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Unleashing the Exploitation of Coriander (*Coriander sativum* L.) for Biological, Industrial and Pharmaceutical Applications

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Coriander (*Coriander sativum* L.) is an annual spice, herb and medicinal plant belonging to the family Umbelliferae. It has been used throughout the world since ancient times for various purposes due to its exceptional phytochemicals that are not common in other plants. Essential oils and fatty acids obtained from its dried fruit can be applied commercially in pharmaceutical, food and beverages, plastic, cosmetic, fragrance and detergent industries. Likewise, it has insecticidal activity of stored products, reduces heavy metal contamination, natural antibiotic poultry feed additive and efficient broiler growth promoter. It is also considered as a good melliferous plant due to its considerable nectar production. Though coriander is a promising versatile plant, the information and knowledge's concerning the plant and its potential applications are scatterdly available. This hinders the proper exploitation of the coriander potentials. For contributing in addressing the existing gap, we conducted a systematic and comprehensive review through searching relevant papers in various databases. Therefore, this publication provides plenty of information summarized from over 594 germplasm obtained from over 53 countries. Moreover, the paper intends to summarize and document the past and current evidences to contribute for coriander cultivation, utilization and perhaps to create further interest in research.

Keywords: Coriander, essential and fatty oil, linalool, medicinal, petroselinic acid, phytonutrients, spice and herb

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INTRODUCTION

Coriander (*Coriandrum sativum* L.) is an annual plant that belongs to the family Umbelliferae possessing spice, aromatic, nutritional as well as medicinal properties (Diederichsen and Hammer, 2003; Khan *et al*., 2014; Laribi*et al*., 2015; Mandal and Mandal, 2015; McAusland *et al*., 2020). The origin of coriander is uncertain, the area suggested by most authors being the Near East (Diederichsen, 1996). Some authors suggested central Asia and Mediterranean countries (Vaidya *et al*. 2000; Meena *et al*., 2014; Laribi*et al*., 2015).Balasubramanian*et al*. (2011) stated that coriander is native to southern Europe, North Africa and southwestern Asia. Major producers are India, Morocco, Canada, Pakistan, Romania, Ukrain, Russia (Priyadarshi *et al*., 2016), United States, Canada, Argentina and Mexico (Sharma *et al*., 2014).

Coriander is one of the important and earliest seed spices crop known to mankind (Meena *et al*., 2014), which can be dated back to the history of Queen of Sheba who visited king Solomon mentioned in the Holy Bible. The aromas and flavors have for many years attracted the attention of man is due to the presence of pleasant aromatic odoror essential oil rich in linalool found in the stem, leaves and fruits of coriander (Taneva *et al*., 2016; Beyzi *et al*., 2017). It can be used directly or indirectly for diverse purposes. It can be used as a spice in culinary (Diederichsen, 1996; Mengesha *et al*., 2010; Geremew *et al*., 2015), medicine (Delaquis *et al*., 2002; Kubo *et al*., 2004; Nadeem *et al*., 2013; Singletary, 2016), food industry (Bhat *et al*., 2014; Pacheco *et al*., 2016; Prachayasittikul *et al*., 2018) in perfumery, beverage and pharmaceuticals industries (Priyadarshi et al., 2016).

Coriander is also a good melliferous plant and studies indicated that coriander can be used for honey bee production (Bhalchandra *et al*., 2014; Abou-Shaara, 2015).Furthermore, leaves and fruits of coriander have significant quantities of protein, fat, carbohydrate, calcium, phosphorous, sodium, zinc, carotene, thiamine, riboflavin, niacin, tryptophase, vitamin B6, Folate, vitamin A, vitamin D, vitamin B-12, vitamin C and vitamin E (Nimish *et al*., 2011; Bhat *et al*., 2014; USDA, 2016). On the other hand, coriander fruit contain significant amount of fatty oil rich in petroselinic acid, linoleic acid, oleic acid, palmitic acid and stearic acid (Beyzi *et al*., 2017). Additionally, the remaining oil cake contains protein, fat, nitrogen free extract, cellulose and ash that can potentially be used as animal feed (Ramadan and Morsel, 2002; Kadiri *et al*., 2017). Despite coriander is a promising spice, herb, aromatic, medicinal and industrial application potentials; it is considered as underutilized and neglected crop (Beemnet and Getinet, 2010; Kalidasu *et al*., 2015). Therefore, this paper was intended to provide information about the overall characteristics and potential uses of coriander and thereby to contribute for its cultivation and utilization.

Taxonomy and Classification of Coriander

Coriander (*Coriandrum sativum* L.) is a dicotyledonous (Singh *et al*., 2017) multipurpose herbaceous annual plant having 2n=22 chromosomes (Arif *et al*., 2014; Song *et al*., 2020) with cross-pollination as mode of reproduction (Singh *et al*., 2017) belongs to the family Umbelliferae (Khan *et al*., 2014).The family Umbelliferae includes a number of economically important crops such as anise (*Pumpinella anisum* L.), caraway (C*arum carvi* L.), fennel (*Fennuclum vulgarae* L.), and parsley (*Petroselinum sativum* L.) (Janick, 1972). Umbellifers are herbs, rarely shrubs or small trees with annual, biennial and perennial growth characteristics, with hollow or pithy stem, alternate or rarely opposite leaves, and usually pinnately or alternatively divided blade (Hedburg and Hedburg, 2003).

The Umbelliferae family consists of about 450 genera and approximately 3550 species (Hedburg and Hedburg, 2003). The genus *Coriandrum* to which coriander belongs contains only 2 species. One is the cultivated plant *C. sativum* and the other is a wild species *C. tordylium* (Hedge and Lamond, 1972).The closest genus to *Coriandrum* is *Bifora* (Rickett, 1969). This genus has three different species namely *B. americana, B. radians, and B. testiculata. B. radians* are morphologically similar to coriander; however, the fruits have a different shape and fatty oil, and do not contain essential oils (Diederichsen, 1996). The green plant of *B. radians* has a very strong smell, which is similar to coriander; however, it is not used as a cultivated plant because of its toxicity to cereals with which it grows and due to its unpleasant smell, which is offensive to consumers (Diederichsen, 1996). There are also perennial plants under the family of umbeliferae with the chromosome numbers (2n=22) are similar in most of the species including coriander, but different number (2n=20) was reported only for *B. radians* (Goldblatt and Johnson, 1994), which might further explain difficulties in crossing coriander and *Bifora* species.

Coriander leaves are small herb having many branches and sub-branches (Khan et al., 2014). New leaves are oval but aerial leaves are elongated (Kassahun, 2018; Diederichsen, 1996; Hedburg and Hedburg, 2003). Flowers are white, having slightly brinjal like shades while fruit are round in shape (Jansen, 1981; Rubatzskey *et al*., 1999; Beemnet and Getinet, 2010; Kassahun *et al*., 2018). Macroscopic characteristic of fruit is globular, mericarps usually united by their margins forming a cremocarp about 2-4 mm in diameter, uniformly brownish-yellow or brown, glabrous, sometimes crowned by then remains of sepals and styles, primary ridges 10, wavy and slightly inconspicuous secondary ridges 8 and straight with aromatic odour (Diederichsen, 1996; Khan *et al*., 2014; Bairwa *et al*., 2017).

Origin and Distribution

Coriander has been known since very ancient times. Coriander seeds have been found in Egyptian tombs of the twenty-first dynasty who ruled Egypt some 3000 years ago (Holland *et al*., 1991). The origin of coriander is uncertain, the area suggested by most authors being the Near East (Diederichsen, 1996; Arif *et al*., 2014). Some authors Vavilov (1992) and Mengesha (2010) for example suggested a much wider origin for coriander which includes central Asia, the Near East and Abyssinia. The others mention central Asia and Mediterranean countries (Vaidya *et al*. 2000; Meena *et al*., 2014; Laribi*et al*., 2015). Balasubramanian *et al*. (2011) stated coriander is native to southern Europe and North Africa to southwestern Asia. Coriander is now reported to be cultivated in Argentina, Brazil, India, Italy, Linia, Mexico, Morocco, the Netherlands

and Paraguay, Peru, Poland, Rumania, Somalia, Spain, USA, former Soviet Union, north African countries and Yugoslavia (Rubatzskey *et al*., 1999; Khan *et al*., 2014). Cultivation of coriander over many continents indicates its wider adaptability to different agro ecological conditions and economic significance of the crop in diversified societies of the world. The major producers are India, Morocco, Canada, Pakistan, Romania, Ukrain, Russia (Priyadarshi *et al*., 2016), United States, Canada, Argentina and Mexico, and more than 80% of total world production of coriander seeds is from India (Sharma *et al*., 2014).

Ecology and Cultivation of Coriander

Coriander can be grown under a wide range of conditions, from temperate to sub tropical climates (UNIDO/FAO, 2005). Coriander is reported to be grown successfully in most soil types provided that there is sufficient moisture; however, it thrives best on medium to heavy soil and locations with good drainage and well-distributed moisture (Macvey *et al*., 1991; Verma *et al*., 2011). Suitable pH ranges from 4.5 to 8.0, with an optimum of 6.3 (Blade *et al*., 2016). Although the crop is heat loving, a temperature range 20-25^{o}C is optimum for germination and early growth of coriander is (Sharma and Sharma, 2004), 10-30^{o}C provides optimum growing conditions for foliage production (Anon., 2000) and growing temperature of 18°C is optimum for coriander seed production (Blade *etal*., 2016).

Coriander is propagated by seed and usually sown in rows at 2 cm depth, with spacing of 15-30 cm between plants after thinning and 25-75 cm between rows (Jan *et al*., 2011; Katiyar *et al*., 2014; Sharma *et al*., 2016). The seeding rate is 10-40 kg/ha depending of row and broadcasting method of sowing (Tindall, 1983; Kizil, 2002; Moniruzzaman *et al*., 2013). Thinning to a permanent spacing is carried out when the seedling reaches a height of about 8 cm (Mackvey *et al*., 1991). In regions with warmer climates, the best sowing time for rain fed crops is at the beginning of the rainy season (Tindall, 1983).Additional plant irrigation is necessary in such regions during different crop growth stages. The requirement of water by the crop depends predominantly on the edaphoclimatic conditions (Angeli *et al*., 2016); however, the uniform and continuous supply of water is desirable due to its relatively shallow root system (Smith *et al*., 2011), and care must be taken to avoid saturated conditions that promote disease.

Application of 90-120 Kg N/ha was found to improve the yield of coriander (Sharma*et al*., 2016); however, Pacheco *et al*. (2016) reportednumber of leaves and antioxidant activity of coriander are not affected by the concentration of fertilizer. Szempliński and Nowak (2015) also reported chemical composition of coriander fruits was more strongly determined by the weather conditions during the growing season than by nitrogen fertilization.

Leaf number, seed yield, essential oil and fatty oil contents of coriander evaluated globally obtained from over 53 countries considering 594 germplasm ranged from 1 to 70 per plant, 160 to 4510 kg/ha, 0.03 to 2.70% and 4.9 to 30.15%, respectively (Table 1). Variation in agronomic and chemical characteristics of coriander can be due to variation in the region, climate and soil conditions in which the plants were grown (Beyzi *et al*., 2017), environmental conditions (Piccaglia and Marotti, 1993; Fuente *et al*, 2003), cultural practices (Kaya *et al*., 2000) and genetic structure (Kassahun *et al*, 2011; Small, 1997; Diederichsen, 1996). As statedfor other seed crops, the increase in harvest index is relatedto the occurrence of more appropriate environmental conditions (Kang *et al*., 2002), which cause an enhancement in both seedyield and plant biomass. It may be concluded that a close associationexists between the productivity levels of coriander and itsaboveground biomass and oil yield.

This association appears to also be linkedto the overall superior vigor of plants thus the higher leaf, seed, essential and fatty oil yield. Hence, agronomic practices, which favor vigorous development, have a meaningful impact on the yield and quality of coriander oil. Comparing different germplasm sources, variations have been noted between the odor characters of oils from different types and sources of the coriander (Telci*et al*., 2006). The oil content in coriander varies with different varieties: small-fruit types contain higher oil content than large-fruited types (Kassahun *et al*., 2013). The oil content of the large-fruit types ranges between 0.03-0.35%, while the oil of small-fruit types range between 0.8-2.7% (Purseglove *et al*., 1981; Small, 1997). Comparing different sources of plants, it was reported that European coriander oils generally have superior quality to Moroccan and Indian (Jansen, 1981). Frost also reduces the yield of coriander very much (Nhed *et al*., 2015) and identifying conducive cultivation season that escapes frost occurrence at critical growth periods is important. Seed treatment after harvest is important to protect loses caused by phatogeneous Chalcid fly (*Systole albipennis* Walk) through six hour fumigation using methyl bromide (Jansen, 1981).

Table 1. Economic traits including leaf number, fruit yield, essential oil and fatty oil content of coriander germplasm at global level

Variables	Range of values	References	Evaluated number of germplasm	Summary of germplasm sources by country
Basal leaf number/plant	1-70	4-21 (Beemnet and Getinet, 2010; n=49), 1->10 (Diedrichsen, 1996; n=237), 2-70 (Lopez *et al*., 2006; n=60), 3-23.2 (Arif *et al*., 2014; n=69)	415	Afghanistan (3), Algeria (4), Armenia (8), Austria (1), Azerbaijan (3), Belorussia (1), Bhutan (7), Bulgaria (1), Canada (2), Chile(3), China(1), Columbia (1), Cuba (2),Czechoslovakia/former (1), Czech Republic(1), Daghestan (4), Egypt (3), Ethiopia (135), France(2), Germany(12), Georgia(5), Hungary (1), India(31), Iraq (2), Iran (3), Italy (2), Jemen (2), Kasachstan (2), Kazakhstan(1), Kirgysia (1), Libya (4), Mexico(7), Mongolia (1), Netherlands(3), Oman(12), Pakistan(75), Poland(1), Romania(2), Russian Federation(5), Somalia (1), Spain (1), Sudan(6), Syria(18), Tadjikistan (2), Tajikistan(2), Tunisia (6), Turkey(1), Ukraine (1), United Kingdom(1), United States of America(5), Uzbekistan (1), Unknown origin (193)
Fruit yield (kg/ha)	160-4510	910-3100 (Beemnet and Getinet, 2010; n=49), 160.4-3045.8 (Geremew *et al*., 2015; n=81), Jansen (1981), Tindall (1983), 126.11-162.22 (Ali *et al*., 2015), 934.8-1036 (Jan *et al*., 2011), 1620-4510 (Meena *et al*., 2014; n=24),	158	
Essential oil content (%)	0.03-2.70	0.07-2.24 (Lopez *et al*., 2006; n=60), 0.23-1.02 (Beemnet and Getinet, 2010; n=49), 0.45-0.9 (Geremew *et al*., 2015; n=81), 0.03-2.6 (Nadeem *et al*., 2013), 0.03-2.7 (Purseglove *et al*., 1981), 0.03-2.6 (Diedrichsen,1996; n=237)	428	
Fatty oil content%	4.9-30.15	4.9-30.15 (Lopez *et al*., 2006; n=60), 7.23-18.6 (Beemnet and Getinet, 2010; n=49), 4.85-11.9(Geremew *et al*., 2015; n=81), 9.9-27.7 (Diedrichsen,1996; n=76)	266	

Major phytochemical compositions of coriander

Nutritional

Coriander nutrition is basically due to its green leaves and dried fruits (Figure 1B and H). Like all other green leafy vegetables, its leaves are a rich source of vitamins, minerals and iron. Its leaves contain high amount of vitamin A (β-carotene) and vitamin C. The green herbs contain vitamin C upto 160 mg/100 g and vitamin A upto 12 mg/100 g (Girenko, 1982). It is very low in saturated fat and cholesterol and a very good source of thiamine, zinc and dietary fiber. Green coriander contains up to 87.9% water (Peter, 2004).Likewise, Pilley 2017 reported that coriander leaf have protein 12.37 g and 2.13 g, total lipid (fat) 17.77 g and 0.52 g, carbohydrate 54.99 g and 3.6 g, fiber 41.9 g and 2.8 g, calcium 709 mg, iron 16.32 mg, phosphorus 409 mg, magnesium 330 mg, potassium 1267mg, sodium 35 mg, zinc 4.70 mg, vitamin C 21 mg and 27 mg, thiamin 0.239 mg and 0.067 mg, riboflavin 0.290 mg and 0.16 mg, niacin 2.130 mg and 1.11 mg, respectively. Coriander dried fruit has got several nutritional constitutes of energy, protein, carbohydrate, minerals, vitamins, minerals (g), starch, pentosans, sugar, and crud fiber (Table 2).

Table 2. Nutritional composition of coriander fruit

Composition	References						
	USDA (2016)	Diedrichsen (1996)	Rajeshwari and Andallu, (2011)	National Nutrition Program (2012)	Verma *et al*. (2011)	Peter (2004)	Nimish*et al* (2011)
Water (g)	7.30	11.37	7.3	11.2	-	-	8.9
Food energy (kcal)	279	-	279	-	23	-	-
Protein (g)	21.93	11.49	21.83	14.4	2	-	-
Fat (g)	4.78	19.15	4.76	16.1	0.5	20	
Ash (g)	-	-	14.02	-	-	-	2.0

Table 2. continues

Carbohydrate (mg)	52.10	-	-	21.6	-	-	-
Calcium	1246	-	-	-	-	-	-
Magnisium	694	-	-	-	-	-	-
Phosphorous (mg)	481	-	-	-	-	-	-
Sodium (mg)	211	-	-	-	-	-	-
Potassium (mg)	4466	-	-	-	-	-	-
Iron (mg)	42.46	-	-	-	-	-	-
Zinc	4.72	-	-	-	-	-	-
Vit-C (mg)	566.7	-	566.7	-	27	-	-
Vitamin B6	0.610	-	-	-	-	-	-
Foliates (µg)	274	-	-	-	-	-	-
Nayacin (mg)	10.707	-	-	-	-	-	-
Pantothenic (mg)	-	-	-	-	-	-	-
acid pyridoxine (mg)	-	-	-	-	-	-	-
riboflavin (mg)	1.500	-	-	-	-	-	-
thiamin (mg)	1.252	-	-	-	-	-	-
vitaminA (IU)	5850	-	-	-	-	-	-
vitamin E (mg)	1.03	-	-	-	-	-	-
vitamin K	1359.5 µg	-	-	-	-	-	-
Crude fiber (g)	10.4	28.43	-	-	-	30	-
Starch (g)	-	10.53	-	-	-	11	-
Pentosans (g)	-	10.29	-	-	-	-	-
Sugar (g)	7.27	1.92	52.10		4	-	-
Minerals (g)	-	4.98	4.98	4.4	-	-	-

Essential oil

Essential oils are colorless or slightly yellow complex mixtures of odorous and volatile compounds which are found in plants in the subcuticular space of glandular hairs, in cell organelles, in execratory cavities and cannals (Rehman *et al*., 2016). Coriander seed oil is included among the major essential oils in the world market (ITC, 2016). The major constituents of coriander fruit essential oils are linalool (19.8-91.77%), α-pinene (0.09-10.7%), γ-terpinene (0.2-9%), geranyl acetate (1.44-8.59%), camphor (2.01-5.67%) terpinolene (0.14-5.85%) and Geraniol (1.84-2.6%) (Table 3). The variation in composition of the volatile oil, which determines the odor and flavor character of coriander, is influenced by the genetic origin and onthogenesis.

Misharina (2001) found the coriander seed in Russia has more concentration of camphor (69.75%) and less concentration of linalool (2.96%), while seed from New Zealand have camphor (5.1%) and linalool (65.8%) (Smallfield *et al*., 2001). On the other hand, Bhuiya *et al*. (2009) and Msaada *et al*. (2009) indicated that the chemical composition of essential oil undergoes changes during ontogenesis, which affects the aroma of the plant, and thus the coriander fruit aroma is completely different from the aroma of the herb (Neffati and Marzouk, 2008). Fan and Sokorai (2002) also reported that the chemical composition of coriander fruits and fresh cilantro was affected by degree of maturity. In the unripe fruit (Figure 1G) and leaves (Figure 1A), aliphatic aldehydes predominate in the steam volatile oil and are responsible for the peculiar, fetid-like aroma that is not liked by most consumers (Bhuiyan *et al*., 2009). Immature fruits and leaves have an unpleasant odour called a “stink bug smell” which is due to trans-tridecen contained in the oil (Mandal and Mandal, 2015). However, upon ripening, the fruits acquire a more pleasant and sweet odor together with the major constituent of the volatile oil.

Table 3: Major constituents of coriander fruit essential oil

Compounds	Reported values							
	Lopez *et al*. (2008)	Hanafi *et al*. (2014)	Diedrichsen (1996, n=237)	Shahwar *et al*. (2012)	Kiralan *et al*. (2009; n=3)	Nadeem *et al*. (2013)	Beyzi *et al*. (2017; n=4)	Eljazi *et al*. (2018)
Linalool	71.21-83.15	70.43	19.8-82.0	55.49	69.31-82.65	60-80	89.44-91.77	79.22
α-pinene	3.71-9.14	3.96	10.7	7.14	1.43-3.6	0.2-8.5	0.09-0.47	2.32
ϒ-terpinene	2.01-3.84	3.5	9	7.47	0.2-0.22	1-8	0.7-1.99	6.26
geranyl acetate	3.52-8.59	2.25	4	4.24	1.44-2.77	0.1-4.7	1.88-2.47	1.75
camphor	2.5-5.67	4.33	3	5.59	3.18-4.03	0.9-4.9	2.01-2.83	2.63
terpinolene	2.22-5.85	0.45	-	-	0.37-0.43	<0.5	0.14-0.2	0.43
geraniol	-	-	1.9	2.23	2.37-2.6	1.2-4.6	1.84-2.37	-

Fatty oil

Solvent extracted coriander fruit commonly yields from 4.9 to 30.15% fatty oil (Table 1). The remaining oil cake usually contains 21% water, 3% protein, 4% fat, 21% nitrogen free extract, 4% cellulose and 7% ash (Ramadan and Morsel, 2002). The fatty oil of the fruit contains 54.6-77.1% petroselinic acid, 14.61-17.37% linoleic acid, 2.94-10.57% oleic acid, 3.74-5.61% palmitic acid and 0.8-5.45 stearic acid (Table 4). Due to the presence of high amount of petroselinic acid and its unique unsaturation characteristics rare among octadecenoic acids offers the opportunity to produce chemical derivatives different from those that can be produced from other oils (Placek, 1963). And hence, the fatty acid of coriander is of interest in industrial applications.

Table 4: Major constituents of coriander fruit fatty acid

Fatty acids	Reported values					
	Lopez *et al*. (2008, n=60)	Diedrichsen (1996; n=76)	Ramadan and Morsel (2002)	Kiralan *et al*. (2009; n=3)	EFSA (2013)	Beyzi *et a*l. (2017; n=4)
Petroselenic	66.75-73.14	54.6-75.7	65.7	72.32-77.1	62.08-71.4	79.78-81.96
Linoleic	14.61-16.51	16.6	16.7	14.76-17.37	13.82-17.3	13.51-14.72
Oleic	8.87-10.57	7.5	7.85	2.94-3.44	9.01-13.29	-
Palmitic	4.59-5.61	3.8	3.96	3.74-5.18	3.19-4.02	3.11-3.72
Stearic	2.60-5.45	-	3.91	0.8-0.96	0.68-1.02	0.7-1.66

Importance/Uses of Coriander

The history of the cultivation and utilization of spices in have played an important role in the history of civilization, exploration and commerce. Their uses can be dated back to the history of Queen of Sheba who visited king Solomon mentioned in the Holy Bible (Purseglove *et al*., 1981). Spices, plants with strong aromas and flavors, have for many years attracted the attention of man, probably at first for fragrances and perfumes, flavoring and condiments, food preservatives, curatives and aphrodisiacs (Janick, 1972).

Spice/Culinary uses of coriander fruit and leaves

Coriander is grown for its fruits and leaves (Figure 1B and H) that have a distinctive fragrant odors and pleasant mild sweet, yet slightly pungent taste (Jansen, 1981). Coriander seeds and leaves as a spice in food products provide nutrition to the diet in addition to aroma and taste (Mahamane *et al*., 2016). It was reported that coriander seed and leaves contribute dietary fiber, iron, magnesium and manganese to the diet (Ensminger and Esminger, 1986). Furthermore, fresh leaves, dried leaves and seeds of coriander have significant quantities of protein, fat, carbohydrate, calcium, phosphorous, sodium, zinc, carotene, thiamine, riboflavin, niacin, tryptophase, vitamin B6, Folate, vitamin A, vitamin D, vitamin B-12, vitamin C and vitamin E (Holland *et al*., 1991; Nimish *et al*., 2011; Bhat *et al*., 2014; USDA, 2016).

Large seeded types of coriander are mainly cultivated for seed spice and vegetable leaf production (Holm and Slinkard, 2002). The finely ground coriander fruit is a major

ingredient in curry powder (Shwell-Cooper, 1973), mixed spice, flavoring bread and cakes, flavoring of spirits (Diederichsen, 1996; Hedburg and Hedburg, 2003; Kaium *et al*., 2015). The leaves of coriander, cilantro, is almost indispensable to daily meal preparations. The leaves give a pleasant taste to soups and dishes prepared from meat and fish (Jansen, 1981; Purseglove *et al*., 1981; Williams *et al*., 1991). Moreover, the young leaves are used in Mexican salsa, Far eastern dishes, and oriental foods (Splittstoesser, 1990).A newer niche for this crop is the organic market, in which it is commanding high premiums. The market for various coriander purees and pastes has increased considerably due to their demand in fast food industries (Ahmed and Shivahu, 2004).

Medicinal usesof coriander leaves and seeds

Coriander seeds and leaves are directly employed for medicinal purposes in different parts of the world and it is high on the list of the healing spices (Nadeem *et al*., 2013). Coriander seeds are mainly used as a drug for indigestion, against worms, rheumatism and pain in the joints (Wichtl, 1994). Recent studies on the direct use of the seed with dishes as a spice have also showed its effects on carbohydrate metabolism (Gray and Flat, 1999; Chithra and Leelamma, 2000). Coriander is a house hold remedy for biliousness (Jansen, 1981), anti-diabetic, anti-inflammatory andagainst stomachache for which either fruits are boiled in water and drunk or the leaves are chewed (Hedburg and Hedburg, 2003). Fresh coriander leaf was found to contain an antibacterial compound dodecenal, which is safe and natural means of fighting Salmonella that causes a deadly food borne illness (Kubo *et al*., 2004). They also recognized that dodecenal is twice as effective as the commonly used antibiotic drug gentamycine at killing Salmonella under laboratory tests. After dodecenal was found in comparable amounts in fresh leaves of coriander, the leaves are usually eaten more frequently as the main ingredients in salsa, along with tomatoes, onions and green chilies (Kubo *et al*., 2004).

Uses of coriander essential oil

Coriander essential oils (Figure 1I) are important compounds used in different industrial application that are present in the seeds and leaves (Shahwar *et al*., 2012), which is responsible for imparting the spicy aroma and taste (Rubatzskey *et al*., 1999). Coriander essential oil has a finer odor than many other commercial essential oils and can be used as a starting point for the manufacture of many products (Jansen, 1981). Its range of utility as flavoring agent is wide and includes pickles, sauces, seasonings and confectionery items. The distilled essential oil from the fruits is used, for instance, in perfumes manufacturing, soaps, candy, cocoa, chocolate, tobacco, meat products, baked foods, canned soups, and alcoholic beverages like gin and to mask offensive odors in pharmaceutical preparations (Kochhar, 1981; Singh *et al*., 2006; Aumatell, 2012; Meena *et al*., 2014; Aumatell, 2016; Dussort *et al*., 2014).

Volatile components in essential oil, from both seeds and leaves, have been reported to inhibit growth of a range of microorganisms (Delaquis *et al*., 2002; Silva and Domingues, 2017; Kačániová*et al*., 2020). The coriander oil has lipid peroxidation (Tanabe *et al*., 2002; Lal *et al*.,2004) andantioxidant properties (Samojlik *et al*., 2010; Laribi *et al*., 2015; Duarte *et al*., 2016; Kačániová*et al*., 2020). Moreover, Antinflamatory activities (Hanafi*et al*., 2014), sedative-hypnotic (Emamghoreishi *et al*., 2006), diuretic activities (Jabeen *et al*., 2009; Abderahim *et al*., 2008), Anti-helminthic activities (Eguale *et al*., 2007; Nimish *et al*., 2011), hypoglycemic activity (Gray and Flatt, 1999; Selvan, 2003)**,**metal detoxification (Abidhusen, 2012), anti-anxiety (Mahendra and Bisht, 2011), anti-proliferative and carminative activities (Kochhar, 1981) activities of the essential oil is also reported. Oleoresin from coriander is used as a flavoring agent, as an ingredient in pharmaceutical formulation and in perfumery (Singh *et al*., 2006).Bha *et al*. (2014) stated that coriander essential oil is very important for growth and for proper functioning of brain. Coriander is found to be rich in pthalides group of compounds which showed the potential anti-cancer activities in various cell lines (Ganesan *et al*., 2013).

Uses of coriander fatty acids

Fatty acids are also important components of coriander seeds; the main fatty acids detected in coriander are petroselenic, linoleic, oleic acid and palmitic acids (Diederichsen, 1996; Ramadan and Morsel, 2002; Ramadan and Morsel, 2003). The fatty acid of coriander is of interest because of the high level of petroselenic acid.It was reported that dietary petroselinic acid, which is present at a high level in coriander oil, was found to strongly reduce the level of arachidonic acid in the heart (Weber*et al*., 1995) and liver (Weber *et al*., 1995; Weber *et al*., 1997).Petroselenic acid has a potential non-food application in oleo chemistry to be used as a plastic lubricant during nylons manufacturing. Petroselenic acid opens up another potential to be used in the manufacture of medium chain acids, since it can be split in to lauric and adipic acids by oxidative cleavage (Lopez *et al*., 2008). Lauric acid used to obtain surfactants and edible products, and adipic acid for nylon synthesis (Kleiman and Spencer, 1982; Isbell *et al*., 2016). At present, adipic acid is derived from mineral oil by a process, which releases gases such as N_2O that damage the ozone layer and contribute to global warming. Adipic acid derived from coriander seed is a more environmentally friendly product (Askew, 1992). Oleic acid is used as a major constituent in the food

industries in particular for salad cream dressing and mayonnaise preparation (Askew, 1992). Residues from distillation can be used for livestock feed, and the fatty acids also have potential uses as lubricants (Purseglove *et al*., 1981).

Biological uses of coriander

A further benefit from coriander is derived from the reproductive biology of the plant. Coriander produces a considerable quantity of nectar and thereby attracts many different insects for pollination (Figure 1F), which shows that coriander is a good melliferous plant (Jerkovic *et al*., 2013; Bhalchandra *et al*., 2014; Bou-Shaara, 2015; Moise, 2015). In Russia, one hectare of coriander allows honeybees to collect about 500 kg of honey (Lukj'anov and Reznikov, 1976; cited by Diederichsen, 1996).

Other uses of coriander

The stubbles after harvest can be used as a fuel wood and the residue of the seed after distillation can be used as cattle feed. Coriander essential oil has insecticidal activity against stored product beetle pests (*Callosobruchus maculates*) (Villalobos, 2003; Eljazi *et al*., 2018).

Recent study results revealed that coriander extract or powder can be used as antibiotic alternative in broiler feeds (Hosseinzadeh *et al*., 2014). Many other health benefits of coriander for the control of swellings, diarrhea, mouth ulcers, anemia, menstrual disorders, small pox, eye care, conjunctivitis, skin disorders are reviewed by Rajeshwari and Andallu (2011). Recently it was proved that the extract of coriander leaves can reduce heavy metal contamination of Pb, Hg and Cu in rod shellfish (Kadiri *et al*., 2017; Winarti *et al*., 2017).Naeemasa *et al*. (2015) and Ahmad *et al*. (2016) reported that coriander powder in the diet and coriander extract in water could replace synthetic antibiotics and could be regarded as natural feed additives and growth promoters in poultry diets.The use of coriander extract or powder as antibiotics alternative in broiler feeds is also reported (Hosseinzadeh *et al*. (2014). Likewise, coriander oil was shown to be an efficient growth promoter in broiler (Ghazanfari *et al*., 2015). Moreover, El-Sayed and Ahmed (2017) investigated that coriander powder enhanced the growth performance and immune status of ratsand can be used as natural feed supplements in the diet. These potentials of coriander are an external effect that has both biological and economical importance which signifies the versatility of plant.

Figure 1. Different growth, development and functional aspects of coriander: (A) Young seedlings; (B) growth attained for green herb utilization; (C) growth transition to generative growth stage; (D) flowering growth stage; (E) individual flower; (F) honey bees collecting nectars form coriander flowers; (G) green mature coriander fruits; (H) Fully matured and dried coriander fruits; (I) Essential oils extracted from coriander fruits.

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