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Quang-Hung Nguyen[a,b], Thierry Talou[a], Philippe Evon[a], Muriel Cerny[a], Othmane Merah[a,c,*]

[a] Laboratoire de Chimie Agro-industrielle, LCA, Université de Toulouse, INRA, Toulouse, France
[b] Institute of Ecology and Biological Resources, Vietnam Academy of Science and Technology, Viet Nam
[c] Université Paul Sabatier, IUT A, Département Génie Biologique, Auch, France

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ABSTRACT

Coriander contains petroselinic acid, an isomer fatty acid of oleic acid. Coriander seed oil has been proposed as novel food ingredient in the European Union. Field experiments were performed at Auch (France) during two seasons (2010 and 2011). From flowering to maturity, fruits were harvested weekly and oil content and fatty acid (FA) compositions were determined. Fruits presented 2% more oil in 2010 than in 2011. Petroselinic acid (PA) contents was higher in 2011 than in 2010. Oil accumulation began earlier after flowering (2 DAF) in 2011. A first step in accumulation was identified between two and 21 DAF characterized by high SFA and PUFA, which decreased 21 DAF. Subsequently, PA increased to its highest concentration (30–55 DAF) and SFA and PUFA reached their lowest. These results suggest that higher concentrations of PA can be achieved by collecting fruits before full maturity.

1. Introduction

Umbelliferae (Apiaceae) is one of the main families of flowering plants and is distributed over the world. Apiaceae species, such as angelica, caraway, carrot, coriander, celery, cumin, fennel and parsley, are used as foods, beverages, spices, cosmetics and fragrances as well as for industrial purposes (Mohammadhosseini, Venditti, Sarker, Nahar, & Akbarzadeh, 2019; Sayed Ahmad, Talou, Saad, Hijazi, & Merah, 2017; Sahib et al., 2013). Coriander (*Coriandrum sativum* L.), an annual Apiaceae native of the Mediterranean region, is distributed across temperate regions around Mediterranean countries, Asia, and Europe (Diederichsen & Hammer, 2003). Green parts of this species are used as a condiment in culinary dishes in Asia and around the Mediterranean basin and its essential oils are used in cosmetics as well as by foods industries (Wei, Liu, Zhao, Xue & Lan, 2019; Aćimović & Kostadinović, 2015; Laribi, Kouki, M'Hamdi, & Bettaieb, 2015; Brindis, González-Andrade, González-Trujano, Estrada-Soto, & Villalobos-Molina, 2014; Emamghoreishi, Khasaki, & Aazam, 2005; Rakhshandeh, Sadeghnia, & Ghorbani, 2012).

In 2013, the European Commission authorised use of coriander seed oil as a novel food ingredient (NFI) in the context of Regulation (EC) No 258/97 of the European Parliament and of the Council (EFSA, 2013). Coriander seed oil is particularly rich in the less-common mono-unsaturated isomer of oleic acid, *i.e.*, petroselinic acid (C18:1n12). This fatty acid (FA) represents 70 to 80% of total FA in Apiaceae fruits (Sayed Ahmed et al., 2018; Uitterhaegen et al., 2016; Nguyen, Talou, Cerny, Evon, & Merah, 2015; Sriti et al., 2010; Angelini, Moscheni, Colonna, Belloni, & Bonari, 1997). The novel food ingredient status means coriander seed oil is considered as safe for healthy adults when used as a food supplement. Maximum permissible doses are 600 mg per day (*i.e.*, 8.6 mg/kg bw per day for a 70 kg person) and, with this legislation in place, the edible oil industry can make use of coriander seed oil.

Coriander confers stability to maize and sunflower oils, which can be blended with a variety of Apiaceae species (Ramadan, 2013). Moser and Vaughn (2010) highlighted that coriander fruit oil methyl esters present a real opportunity for biodiesel fuel with excellent oxidative stability. Indeed, coriander oil contains mainly 6Z-octadecenoic acid, known as petroselinic acid, oxidative cleavage of which results in lauric and adipic acids that are of interest to detergent and nylon polymer industries (Sahib et al., 2013; Msaada et al., 2009a).

Coriander fruit oils also appears to be of interest for food uses. Msaada et al. (2009a) and Lakshminarayana, Rao, Sita Devi, and Kaimal (1981) reported coriander oil and fatty acid accumulation, but these studies were based on a single year under semi-controlled greenhouse conditions or conventional cultivation, which implies the use of agro-chemicals during plant growth. Our first study, performed in 2009, was also carried out in a single year under organic cultivation without chemicals (Nguyen et al., 2015), but the impact of weather conditions was not considered. Therefore, the aim of this study was to

* Corresponding author at: Laboratoire de Chimie Agro-industrielle, LCA, Université de Toulouse, INRA, Toulouse, France.
E-mail address: othmane.merah@ensiacet.fr (O. Merah).

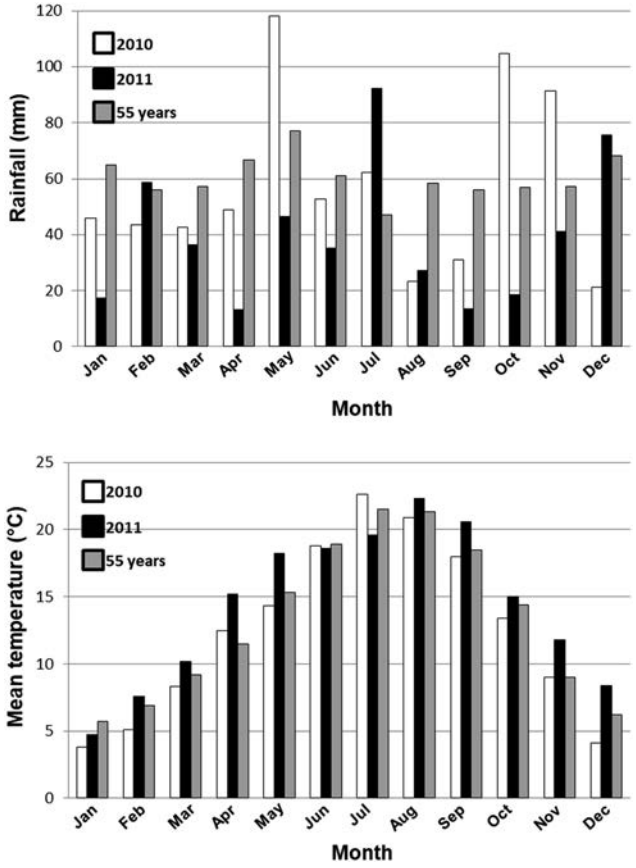

Fig. 1. Rainfall and mean temperature recorded monthly in 2010 and 2011 in Auch (France). Comparison was made with average data of 55 past years in the same region.

Table 1
Mean temperatures and rainfall during important periods of the cropping seasons of 2010 and 2011 in Auch (France).

period	Rainfall (mm)			Temperature (°C)		
	2010	2011	55 years	2010	2011	55 years
Average				12.6	14.4	13.2
Sum year	685.5	475.8	726.3			
Mean mar-Sept				16.5	17.8	16.6
Sum Mar-Sept	378.7	264.3	423.3			
Mean May-July				18.6	18.8	18.6
Sum May- July	233.0	174.0	185.4			

investigate accumulation of oil and fatty acid composition during fruit development (from flowering to maturity) and the effects of weather conditions on these traits during two cropping seasons.

2. Materials and methods

2.1. Plant material, Crop management and experimental conditions

Coriander (*Coriandrum sativum* L.) seeds were sown in field trials at the Regional Centre of Experimentation in Organic Agriculture, Auch (near Toulouse, France, 43°38′47″N, 0°35′08″E) in 2010 and 2011. The soil was characterized as high levels of sand-loam, pH 8.1, and 3.2% organic matter content. Seeds (provided by GSN, Riscles, France) were sowed on 9th April 2010 and 25th March 2011, respectively, at a density of 1.5 $g.m^{-2}$ and depth of 3 cm. Plants were managed under organic cultivation (*i.e.*, neither chemicals nor water were supplied). During both years, flowering took place at the end of May and maturity stage was reached in August.

Weather conditions that prevailed during 2010 and 2011 cropping seasons are presented in Fig. 1. These data were compared with those recorded over the last 55 years. In 2010 and 2011, respectively, rainfall was 40 and 250 mm less than the half century values observed for the same period. The plants received less rain and grew in warmer conditions during both seasons than the average data for 55 years. The driest and hottest year was 2011 and 2010 was wetter. During the grain filling period, 2011 was hotter and less wet than 2010 and the half century average. Therefore, 2010 was representative of the half century average. In contrast, 2011 was characterized by less rainfall and higher temperatures.

2.2. Agronomic measurements

Thirty plants, randomly chosen, were harvested each five (average) days during ripening (between the beginning of flowering and the physiological maturity). The sampling period started two days after flowering (DAF) and ended 55 DAF. The colour and relative moisture content of fruits were adopted as development criteria, as described by Ross and Murphy (1992). The fruits were harvested from the thirty plants and pooled. Moisture contents were determined by drying fruits in an air-oven at 60 °C to a constant weight. The fruit water content (FWC: % of the fruit dry matter) was measured in each sample as an indicator of physiological maturity to make comparison between years possible. The dried fruits were then used for oil extraction and fatty acid composition determination.

2.3. Determination of oil and fatty acid contents

Coriander power was obtained by grinding dried fruits (IKA Werke MF 10 basic, Staufen, Germany). From this powder, three samples (20 g), as technical replicates, were used for oil extraction (5 h) at atmospheric pressure in a Soxhlet-type apparatus (Fischer, Illkirch, France). The solvent was cyclohexane (VWR, Fontenay-sous-Bois, France). Subsequently, a rotary evaporator (Fischer, Illkirch, France) at low pressure (around 150 mbars thanks to its connection to a laboratory filter pump) and 35 °C was used to remove the solvent. The extracted oil was dried at 35 °C for at least 12 h and the yield calculated from the oil masses obtained.

Tert-butyl methyl ether (1 mL; Merck KGaA, Darmstadt, Germany) was used to extract the coriander oil and the mixture filtered (glass fiber filter, 0.45 µm, VWR, Briare, France). The filtrate (100 µL) was mixed with 50 µL of trimethylsulphonium hydroxide (0.5 M in methanol) and agitated gently. A gas chromatography system (GC 3900, Agilent Technologies, Les Ulis, France) with a flame ionization detector (FID) and a CP-select CB column (fused silica WCOT; 50 m length; 0.25 mm internal diameter; 0.25 µm film thickness, proQuarz GmbH, Mainz, Germany) was used for fatty acid composition analyses. Helium was used as carrier gas at a flow rate of 1.2 mL/min with a split ratio of 1:100. Initial temperature used was 185 °C for 40 min and was increased by 15 °C each min to reach 250 °C. This temperature was maintained for 10.7 min. The temperatures of the injection and detector was 250 °C. Fatty acid percentages represent area-under-the-curve on chromatograms. Each sample was analysed in three technical replicates.

2.4. Statistical analyses

Analyses of variance was performed using SAS GLM (SAS Institute, 1987, Cary, NC, USA) to examine the effects of years and dates of sampling (*i.e.*, DAF) on all traits (*i.e.*, oil content, fatty acid composition and water content). Means for each trait were compared using the Duncan's test at a 5%.

Table 2
Fatty acids, oil and water accumulation during ripening stage of coriander fruit in 2010.

Fatty acid (%)	Days after flowering					
	2	5	10	15	21	24
Saturated fatty acid (SFA)						
C14:0	3.8 ± 0.5d	4.4 ± 0.4d	7.4 ± 0.2c	8.6 ± 0.2b	11.7 ± 0.1a	4.6 ± 0.1d
C16:0	23.5 ± 0.4a	21.9 ± 0.3b	24.5 ± 0.1a	23.8 ± 0.3a	17.4 ± 0.2c	8.9 ± 0.1d
C18:0	2.6 ± 0.0b	2.8 ± 0.0b	2.7 ± 0.0b	3.4 ± 0.0a	3.2 ± 0.0a	1.5 ± 0.1d
C20:0	0.9 ± 0.0b	1.3 ± 0.1a	1.5 ± 0.0a	1.6 ± 0.1a	1.4 ± 0.1a	0.5 ± 0.0c
C22:0	1.5 ± 0.0a	1.9 ± 0.0a	1.4 ± 0.1a	1.3 ± 0.1a	1.9 ± 0.0a	0.4 ± 0.0b
Total	32.3 ± 0.1c	32.3 ± 0.2c	37.6 ± 0.0a	38.7 ± 0.1a	34.6 ± 0.2b	15.9 ± 0.1d
Monounsaturated fatty acid (MUFA)						
C16:1n7	0.0 ± 0.0c	0.0 ± 0.0c	0.0 ± 0.0c	0.0 ± 0.0c	0.0 ± 0.0c	0.0 ± 0.0c
C18:1n12	1.8 ± 0.9f	0.9 ± 0.3f	1.2 ± 0.1f	7.3 ± 0.0e	27.8 ± 0.2d	53.6 ± 0.2c
C18:1n9	5.2 ± 0.2 h	2.6 ± 0.3i	6.5 ± 0.1e	7.4 ± 0.2d	11.3 ± 0.1a	9.1 ± 0.2b
Total	6.9 ± 1.1 h	3.5 ± 0.5i	7.6 ± 0.2 g	14.8 ± 0.2f	39.0 ± 0.3e	62.7 ± 0.1d
Polyunsaturated fatty acid (PUFA)						
C18: 2n6	42.4 ± 0.7b	44.5 ± 0.5a	38.2 ± 0.1c	35.4 ± 0.1d	22.6 ± 0.1e	19.9 ± 0.1f
C18:3n3	18.4 ± 0.4b	19.8 ± 0.2a	16.6 ± 0.1c	11.2 ± 0.0d	3.8 ± 0.0e	1.6 ± 0.0f
Total	60.8 ± 1.0b	64.2 ± 0.6a	54.8 ± 0.2c	46.5 ± 0.1d	26.4 ± 0.1e	21.4 ± 0.1f
SFA/PUFA	0.53c	0.50c	0.69bc	0.83b	1.31a	0.74b
OY (%)	5.8 g	10.5f	11.0f	15.2e	18.7d	19.6c
Fruit water content (%)	90,0a	86,9b	80,5c	72,6d	60,9e	52,9f

Fatty acid (%)	Days after flowering							
	27	31	34	36	39	43	49	55
Saturated fatty acid (SFA)								
C14:0	1.0 ± 01e	0.1 ± 0.0f	0.1 ± 0.0f	0.5 ± 0.0f	0.3 ± 0.1f	0.4 ± 0.0f	0.3 ± 0.0f	0.2 ± 0.0f
C16:0	5.8 ± 0.0e	4.2 ± 0.0f	4.0 ± 0.1f	4.2 ± 0.0f	4.0 ± 0.1f	4.1 ± 0.0f	4.1 ± 0.0f	4.0 ± 0.1f
C18:0	1.0 ± 0.0e	0.9 ± 0.0e	0.8 ± 0.0e	0.7 ± 0.0e	0.8 ± 0.0e	0.8 ± 0.0e	0.8 ± 0.0e	0.8 ± 0.0e
C20:0	0.4 ± 0.0c	0.2 ± 0.0c	0.2 ± 0.0c	0.2 ± 0.0c	0.2 ± 0.0c	0.2 ± 0.0c	0.2 ± 0.0c	0.2 ± 0.0c
C22:0	0.4 ± 0.0b	0.3 ± 0.0b	0.2 ± 0.0b	0.2 ± 0.0b	0.2 ± 0.0b	0.2 ± 0.0b	0.2 ± 0.0b	0.2 ± 0.0b
Total	8.6 ± 0.1e	5.6 ± 0.0f	5.2 ± 0.0f	5.7 ± 0.0f	5.4 ± 0.8f	5.7 ± 0.0f	5.6 ± 0.0f	5.3 ± 0.1f
Monounsaturated fatty acid (MUFA)								
C16:1n7	0.4 ± 0.2a	0.2 ± 0.0b	0.4 ± 0.0a	0.2 ± 0.0b	0.2 ± 0.0b	0.2 ± 0.0b	0.2 ± 0.0b	0.2 ± 0.0b
C18:1n12	63.5 ± 0.3b	73.5 ± 0.5a	74.0 ± 0.4a	72.7 ± 0.4a	72.7 ± 0.7a	72.5 ± 0.7a	72.7 ± 0.5a	72.6 ± 0.5a
C18:1n9	9.5 ± 0.3b	7.2 ± 0.5d	8.5 ± 0.4c	7.2 ± 0.4d	7.2 ± 0.6d	7.1 ± 0.7d	6.5 ± 0.5e	6.8 ± 0.5e
Total	73.4 ± 0.1c	80.9 ± 0.2b	82.8 ± 0.5a	80.1 ± 0.3b	80.1 ± 0.1b	79.9 ± 0.3b	79.4 ± 0.5b	79.6 ± 0.4b
Polyunsaturated fatty acid (PUFA)								
C18: 2n6	17.3 ± 0.0 g	13.3 ± 0.0 h	11.4 ± 0.0i	14.1 ± 0.0 h	14.4 ± 0.0 h	14.2 ± 0.0 h	14.8 ± 0.0 h	14.8 ± 0.1 h
C18:3n3	0.7 ± 0.0 g	0.2 ± 0.0 h	0.6 ± 0.0 g	0.2 ± 0.0 h	0.2 ± 0.0 h	0.2 ± 0.0 h	0.3 ± 0.0 h	0.2 ± 0.1 h
Total	18.0 ± 0.0 g	13.5 ± 0.0i	12.0 ± 0.0j	14.3 ± 0.0 h	14.6 ± 0.0 h	14.5 ± 0.0 h	15.0 ± 0.0 h	15.1 ± 0.1 h
SFA/PUFA	0.48c	0.41 cd	0.43 cd	0.40d	0.3d7	0.39d	0.37d	0.35d
OY (%)	20.8c	22.6b	23.0b	23.9ab	24.1a	24.5a	24.7a	24.9a
Fruit water content (%)	50,9f	46,8g	44.0 g	39,9h	37,5h	32,1i	23,4j	14,3k

Data were means ± S.D of three replicates. C14:0 (Myristic acid); C16:0 (Palmitic acid); C16:1n7 (Palmitoleic acid); C18:0 (Stearic acid); C18:1n12c (Petroselenic acid); C18:1n9c (Oleic acid); C18: 2n6c (Linoleic acid); C18:3n3 a (Linolenic acid); C20:0 (Arachidic acid); C22:0 (Behenic acid); OY (Oil Yield); Water (water content). In same line, means with the same letter are not significantly different.

Table 3
Fatty acids, oil and water accumulation during ripening of Coriander fruit in 2011.

Fatty acid (%)	Days after flowering					
	3	11	24	30	35	59
Saturated fatty acid (SFA)						
C14:0	5.9 ± 0.0b	8.9 ± 0.4a	3.0 ± 0.1c	2.9 ± 0.0c	0.7 ± 0.0d	0.0 ± 0.0e
C16:0	27.6 ± 0.2a	24.2 ± 1.1b	10.0 ± 0.1c	9.8 ± 0.2c	4.1 ± 0.1d	3.8 ± 0.2d
C18:0	3.9 ± 0.1a	3.3 ± 0.1b	1.9 ± 0.1c	1.9 ± 0.0c	0.9 ± 0.0d	0.7 ± 0.1d
C20:0	2.4 ± 0.3b	5.9 ± 0.1a	0.8 ± 0.0c	0.7 ± 0.0c	0.2 ± 0.0d	0.1 ± 0.0d
C22:0	2.3 ± 0.0a	1.8 ± 0.1b	0.6 ± 0.0c	0.6 ± 0.0c	0.2 ± 0.0d	0.1 ± 0.0d
Total	42.1 ± 0.1b	44.1 ± 1.6a	16.3 ± 0.2c	16.0 ± 0.3c	6.1 ± 0.2d	4.8 ± 0.3e
Monounsaturated fatty acid (MUFA)						
C16:1n7	0.4 ± 0.1b	0.7 ± 0.1a	0.3 ± 0.0c	0.3 ± 0.0c	0.2 ± 0.0c	0.2 ± 0.0c
C18:1n12	1.0 ± 0.3d	6.2 ± 3.1c	52.0 ± 0.6b	51.8 ± 0.3b	72.3 ± 0.4a	74.3 ± 1.4a
C18:1n9	2.3 ± 0.2d	3.5 ± 0.9d	10.4 ± 0.4a	9.7 ± 0.2a	7.0 ± 0.4b	5.9 ± 1.0c
Total	3.6 ± 0.3d	10.5 ± 3.9c	62.7 ± 0.18b	61.8 ± 0.5b	79.5 ± 0.2a	80.4 ± 0.4a
Polyunsaturated fatty acid (PUFA)						
C18: 2n6	35.6 ± 0.2a	32.7 ± 1.5a	19.6 ± 0.0b	20.1 ± 0.1b	14.1 ± 0.0c	14.7 ± 0.2c
C18:3n3	18.7 ± 0.1a	12.7 ± 0.9b	1.4 ± 0.0c	2.1 ± 0.1c	0.3 ± 0.0d	0.2 ± 0.0d
Total	54.3 ± 0.3a	45.4 ± 2.3b	21.0 ± 0.0c	22.2 ± 0.2c	14.4 ± 0.0d	14.9 ± 0.2d
SFA/PUFA	0.77	0.97	0.78	0.72	0.42	0.32
OY (%)	6.4e	11.0d	17.2c	19.5b	22.4a	22.9a
Water (%)	94.2a	81.1b	80.6b	72.7c	40.1d	10.4e

Data were means ± S.D of three replicates. C14:0 (Myristic acid); C16:0 (Palmitic acid); C16:1n7 (Palmitoleic acid); C18:0 (Stearic acid); C18:1n12c (Petroselenic acid); C18:1n9c (Oleic acid); C18: 2n6c (Linoleic acid); C18:3n3 a (Linolenic acid); C20:0 (Arachidic acid); C22:0 (Behenic acid); OY (Oil Yield); Water (water content). In same line, means with the same letter are not significantly different.

3. Results and discussion

Oil and water contents as well as fatty acid compositions are presented in Table 1 for 2010 and Table 2 for 2011. Maturity was achieved at 55 and 59 days after flowering (DAF), respectively.

A higher oil yield was observed in 2010 (Tables 1 and 2), as expected, the greater rainfall meant plants grew more and accumulated more oil. Similar trends have also been observed for rapeseed, sunflower, woad, brown mustard, (Gravé et al., 2019; Roche, Bouniols, Cerny, Mouloungui, & Merah, 2016; Merah, 2015; Roche et al., 2010a). Oil yield was found to vary between 5.8% and 24.9% at different stages of ripening (Tables 1 and 2). Oil contents increased gradually from blooming to maturity. This trait rose three-fold from two DAF to 24 DAF, and reached a plateau at maturity of 24.9% and 22.9% in 2010 and 2011, respectively.

In this study, plants grew under organic cultivation (*i.e.*, without chemical inputs) and, at maturity, fruits yielded less oil than reported previously for coriander cultivated under conventional systems (*i.e.*, with the use of chemicals) (Uitterhaegen et al., 2016; Laribi et al., 2015; Sriti, Talou, Faye, Vilarem, & Marzouk, 2011; Msaada et al., 2009b). Conversely, results reported by Angelini et al. (1997) showed lower oil contents than those reported in our study (Table 1 and Table 2). As expected, oil content in 2010 were similar to those reported in a previous study with the same genotype cultivated in the same location (Nguyen et al., 2015). However, oilseed crops store less oil under drier conditions than under more favourable (wetter) ones (Sidorov & Tsydendambaev, 2014; Merah et al., 2012; Roche et al., 2010b; Lionneton, Aubert, Ochatt, & Merah, 2004; Ross & Murphy, 1992).

Saturated fatty acids constituted at least a third of total fatty acids from 2 to 21 DAF in both years. Subsequently, saturated fatty acid contents decreased two-fold in 2010 and three-fold in 2011 (Tables 1 and 2). The same trend, during the same period, was observed for polyunsaturated fatty acids, which decreased from 55% (at 2 DAF) to 20% (at 21 DAF) in both years. Monounsaturated fatty acids, however, increased markedly during the same period (Tables 2 and 3). Several studies on different oil species have highlighted the effects of environmental conditions on oil contents and fatty acid compositions (Roche, Mouloungui, Cerny, & Merah, 2019; Chehade et al., 2016; Gouzy, Massol, Mouloungui, & Merah, 2016; Roche et al., 2016). In olives, higher temperatures reduced oleic oil and increased either palmitic or linoleic acids (Chehade et al., 2016). In sunflower and safflower, a decrease in both oleic and palmitic acids was noticed during ripening (Gouzy et al., 2016; Roche et al., 2016; Merah et al., 2012).

Ten fatty acids (5 saturated, 3 mono-unsaturated and 2 poly-unsaturated) were detected in coriander fruits harvested in either year (Tables 1 and 2). Petroselinic, linoleic, oleic and palmitic acids were the major fatty acids (Tables 1 and 2). Nevertheless, fatty acid accumulation did not proceed the same way. Indeed, at earlier stages, in newly formed fruits, linoleic, palmitic, linolenic and stearic acids were the principal fatty acids two DAF. Then, the contents of these fatty acids gradually decreased to their lowest concentrations around 35 DAF. At the same time, monounsaturated fatty acids followed the opposite path with the highest values being reached between 30 and 35 DAF (Tables 1 and 2). Msaada et al. (2009a,b) as well as Lakshminarayana et al. (1981) observed comparable trends in fatty acid accumulation. Minor differences (concentrations of different fatty acids) were probably due to genotype and growing conditions (Wei et al., 2019; Beyzi, Karaman, Gunes, & Beyzi, 2017; Merah et al., 2012; Roche et al., 2010b; Lionneton et al., 2004).

Fatty acids biosynthesis, as described in Kennedy pathway, involves acyl-CoA elongase and Δ9 and Δ 6 desaturases. Activities of these enzymes can explain decreased saturated fatty acids, which are used to synthetize polyunsaturated fatty acids (Sidorov & Tsydendambaev, 2014). This decrease coincided with increased monounsaturated fatty acids (Tables 1 and 2). Petroselinic acid biosynthesis in coriander fruits has been shown to involve acyl-ACP associated reactions (Dörmann, Frentzen, & Ohlrogge, 1994) as well as Δ 4-palmitoyl-ACP desaturase and A seed-specific 3-ketoacyl-ACP synthase (Jaworski & Cahoon, 2003; Mekhedov, Cahoon, & Ohlrogge, 2001; Cahoon, Shanklin, & Ohlrogge, 1992). The latter study suggested that 3-ketoacyl-ACP synthase is highly specific for conversion of 16:1 Δ4 to 18:1 Δ6 in coriander fruits. However, our results suggested an increase in monounsaturated fatty acids while, at the same time, polyunsaturated fatty acids decreased, mainly linolenic acid, which is desaturated at positions 6 and 9. A decrease in the contents of polyunsaturated (linoleic and linolenic) fatty acids, and an increase in monounsaturated (petroselinic and oleic) and saturated (palmitic and stearic) fatty acid concentrations, have been reported in coriander cultivated under water stress (Yeganehpoor,

Zehtab-Salmasi, Ghassemi-Golezani, Shafagh-Kolvanagh, & Dastborhan, 2017). It is well known that Δ-9 and Δ-12 desaturase catalyse desaturation of stearic acid to oleic acid, which in turn serves as a source of linoleic acid, and the activities of these enzymes start when oil content increases (Roche et al., 2016; Sidorov & Tsydendambaev, 2014). The augmentation of monounsaturated fatty acids (particularly petroselenic acid) in 2011 (stressed conditions) can be attributed to declining activity of Δ-12 desaturase, which diminished conversion of monounsaturated acids to linoleic acid (Sidorov & Tsydendambaev, 2014). Other works have reported that water limitation decreased activity of desaturase enzymes in several species (Yeganehpoor et al., 2017; Laribi, Benttaieb, Kouki, Sahli, Mougou, & Marzouk, 2009; Mekki, El-Kholy, & Mohamad, 1999; Dwivedi, Nigam, Nageswara-Rao, Singh, & Rao, 1996). Indeed, transcriptional as well as post-transcriptional regulations occur for Δ-9 and Δ-12 desaturase activities (Rolletschek et al., 2007). Post-transcriptional regulation depends on temperatures during fatty acid synthesis, which can affect fi nal fatty acid compositions (Iyer et al., 2008; Byfield & Upchurch, 2007).

Highest concentrations of petroselinic FA were reached at around 35 DAF and a slight decrease was observed at ripening (Tables 1 and 2). These changes have already been reported in our previous study (Nguyen et al., 2015) as well as in studies dealing with other oilseed species (Zhao, Wang, Huang, Cui, & Hua, 2018; Claver, Rey, López, Picorel, & Alfonso, 2017; Zhu, Wilkinson, & Wirthensohn, 2017; Roche et al., 2010b, 2016; Ichihara & Suda, 2003). Petroselinic acid contents observed in our study were similar to previous reports on coriander (Uitterhaegen et al., 2015; Sriti et al., 2011, Msaada et al., 2009b).

4. Conclusion

The aim of this work was to understand more about the accumulation of oil and fatty acids during ripening of coriander fruits under organic cultivation in a two-year experiment. As expected, oil contents depended on weather conditions and water availability favored greater oil content. As a result of variations in weather conditions, fatty acid compositions different between the two years. Fatty acid profiles and contents also varied greatly during ripening. Petroselinic acid (75–79% of total fatty acids at maturity) reached its highest concentration between 20 and 40 DAF. Moreover, monounsaturated fatty acids increased during fruit development, whereas saturated and polyunsaturated fatty acids decreased significantly. Therefore, to enhance concentrations of petroselinic acid, the use of immature fruits (30–40 DAF) might be preferable for many industries, but this would require the development of specific techniques for harvesting, storing, and drying fruits.

CRediT authorship contribution statement

Quang-Hung Nguyen: Conceptualization, Methodology, Software, Validation, Data curation, Formal analysis, Writing - original draft. **Thierry Talou:** Conceptualization, Methodology, Software, Validation, Supervision, Writing - review & editing. **Philippe Evon:** Conceptualization, Validation, Supervision, Writing - review & editing. **Muriel Cerny:** Methodology, Software, Validation, Data curation, Formal analysis, Writing - review & editing. **Othmane Merah:** Conceptualization, Validation, Data curation, Supervision, Writing - original draft, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodchem.2020.127034.

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