Effect of the Environment on Content and Composition of Essential oil in Coriander

Siddharth Priyadarshi, Babasaheb Bhaskarrao Borse*

Abstract— *Coriandrum sativum* L. has a distinct flavour and aroma which is due to the essential oil present in it. The main component of the essential oil of the fruit is monoterpenoids and linalool. All parts of the plant are edible. The content and composition of essential oil is influenced by climatic conditions, agro technology and stage of maturity at time of harvesting, geography of growing region, abiotic stress such as salinity and process of extraction of oils.

Index Terms— *Coriandrum sativum* L., Cultivars, Cultivation and usage, Identified volatile compounds, Nutrient composition, Pharmacological properties, Sowing time, Stages of maturity

1 INTRODUCTION

Coriandrum sativum L. is a vital spice crop and inhabits a key position in flavouring substances. Dhanyaka consist of dried ripe fruits of *Coriandrum sativum* Linn *Apiaceae* [1]. The whole plant and particularly the unripe fruit when rubbed give characteristic aroma [2] and strong odour hence the name coriander [3]. All parts of the plant are edible but in cooking mostly the fresh leaves and the dried seeds are used. Coriander which is available throughout the year and provides a fragrant flavour that is indicative of both citrus peel and sage. The main component of the essential oil of the fruit is monoterpenoids and linalool. It is originated around the Mediterranean regions and is cultivated mainly in the tropical areas. It is commercially grown in Argentina, India, Mexico, Morocco, Romania, Russia and Ukraine etc. [4]. India being the largest producer of coriander in world. The main coriander growing states in India are Rajasthan, Madhya Pradesh, Andhra Pradesh and Tamil Nadu. Coriander is also grown in some other states of India like Uttar Pradesh, Himachal Pradesh, Gujarat, Uttaranchal, Bihar, West Bengal, Jharkhand, Chhattisgarh, Karnataka and Orissa (Figure 1). The major markets in India are located in Rajasthan and Madhya Pradesh but the three largest markets in Rajasthan are Kota, Ramganj Mandi and Baran. The genus *Coriandrum* L. has two species. The *Coriandrum sativum* L. is approximately 30–100 cm in height, with strong-smelling leaves.

The mature fruits and leaves have a fresh and pleasant flavour. They are mainly used all over the world in ground or volatile isolate form for flavouring sweets, tobacco products, beverages, baked goods and as a vital ingredient for curry powder. The fruits gives essential oil ranging from approximately 0.5 to 2.5% which is used both in the manufacture of soaps and perfumes and in flavours. It is cultivated as a domestic plant [5]. At commercial level, coriander exists in two categories: the small-fruited *C. sativum* L. var. *microcarpum DC* and the larger fruited *C. sativum* L. var. *vulgare Alef* [6]. The former is represented by the volatile oil-rich Russian coriander, while the latter includes Moroccan, Indian and some other Asiatic types of coriander; all of them have very low volatile oil contents [7], [8].

Figure 1: Coriander Growing States in India

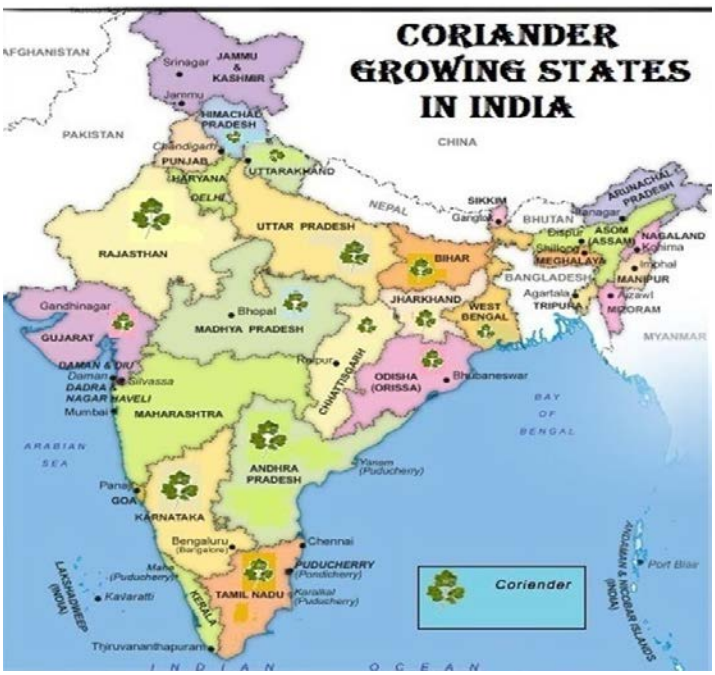

Figure 1: Coriander Growing States in India

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2 BOTANICAL CLASSIFICATIONS

Coriandrum sativum L. belongs to the family *Apiaceae* with botanical classification [9] as shown in Table 1. It is small herb having several branches and sub-branches. The newly formed leaves are oval but aerial leaves are elongated in shape. The fruits are round in shape while flowers are white in colour, having slightly brinjal like shades [10], [11], [12], [13].

2.1 Common Indian names (Vernacular names)

Telugu: dhaniyalu; Tamil: kothamali; Punjabi: dhania; Oriya: dhania; Marathi: dhana, kothimber; Malayalam: kothumpkalari bija, kothumpalari; Kashmiri: daaniwal, kothambalari; Kannada: kothambri, kothmiri bija; Gujarati: kothmiri, konphir, libdhane; Bengali: dhane, dhania.

Table 1: Botanical Classifications

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Kingdom	*Plantae* – Plants
Subkingdom	*Tracheobionta* – Vascular plants
Superdivision	*Spermatophyta* – Seed plants
Division	*Magnoliophyta* – Flowering plants
Class	*Magnoliopsida* – Dicotyledons
Subclass	*Rosidae*
Order	*Apiales*
Family	*Apiaceae* – Carrot family
Genus	*Coriandrum* L. – coriander
Species	*Coriandrum sativum* L. – coriander

3 NUTRIENT COMPOSITION

The nutrient composition of coriander, commonly known as 'cilantro' is given in (Table 2). Coriander oil functions as an essential ingredient in curry mixes and is also used in baked foods, spices [14]. Coriander seeds contain petroselinic acid, linoleic acid, oleic acid and palmitic acid (Figure 2). Major components of essential oil are linalool, α-pinene, camphor and geraniol. On the basis of different parts of the plant, coriander has very different uses. The traditional use which is based on the primary products of the plant (i.e. the fruits and the green herb), is two-fold: medicinal and culinary. Both the fatty acids and essential oils are used either separately or in combined form in the industry [4].

Coriandrum sativum has good antioxidant property and some of its active components have also been identified. Coriander contains active phenolic acid compounds, including caffeic and chlorogenic acid. The flavonoids include quercetin, keampferol, rhamnetin and apigenin**.** Most of these compounds are obtained through the diet and known to inhibit free radicals generated in the body. There is still narrow knowledge of the mechanisms through which they act but initial research indicates that *Coriandrum sativum* is effective in both treatment and prevention of several chronic diseases.

Table2: Chemical composition of *Coriandrum sativum*

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SI	Components		Composition % [4]	Composition per 100g [6]	Composition per 100g [9]
1.	Energy		-	279.00 (kcal)	23 (kcal)
2.	Sugar		1.92 %	52.10 (g)	4 (g)
3.	Pentosans		10.29 %	-	-
4.	Starch		10.53 %	-	-
5.	Water		11.37 %	7.3 (g)	-
6.	Protein		11.49 %	21.83 (g)	2 (g)
7.	Fat		19.15 %	4.76 (g)	0.5 (g)
8.	Ash		-	14.02 (g)	-
9.	Fiber		28.43 %	-	3 (g)
10	Vitamin- C		-	566.7 (mg)	27 (mg)
11.	Mineral Constituents	Calcium	4.98 %	1.246 (mg)	-
		Potassium		4.466 (mg)	
		Iron		42.46 (mg)	
		Sodium		211.00 (mg)	
		Phosphorus		481.00 (mg)	
12.	Essential Oils (0.03 to 2.6 %)	Geraniol	1.9 %	1.9 %	-
		Camphor	3.0 %	3.0 %	-
		Geranylacetate	4.0 %	4.0 %	-
		Gamma-terpinene	9.0 %	9.0 %	-
		Alpha-pinene	10.5 %	10.5 %	-
		Linalool	67.7 %	67.75 %	-
13.	Fatty Acids (9.9 to 27.7 %)	Palmitic acid C16:0	3.8 %	3.8 %	-
		Oleic acid C18:1	7.5 %	7.5 %	-
		Linoleic acid C18:2	16.6 %	16.6 %	-
		Petroselinic acid C18:1	68.8 %	68.6 %	-

Figure 2: Chemical structures of Essential Oil and Fatty acids present in Coriander

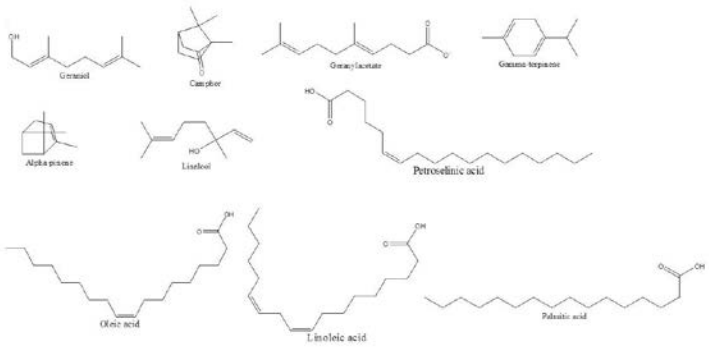

Figure 2: Chemical structures of Essential Oil and Fatty acids present in Coriander

3.1 Constituents coriander essential oils identified in

Coriander essential oil was reported to contain a number of compounds [15], [16] (Table 3). The major compounds in coriander are Aliphatic Alcohols, Aliphatic Aldehydes, Aliphatic Hydrocarbons, Monoterpene Alcohols, Monoterpene Esters, Monoterpene Hydrocarbons, Monoterpene oxides and Carbonyls, Phenols, Sesquiterpenes and some Miscellaneous compounds like Acetic acid and α-*p*dimethyl styrene.

Table 3: Classification of identified volatile compounds in *Coriandrum sativum*

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Sl	Compounds	Constituents
1.	Aliphatic Alcohols	Decanol; dodecanol
2.	Aliphatic Aldehydes	Octanal; nonanal; decanal; undecanal; dodecanal; tridecanal; tetradecanal; 3- octenal; 2-decenal; 5-decenal; 8-methyl-2-nonenal; 8- methyl-5 nonenal; 6-undecenal; 2-dodecenal; 7- dodecenal; 2-tridecenal; 8- tridecenal; 9 tetradecenal; 10-pentadecenal; 3,6-undecadienal; 5,8-tridecadienal
3.	Aliphatic Hydrocarbons	Heptadecane; octadecane
4.	Monoterpene Alcohols	Borneol; citronellol; geraniol; linalool; nerol; α-terpineol; 4-terpinenol
5.	Monoterpene Esters	Bornyl acetate; geranyl acetate; linalyl acetate; α-terpinyl acetate
6.	Monoterpene Hydrocarbons	p-cymene; camphene; Δ-3-carene; limonene (dipentene); myrcene; cis- and trans-ocimene; α-phellandrene; β-phellandrene; α- pinene; β-pinene; sabinene; α-terpinene; γ-terpinene; terpinolene; α-thujene
7.	Monoterpene oxides and Carbonyls	Camphor; 1,8- cineole; linalol oxide; carvone; geranial
8.	Phenols	Anethole; myristicin; thymol
9.	Sesquiterpenes	β-Caryophyllene; caryophellene oxide; elemol; nerolidol
10.	Miscellaneous compounds	Acetic acid; α-pdimethyl styrene

4 VARIATIONS IN THE CONTENT AND COMPOSITION OF ESSENTIAL OIL

The content and composition of essential oil is influenced by various climatic conditions like geography of growing region, season, variety and agro technology, stage of maturity at time of harvesting, nature of fruit part, abiotic stress such as salinity, water stress and process of extraction of oils. Many scientists have worked on the effect of various environmental factors on the composition and content of essential oil in the coriander.

4.1 Effect of different growing regions, stages of maturity and their interaction

Masaada and his co-worker while working on the essential oils composition of coriander (*Coriandrum sativum* L.) fruits obtained by hydro distillation at three stages of maturity found (Table 4) that the yield of essential oil showed remarkable increase during maturity process and various compounds were identified at different stages of maturity [17]. Monoterpene alcohols and ketones were also observed during the process of maturation of coriander fruit. The yield of essential oil at initial, middle and the final stage of maturity were 0.01%, 0.12% and 0.35% (w/w) respectively. The first stage of maturity mainly contained monoterpene esters (46.27%). The compounds detected in the fruit at the middle stage were monoterpene alcohols (76.77%), ketones (3.43%), esters (2.85%) and ethers (1.87%) while major constituents of oil were linalool (76.33%), cis-dihydrocarvone (3.21%), geranyl acetate (2.85%) and anethole (1.41%) while monoterpene alcohols (88.51%) and ketones (2.61%) were the main compounds in essential oil at final stage of maturity.

Masaada and his co-worker studied changes in oil yield and fatty acid profiles during maturation of coriander (*Coriandrum sativum* L.) fruits cultivated in Menzel Temime and Oued Beja. They found that rapid accumulation of oil started at newly formed fruits and continued till the full maturity of fruits [18]. Their result showed that during fruit maturation, fatty acid profiles varied significantly among the growing regions and stages of maturity. Fatty acid profile of fruits at full maturity cultivated in Oued Beja showed that petroselinic acid (80.90 ± 9.45%) was the main component followed by oleic (14.79 ± 2.25%), palmitic (3.50 ± 0.65%) and stearic (0.49 ± 0.09%) acids. While in Menzel Temime, at full maturity, the main fatty acids were petroselinic acid (80.86 ± 7.23%) followed by oleic (14.83 ± 2.05%), palmitic (3.27 ± 3.12%) and stearic (0.31 ± 0.05%) acids. They concluded that fruit development resulted mainly in a decrease of palmitic acid and an increase of petroselinic acid in both growing regions. Monounsaturated fatty acids increased however, saturated and polyunsaturated fatty acids decreased considerably during maturation of fruit. At the first four stages of maturity oil composition has a healthy and nutritionally value and the last stages were important in terms of economic and industrial applications.

Masaada and his co-worker while working on coriander (*Coriandrum sativum* L.) fruits to investigate the composition of volatile components of the essential oils extracted; found that the highest yield of the oil were observed at final stages of maturity [19]. The yield of the essential oil was highly affected by the growing region, stages of maturity and their interaction. The composition of essential oil changed significantly among the various growing region and stages of maturity. At final stages of maturity, the highest yield of 0.324 ± 0.09% and 0.327 ± 0.08% was observed in both Menzel Temime and Borj El Ifaa, respectively.

In another experiment carried out by Masaada and his co-worker on the composition of volatile components of the essential oils extracted from fruits of coriander (*Coriandrum sativum* L.) at four stages of maturity, they reported that the yield of the essential oil showed noticeable increase during maturation process. They identified 41 different compounds at different stages of maturity and observed the accumulation of monoterpene alcohols during maturation process of coriander fruit [20]. The yield of essential oil increased during maturation process. The main compound was linalool at all stages of ripening which ranges between 36.69 -72.35%. At the first stage of maturity the main compound identified were Geranyl acetate (35.17%), β-caryophyllene (3.47%) and borneol (3.26%) while at second stage the main compound were geranyl acetate (8.21%), camphor (4.01%) and menthol (2.96%). In the third stage, geranyl acetate (20.66%), α-humulene (5.44%) and limonene (1.68%) was the main compound but at the final stage of maturity linalool (72.35%) was the main content followed by geranyl acetate (1.49%) and borneol (0.97%).

The essential oil yield at immature fruits is more than any other stages of maturity [21]. Wierdak also studied the effect of different plant growth stages on content and chemical composition of coriander. They found more compounds in coriander oil during vegetative phase as compared to generative phase [22]. Coriander herb essential herb contained highest amount of aliphatic aldehyde and after each subsequent harvest of herb there was decrease in the content of aliphatic aldehyde.

4.2 Effect of different accession, cultivars and different sowing time

Ebrahimi and his co-worker cultivated *Coriandrum sativum* L. in different parts of Iran and analysed the chemical profiles of different accessions of coriander. The result showed that Linalool, neryl acetate, γ-terpinene and α-pinene were the major components in oil of coriander accessions and almost all accessions studied contain 60% linalool [23]. The dried seed contained the essential oil between 0.1-0.36 percent. They also concluded that variation in oil content and composition in Iran is due to influence of agricultural practices, environmental and genetic factors.

Arganosa and his co-worker grew cultivars of *Coriandrum sativum* L. at several locations in Western Canada in different years to analyze essential oil content of seed, seed weights and percentage of linalool in the essential oil. The result for both small-seed and large-seed cultivars showed highest seed yield, essential oil yield, linalool content and seed weight [24]. The average seed yields of six large varieties over three years was 1999 kg/ha in comparison to average yield of six smallvarieties over three years and also the average weight of 1000 large seed were greater than average weight of 1000 small seed cultivars. Coriander plants under irrigation produced higher seed yield of 2401 kg/ha as well as higher essential oil content (0.88%) whereas plants under dryland conditions has seed yield of 2286 kg/ha and essential oil content of 0.82% . The splitting of seed for reducing seeding costs prior to seeding did not adversely affect chemical composition of essential oil, seed size and seed yield but the irrigation increased the essential oil content and seed yield while it decreased the percentage of linalool in essential oil and seed weight. The average linalool content in small seeded cultivars was higher (65.3%) in comparison to the large-seeded cultivars (61.6%).

Table 4: Chemical composition of essential oil in *Coriandrum sativum* herbs and fruits at different stages of maturity

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Coriander Herb				Coriander Fruit			
Sl. No	Compounds	Generative stage %	Vegetative stage %	Volatile compound Classes	% at Immature stage	% at Intermediate stage	% at Mature stage
1	Nonane	1.4	3.4	Monoterpene hydrocarbons	0.24	0.48	0.3
2	Heptanal	tr.	0.1	Aromatic hydrocarbons	tr	tr	tr
3	α-pinene	tr.	tr	Monoterpene alcohols	14.66	76.77	88.51
4	Decane	0.1	0.1	Phenols	1.06	1.1	2.31
5	n-octanal	0.2	0.2	Monoterpene esters	46.27	2.85	0.90
6	p-cymene	tr.	tr	Monoterpene ketones	0.97	3.43	2.61
7	Benzene acetaldehyde	tr.	tr	Monoterpene aldehydes	2.07	0.10	0.16
8	γ-terpinene	tr.	0.1	Monoterpene ethers	0.87	1.87	0.48
9	Undecane	0.1	0.1	Sesquiterpenes	0.15	0.31	0.11
10	Linalool	0.3	1.0	Non terpenic	tr	tr	0.01
11	Nonanal	0.7	0.6	**Compounds in Essential Oil**			
12	Cyclodecanol	tr.	tr	Heptanal	tr	tr	tr
13	Z-2-nonenal	tr.	tr	α-Thujene	tr	tr	tr
14	n-nonanol	0.2	0.2	α-Pinene	0.01	tr	0.02
15	4,Z-decenal	0.2	0.3	Sabinene	tr	tr	0.03
16	4,E-decenal	0.5	0.8	β-Pinene	tr	0.20	0.05
17	Decanal	15.3	17.2	δ^3-Carene	0.09	0.10	0.02
18	E-2-decenal	0.6	0.8	α-Terpinene	tr	tr	0.01
19	E-2-decenol	11.9	14.2	p-Cymene	tr	tr	tr
20	1-decanol	4.2	3.0	Limonene	0.04	tr	0.02
21	2-n-octylfuran	0.3	0.3	1,8-Cineole	0.23	0.14	0.20
22	Undecanal	2.2	2.1	(Z)-β-Ocimene	0.08	tr	tr
23	E-2-undecenal	2.0	2.2	γ-Terpinene	tr	tr	tr
24	Dodecanal	4.7	4.6	cis-Linalool oxide (furanoid)	0.32	0.32	0.27
25	γ-elemene	0.3	0.1	erpinolene	0.02	0.18	0.15
26	E-2-dodecanal	1.0	1.0	Linalool	10.96	76.33	87.54
27	E-2-dodecanol	17.8	16.5	trans-Linalool oxide (furanoid)	0.27	tr	tr
28	Tridecanal	0.5	0.6	Camphor	0.86	0.13	0.17
29	E-2-tridecenal	0.1	0.2	Borneol	0.08	0.28	0.34
30	E-nerolidol	0.1	0.2	Menthol	0.14	0.16	0.05
31	Germacrene D	0.3	0.2	Terpinene-4-ol	tr	tr	tr
32	E-2-tridecenol	1.7	1.7	p-Cymen-8-ol	1.36	tr	tr
33	Dodecanoic acid	0.3	0.3	cis-Hex-3-enyl butyrate	tr	tr	0.01
34	2-dodecenol	0.6	0.7	α-Terpineol	0.39	tr	0.05
35	Tetradecanal	2.2	1.9	cis-Dihydrocarvone	0.01	3.21	2.36
36	Cubenol	1.5	0.7	Nerol	1.53	tr	tr
37	Pentadecanal	0.2	0.2	β-Citronellol	0.11	tr	0.52
38	Heptadecane	1.6	1.6	Neral	1.42	0.10	0.13
39	1-dodecanal	1.0	0.7	Carvone	0.10	0.09	0.08
40	Dodecanal	0.4	0.1	Geraniol	tr	tr	tr
41	α-humulene	1.2	1.0	Geranial	0.65	tr	0.03
42	Trans-/?-famesene	0.2	0.2	Anethole	0.05	1.41	0.01
43	1-dodecanol	tr.	0.1	Thymol	0.02	0.99	1.85
44	Oleic acid	2.0	0.9	Carvacrol	1.04	0.11	0.46
45	Phytol	2.8	2.1	δ-Elemene	tr	0.05	0.01
46	n-octadecanol	0.6	0.2	Eugenol	0.09	tr	0.01
47	Limonene	-	tr	Neryl acetate	tr	tr	tr
48	1,8-cineole	-	tr	Geranyl acetate	46.27	2.85	0.83
49	Camphor	-	0.1	β-Cayophyllene	0.02	0.07	0.03
50	Geraniol	-	tr	α-Humulene	0.09	tr	0.02
51	-	-	-	Germacrene-D	0.04	0.19	0.05
52	-	-	-	Eugenyl acetate	tr	tr	0.07

tr: trace (<0.01%), % in (w/w)

Toncer et al. conducted two year trials with *Coriandrum sativum* L to find the most suitable sowing time for essential oil production of coriander in GAP region. They used five different sowing times and the result for highest seed yield, highest plant height and highest essential oil content was obtained from plants sown on 15 November [25].

Yildirim and Gok worked on ecological condition in different sowing time (April 5 and 20, May 5 and 20) to determine the essential oil ratio and components of different varieties of coriander. They found that the essential oil ratio was influenced by the variety (highest 0.45% from Gurbuz variety) and sowing time (highest 0.5% from May 20) [26]. The average yield of essential oil changed from 0.09 to 0.116 L ha^{-1}. The ratio of Linalool changed from 68.3 to 74.8% while Gamma terpinene ratio changed from 7 to 8%.

Zheljazkov et al. studied the effect of cultivars ('Alekseevski' and 'Jantar'), sowing date (24 May and 8 June) and regions (Truro and Canning, Nova Scotia) on seed essential oil composition of *Coriandrum sativum* in Atlantic Canada (Table 5). The result showed that coriander grown in Nova Scotia has low yield. The maximum yield (429 kg ha^{-1}) was achieved during the two summers. The overall essential oil content of coriander seed was high for Truro in 2001 which ranged from 0.8 to 2.2% (v/w) for both cultivars. The 'Alekseevski' performed better than 'Jantar' cultivar in Truro in 2001 while in Canning during 2002 coriander seeded on 8 June did not survive due to the low precipitation in June. Significant interaction was observed between date and cultivar for the Truro location in 2001. The date was the most significant factor for both locations in 2001 and for Canning in 2002 [27]. The overall coriander seed essential oil content was high for both cultivars although the seed yields were low. There was a significant effect of cultivar on essential oil content with 'Jantar' having higher essential oil content than 'Alekseevski' in Truro. The earlier seeding date of both cultivars in both locations resulted in higher essential oil yield relative to the second seeding date in 2001 but in 2002 'Jantar' from Truro had greater oil yield. The result also showed that linalool was major constituent ranging from 64% to 84.6% which is respectively 70.0% and 68.2% in Hungary and India.

4.3 Effect of water stress and chemical compounds

Saxena et al. evaluated twelve coriander (*Coriandrum sativum*) accessions to check the effect of water stress on seed quality parameters such as seed size, test weight, essential oil and total oil. Their result showed considerable genotypic variation as well as considerable interaction of genotype with environment [28]. The terminal water stress showed decrease in quality parameters while mid-term water stress do not have any adverse effect on the studied quality parameters in most of the accessions. Under control (non-stress) condition, the essential oil content ranged between 0.01- 0.51% and total oil varied between 9.25-16.59%. The size of seed ranged from 3.11 mm to 4.38 mm. Ghamarnia and Daichin conducted an experiment to evaluate the effects of different water stress treatments on different coriander. The result showed significant decrease in seed yield, oil yield and water use efficiency based on seed and oil with increasing water stress [29]. The result of treatments T1 (100 %) and T4 (40 %) of crop water requirement in 2011 showed that maximum seed yield was 240 Kg/ha while minimum was 46 Kg/ha and maximum oil yield was 142 Kg/ha while minimum was 9 Kg/ha.

Table 5: Effect of cultivars ('Alekseevski' and 'Jantar') sowing date and regions (Truro and Canning) on seed essential oil composition of *Coriandrum sativum* in Atlantic Canada

Table 5 Effect of cultivars ('Alekseevski' and 'Jantar') sowing date and regions (Truro and Canning) on seed essential oil composition of *Coriandrum sativum* in Atlantic Canada

SI	Constituents	Seeds of different cultivar from different location collected on different seeding date												Commercial oils	
		2001 Truro				2001 Canning				2002 Truro					
		'Alekseevski'		'Jantar'		'Alekseevski'		'Jantar'		'Alekseevski'		'Jantar'		Hungary	India
		24 May	8 June	24 May	8 June	24 May	8 June	24 May	8 June	24 May	8 June	24 May	8 June		
1	α-Pinene	1.8	-	1.8	-	1.8	-	1.8	-	2.1	-	3.1	-	5.8	7.3
2	para-Cymene	1.3	-	0.8	-	1.3	-	0.8	-	0.7	0.8	0.5	0.9	7.0	5.3
3	Limonene	1.0	0.7	1.3	1.1	0.7	1.0	1.0	1.3	1.1	-	1.7	-	2.4	2.7
4	Phellandrene	2.5	-	2.1	-	2.5	-	2.1	-	3.7	-	3.6	-	4.0	1.4
5	Linalool	82	-	79.9	-	82	-	79.9	-	78.1	70.7	76.9	64.6	70.0	68.2
6	Camphor	4.3	3.8	6.2	5.5	3.8	4.3	5.5	6.2	4.2	-	5.5	-	3.0	5.2
7	Linalyl acetate	2.9	-	3.1	-	2.9	-	3.1	-	2.8	2.5	2.5	2.3	-	-
8	Decanal	0.6	0.5	0.9	1.2	0.6	1.2	0.5	0.9	1.4	3.7	1.2	3.7	-	-
9	Geranyl acetate	0.9	-	1.2	-	1.2	-	1.2	-	0.9	-	1.3	-	1.0	3.6
10	Camphene	-	-	-	-	-	-	-	-	-	-	-	-	0.7	1.3
11	Identified (%)	97.1	96.7	97.3	96.9	97	-	97	-	96.2	93.4	96.9	90.8	93.9	95.1

The highest water use efficiency obtained for seed was 4.76 and for oil was 2.79 Kg/ha/mm while minimum for seed was 0.9 and for oil was 0.17 Kg/ha/mm. The maximum seed (240 Kg/ha) and oil yield (140 Kg/ha) in 2012 was achieved by treatment T1 while the minimum seed (36 Kg/ha) and oil yield (5 Kg/ha) was achieved by treatment T4. The highest plant height (42 and 39 cm) and root length (42 and 43 cm) was obtained with treatment T1 and the lowest plant height (18 and 17cm) and root length (15 and 13 cm) was obtained with T4 treatment in 2011 and 2012 respectively. In 2011, the highest (71 g) dry weight was achieved by treatment T1 and lowest (18 g) dry weight was achieved by treatment T4. While in 2012, the highest (73 g) dry weight was achieved by treatment T1 and lowest (19 g) dry weight was achieved by treatment T4.Thus they concluded that coriander is sensitive to water stress.

The total phenolic amount, antioxidant activity in methanolic extracts and fruit essential oil composition of *Coriandrum sativum* under saline conditions was done by Neffati and his co-worker. They found significant reduction in fruit yield and an increase in essential oil with increasing levels of NaCl [30]. There was decrease in fruit yield by 25, 32 and 36% with increasing salinity level to 25, 50 and 75 mM NaCl respectively. The essential oil yield was 0.3 % in control (0 mM NaCl) plant but it increased to 0.53% and 0.55% under 50 and 75 mM NaCl respectively. The amount of linalool and camphor also increased with increasing NaCl concentrations.

Hesami and his co-worker studied the effects of application of salicylic acid, irrigation intervals and their interaction on growth of plant height, number of branches per plant, seed yield and plant biomass. The result showed that extending the irrigation interval from 4 to 8 days decreased the plant height from 44.4 to 41.4 cm while there was no significant effect of salicylic acid application as well as interaction of irrigation interval and salicylic acid application on plant height and number of branches per plant [31]. The highest seed yield of 1440.5 kg ha^{-1} and plant biomass of 2839.7 kg ha^{-1} was produced by application of 0.01 mM salicylic acid at 4 days interval of irrigation.

Bhunia and his co-worker conducted an experiment to study water use, water use efficacy, nitrogen uptake, yield and economics of different cultivars *Coriandrum sativum* under various levels of irrigation and nitrogen. The result showed that with increasing levels of nitrogen there was increase in nitrogen uptake and water consumption as plants extracted more water from lower depth under high level of nitrogen [32]. The highest seed yield of 11.3 q ha^{-1} and stover of 37.38 q ha^{-1} were recorded at higher (60 kg ha^{-1}) dose of nitrogen. Yield and yield attributes also increased with increase in irrigation frequency.

4.4 Effect of different locations and land races

Telci and his co-worker conducted field experiments in two different locations of Turkey on two varieties of *Coriandrum sativum* L. (var. *vulgare Alef.* and var. *microcarpum DC.*) to investigate composition, oil content and yield of the varieties. They reported that seed yield varied between 953-1006 kg/ha and 743-1102 kg/ha in Diyarbakır and Tokat region respectively. They concluded that biomass and seed yields were affected by ecological variation and variety also had effect on oil content i.e. *microcarpum* had higher oil content than *vulgare* [33].

Bandoni et al. analysed the essential oils obtained from fruits of coriander grown in six different zones of Argentina. They identified twenty components which accounted for 96.6-99.70/ of the total oils composition. There were low content of cis- and trans-linalool oxide [34].

Hadian et al. studied the variability in the essential oil content and composition of different Iranian landraces of *Coriandrum sativum* L. cultivated in a common environment. They found considerably differed essential oil production among the local landraces. The oil content of landraces varied from 0.4 % to 1.6 % (w/w) of the dry weight. They identified total thirty-three constituents that represented about 95.7 % to 99.8 % of the composition of essential oils [35]. The linalool was the main component with an average of 80.1%. They concluded that as variation in chemical composition of studied landraces is mainly attributed to their genetic background so selection of landraces with special aroma and/or activities is possible and they further can be subjugated for use in industry or as starting material for use in the breeding programs of the coriander.

Nadjafi and his co-worker studied the termination of irrigation in different phenological stages in different land races of coriander with three irrigation treatments: irrigation terminated at the start of blooming, irrigation terminated at the start of flowering and irrigation terminated at start of seed formation. The result showed that irrigation regimes do not have any significant effect on yield yet irrigation terminated at start of seed formation gave the highest seed yield. The highest see yield (43.06 $g.m^{-2}$) was obtained in irrigation terminated at start of seed formation [36]. There was significant increase in the Linalool content in seeds and essential oil percentage of coriander in water deficit condition. No significant difference was observed in seed yield and essential oil yield between the land races, seed weight per plant, plant height and number of umbellets per umbel but significant difference was observed in essential oil main components between different land races. Apart from this, no significant interaction between land races and irrigation regimes was also observed.

5 Cultivation and Usage of Coriander

5.1 Cultivation

Coriander is a crop of tropical region. For high yield and good quality of coriander, it requires a cool and fairly dry frost free climate mainly at the time of flowering and seedling stages. The coriander requires an optimum temperature of 20-25 ^{0}C for germination and early growth [6]. The seeds have diuretic

and carminative property and are also used in the preparation of many house hold medicines to cure seasonal fever, stomach disorders, bed cold and nausea.

5.2 Medicinal and Pharmacological Properties

Coriander has carminative, stimulant, diuretic and diaphoretic activity so it is used in disorders of respiratory, digestive and urinary systems in the Indian traditional medicine. It also has been indicated for a number of medical problems in Iranian traditional medicine such as convulsion, dyspeptic complaints, insomnia and loss of appetite [37], [38], [39], [40], [41].The chemical compounds of the plant and their pharmacological properties are given in Table 6.

Table 6: Chemical compounds in *Coriandrum sativum* L. and their pharmacological properties

Table 6: Chemical compounds in *Coriandrum sativum* L. and their pharmacological properties

SI	Pharmacological Properties	Chemical Compounds responsible for Pharmacological Properties
1.	Anti-aging	Apigenin, Ascorbic acid (Leaf), Beta-carotene, Chromium (Seed)
2.	Anticancer	Alpha-pinene, Apigenin, Ascorbic acid (Leaf), Beta-carotene, Beta-sistosterol, Caffeic acid, Carvone, Chlorogenic-acid (Plant), Fiber, Geranial, Isoquercitrin, Linoleic acid, Nerol, Niacin, Oleic-acid, Psoralen, Quercetin, Rhamnetin, Rutin, Tannin, Vanillie acid
3.	Anti-diabetic	Ascorbic acid (Leaf), Chlorogenic-acid (Plant), Chromium (Seed), Copper, Fructose, Magnesium, Niacin, Pectin, Protocatechuic acid, Rutin, Zinc
4.	Anti-inflammatory	Alpha-pinene, Apigenin, Ascorbic acid (Leaf), Beta-pinene (Fruit), Beta-sistosterol, Borneol, Caryophyllene, Copper, Limone, Linoleic acid, Magnesium, Myristicin, Oleic-acid, Quercetin, Protocatechuic acid, Rhamnetin, Rutin, Sabinene, Umbelliferone, Vanillie acid
5.	Antimicrobial	Acetic acid (Fruit), Alpha-phellandrene, Alpha-pinene, Alpha-terpinene, Alpha-terpineol, Angelicin, Apigenin, Ascorbic acid (Leaf), Beta-sistosterol, Borneol, Bornyl-acetate, Caffeic acid, Caryophyllene, Chlorogenic-acid (Plant), Cis-ocimene (Fruit), Citronellol, Dipentene, Geranial, Isoquercitrin, Limone, Myrcene, Nerol, Nerolidol, p-cymene, p-hydroxy-benzoicacid, Quercetin, Pectin, Rhamnetin, Rutin, Sabinene, Tannin, Terpine-0l, Umbelliferone, Zinc
6.	Antioxidant	Apigenin, Ascorbic acid (Leaf), Beta-carotene, Caffeic acid, Camphene, Gamma-Terpinene, Isoquercitrin, Myristic-acid, Myristicin, p-hydroxy-benzoic acid, Palmitic acid, Protocatechuic acid, Terpinen-4-0l, Terpinolene, Trans-anethole
7.	Antitumor	Angelicin, Apigenin, Ascorbic acid (Leaf), Beta-carotene, Beta-sistosterol, Caffeic acid, Caryophyllene, Chlorogenic-acid (Plant), Fiber, Geranial, Isoquercitrin, Limone, Myrcene, p-hydroxy-benzoic acid, Psoralen, Quercetin, Pectin, Protocatechuic acid,Rutin, Tannin, Umbelliferone, Vanillie acid
8.	Antiulcer	Ascorbic acid (Leaf), Beta-carotene, Caryophyllene, Chlorogenic-acid (Plant), Elemol, Fiber, Pectin, Sabinene, Tannin,Terpinen-4-0l, Zinc

5.3 Culinary utility

Coriander is commonly used as a flavouring substance. The stems, leaves and fruits have a pleasant aromatic odour. The entire young plant of the coriander is used in preparing chutneys and the leaves are also used for flavouring sauces, soups and curries; coriander oil and oleoresin are primarily used in seasonings for sausages and other meat products. They are also used in baked goods, condiments, chewing gums and in curry mix [6].

6 Conclusions

There is a great influence of the environment on the yield of the coriander herb, seed and oil. The essential oil is greatly influenced by growing region, stages of maturity and their interaction, growing seasons, water stress and varieties of the coriander. At full maturity main fatty acids of coriander grown in Oued Beja were petroselinic acid (80.90 ± 9.45%), followed by oleic (14.79 ± 2.25%), palmitic (3.50 ± 0.65%) and stearic (0.49 ± 0.09%) acids. While fruits cultivated in Menzel Temime at full maturity showed that, petroselinic acid is the main compound (80.86 ± 7.23%) followed by oleic (14.83 ± 2.05%), palmitic (3.27 ± 3.12%) and stearic (0.31 ± 0.05%) acids. Considering growing seasons the plants sown on November 15 in Diyarbakir during 1996-97 has highest seed yield of 66.77 kg/da as well as highest essential oil content of 0.34 % in comparison to the plants sown on December 15, January 15, February 15 and March 15. Water stress also effect the seed and oil yield and water use efficacies based on seed and oil yield. There is significant decrease in these evaluated parameters with increasing water stress. In comparison to control treatment (100%), the seed and oil yield for different treatments with water stress of 40, 60 and 80% were respectively (83, 95), (67, 82) and (24, 44)%. This shows that coriander is sensitive to water stress. So it is required to take into consideration the effects of growing region, maturity process, season, variety and water stress; as these factors affect the composition, quality and yield of essential oil. Such environmental variations causes change in the content and composition of essential oil, seed and coriander herb.

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REFERENCES

[1] Evans, W.C.; 2002. Trease and Evans Pharmacognocy. Fifteenth International edition. WB Saunders, Edinburgh, London, New York; pp. 262.

[2] Gruenwalded, J.; P.D.R.H.M.; 2004. Physicians' desk reference for herbal medicine. Medical Economics N.J.; 08, pp 378-384.

[3] Pathak, N.L.; Kasture, S.B.; Bhatt, N.M.; Rathod, J.D.; 2011. Phytopharmacological Properties of *Coriander sativum* as a Potential Medicinal Tree: An Overview. Journal of Applied Pharmaceutical Science 01 (04), pp 20-25.

[4] Diederichsen, A.; 1962. Promoting the conservation and use of underutilized and neglected crops Coriander (*Coriandrum sativum* L), 1st edition International Plant Genetic Resources Institute IPGRI Italy; pp.1-82.

[5] Carrubba, A.; Torre, R.; Di Prima, A.; Saiano, F.; Alonzo, G.; 2002. Statistical analysis on the essential oil of Italian coriander (*Coriandrum sativum* L.) fruits of different ages and origins. Journal of Essential Oil Research; 14 (6), pp 389–396.

[6] Rajeshwari, U.; Andallu, B.; 2011. Medicinal benefits of coriander (*Coriandrum sativum* L). Spatula D.D.1 (1), pp 51-58.

[7] Purseglove, J.W.; Brown, E.G.; Green, C.L.; Robbins, S.R.J.; 1981. Spices. Longman, London and New York, II; pp 736-788.

[8] Singh, V.P.; Ramanujam, S.; 1973. Expression of andromonecy in coriander, *Coriandrum sativum* L. Euphytica; 22 (1), pp 181-188.

[9] Verma, A.; Pandeya, S.N.; Yadav, S.K.; Singh, S.; Soni, P.; 2011. A Review on *Coriandrum sativum* (Linn.): An Ayurvedic Medicinal Herb of Happiness. Journal of Advances in Pharmacy and Healthcare Research; 1 (3), pp 28-48.

[10] British pharmacopoeia; 2003. Introduction General Notices Monographs, medicinal and Pharmaceutical. British pharmacopeia commission, London; 1 (A-I), pp 542-543.

[11] Monograph of the fifth edition of European Pharmacopoeia 2004 Stationary office on behalf of the medicines and healthcare products Regulatory agency (MHRA). London: The stationary office, 2008; pp 617 .

[12] USP 27-The United States pharmacopoeia & NF 22; 2004. The National formulary; Asian edition; by authority of the United States pharmacopial convention, Inc., Washington; pp 2853.

[13] Handa, S.S.; Kaul, M.K.; 1996. Supplement to cultivation and utilization of medicinal plant. National Institute Of science communication, Regional research laboratory (CSIR), Jammu-Tavi, India; pp 818.

[14] Sharma, M.M.; Sharma, R.K.; 1999. Coriander Handbook of herbs and spices. Woodhead publishing limited; pp 1-6.

[15] Parthasarathy, V.A.; Chempakam, B.; Zachariah, T.J.; 2008. Coriander in Chemistry of Spices. CAB International UK; pp 190-206.

[16] Ramezani, S.; Rahamanian, M.; Jahanbin, R.; Mohajeri, F.; Rezaei, M.R.; Solaimani, B.; 2009. Diurnal Changes Essential oil content of Coriander (*Coriandrum sativum* L.) Aerial parts from Iran. Research Journal of Biological Sciences; 4 (3), pp 277-281.

[17] Msaada, K.; Hosni, K.; Taarit, M.B.; Chahed, T.; Kchouk, M.E.; Marzouk, B.; 2007. Changes on essential oil composition of coriander (*Coriandrum sativum* L.*)* fruits during three stages of maturity. Food Chemistry; 102 (4), pp 1131–1134.

[18] Msaada, K.; Hosni, K.; Taarit, M.B.; Hammami, M.; Marzouk, B.; 2009. Effects of growing region and maturity stages on oil yield and fatty acid composition of coriander (*Coriandrum sativum* L.) fruit. Scientia Horticulturae; 120, pp 525–531.

[19] Msaada, K.; Taarit, M.B.; Hosni, K.; Hammami, M.; Marzouk, B.; 2009. Regional and maturational effects on essential oils yields and composition of coriander (*Coriandrum sativum* L.) fruits. Scientia Horticulturae; 122, pp 116–124.

[20] Msaada, K.; Hosni, K.; Taarit, M.B.; Ouchikh, O.; Marzouk, B.; 2009. Variations In Essential Oil Composition During Maturation Of Coriander (*Coriandrum Sativum* L.) Fruits. Journal of Food Biochemistry; 33 (5), pp 603–612.

[21] Ramezani, S.; Rasouli, F.; Solaimani, B.; 2009. Changes in Essential Oil Content of Coriander (*Coriandrum sativum* L.) Aerial Parts during Four Phonological Stages in Iran. Journal of Essential Oil Bearing Plants; 12 (6), pp 683–689.

[22] Wierdak, R.N.; 2013. Essential Oil Composition of the Coriander *(Coriandrum sativum* L.) Herb Depending On the Development Stage. Acta Agrobotanica; 66 (1), pp 53-60.

[23] Ebrahimi, S.N.; Hadian, J.; Ranjbar, H.; 2010. Essential oil compositions of different accessions of *Coriandrum sativum* L. from Iran. Natural product research; 24 (14), pp 1287–1294.

[24] Arganosa, G.C.; Sosulski, F.W.; Slikard, A.E.; 1996. Seed Yields and Essential Oil of Northern-Grown Coriander (*Coriandrum sativum* L.). Journal of Herbs, Spices & Medicinal Plants**;** 6 (2), pp 23-32.

[25] Toncer, O.; Tansi, S.; Kizil, S.; 1998. The Effect of Different Sowing Time on Essential Oil of Coriander in Gap Region. Anadolu, Journal of AARI; 8 (2), pp 101–105.

[26] Yildirim, B.; Gok, N.; 2012. Effect of Sowing Date

and Varieties on Essential Oil Ratio and Essential Oil Components of Coriander *(Coriandrum sativum* L.) in Van Ecological Condition. Journal of Animal and Veterinary Advances; 11 (11), pp 1925-1929.

[27] Zheljazkov, V.D.; Pickett, K.M.; Caldwell, C.D.; Pincock, J.A.; Roberts, J.C.; Mapplebeck, L.; 2008. Cultivar and sowing date effects on seed yield and oil composition of coriander in Atlantic Canada. Industrial crops and products; 28, pp 88–94.

[28] Saxena, S.N.; Kakani, R.K.; Saxena, R.; Anwer, M.M.; 2010. Effect of water stress on seed quality of coriander (*Coriandrum sativum* L.). Journal of Spices and Aromatic Crops; 19 (1&2), pp 53–56.

[29] Ghamarnia, H.; Daichin, S.; 2013. Effect of different water stress regimes on different Coriander (*Coriander sativum* L.) Parameters in a semi-arid climate. International Journal of Agronomy and Plant Production; 4 (4), pp 822-832.

[30] Neffati, M.; Sriti, J.; Hamdaoui, G.; Kchouk, M.E.; Marzouk, B.; 2011. Salinity impact on fruit yield, essential oil composition and antioxidant activities of *Coriandrum sativum* fruit extracts. Food Chemistry 124, pp 221–225.

[31] Hesami, S.; Nabizadeh, E.; Rahimi, A.; Rokhzadi, A.; 2012. Effects of salicylic acid levels and irrigation intervals on growth and yield of coriander (*Coriandrum sativum*) in field conditions. Environmental and Experimental Biology 10, pp 113–116.

[32] Bhunia, S.R.; Ratnoo, S.D.; Kumawat, S.M.; 2009. Effect of irrigation and nitrogen on water use, moisture extraction pattern, nitrogen uptake and yield of coriander (*Coriandrum sativum* L.) in north-western irrigated plains of Rajasthan. Journal of Spices and Aromatic Crops 18 (2), pp 88–91.

[33] Telci, I.; Toncer, O.G.; Sahbaz, N.; 2013. Yield, Essential Oil Content and Composition of *Coriandrum sativum* Varieties (var. *vulgare Alef* and var. *microcarpum DC*.) Grown in Two Different Locations. Journal of Essential Oil Research 18 (2), pp 189-193.

[34] Bandoni, A.L.; Mizrahi, I.; Juarez, M.A.; 1998. Composition and Quality of the Essential Oil of Coriander (*Coriandrum sativum* L.) from Argentina. Journal of Essential Oil Research 10 (5), pp 581-584.

[35] Hadian, J.; Ebrahimi, S.N.; Akramian, M.; Mumivand, H.; 2012. Variability in the Essential Oil Content and Composition of Iranian Landraces of Coriander (*Coriandrum sativum* L.), Cultivated in a Common Environment. Journal of Essential Oil Bearing Plants; 15 (1), pp 89-96.

[36] Nadjafi, F.; Damghani, A.M.M.; Ebrahimi, S.N.; 2009. Effect of Irrigation Regimes on Yield, Yield components, Content and Composition of the Essential Oil of Four Iranian Land Races of Coriander (*Coriandrum sativum*). Journal of Essential Oil Bearing Plants; 12 (3), pp 300-309.

[37] Benjumea, D.; Abdala, S.; Hernandez-L.F.; Perez, P.P.; Martin, H.D.; 2005. Diuretic activity of *Artemisia thuscula*, an endemic canary species. Journal of Ethnopharmacology; 100 (1-2), pp 205–209.

[38] Maghrani, M.; Zeggwagh, N.A.; Haloui, M.; Eddouks, M; 2005.. Acute diuretic effect of aqueous extract of *Retama raetam* in normal rats. Journal of Ethnopharmacology; 99 (1), pp 31-35.

[39] Mir, H.H.; 1992. *Coriandrum sativum* In: Application of Plants in Prevention and Treatment of Illnesses. Islamic Cultural Publication, Tehran; 1, pp 247-252.

[40] Zargari, A.; 1991. *Coriandrum sativum* L. In. Herbal Medicine; 1, pp 586–590.

[41] Duke, J.A.; 2002. Handbook of Medicinal Herbs, second ed., CRC Press LLC, Boca Raton, Florida, USA; pp 222-223.