0.5%
A_2: 75% of RDN through FYM	B_2: Phosphorus Solubilising Bacteria (PSB)	C_2: Fe @ 0.5%
A_3: 50% of RDN through VC	B_3: Potash Mobilizing Bacteria (KMB)	
A_4: 75%of RDN through VC		

	Seed yield(Kg ha^{-1})			Test weight of seed (g)		
	2017-18	**2018-19**	**Pooled**	**2017-18**	**2018-19**	**Pooled**
A x B x C (Organic manures x PGPR x Micronutrients)						
$A_1B_1C_1$	1321.48	1315.43	1318.46	1.17	1.14	1.16
$A_1B_1C_2$	1228.89	1213.87	1221.38	1.13	1.08	1.11
$A_1B_2C_1$	1224.36	1195.55	1209.96	1.13	1.07	1.10
$A_1B_2C_2$	1142.96	1117.98	1130.47	1.03	0.91	0.97
$A_1B_3C_1$	1282.04	1274.34	1278.19	1.15	1.11	1.13
$A_1B_3C_2$	1176.28	1167.21	1171.75	1.07	0.96	1.02
$A_2B_1C_1$	1173.33	1155.09	1164.21	1.06	0.97	1.02
$A_2B_1C_2$	1091.31	1075.34	1083.33	0.90	0.85	0.88
$A_2B_2C_1$	1016.70	923.14	969.92	0.84	0.74	0.79
$A_2B_2C_2$	925.90	864.78	895.34	0.79	0.70	0.75
$A_2B_3C_1$	1093.10	1089.09	1091.10	0.93	0.86	0.90
$A_2B_3C_2$	1031.85	982.45	1007.15	0.85	0.77	0.81
$A_3B_1C_1$	1345.19	1327.67	1336.43	1.19	1.16	1.18
$A_3B_1C_2$	1274.07	1265.90	1269.99	1.14	1.10	1.12
$A_3B_2C_1$	1189.63	1179.33	1184.48	1.10	1.02	1.06
$A_3B_2C_2$	1164.07	1134.24	1149.16	1.05	0.95	1.00
$A_3B_3C_1$	1308.15	1298.09	1303.12	1.16	1.13	1.15
$A_3B_3C_2$	1197.04	1184.67	1190.86	1.12	1.05	1.09
$A_4B_1C_1$	1179.26	1170.56	1174.91	1.09	0.99	1.04
$A_4B_1C_2$	1133.49	1105.78	1119.64	0.99	0.90	0.95
$A_4B_2C_1$	1066.28	1024.77	1045.53	0.87	0.80	0.84
$A_4B_2C_2$	971.46	954.12	962.79	0.82	0.73	0.78
$A_4B_3C_1$	1102.96	1096.21	1099.59	0.96	0.88	0.92
$A_4B_3C_2$	1090.47	1068.34	1079.41	0.88	0.83	0.86
SEm±	11.62	8.81	10.65	0.01	0.01	0.01
CD (P=0.05)	35.10	26.34	31.87	0.03	0.03	0.03
Controlvz Rest	881.49	852.64	867.07	0.73	0.68	0.71
SEm± (Control)	37.48	33.99	36.48	0.04	0.03	0.03
CD (P=0.5) (Control)	112.38	101.96	109.40	0.10	0.10	0.10
CV%	5.64	5.38	5.51	5.80	5.20	5.50

The seed and stover yields being functions of growth and yield attributes improved significantly due to the cumulative effect of these attributes. Further, vermicompost might have increased the efficiency of added chemical fertilizers in soil, activities of N fixing bacteria and rate of humification. Increased fruit yield in vermicompost treatments could be as a result of improvement of yield components such as; plant height, umbel number per plant, umbellets per umbel and biomass yield which are directly or indirectly influenced the number of seeds. These findings are in accordance with the observations of Yogesh *et al*. (2015) and Ravi (2016) [6] in Coriander and Shekofteh *et al*. (2013) [7] in Ajwain.

In the present study, the interaction between organic manures, PGPR and micronutrients on seed yield of Ajwain was significant. As the organic manures were incorporated with plant growth promoting rhizobacteria, they have not only improved the soil quality but also provided feed to the soil microbes. The foliar spray of micronutrients also helped them to do their functions more efficiently.

Quality parameters

The data presented in Table (4) showed that there was a significant difference in essential oil content, thymol and fixed oil content of Ajwain for different treatments of sole application of organic manures, PGPR and micronutrients for both the years. Significantly maximum essential oil content was recorded in treatment received 50% of RDN through vermicompost (3.14%), thymol content (47.89%) and fixed oil content (8.63%). Among the plant growth promoting rhizobacteria, seed priming with *Azospirillum* recorded significantly high essential oil content (3.09%), thymol content (47.46%) and fixed oil content (8.51%). In case of micronutrients application, foliar spray of Zn at 0.5% produced an essential oil content of 3.02%, higher thymol content of 47.16% and fixed oil content of 8.39%.

Table 4: Essential oil content, fixed oil content and thymol content of Ajwain as influenced by organic manures, plant growth promoting rhizobacteria and micronutrients

	Essential oil content			Fixed oil content			Thymol content		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Organic manures (A)									
A_1	3.11	3.08	3.09	8.64	8.51	8.58	48.55	46.75	47.65
A_2	2.80	2.68	2.74	7.89	7.79	7.84	46.45	43.94	45.19
A_3	3.16	3.11	3.14	8.70	8.56	8.63	48.68	47.10	47.89
A_4	2.88	2.78	2.83	8.01	7.90	7.96	46.98	44.45	45.71
SEm±	0.01	0.01	0.02	0.17	0.13	0.15	0.03	0.06	0.07
CD (P=0.05)	0.03	0.02	0.04	0.45	0.34	0.41	0.10	0.15	0.20
Plant Growth Promoting Rhizobacteria (B)									
B_1	3.11	3.06	3.09	8.59	8.43	8.51	48.41	46.52	47.46
B_2	2.84	2.73	2.79	8.06	7.95	8.01	46.78	44.49	45.64
B_3	3.01	2.95	2.98	8.28	8.19	8.24	47.80	45.67	46.73
SEm±	0.03	0.02	0.03	0.09	0.07	0.10	0.19	0.18	0.21
CD (P=0.05)	0.08	0.07	0.09	0.20	0.18	0.25	0.54	0.50	0.58
Micronutrients (C)									
C_1	3.05	2.99	3.02	8.45	8.33	8.39	48.12	46.20	47.16
C_2	2.92	2.84	2.88	8.18	8.05	8.11	47.20	44.92	46.06
SEm±	0.03	0.03	0.04	0.07	0.09	0.10	0.16	0.19	0.21
CD (P=0.05)	0.08	0.09	0.11	0.20	0.23	0.25	0.44	0.55	0.62

Treatment details		
A-Organic manures	**B- Plant Growth Promoting Rhizobacteria**	**C-Micronutrients**
A_1: 50% of RDN through FYM	B_1: Azospirillum	C_1: Zn @ 0.5%
A_2: 75% of RDN through FYM	B_2: Phosphorus Solubilising Bacteria (PSB)	C_2: Fe @ 0.5%
A_3: 50% of RDN through VC	B_3: Potash Mobilizing Bacteria (KMB)	
A_4: 75%of RDN through VC		

	Essential oil content			Fixed oil content			Thymol content		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
A x B x C (Organic manures x PGPR x Micronutrients)									
$A_1B_1C_1$	3.28	3.21	3.25	8.97	8.83	8.90	49.25	48.72	48.99
$A_1B_1C_2$	3.10	3.10	3.10	8.77	8.64	8.71	48.64	46.82	47.73
$A_1B_2C_1$	3.07	3.08	3.08	8.57	8.48	8.53	48.57	46.79	47.68
$A_1B_2C_2$	2.96	2.92	2.94	8.27	8.12	8.20	47.72	45.22	46.47
$A_1B_3C_1$	3.18	3.17	3.18	8.80	8.70	8.75	48.93	47.45	48.19
$A_1B_3C_2$	3.05	3.01	3.03	8.47	8.30	8.39	48.16	45.52	46.84
$A_2B_1C_1$	3.00	2.98	2.99	8.47	8.28	8.38	48.06	45.34	46.70
$A_2B_1C_2$	2.91	2.84	2.88	7.90	7.83	7.87	47.19	44.35	45.77
$A_2B_2C_1$	2.63	2.44	2.54	7.57	7.43	7.50	45.80	43.16	44.48
$A_2B_2C_2$	2.59	2.34	2.47	7.77	7.68	7.73	44.29	42.65	43.47
$A_2B_3C_1$	2.93	2.86	2.90	8.00	7.95	7.98	47.41	44.68	46.05
$A_2B_3C_2$	2.75	2.64	2.70	7.63	7.57	7.60	45.92	43.46	44.69
$A_3B_1C_1$	3.38	3.34	3.36	9.10	8.87	8.99	49.47	48.94	49.21
$A_3B_1C_2$	3.20	3.12	3.16	8.77	8.57	8.67	48.67	46.94	47.81
$A_3B_2C_1$	3.07	3.03	3.05	8.63	8.52	8.58	48.33	46.13	47.23

$A_3B_2C_2$	2.98	2.96	2.97	8.30	8.18	8.24	48.01	45.28	46.65
$A_3B_3C_1$	3.25	3.18	3.22	8.87	8.78	8.83	49.08	48.66	48.87
$A_3B_3C_2$	3.08	3.04	3.06	8.53	8.44	8.49	48.53	46.66	47.60
$A_4B_1C_1$	3.06	3.03	3.05	8.50	8.38	8.44	48.32	45.87	47.10
$A_4B_1C_2$	2.95	2.89	2.92	8.27	8.03	8.15	47.67	45.18	46.43
$A_4B_2C_1$	2.80	2.71	2.76	7.80	7.75	7.78	46.73	43.82	45.28
$A_4B_2C_2$	2.61	2.39	2.50	7.57	7.46	7.52	44.78	42.88	43.83
$A_4B_3C_1$	2.93	2.87	2.90	8.07	8.01	8.04	47.54	44.89	46.22
$A_4B_3C_2$	2.90	2.81	2.86	7.87	7.79	7.83	46.81	44.05	45.43
SEm±	0.02	0.03	0.04	0.06	0.04	0.05	0.03	0.04	0.06
CD (P=0.05)	0.08	0.09	0.10	0.15	0.08	0.13	0.12	0.15	0.17
Controlvz Rest	2.84	2.38	2.75	7.47	7.39	7.43	44.14	42.38	43.26
SEm± (Control)	0.11	0.08	0.09	0.15	0.11	0.13	0.57	0.53	0.55
CD (P=0.5) (Control)	0.31	0.18	0.23	0.41	0.28	0.32	1.63	1.54	1.60
CV%	5.79	5.34	5.57	4.51	4.06	4.32	1.97	1.58	1.78

It was also evident from the table that an essential oil content of 3.36%, fixed oil (8.99%) and thymol (49.21%) was recorded with combined application of 50% of RDN through vermicompost along with seed priming with *Azospirillum* and foliar application of zinc

The result of the present study revealed that vermicompost and FYM had significant effect on essential oil content, thymol per cent and fixed oil content of Ajwain. Vermicompost application through increase of the mineral uptake suchas nitrogen and phosphorus has a positive effect on proper biomass production and subsequently enhances the essential oil content. Nitrogen fixing bacteria, *Azospirillum* stimulates the uptake of nitrogen in the soil, increases the synthesis of secondary metabolites, and thus increased the amount of essential oil content in the plant. Similar values of essential content, thymol content was reported by Chahal *et al*. (2017) [4] and Yogita *et al*. (2013) [9] in Ajwain.

Conclusion

The substitution of inorganic nutritional source with organics was found to be significantly influencial on the growth, flowering and yield aspects of Ajwain. Among the organic sources, 50% of RDN through VC and 50% of RDN through FYM was found superior in improving the vegetative traits, yield and its attributes in Ajwain. The biochemical analysis revealed that quality parameters of the seeds like higher essential oil, fixed oil and thymol content was significantly improved by application of VC. Among the PGPR, seed priming with *Azospirillum* found significantly superior in promoting growth, yield and its attributes and quality components. Among the micronutrients application, foliar spray of Zn @ 0.5% was found promising with better vegetative growth, yield and its attributes and quality parameters.

Among the combined effect of organic manures, PGPR and micronutrients, application of 50% of RDN through vermicompost +seed priming with *Azospirillum*+foliar spray of Zn @ 0.5% and with 50% of RDN through FYM + seed priming with *Azospirillum*+ foliar spray of Zn @ 0.5% was found on par with superior morphological growth, yield and its attributes. Oil quality in terms of bio-chemical characters like essential oil content, fixed oil content and thymol content were found to be significantly superior with substitution of nutritional source using vermicompost at 50% level along with seed priming with *Azospirillum* and foliar spray of Zn @ 0.5%.

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