Europ.J.Hort.Sci., **71** (6). S. 267–271, 2006, ISSN 1611-4426. © Verlag Eugen Ulmer KG, Stuttgart

Changes in Yields, Essential Oil and Linalool Contents of *Coriandrum sativum* Varieties (var. *vulgare* Alef. and var. *microcarpum* DC.) Harvested at Different Development Stages

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Summary

Coriander (*Coriandrum sativum* L.) belonging to *Apiaceae* family is one of the essential oil and spice plants in the world. Developmental stage at harvest is an important factor influencing seed yield and essential oil quality in coriander because of the changes during maturation period in fruits. This research was conducted in order to investigate adaptation and suitable harvesting stage in two coriander varieties (var. *vulgare* Alef. and var. *microcarpum* DC.) during 1999 and 2000 in temperate climatic conditions of the Central Black Sea region (Tokat) in Turkey. Field study was designed as a randomised block with a split-plot arrangement. Varieties were harvested at six different harvesting stages, from unripe-fruit periods to over ripened periods. The results indicated that var. *microcarpum* of coriander was more suitable for mild temperate climatic conditions of Central Black Sea Region. Brown-fruit stage in fruit developmental stage (45 days in var. *vulgare* and 40 days in var. *microcarpum* after the flowering) was suitable for harvesting stage. Both early and late harvesting stages caused yield losses and lower linalool content.

Key words. Coriander – *Coriandrum sativum* L. var. *vulgare* Alef. – *Coriandrum sativum* L. var. *microcarpum* DC. – adaptation – harvesting stage – essential oil – linalool

Introduction

Coriandrum sativum L., a member of *Apiaceae* family, is one of the most widely used aromatic plants. Coriander fruit is commercially known as "coriander seed". The plant is among the top 20 essential oil plants (Lawrence 1993) and is used extensively in perfumery, liquor industry and tobacco flavouring (Bandoni et al. 1998**).** Additionally, fresh herbs are consumed as spice and fresh vegetable in some countries such as US, Chine, India (Potter 1996) and Turkey (Baytop 1994).

The composition of the essential oil, which determines the odour and flavour properties, has been under particular investigation by several researches (Anitescu et al. 1997; Bandoni at al. 1998; Telci et al. 2006). The researches indicate that linalool (1,6-octadien-3-ol, $C_{10}H_{18}O$, Mr=154.25, d_{20}= 0.862 and boiling point 196–198 ° C) is the main component in coriander essential oil, and it has potential usage as antisposmadic (Lis-Balchin and Hart 1999), immunostimulatory (Chiang et al. 2003), antinociceptive (Peana et al. 2003), and is also used in perfumery and liquor industry (Bandoni at al. 1998). α-pinene, γ-terpinene geranyl acetate, p-cymene and hexadeconoic acid in the coriander essential oil are also other important components. (Anitescu et al. 1997; Bandoni et al. 1998).

The amount and quality of the product depend on internal and external factors affecting the plant such as genetic structures (Diederichsen 1996) and ecological conditions (Fuente et al. 2003). Agricultural practices also have critical effects on yield and quality characters of coriander. The effects of sowing date, genotypes, fertilization and row spacing have been studied on seed yields of coriander (Kirici et al. 1997; Kaya et al. 2000; Ayanoglu et al. 2002). Harvesting stage is an important factor influencing seed yield and essential oil production in the coriander because of the changes during maturation period. Late harvest allowing fully maturity can result in fruits on the primary umbel shattering. Early harvesting also causes yield loses because of the premature fruits. This research was conducted to determine the variation of yield and essential oil composition during the maturating period in order to minimize the harvesting loses and to maximize the essential oil quality.

Material and Methods

Plant material

Two coriander varieties were tested in this study. The first one was the large-fruited type (var. *vulgare* or *macrocarpum* Alef.) and widely grown in tropical and sub tropical climates. The second one was the small-fruited type (var. *microcarpum* DC.) and suitable for temperate climate

Table 1. Meteorological conditions in Tokat (Turkey) during the experiments.

Month	Monthly rainfall (mm)			Mean monthly temp (°C)		
	1999	2000	Long term years	1999	2000	Long term years
March	34.8	36.9	39.7	7.9	5.7	6.9
April	67.9	91.6	62.0	12.8	15.0	12.5
May	47.3	88.9	61.1	16.1	14.9	16.4
June	34.8	14.5	40.5	20.7	18.7	19.6
July	1.9	–	10.8	23.7	24.6	22.0
Total	186.7	231.9	214.1			
Mean				16.2	15.8	15.5

such as Russian and Central European (Husain et al. 1988; Small 1997). The seeds were obtained from local growers of eastern (var. *microcarpum* DC.) and southern (var. *vulgare* Alef.) of Turkey.

Field studies

Field experiments were established at the Agricultural Experiment and Research Area of the Agricultural Faculty, Gaziosmanpasa University in Tokat (35.3 and 37.9 ° N. latitudes, 39.5 and 40.5 ° E. longitudes with an altitude of 650 m), Turkey during the 1999 and 2000 vegetation periods. The experimental field was located in semi arid climate of the Central Black Sea Region, and some climatic data for the area was given in Table 1.

The soil at the experimental field was a clay loam with pH 7.7, organic carbon 1.68 %, total nitrogen 0.168 %, available P (P_2O_5) 15.4 kg ha^{-1} and available K (K_2O) 268.8 kg ha^{-1}. The experiment was designed as a randomised block with a split-plot arrangement and four replications. Varieties were sown in main plots, and the main plots were divided to six sub-plots of harvesting stage from unripe-fruit periods to full mature periods. Each sub plot included 7 rows, 30 cm apart and 4 m long and was fertilized with 50 kg ha^{-1} N and 50 kg ha^{-1} P_2O_5. Seeds were sown on March 10th in 1999 and March 12th in 2000. Sowing density was 400–450 seed m^{-2}. The plants were grown without irrigation, and kept weed free by hand hoeing.

Phenological properties were observed in plants. Harvested-biomass was dried in a drying chamber (33±2 °C) until constant weight. Then, plants were threshed by hand and fruits were separated from stalk and weighted for determination of fruit yields (kg ha^{-1}). The fruit is called as schizocarp and constituted of two half fruits, called as mericarp containing a seed. Since coriander fruit is frequently named as 'coriander seed' commercially, thousand fruit weight have been determined from fruits having two mericarpes.

Isolation of essential oil

Seeds from each plot were crushed in water by using mortar and pestle to minimize essential oil loses. Extraction process was determined by a Schilcher apparatus (Schilcher 1964), which is similar to Clevenger apparatus and has two cooler. Distilled water was used and 20 g samples were watered with 200 ml distilled water (1:10 w v^{-1}). Distillation was continued for approximately 4 hour. The essential oils were stored in dark glass bottles at 4 °C (Marotti et al. 1996) until analysis.

Analysis of linalool content

Linalool contents were determined with a Carlo Erba gas chromatograph equipped with FID in a laboratory of the Agricultural Faculty, Aegean University. A glass column (3 m x 18 mm) packed with 3 % OV1 50 cromosorb 80/100 mesh was employed. The carrier gas was N_2 with a flow rate of 25 ml min^{-1}. Injection temperature was 230 °C, detector temperature was 250 °C; temperature programming was 60 °C for 3 min, rising to 180 at 3 °C per minute. The identification of linalool was based on comparison of the relative retention time with that of authentic standard.

Statistical analysis

The numerical data for yields and essential oil contents were subjected to analysis of variance (ANOVA) using split plot design. The significance of differences among the harvesting stage was determined using Duncan's Multiple Range Test (Gomez and Gomez 1984). All statistical analyses were carried out using MSTATC software (Mstatc 1991).

Results and Discussion

Fruit yields and thousand fruit weight

Marked differences were revealed in the phonological traits between var. *vulgare* and var. *microcarpum*. The flowering times after emergence were 41 days and 66 days for var. *vulgare* and var. *microcarpum,* respectively (Fig. 1). Var. *microcarpum* has a longer vegetation period, as reported earlier (Angelini et al. 1997). Therefore, it has a potential to use as a fresh and dried herb.

On contrast to vegetative periods, var. *vulgare* reached the 1st harvesting time later than var. *microcarpum* did, 25 and 20 days after the flowering, respectively (Fig. 1). Fruits in 1st harvest were immature and green and have low dried matter content (31 % in var. *vulgare* and 19 % in var. *microcarpum)*. There was a five-day interval between the harvesting times. Dry matter contents increased regularly from 1st to 6th harvesting stage and

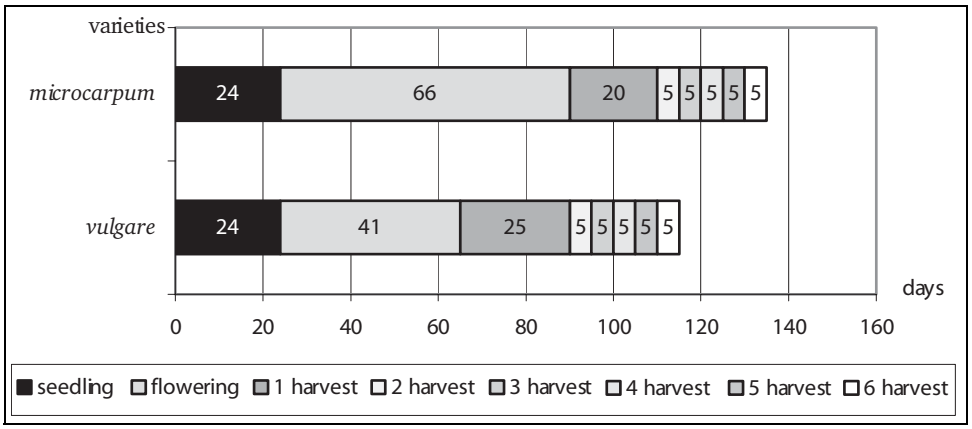


Fig. 1. Phonological observations of *Coriandrum sativum* L. varieties (mean of two year).

reached to 95 % in var. *microcarpum* and 93 % in var. *vulgare* in the last harvest (Fig. 2).

Data of fruit yields, thousand fruit weight and essential oil contents were given in Table 2. Fruit yield showed significant variety x harvesting time interaction ($p<0.05$), and fruit yields varied in the different harvesting periods, ranging from 707.2 to 1069.7 kg ha^{-1} in var. *vulgare* and from 1183.3 to 1452.6 kg ha^{-1} in var. *microcarpum* in 1999. On the other hand, fruit yield did not show a significant variety x harvesting time interaction, whereas significant differences ($p<0.01$) were found between varieties and harvesting periods in 2000. In 1999, the highest fruit yield was obtained in the 4th harvesting time (1069.7 kg ha^{-1}) for var. *vulgare* while it was recorded in 5th harvest (1452.6 kg ha^{-1}) for var. *microcarpum*. The mean fruit yields of coriander harvested in 3rd, 4th and 5th harvesting stages were significantly superior to 1st and 6th harvesting stages (Table 2).

Mean fruit yields in 1999 harvested in the 3rd, 4th and 5th harvesting stages were 8.67, 9.63 and 11.23 % higher than at the last (6th) harvesting stage (Table 2). The cause of reduction in the yield of the last harvest was due to over-maturation of plants and shattering of fruits. So, over ripening of fruits caused yield losses, because of shattering during harvesting and post harvest handling of the varieties.

Fruit yield losses in 6th harvesting stage compared to maximum yields of varieties were higher (Table 2) in var. *vulgare* than in var. *microcarpum*. High thousand fruit weights and fragile stalk of var. *vulgare* may cause the higher yield losses than that of var. *microcarpum*.

In 2000, fruit yields were markedly decreased in both varieties, because of the climatic conditions (Table 1). According to DIEDERICHSEN (1996), coriander is a cross-pollinating plant, and low temperature and rainfall in flowering periods limited insect visiting and pollination. Main umbel was half-fruitless in 2000, especially for var. *vulgare*.

The overall varieties' mean data showed that fruit yields in var. *microcarpum* were higher than those of var. *vulgare* during the study, and maximum yields were obtained from the first year. Fruit yields, especially in var. *vulgare*, decreased in the second year because of climatic conditions. Var. *vulgare* is reported to be sensitive to temperate climatic conditions but it is suitable for tropic and sub-tropic climate (SMALL 1997).

Like the fruit yield data, thousand fruit weight showed significant variety x harvesting time interaction in 1999 (Table 2). There was no interaction in 2000, whereas significant differences were found between varieties and between harvesting time in both years. During the study, the highest thousand fruit weight value was obtained in the 4th harvesting time in 1999 for var. *vulgare,* and minimum values were obtained in the 1st harvesting time in 1999 for var. *microcarpum*. Thousand fruit weight increased regularly from 1st to 5th harvesting periods as a result of ripening and dry matter accumulation. There was an insignificant decrease in the 6th harvesting stage compare to the 5th harvesting stage. It was attributable to shattering of fruits from the main umbels in the 6th harvesting stage. These results are in close agreement with those reported by DIEDERICHSEN (1996).

Some researchers named coriander varieties as small-fruit coriander (var. *microcarpum*) and big-fruit coriander (var. *vulgare*) (HUSAIN et al. 1988; SMALL 1997). Correspondingly, in this study the thousand fruit weight of var. *vulgare* was higher than that of var. *microcarpum*. The thousand fruit weight was higher in the first year than in the second year in both varieties. In var. *microcarpum,* thousand fruit weight varied between 4.88 and 6.00 g in harvesting stages of 1999, and 4.89 and 5.85 g in 2000 (the highest values for ripened fruits). Variation between years was prominently different in the var. *vulgare* and thousand-fruit-weight varied between 6.63–10.06 g in the first year, but it was between 7.46 and 8.55 g in the second year. This can be explained by increased rainfall during the maturation of var. *vulgare* and

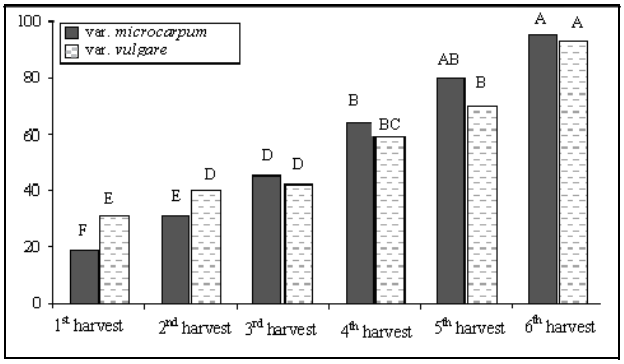


Fig. 2. Mean dry matter contents of coriander fruits harvested at different developmental stages ($P<0.05$).

Table 2. Fruit yield, thousand fruit weight and essential oil contents of *Coriandrum sativum* varieties harvested at different developmental stages.

Harvesting time	Fruit yield (kg ha^{-1})			1000 fruit weight			Essential oil contents (%)		
	Var. *vulgare*	Var. *microcarpum*	Mean value	Var. *vulgare*	Var. *microcarpum*	Mean value	Var. *vulgare*	Var. *microcarpum*	Mean value
1999									
1st harvest	707.2 J	1183.3 E		6.63 D	4.88 F		0.40	0.61	0.50 A
2nd harvest	942.1 HI	1277.0 D		9.05 C	5.28 F		0.40	0.47	0.44 AB
3rd harvest	993.3 GH	1417.8 AB		9.38 BC	5.86 E		0.31	0.55	0.43 B
4th harvest	1069.7 F	1362.6 BC		10.06 A	5.78 E		0.30	0.41	0.35 C
5th harvest	1015.2 FG	1452.6 A		9.56 AB	6.00 E		0.36	0.50	0.43 B
6th harvest	908.3 I	1310.3 CD		9.07 C	5.83 E		0.33	0.46	0.39 BC
Mean	939.3 B	1333.9 A		8.96 A	5.60 B		0.35 B	0.50 A	
Variety (V)	**			**			**		
Harvest (H)	**			**			*		
Interaction (V x H)	*			**			NS		
2000									
1st harvest	680.3	977.0	828.6 B	7.46	4.89	6.18 C	0.30	0.52	0.41 A
2nd harvest	673.8	1021.6	847.7 B	7.80	5.45	6.63 B	0.32	0.44	0.38 AB
3rd harvest	770.3	1060.3	919.0 B	8.22	5.59	6.91 AB	0.30	0.36	0.33 BC
4th harvest	785.4	1096.1	990.7 AB	8.22	5.63	6.93 AB	0.23	0.40	0.31 C
5th harvest	988.8	1239.1	1113.9 A	8.49	5.85	7.17 A	0.28	0.40	0.34 BC
6th harvest	736.6	1027.8	882.2 B	8.55	5.72	7.14 A	0.27	0.35	0.31 C
Mean	772.5 B	1070.3 A		8.12 A	5.52 B		0.28 B	0.41 A	
Variety (V)	**			**			*		
Harvest (H)	**			**			*		
Interaction (V x H)	NS			NS			NS		

*P<0.05; **p<0.01; NS: Not Significant

pollination problems. So, contents of fruits in the main umbel decreased and fruits from branch caused lower thousand fruit weight in 2000. From previous records (KARADOGAN and ORAL 1994; GUL and TANSI 1997), it was reported that the thousand fruit weight varied between 5.01 and 6.53 g in var. *microcarpum* and between 10.35 and 11.56 g in var. *vulgare* in ripened fruits.

Essential oil contents

Essential oil production has been reported to be associated with early growing periods (SANGWAN et al. 2001). In this study, essential oil contents varied significantly according to harvesting time in both years (Table 2). Essential oil contents of premature fruits (1st or 2nd harvests) were higher than that of ripened fruits (5th and 6th harvest) in both varieties.

The results also showed that there were differences between varieties for essential oils and var. *microcarpum* had higher essential oil contents than var. *vulgare* similar to previous records (SMALL 1997; HUSAIN et al. 1988; FUENTE et al. 2003). Maximum essential oil were 0.40 % in var. *vulgare* and 0.61 % in var. *microcarpum* in the 1st harvest of 1999. Essential oil contents of both varieties were decreased in 2000, because of rainfall and lower temperature during the seed maturation periods (SANGWAN et al. 2001).

Linalool content

Linalool contents increased regularly from early periods to subsequent periods and maximum linalool contents were obtained from latest harvests (5th and 6th harvest) in both varieties (Table 3.). Linalool, an oxygenated monoterpene, was the main component in essential oil of ripened fruits. It is known that linalool content in essential oil of ripened coriander fruits was higher than that of premature fruits (LAWRENCE 1993; DIEDERICHSEN 1996).

In the first year, linalool contents in ripened fruits were relatively higher in both varieties. It has been known that climatic factors such as cloudy days and lower temperature during maturation and high amount of rain-

Table 3. Linalool contents of *Coriandrum sativum* varieties harvested at different development stages.

Harvesting time	Var. *vulgare*	Var. *microcarpum*	Mean
1999			
1st harvest	35.00	37.29	36.14
2nd harvest	48.28	40.13	44.20
3rd harvest	55.00	67.31	61.15
4th harvest	65.10	75.13	70.56
5th harvest	64.20	77.41	70.80
6th harvest	65.40	73.22	69.31
2000			
1st harvest	30.20	37.29	33.74
2nd harvest	32.50	40.13	36.31
3rd harvest	49.50	67.31	58.40
4th harvest	55.80	72.26	64.03
5th harvest	60.40	75.13	67.76
6th harvest	60.70	77.41	69.05

fall may have adverse effect on the accumulation of linalool contents (SANGWAN et al. 2001).

Conclusions

This field investigation demonstrated that:

a) Coriander was suitable for semi arid climatic conditions of the Central Black Sea Region and var. *microcarpum* had higher yield and essential oil content than var. *vulgare*. Since var. *vulgare* flowered earlier than var. *microcarpum*, pollination problems may cause yield losses in the years with late spring rainfall.
b) Yield losses in earlier harvests were due to premature fruits. Delaying harvest caused yield losses as a result of shattering during harvest and post harvest handling. Over ripening also caused splitting of fruits that it was undesirable for heterogonous spoiling products. Plants must be harvested during brown fruit stage on the main umbel (5th harvest stage).
c) Although unripe fruits contained higher essential oil, plants should be harvested in full-ripened periods (4th and 5th harvesting stage) for essential oil content that has high linalool contents.

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Received May 18, 2005 / Accepted January 04, 2006

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