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Short communication

Crithmum maritimum seeds, a potential source for high-quality oil and phenolic compounds in soils with no agronomical relevance

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ABSTRACT

The objective of the present study was to analyse the fruit yield and the lipid and phenolic composition of the seeds from the edible halophyte *Crithmum maritimum* growing in different types of soil with variable physicochemical properties. Seed oil content ranged between 8.39–11.66 % and showed high nutritional value, and the phenolic composition (423–603 mg TPC 100 g^{-1}) presented high levels of quercetin-type compounds with high pharmaceutical interest. The strong conservation of these traits, together with a high and stable fruit production, suggests that *C. maritimum* could be cultivated in soils with no agronomical relevance to produce seeds as an accessible and environmentally friendly source of good quality oil and phenolics for industrial purposes.

1. Introduction

Crithmum maritimum L. (Apiaceae), also known as sea fennel and rock samphire, is a wild edible halophyte whose phytochemical constituents in leaves have potential application for food and pharmaceutical industries. However, chemical traits of their seeds have barely explored and fruit yield production remains unknown. It is commonly found in coasts of Western Europe, where it grows on soils with highly variable physicochemical properties. Its leaves are currently consumed in salads, soups, pickled in vinegar and as a condiment. The aerial parts have considerable nutritional value and they are rich mineral elements (Nabet et al., 2017). In addition, this species is considered a valuable source of products for the food industry because of its high antioxidant profile (Sánchez-Faure et al., 2020). The phytochemical profile of *C. maritimum* aerial parts can be variable depending on geographic location (Özcan et al., 2001; Pavela et al., 2017) and it can be influenced by different abiotic factors (Özcan et al., 2001; Meot-Duros and Magne, 2009). Nevertheless, many studies have highlighted its potential as a promising candidate in the food and pharmaceutical industries (reviewed in Renna, 2018). Moreover, due to its high salinity tolerance, *C. maritimum* has been proposed as a cash crop in saline agriculture, being a sustainable solution to the high rate of soil salinization worldwide, which limits the productivity of conventional crops (Fita et al., 2015).

Despite its large potential, the seed chemical composition of this halophyte has been barely explored and existing research has been only focused on a narrow range of plant material. On the one hand, appreciable amounts of good quality edible oil were reported in the seeds from Tunisian accessions, with oleic and linoleic acids accounting for more than 91 % of total fatty acids (Zarrouk et al., 2003; Atia et al., 2010). On the other hand, a high content of flavonoids (a group of phenolic compounds) were found in seeds extracts of *C. maritimum*, which suggests its potential as an antioxidant (Houta et al., 2011). However, the specific phenolic compounds in the seeds have never been quantified and data about fruit and seed production are still lack in this non-domesticated species, being this a crucial information to accurately evaluate the actual potential yield of its chemical constituents. In addition, seed production and seed chemical composition are determined by different

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factors besides genotype, including variable abiotic conditions (da Silva et al., 2017; Cohen et al., 2021). In this context, the diversity of abiotic factors to which *C. maritimum* is commonly exposed across its geographical distribution could influence the seed yield and chemical traits, but the variability in the production and quality of seed compounds is still unknown.

The aim of the study was to analyse fruit and seed yield production of *C. maritimum* and quantify the phenolic and oil composition in its seeds. Moreover, the present study was aimed to explore whether the variability of soil physicochemical properties in the contrasting habitats of the species can influence fruit and seed yield and seed chemical traits. These findings build towards a better understanding of the phytochemistry of this plant species, providing useful information for future domestication processes and commercial cultivation.

2. Materials and methods

2.1. Field sampling

Three wild populations of *C. maritimum* were surveyed growing in the three main types of habitats in southeast Spain with different topographies to span the variety of ecosystems where it naturally grows: El Toyo (sandy beach; Almería; 36.835718, -2.325802), Los Muertos (rocky beach; Almería; 36.956220, -1.899545), and Calblanque (cliffs; Murcia; 37.602117, -0.731187). Each population was comprised of at least 30 adult sea fennel plants. In mid-September 2019, twelve adult reproductive plants with similar height (37.81 $\pm$ 2.22 cm (mean $\pm$ SE)) were randomly selected at each population. Seven umbels per plant bearing mature fruits bearing dry seeds were collected and transported to the laboratory for seed counts and further chemical analyses. Each fruit contains a single dry seed from 4 to 10 mm long.

2.2. Soil characterisation

In each population, twelve top soil samples (0−30 cm depth) adjacent to the selected plants were collected for different soil analyses. Soil pH was potentiometrically determined in a 1:2.5 (w/v) soil:water suspension with a digital meter (Crison pH-25, Spain). The organic matter content was determined by using a muffle furnace calcination at 450 °C for 4 h. The nitrogen content was estimated by the Kjeldahl method (Kjeldahl, 1883). The electrical conductivity was determined as a soil salinity measure by using a conductivity meter (Crison-522, Spain) in a 1:5 (w/v) soil:water suspension. The coarse elements of soil fractions were removed by sieving (> 2 mm) and the percentage of gravel was estimated. Then, the soil texture analysis was performed in the < 2 mm soil fraction according to the Bouyoucos method (Bouyoucos, 1962).

2.3. Estimation of fruit and seed yield

The total number of umbels per plant was recorded. Then seven umbels per plant were collected and the total number of fruits per umbel was counted. Each fruit contains a single seed. The fruits were opened to obtain the seeds and both fruits and seeds were weighed. To estimate the fruit yield production, the area occupied by each selected plant was calculated from two orthogonal diameters and the production was expressed in kg fruits ha^{-1}. Thousand seed weight (TSW) was determined by taking one hundred seeds randomly, weighing them using a precision balance and multiplying with factor 10.

2.4. Lipid extraction and fatty acid composition

Total lipids were extracted from approximately 20 mg of seeds per plant according to Hara and Radin (1978). Methylation of lipid samples and fatty acid methyl esters (FAMEs) analysis were performed by gas chromatography and the FAMEs were identified by comparison with a combination of commercial standards as described by Moreno-Pérez et al. (2011). Heptadecanoic acid (17:0), added during lipids extraction step, was used as an internal standard for fatty acid quantification. The nutritional value of fatty acid composition was assessed by calculating the atherogenicity index (AI) and thrombogenicity index (TI) according to Ulbricht and Southgate (1991) and the polyunsaturated to saturated fatty acid ratio (PUFA/SFA).

2.5. Identification and quantification of phenolic compounds

Phenolic compounds were extracted from mature seeds using 20 mg of dry material per plant (oven-dried for 48 h at 40 °C) with 0.25 mL of 70 % methanol in an ultrasonic bath for 15 min, followed by centrifugation (Moreira et al., 2014). For phenolic compound identification, an ultra-performance liquid chromatography coupled with electrospray ionization quadrupole (Thermo Dionex Ultimate 3000 LC) time-of-flight mass spectrometry (UPLC-Q-TOF-MS/MS) (Bruker Compact™) (Moreira et al., 2020) was used. MS analysis was operated in spectra acquisition range from 50 to 1200 *m/z*. Both polarities ($\pm$) of ESI mode were used under the following specific conditions: gas flow 9 L/min, nebulizer pressure 38 psi, dry gas 9 L/min, and dry temperature 220 °C. Capillary and end plate offset were set to 4500 and 500 V, respectively. MS/MS analysis was performed based on the previously determined accurate mass and RT and fragmented by using different collision energy ramps to cover a range from 15 to 50 eV. The algorithm T–Rex 3D from the MetaboScape 4.0 software (Bruker Daltoniks, Germany) was used for peak alignment and to elucidate the metabolite molecular formula. Identification of putative metabolites was performed using accurate mass metabolites reported in different publicly available databases such as METLIN, KEGG, Pubchem, HMDB and Plant Metabolic Network. Additionally, further identification was made by comparison of MS/MS fragmentation patterns against reference compounds. Phenolic compounds from two groups were identified: flavonoids (N = 7) and hydroxycinnamic acids (N = 3). For phenolic compound quantification, an UHPLC (Nexera LC-30AD; Shimadzu) equipped with a Nexera SIL-30AC injector and one SPD-M20A UV/VIS photodiode array detector was used (Moreira et al., 2018). Flavonoids were quantified as rutin equivalents and hydroxycinnamic acids as ferulic acid equivalents (Moreira et al., 2018). The quantification of these phenolic compounds was achieved by external calibration using calibration curves at 0.25, 0.5, 1, 2 and 5 μg mL^{-1}. Phenolic compound concentrations were expressed in mg g^{-1} tissue on a dry weight basis and analysed plant-level data for total concentration of phenolics and by type of phenolic compounds.

2.6. Statistical analyses

Statistical differences in seed and fruit yield, phenolics, lipid content and fatty acid composition and nutritional indices among the different populations were tested by one-way ANOVA test. Data were tested for normality (Kolmogorov-Smirnov test) and homogeneity of variance (Levene test) and significant differences were set when $p < 0.05$ by Tukey test. The non-parametric Kruskal-Wallis test followed by Mann-Whitney *U* test were used for data not normally distributed. Statistical analyses were performed with IBM SPSS v. 24.0 software (IBM Corp., USA).

3. Results and discussion

While *C. maritimum* aerial parts present a large potential in food and pharmaceutical industries (Renna, 2018), little is known about its seed yield and seed chemical constituents and how abiotic factors could influence these traits. In this work, three *C. maritimum* populations growing on soils with contrasting physicochemical characteristics were surveyed, which are typical for the species, including different topographies, organic matter content, nitrogen, electrical conductivity and soil physical properties (Table 1). Both rocky and sandy beaches

Table 1
Physicochemical properties of the soil in the different studied populations. Data represent mean ± SE of seven-twelve independent replicates. Different letters indicate significant differences ($p < 0.05$).

	Geographical coordinates	Organic matter (mg C/g dry weight)	Nitrogen (%)	pH	Conductivity (µS cm^{-1})	Gravel (%)	Texture			
							Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)
Sandy beach	36.835718/ -2.325802	23.78 ± 4.40a	0.012 ± 0.002a	9.50 ± 0.11a	525.54 ± 157.69a	13.50 ± 4.23a	83.84 ± 5.94a	4.71 ± 1.36a	7.72 ± 2.90a	3.73 ± 1.88a
Rocky beach	36.956220/ -1.899545	31.37 ± 9.79a	0.049 ± 0.015b	9.81 ± 0.10a	466.40 ± 88.31a	75.88 ± 7.11b	88.78 ± 2.78a	2.98 ± 1.14a	6.81 ± 1.47a	1.41 ± 0.37a
Cliffs	37.602117/ -0.731187	51.15 ± 9.72b	0.048 ± 0.009b	9.53 ± 0.14a	160.03 ± 22.67b	2.58 ± 1.18a	93.08 ± 1.09a	2.12 ± 0.63a	3.38 ± 0.50a	1.42 ± 0.37a

displayed similar values regarding organic matter content and electrical conductivity, showing the sandy beach the lowest nitrogen content ($p < 0.05$), whereas cliffs showed the highest organic matter content and electrical conductivity ($p < 0.05$). Despite the observed variability of soil properties, which could have an impact on plant reproductive stage and seed-filling process, *C. maritimum* seeds exhibited a high and stable fruit and seed yield, together with a strong conservation of the chemical traits here analysed, which are discussed in more detail below.

3.1. Fruit and seed yield

C. maritimum plants displayed fruit yield within the range of 1207.19–1264.91 kg fruits ha^{-1}, without significant differences among the studied populations despite the highly variable soil physicochemical properties (Table 2). Plants growing on cliffs showed the lowest fruit number per plant ($p < 0.05$) (Table 2). However, no significant differences were observed regarding fruit productivity per unit area (kg ha^{-1}), likely due to these plants showed the lowest plant surface (Table 2). By comparison with other halophytes, the observed yield was higher than that previously reported for *Kosteletzkya virginica* (603−957 kg ha^{-1}) (Ruan et al., 2010), although lower than *Salicornia bigelovii* (1.39-2.46 t ha^{-1}) (Glenn et al., 1991) and *Salicornia europaea* (2 t ha^{-1}) (Gooding et al., 1990), which displayed yields close to conventional crops like wheat. The thousand seed weight (TSW) of *C. maritimum* displayed values between 2.22–2.60 g, without significant differences among the three populations (Table 2). This result suggests that seed weight is a stable trait in this species, since it remained high despite the large variability in soil properties of the studied populations. These values were similar to the previously reported for the halophyte *Suaeda salsa,* which showed TSW values between 2.1–2.95 g in greenhouse experiments (Guo et al., 2020) and higher than several *S. bigelovii* lines and *S. europaea* ecotypes under greenhouse conditions (Zerai et al., 2010; Araus et al., 2021). Furthermore, breeding programs could be achieved to increase seed size as has been previously demonstrated in the halophyte *S. bigelovii* (Zerai et al., 2010), leading to a higher productivity. Unlike other species, in which fruit and seed productivity can be strongly influenced by soil factors (Huang et al., 2013; Cohen et al., 2021), these results suggest a high seed productivity could be obtained in *C. maritimum* even in poor quality soils with variable physicochemical properties not suitable for conventional crop species.

Table 2
Average fruit and seed yield in three populations of *C. maritimum*. Data represent mean ± SE of twelve independent replicates. TSW, thousand seed weight. Different letters indicate significant differences ($p < 0.05$).

	sandy beach	rocky beach	cliffs
Plant surface (m^2)	3.04 ± 0.42**a**	2.66 ± 0.31**a**	0.86 ± 0.18**b**
Fruits number per plant	75736 ± 14365**a**	62754 ± 7106**a**	23465 ± 6324**b**
Fruit yield (kg fruits ha^{-1})	1264.91 ± 210.48**a**	1207.19 ± 163.29**a**	1263.74 ± 170.75**a**
TSW (g)	2.60 ± 0.12**a**	2.22 ± 0.18**a**	2.31 ± 0.08**a**

3.2. Seed oil content and quality

Regarding seed oil content, *C. maritimum* displayed similar values regardless the variability of soil properties, from 8.39 % DW (in the sandy beach) to 11.66 % DW (in the rocky beach) (Table 3). This oil content was much lower than that reported by Atia, et al. (2010), which was around 44 % in *C. maritimum* seeds collected in a rocky coast in Tunisia. Seed oil biosynthesis is related to genetic factors but it is also influenced by environmental conditions (Baud and Lepiniec, 2010) as well as by the interaction between both factors (Huang et al., 2013). The present results seem to indicate that soil physicochemical properties do not strongly affect the oil content and composition in *C. maritimum* seeds. Accordingly, the observed differences in oil content with regard to previous works could be related to genotype or other environmental factors not evaluated in this study.

Concerning the lipid profile, the seed oil fraction was characterised by a constant fatty acid profile across the studied populations, with high level of unsaturated fatty acids (83.83–89.24 %) (Table 3). Oleic acid ($18{:}1\Delta^9$) was the most abundant fatty acid in all samples (67.02–73.43 %), following by linolenic acid (18:2Δ9,12) (11.46–11.79 %). This profile was in accordance with that previously reported for the Tunisian accession (Zarrouk et al., 2003; Atia et al., 2010). Oleic and linoleic were the major fatty acids detected in other seed oils from Umbelliferae species (Matthäus et al., 2015). Notwithstanding, other fatty acids were detected in minor proportion, such as petroselinic acid ($18{:}1\Delta^6$) (Table 3), which is largely present in Apiaceae seeds (Sayed-Ahmad et al., 2017). Petroselinic acid has large potential as oleo-chemical raw material for industry (Avato et al., 2001), thus representing an added value of *C. maritimum* seed oil that was not previously reported.

The present study, in accordance with previous ones, suggest a high

Table 3
Fatty acid species (mol%) detected in *C. maritimum* seeds and oil percentage (on dry weight. Data represent mean ± SE of twelve independent replicates. Different letters indicate significant differences ($p < 0.05$) among populations. MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids, SFA, saturated fatty acids; PUFA/SFA, polyunsaturated to saturated ratio; AI, atherogenicity index; TI, thrombogenicity index.

Fatty acids	sandy beach	rocky beach	cliffs
14:0	1.06 ± 0.15**a**	6.72 ± 0.86**b**	8.21 ± 0.34**b**
16:0	7.75 ± 0.44**a**	6.81 ± 0.39**a**	6.35 ± 0.50**a**
18:0	1.82 ± 0.14**a**	1.42 ± 0.08**b**	1.48 ± 0.11**ab**
$18{:}1\Delta^9$	73.43 ± 1.00**a**	72.02 ± 0.98**a**	67.02 ± 1.14**b**
$18{:}1\Delta^{11}$	1.32 ± 0.36**a**	0.77 ± 0.05**b**	0.80 ± 0.10**b**
$18{:}1\Delta^6$	3.04 ± 0.79**a**	0.33 ± 0.26**b**	4.41 ± 0.94**a**
18:2Δ9,12	11.46 ± 1.23**a**	11.79 ± 0.37**a**	11.60 ± 0.32**a**
20:0	0.13 ± 0.02**a**	0.13 ± 0.01**a**	0.13 ± 0.01**a**
MUFA	77.79 ± 1.58**a**	73.12 ± 0.90**b**	72.23 ± 0.60**b**
PUFA	11.46 ± 1.23**a**	11.79 ± 0.37**a**	11.60 ± 0.32**a**
SFA	10.77 ± 0.67**a**	15.09 ± 0.90**b**	16.17 ± 0.64**b**
PUFA/SFA	1.08 ± 0.13**a**	0.82 ± 0.06**b**	0.73 ± 0.04**b**
AI	0.14 ± 0.01**a**	0.40 ± 0.04**b**	0.47 ± 0.02**b**
TI	0.24 ± 0.02**a**	0.36 ± 0.02**b**	0.38 ± 0.02**b**
% oil	8.38 ± 0.73**a**	11.66 ± 0.86**b**	10.08 ± 0.68**ab**

quality of the oil extracted from *C. maritimum* seeds, based on its fatty acid profile, which is close to that of the best edible oils, such as olive and canola. Here, different parameters used to assess the potential effects of fatty acid composition of lipids on cardiovascular health were calculated, such as the polyunsaturated to saturated ratio (PUFA/SFA), atherogenicity index (AI) and thrombogenicity index (TI). Seed oil from plants growing on sandy beach showed the highest PUFA/SFA ratio, which it is better from a nutritional point of view, whereas no differences were observed among the other two populations (Table 3). However, the PUFA/SFA ratio met the recommended threshold in all analysed samples (>0.45) (World Health Organization/Food And Agriculture Organization (WHO/FAO, 2003), showing values between 0.73–1.08 (Table 3). These PUFA/SFA values were within the range of many seaweeds (0.30–2.12), which are other underutilized resource suggested as high-quality PUFAs and potential functional foods (Kumar et al., 2011). On the other hand, lipids with low AI and TI indexes have a good nutritional quality, and its consumption is related with the reduction of risk of coronary heart disease (Chen and Liu, 2020). *C. maritimum* seeds from all the studied populations showed AI and TI values between 0.14−0.47 and 0.24−0.38 (Table 3), which are desirable regarding the prevention of cardiovascular diseases (Ulbricht and Southgate, 1991). These AI and TI values were lower than those previously reported for seeds bearing edible oil like pumpkin seeds (AI, 0.19; TI, 0.50) (Montesano et al., 2018). These findings support the good nutritional composition of *C. maritimum* seed oil and reveal its large stability to maintain these traits, both quantitatively and qualitatively, despite the high variability in physicochemical properties of the soils where the species naturally grows. Nevertheless, further studies with a broader range of sampled populations and soil properties should be performed to fully explore the nutritional oil quality and to understand the involvement of the edaphic factors on lipid biosynthesis in this species.

3.3. Phenolic composition

Concerning the phenolic composition, the total phenolic content (TPC) of *C. maritimum* seeds displayed values between 423−603 mg of total phenolic compounds 100 g^{-1} DW, without significant differences among the three studied populations (Table 4). This TPC was in agreement with that previously reported by Houta et al.(2011), who found high phenolic content in seed extract (17.11 mg of TPC g^{-1} extract) from a Tunisian *C. maritimum* accession. TPC was within the range of other Apiaceae seeds (160−550 mg gallic acid equivalent (GAE) 100 g^{-1} DW) (Ksouda et al., 2018) and higher than other halophytes seeds like *Aeluropus lagopoides*, *Eragrostis ciliaris*, *Eragrostis pilosa*, *Panicum antidotale* and *Sporobolus ioclados*, that were within the range of 2.8–4.2 mg g^{-1} DW (Toqeer et al., 2018). Furthermore, TPC was also higher than some quinoa ecotypes (Aloisi et al., 2016), which is a halophyte well-known for its nutraceutical properties.

Table 4
Phenolic compounds (% on total phenolics) detected in *C. maritimum* seeds. Flavonoids and hydroxycinnamic acids are expressed in %. TPC, total phenolic content (mg 100 g^{-1} DW). Data represent mean ± SE of eleven-twelve independent replicates. Different letters indicate significant differences ($p < 0.05$) among populations.

	sandy beach	rocky beach	cliffs
3-caffeoyl quinic acid	0.28 ± 0.07**a**	0.37 ± 0.04**a**	0.25 ± 0.04**a**
5-caffeoyl quinic acid	4.96 ± 0.78**a**	4.63 ± 0.50**a**	4.21 ± 0.41**a**
p-coumaroyl quinic acid	1.08 ± 0.08**a**	1.06 ± 0.08**a**	1.17 ± 0.07**a**
Feruloyl quinic acid	0.62 ± 0.10**a**	0.65 ± 0.07**a**	0.66 ± 0.04**a**
Ferulic acid	1.19 ± 0.09**a**	1.41 ± 0.11**a**	1.40 ± 0.07**a**
3,5-Di-Caffeoyl quinic acid	5.26 ± 0.63**a**	3.56 ± 0.41**a**	4.77 ± 0.36**a**
4,5-Di-Caffeoyl quinic acid	5.01 ± 00.57**a**	4.06 ± 0.49**a**	4.05 ± 0.37**a**
Quercetin-O-hexoside	43.00 ± 1.93**a**	46.76 ± 1.29**a**	45.36 ± 1.31**a**
Quercetin-7-xyloside	11.98 ± 1.47**a**	13.38 ± 0.81**a**	11.38 ± 1.10**a**
Chrysoeriol-7-O-neohesperidoside	26.62 ± 2.06**a**	24.12 ± 1.26**a**	26.76 ± 1.23**a**
Flavonoids	81.60 ± 1.74**a**	84.26 ± 1.24**a**	83.50 ± 0.69**a**
Hydroxycinnamic acids	18.40 ± 1.74**a**	15.74 ± 1.24**a**	16.50 ± 0.69**a**
TPC	603 ± 1.04**a**	423 ± 0.53**a**	559 ± 0.67**a**

Phenolic compounds are plastically generated in plants as a response to environmental conditions; thereby TPC can be the result of several factors including genetic, environmental constraints and the interplay between both (Brunetti et al., 2018). In this context, previous studies (Meot-Duros and Magne, 2009) have shown that the polyphenol profile of aerial parts in *C. maritimum* varies depending on several abiotic factors, including salinity exposure and plant physiological stage. However, the phenolic profile in seeds of *C. maritimum* was strongly maintained in the studied populations (Table 4), regardless the variability of soil properties, which includes different salinity levels (Table 1). Phenolic compounds from two groups were detected: flavonoids, which represented 81–83 % (353−519 mg 100 g^{-1} DW) of TPC and hydroxycinnamic acids, accounting for 15–18 % (71−131 mg 100 g^{-1} DW) (Table 4). These observations are in agreement with previous studies that revealed that many Apiaceae species contain important phenolic content, including flavonoids and phenolic acids (Shan et al., 2005). Moreover, this profile was in accordance with that previously reported by Houta et al. (2011), who detected high levels of flavonoids within the TPC of seed extracts (7.06 mg g^{-1} extract) from a Tunisian *C. maritimum* accession.

Regarding hydroxycinnamic acids, significant amounts of chlorogenic acid isomers, namely caffeoylquinic, di-caffeoylquinic and feruloylquinic acids, were found (Table 4). These compounds have been recognized as bioactive components with biological properties, in particular concerning antibacterial, anti-inflamatory and antioxidant properties (Liang and Kitts, 2016). On the other hand, flavonoids were the major components of TPC in *C. maritimum* seeds, with quercetin derivatives (quercetin-O-hexoside and quercetin-7-xyloside) representing more than 50 % of TPC in the studied populations (Table 4). Quercetin and its derivatives are well known compounds for its pharmacological potential (Lesjak et al., 2018), playing important roles in the prevention and treatment of neurodegenerative and cardiovascular diseases as well as some types of cancer (Russo et al., 2012). Therefore, the relevant content of quercetin derivatives in *C. maritimum* seeds represents an added value for the full exploitation of this species.

The similar levels of the phenolic content and composition in the studied populations suggest that the phenolic biosynthesis in *C. maritimum* seeds is not strongly influenced by soil abiotic factors. This would offer the possibility to cultivate the plants in poor soils, under a wide range of variable physicochemical properties, without affecting the production of these specific metabolites. This is particularly interesting since there is a growing interest in the use of natural antioxidant as additives for controlling the oxidation of lipids in food (e.g. Maisuthisakul et al., 2007) to replace synthetic antioxidants due to its possible toxic and carcinogenic effects (Kahl and Kappus, 1993). Although a direct relation between TPC and antioxidant activity has been proved in many plants (Shan et al., 2005; Ksouda et al., 2018), further investigations should be performed to confirm the antioxidant activities of the detected phenolic compounds in *C. maritimum* seeds.

4. Conclusions

C. maritimum has been previously proposed as a potential cash crop in poor-nutrient, saline or salinized soils due to the potential use of its aerial parts for food and pharmaceutical industries. In this work, data on fruit and seed yield were provided and specific phenolic compounds in *C. maritimum* seeds were analysed. These findings suggest that *C. maritimum* seeds could be considered as a potential source of phenolic compounds, particularly quercetin derivatives, which are highly appreciated in the pharmaceutical industry. The fruit and seed yield of *C. maritimum*, as well as seed oil and phenolic composition, were similar among the three studied populations, regardless the high variability of soil physicochemical properties. These findings suggest that *C. maritimum* could be cultivated under a wide range of soil physicochemical properties (from fertile soils to soils with no agronomical relevance) to produce seeds. This would result in an accessible, cheap and environmentally friendly source of chemical constituents for several industrial and commercial uses.

CRediT authorship contribution statement

Raquel Martins-Noguerol: Conceptualization, Investigation, Writing – original draft, Writing – review & editing. **Ignacio M. Pérez-Ramos:** Conceptualization, Writing – review & editing. **Luis Matías:** Conceptualization, Writing – review & editing. **Xoaquín Moreira:** Writing – review & editing, Funding acquisition. **Marta Francisco:** Investigation. **Alberto García-González:** Investigation. **Adrián M. Troncoso-Ponce:** Investigation, Writing – review & editing. **Brigitte Thomasset:** Supervision. **Enrique Martínez-Force:** Supervision. **Antonio J. Moreno-Pérez:** Supervision, Conceptualization, Writing – review & editing. **Jesús Cambrollé:** Conceptualization, Supervision, Investigation, Writing – review & editing, Funding acquisition.

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.

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