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Seed and Fruit Fatty Acid Compositions of *Crambe orientalis* and *Crambe tataria* Oils Collected from Three Different Provinces in Turkey

Muzaffer BARUT[1], Leyla Sezen TANSI[2], Emel-Diraz YILDIRIM[3], Sengul KARAMAN[4]
[1,2]Department of Field Crops, Faculty of Agriculture, Çukurova University, 01330 Adana, Türkiye, [3, 4]Biology Department, Science and Letter Faculty, Kahramanmaras Sutcu Imam University, 46100, Kahramanmaras, Türkiye
[1]https://orcid.org/0000-0002-9095-8225, [2]https://orcid.org/0000-0003-0726-3332, [3]https://orcid.org/0000-0001-5299-8122
[4]https://orcid.org/0000-0001-7617-9957
✉: muzafferbarut1@gmail.com

ABSTRACT

Crambe is an annual or perennial plant belonging to the Brassicaceae family. The interest in Crambe is mainly due to its unique fatty acid profile, low input management, and broad adaptability to the environment. Thus, Crambe seed and fruit fatty acids were investigated by GC / MS in order to examine the chemical variability which correlates with the environmental variability. In the study, *Crambe orientalis* var. *orientalis* and *Crambe tataria* var. *tataria* were used and they were collected from the different areas of three provinces of Türkiye. Fifteen compounds were found, representing 84.6-100% of the total seed and fruit oils. The major components in both species were erucic acid (24.7-44.7%), gondoic acid (19.0-28.3%), oleic acid (14.9-28.5%), and linoleic acid (8.1-17.6%). As a consequence, it is needed to increase the production of erucic acid (C22:1) and gondoic acid (C20:1) in Crambe by using wild populations via plant breeding. These two promising fatty acids may be an alternative to meet industrial fatty acid market demand in a more environmentally friendly way compared to using fatty acids from fossil oil.

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Türkiye'de Üç Farklı İlden Toplanan *Crambe orientalis* ve *Crambe tataria* Tohum ve Meyvelerinin Yağ Asidi Kompozisyonu

ÖZET

Crambe, Brassicaceae familyasına ait tek yıllık veya çok yıllık bir bitkidir. Crambe'ye olan ilgi, temel olarak benzersiz yağ asidi profili, düşük girdi yönetimi ve çevreye geniş ölçüde uyum sağlama yeteneğinden kaynaklanmaktadır. Bu nedenle, çevresel değişkenlik ile ilişkili olan kimyasal değişkenliği incelemek için Crambe tohumlarının ve meyvelerinin yağ asidi bileşenleri GC/MS ile araştırılmıştır. Çalışmada *Crambe orientalis* var. *orientalis* ve *Crambe tataria* var. *tataria* kullanılmış ve Türkiye'nin üç ilinin farklı bölgelerinden toplanmıştır. Toplam tohum ve meyve yağlarının %84.6-100'ünü temsil eden on beş bileşen saptanmıştır. Her iki türdeki lokasyona göre ana bileşenler erusik asit (%24.7-44.7), gondoik asit (%19.0-28.3), oleik asit (%14.9-28.5) ve linoleik asit (%8.1-17.6) olarak belirlenmiştir. Sonuç olarak Crambe'de yabani populasyonlar kullanılarak erusik asit (C22:1) ve gondoik asit (C20:1) üretiminin bitki ıslahı yoluyla artırılmasına ihtiyaç duyulmaktadır ve bu iki ümitvar yağ asidi, fosil yağlardan elde edilen yağ asitlerinin kullanılmasına kıyasla daha çevre dostu bir şekilde piyasanın talebi olan endüstriyel yağları karşılamak için bir alternatif olabilir.

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INTRODUCTION

Crambe is an oilseed plant from the Brassicaceae family and it is native to the Mediterranean region (Comlekcioglu et al., 2008). Although widespread in the flora of Türkiye, it is a little-known species as it has not yet been grown commercially and has no traditional use among the people. (Tansı et al., 2003). Davis (1965) reported 4 taxa, 2 species (*C. orientalis* and *C. tataria*) registered in the flora of Türkiye, and 2 varieties belonging to the species. However, with subsequent flora studies, 4 more species were added to the flora of Türkiye (*C. maritima* L., *C. hispanica* L., *C. grandiflora* DC., and *C. alutacea* Hand.-Mazz.) and the number of taxa was determined as 10 with a total of 6 species and subspecies (Arslan et al., 2015). It was initially grown as a crop in 1933 at the Boronez Botanical Station in the Soviet Union, and it was included in a Swedish breeding program in 1949 (Oplinger et al., 1991). *Crambe* came to the forefront with its high erucic acid content among 8000 plant species with the examination of new potential species as a result of 16 years of systematic studies of USDA in 1957 (Glaser, 1996).

Cultivation experiments of Crambe in Türkiye were started for the first time in Çukurova, and seed yields and oil rates were determined (Tansı et al., 2003; Köybaşı and Tansı, 2008). It is still in its early stages of development as an agricultural crop and is not commonly cultivated in Türkiye, but due to potential uses of the seed oil for the production of many valuable products, many developed countries have shown a scientific interest in it. Presently, *C. abyssinica* Hochst. is the only species of the Crambe genus utilized in the industry.

Crambe is a cool-climate plant and can withstand temperatures as low as 5 °C. (Oplinger et al., 1991; Adamsen et al., 2005). It is cultivated as both a spring and a winter crop. It can be cultivated in regions with annual precipitation ranging from 350 to 1200 mm, an annual average temperature ranging from 5.7 °C to 16.2 °C, and soils with a pH ranging from 5.0 to 7.8 (Falasca et al., 2010). Its oil-bearing seeds, high yield capacity, and adaptability to regional conditions make it an appealing alternative oil crop for Eurasian regions (Rudloff and Wang, 2011). It requires modest agricultural inputs compared to many other oilseed crops that may be grown all over the world and provides the opportunity to minimize the consumption of inputs such as fertilizers and water (Rogério et al., 2013). Therefore, *C. abyssinica* cultivation has less environmental impacts than other crops such as canola or maize (Costa et al., 2019).

Erucic acid and gondoic acid have been in fighting with petroleum alternatives for many years. Priorly, the cost has been a major problem for the development of new plant-derived oils. But now people are concerned about finite supply. Because of these reasons, there is a need to develop renewable products from plant oils. Erucic acid (C22:1) and gondoic acid (C20:1) is monounsaturated, non-edible, long-chain fatty acid and it is found only in seed oil from plants belonging to Brassicaceae and Tropaeolaceae families (Qi et al., 2018). In higher plants, gondoic acid is a precursor of erucic acid (Kikukawa et al., 2015). Gondoic acid has several advantages, for example, it improves the skin permeation of indomethacin which is an anti-inflammatory drug, and is used as raw material for medical material and moisturizing ingredient in cosmetic creams (Morimoto et al., 1996; Kikukawa et al., 2015).

The ability to withstand high temperatures and remain liquid at low temperatures makes Crambe oil a good lubricant in plastics manufacturing (Nelson et al., 1993). Moreover, it is a chemical compound that is used in the manufacturing of inks, pharmaceuticals, and other products. Also, Crambe fruit oil has the potential to be used as an acaricide against the Cattle Tick (*Rhipicephalus microplus*) in the pesticide industry (Mattos et al., 2021). Additionally, the oxidative stability of Crambe oil-derived biodiesel is higher than soybean oil-derived biodiesel, which opens another potential usage for Crambe (Wazilewski et al., 2013). Crambe oil is not used as cooking oil due to the presence of erucic acid, which has been found to cause health problems in humans. For instance, food contaminated with erucic acid can increase cardiovascular disease in humans (Hebard, 2016). Alternative erucic acid sources, such as Crambe, can help to solve the current risks of growing high erucic acid rapeseed. To avoid the entry of erucic acid into the food chain, the USA, Canada, and EU cultivate as an identity-preserved crop under contract. These strict limitations can result in time-consuming and expensive cultivation, transportation, processing and storage, and traceability. Hence, there is a need to find alternative and possibly cheaper sources of erucic acid.

Germplasm collection and ex situ conservation in gene banks are two of the most important tools for conservation biological diversity. As wild relatives of crops, several Crambe species are of additional interest with a view to using them to improve crops by plant breeding. All across the world, 1.117 Crambe accessions are present and *C. hispanica* shares 44% and *C. abyssinica* 22% of these accessions, respectively (Genesys, 2021). North Central Regional Plant Introduction Station (NCRPIS), USDA-ARS, United States, conserves the world's largest and most diverse collection of Crambe. NCRPIS contains 524 Crambe accessions and it shares 47 % of the conserved Crambe germplasm. When checked on the basis of countries, the USA (605), Spain (100), Germany (79), Australia

(72), and the UK (42) are the top five countries that conserve Crambe accessions.

Given the increasing pollution and global warming from the petroleum industry, it is important today to bring environmentally friendly plants as raw materials to the industry where environmental awareness is increasing. Biodegradability and naturality of the oil have increased the number of studies on Crambe in recent years. Because of the climatic unpredictability, the plant resources have to be diversified to a greater variety of crops to achieve a higher resistance. However, there is not enough information about the high erucic and gondoic acid Crambe species demanded by the industry, which originates from wild populations. Therefore, the study aimed to select the accessions with high oil quality potentials from Crambe species, which are naturally distributed in the Central Anatolian and Mediterranean regions.

MATERIAL and METHOD

The areas where some Crambe species naturally spread were determined in the flora of Niğde, Karaman, and Kahramanmaraş provinces (Table 1, Figure 1). Crambe plants were identified according to the identification keys of Davis (1965) by the taxonomist Prof. Dr. Ahmet İlçim. *C. orientalis* L. var. *orientalis* and *C. tataria* Sebeök var. *tataria* were collected in June-July 2020. *C. tataria* Sebeök var. *tataria* is distributed in Central Anatolia, stony slopes, and fallow areas. Its distribution altitude is 900-1400 m (Davis, 1965). *C. orientalis* L. var. *orientalis* is an Iran Turan element and is distributed in arid, hilly areas, cultivated field edges, and fallow areas in Central Anatolia, Eastern, and Southeastern Anatolia. The distribution altitude for *C. orientalis* is 500-2800 m according to Davis (1965).

Figure 1. Collection centers of the investigated Crambe species (1: Niğde 2: Karaman 3: Kahramanmaraş) (Google Earth, 2021)

Şekil 1. İncelenen Crambe türlerinin toplama merkezleri (1: Niğde 2: Karaman 3: Kahramanmaraş) (Google Earth, 2021)

Sample Preparation

For the determination of the fatty acid composition of the oils, fatty acid methyl esters were prepared from Crambe oil, using a methylation method (Stefanoudaki et al., 1999). The fatty acids were converted to fatty acid methyl esters before analysis by shaking a solution of 0.5 ml oil and 5 mL of hexane for 5 mins and added 0.5 mL of 2 N methanolic potassium hydroxide and shaken for 5 mins more and centrifuged 5 mins. 1 µl of the samples given to the GC-MS device.

Gas Chromatography±Mass Spectrometry (GC/MS) Analysis

GC-MS analyses were conducted in the Plant Physiology Laboratory in Biology Dept. of Kahramanmaras Sutcu Imam University, Kahramanmaras, Türkiye. Qualification of the oil was analyzed on an Agilent 5975C Mass Spectrometer coupled with an Agilent GC-6890II series. The GC was equipped with an HP-88 capillary column (100 m x 250 µm m x 0.20 µm film thickness) and He was used as carrier gas with a flow rate of 0.8 mL/min. The GC oven temperature was programmed as follows: 170 °C (1 min), 230 °C at 15 °C/min and then kept at 230 °C at 20 min. The injector temperature was 250 °C. The mass spectrometer was operating in EI mode at 70 eV. The split ratio was 20:1. Mass range 35-400m/z; scan speed (amu/s): 1000. Wiley7n.1, Famdbwax.L, Famedb23.L libraries were used for identifying the compounds. The chemical analyses were performed in triplicate.

Statistical analysis

Principal components analysis on correlations was performed using statistical software JMP® (version 14.0, SAS Institute Inc., Cary, NC, 1989-2019). The heat map was constructed using Flourish studio.

Table 1. List of investigated *Crambe* germplasm and localities
Çizelge 1. İncelenen Crambe gen kaynakları ve lokasyon listesi

Sample No (*Örnek No*)	Name of Accessions (*Aksesyon*)	Taxon (*Takson*)	Organ (*Organ*)	Collection Province (*Toplanan İl*)	District (*İlçe*)	Village (*Köy*)	Altitude (m) (*Rakım (m)*)	Coordinates (*Koordinantlar*)
S1	K-1	*C. tataria*	fruit	Karaman	Ayrancı	Hüyükburun	1124	37°21'17.0"N 33°40'06.2"E
S2	K-2	*C. orientalis*	fruit	Karaman	Merkez	Bölükyazı	1022	37°11'59.4"N 33°07'00.9"E
S3	K-3	*C. orientalis*	fruit	Karaman	Merkez	Ağılönü	1030	37°14'29.5"N 33°21'38.2"E
S4	K-4	*C. tataria*	fruit	Karaman	Kazımkarabekir	Yollarbaşı	1033	37°12'40.4"N 33°01'27.5"E
S5	K-5	*C. tataria*	fruit	Karaman	Ayrancı	Hüyükburun	1125	37°21'15.7"N 33°40'02.3"E
S6	K-6	*C. orientalis*	fruit	Karaman	Merkez	Çakırbağ	1023	37°11'46.2"N 33°08'03.3"E
S7	K-7	*C. tataria*	fruit	Karaman	Kazımkarabekir	Pazar	1077	37°12'55.4"N 32°59'04.5"E
S8	K-8	*C. tataria*	fruit	Karaman	Merkez	Merkez	1036	37°10'51.3"N 33°14'56.4"E
S9	K-9	*C. orientalis*	fruit	Karaman	Merkez	Merkez	1040	37°10'49.1"N 33°15'35.1"E
S10	K-10	*C. tataria*	fruit	Karaman	Merkez	Ağılönü	1029	37°15'01.7"N 33°23'04.8"E
S11	N-1	*C. orientalis*	fruit	Niğde	Merkez	Ovacık	1340	38°04'29.5"N 34°47'45.8"E
S12	N-1	*C. orientalis*	seed	Niğde	Merkez	Ovacık	1340	38°04'29.5"N 34°47'45.8"E
S13	N-2	*C. orientalis*	fruit	Niğde	Merkez	Ovacık	1346	38°04'40.6"N 34°48'04.9"E
S14	N-2	*C. orientalis*	seed	Niğde	Merkez	Ovacık	1346	38°04'40.6"N 34°48'04.9"E
S15	N-3	*C. orientalis*	fruit	Niğde	Merkez	Çarıklı	1340	38°05'02.8"N 34°48'51.8"E
S16	N-3	*C. orientalis*	seed	Niğde	Merkez	Çarıklı	1340	38°05'02.8"N 34°48'51.8"E
S17	N-4	*C. orientalis*	fruit	Niğde	Merkez	Çarıklı	1368	38°10'52.5"N 34°57'29.5"E
S18	N-4	*C. orientalis*	seed	Niğde	Merkez	Çarıklı	1368	38°10'52.5"N 34°57'29.5"E
S19	N-5	*C. tataria*	fruit	Niğde	Merkez	Karaatlı	1368	38°10'44.3"N 34°57'10.5"E
S20	N-6	*C. orientalis*	fruit	Niğde	Merkez	Karaatlı	1362	38°09'11.9"N 34°54'38.3"E
S21	N-7	*C. orientalis*	fruit	Niğde	Merkez	Yeşilgölcük	1340	38°10'24.3"N 34°47'26.5"E
S22	N-7	*C. orientalis*	seed	Niğde	Merkez	Yeşilgölcük	1340	38°10'24.3"N 34°47'26.5"E
S23	N-8	*C. orientalis*	fruit	Niğde	Merkez	Yaylayolu	1360	38°03'56.4"N 34°43'17.6"E
S24	N-8	*C. orientalis*	seed	Niğde	Merkez	Yaylayolu	1360	38°03'56.4"N 34°43'17.6"E
S25	N-9	*C. orientalis*	fruit	Niğde	Merkez	Aktaş	1312	38°02'39.8"N 34°44'07.1"E
S26	N-9	*C. orientalis*	seed	Niğde	Merkez	Aktaş	1312	38°02'39.8"N 34°44'07.1"E
S27	N-10	*C. orientalis*	seed	Niğde	Merkez	Edikli	1356	38°13'22.9"N 34°57'51.2"E
S28	N-10	*C. orientalis*	fruit	Niğde	Merkez	Edikli	1356	38°13'22.9"N 34°57'51.2"E
S29	M-1	*C. orientalis*	fruit	Kahramanmaraş	Dulkadiroğlu	Ulutaş	1588	37°37'25.2"N 37°00'54.0"E
S30	M-1	*C. orientalis*	seed	Kahramanmaraş	Dulkadiroğlu	Ulutaş	1588	37°37'25.2"N 37°00'54.0"E

RESULTS and DISCUSSION

The chemical composition of fatty acids was analyzed by GC/MS, and obtained results were summarized (Table 2). The chemical composition of Crambe oil varied according to location and species. Fifteen compounds were found, representing 84.6-100% of the total seed oils. The major components based on the location and the species were erucic acid (24.7-44.7%), gondoic acid (19.0-28.3%), oleic acid (14.9-28.5%), and linoleic acid (8.1-17.6%). In the study, seed and fruit of Crambe accessions collected from three provinces were examined separately and no statistical difference was found in terms of fatty acid compounds. Similarly, Mridula et al. (2015) revealed that a minor change in whole and dehulled flaxseed oil samples were observed, although it was not statistically significant. This result will provide convenience by reducing the need for additional labor during oil extraction.

The erucic acid content of *C. tataria* ranged from 25.6 to 29.7% based on the location and the species with a mean of 27.5%. When we compared the erucic acid content of *C. tataria* with the earlier studies, diverse results were found; 27.0% (Miller et al., 1965), 29.9% (Comlekcioglu et al., 2008), 20.7% (Dolya et al., 1977), 30.8% (Subasi, 2020). The erucic acid content of *C. orientalis* ranged from 30.9 to 44.7% with a mean of 35.1%. Diverse results based on the erucic acid content of *C. orientalis* were also reported by the researchers; 36.0% (Miller et al., 1965), 39.4% (Comlekcioglu et al., 2008), 34.7% (Dolya et al., 1977), 37.8% (Subasi, 2020).

These diverse results are thought to be due to differences between plant material and climatic conditions. The erucic acid content was reported for *C. abyysinica* seeds; 50-58.6% (Warwick et al., 2003), 50.0-60.0% (Yaniv et al., 1998), 57.2% (Oliveira et al., 2013), and for *C. hispanica* seeds; 48.5-57.9% (Warwick et al., 2003) and 45.05-56.25% (Arslan et al., 2015). Although the differences in the findings vary according to the plant species, it has been stated that it may vary according to the plant organs, development periods, time of collection, ecological factors, and genetic structure (Yaniv et al., 1991; Mastebroek et al., 1994). However, some researchers have pointed out that the erucic acid content is quite stable and is not affected by the environment (Bondioli et al., 1998; Fontana et al., 1998). Compared to other oil plants of the Brassicaceae family, which are rich in erucic acid, it was reported in *Brassica oleraceae*, 45.7%; in *Brassica napus*, 46.4%; in *Sinapis alba*, 37.6% and in hybrids of both species with 44.5% (Ayaz et al., 2006). In the findings, it can be observed that the erucic acid content of *C. orientalis* and *C. tataria* does not reach the erucic acid content of *C. hispanica* and *C. abyysinica*. In addition, as in annual species, the main component was determined as erucic acid in this study which was perennial species.

The gondoic acid content of *C. tataria* ranged from 20.4 to 28.0% with a mean of 24.6%. Differences in the gondoic acid content were also reported by the researchers; 16.5% (Dolya et al., 1977), 7.7% (Comlekcioglu et al., 2008), 21.0% (Miller et al., 1965), 19.4% (Subasi, 2020). Gondoic acid content of *C. orientalis* ranged from 19.0 to 28.3% with a mean of 25.3%. When we compared the gondoic acid content of *C. orientalis* with the earlier studies, diverse results were found; 19.4% (Dolya et al., 1977), 11.3% (Comlekcioglu et al., 2008), 20.0% (Miller et al., 1965), 16.0% (Subasi, 2020). The gondoic acid content was reported for *C. abyysinica* seeds; 2.8% (Dolya et al., 1977), 3.7-5.6% (Warwick et al., 2003), and for *C. hispanica* seeds; 2.6-6.6% (Warwick et al., 2003). The gondoic acid findings are higher when compared to the annual Crambe species. Compared to other oil plants of the Brassicaceae family, which are rich in erucic acid, it was reported in *Brassica oleraceae*, 45.7%; in *Brassica napus*, 46.4%; in *Sinapis alba*, 37.6% and in hybrids of both species with 44.5% (Ayaz et al., 2006).

The oleic acid content of *C. tataria* ranged from 15.3 to 28.5% with a mean of 19.4%. Previous studies have reported that the oleic acid content of *C. tataria* varied; 28.7% (Dolya et al., 1977), 21.0% (Miller et al., 1965), 1.4% (Comlekcioglu et al., 2008), 34.7% (Dolya et al., 1977), 23.8% (Subasi, 2020). The oleic acid content of *C. orientalis* ranged from 14.9 to 24.9% with a mean of 20.4%. Variations in the oleic acid content have also been reported by other researchers; 1.6% (Comlekcioglu et al., 2008) 18.0% (Miller et al., 1965) 18.1% (Dolya et al., 1977) 21.7% (Subasi 2020). The difference in the oleic acid rate observed across these studies may simply reflect the environmental influences. The oleic acid content was reported for *C. abyysinica* seeds; 16.0-22.8% (Warwick et al., 2003), 15% (Yaniv et al., 1998), 17.2% (Oliveira et al., 2013), and for *C. hispanica* seeds; 17.0-20.6% (Warwick et al., 2003). The findings are higher when compared to the annual Crambe species.

The linoleic acid content of *C. tataria* ranged from 12.5 to 17.6% with a mean of 13.6%. The linoleic acid content results are close or higher than the other results; 22.1% (Dolya et al., 1977), 9.0% (Comlekcioglu et al., 2008), 15.0% (Miller et al., 1965), 12.4% (Subasi, 2020). The linoleic acid content of *C. orientalis* ranged from 8.1 to 13.6% with a mean of 10.5%. Similar results based on the linoleic acid content of *C. orientalis* were also reported by the researchers; 13.0% (Dolya et al., 1977), 12.4% (Comlekcioglu et al., 2008), 11.0% (Miller et al., 1965), 9.38% (Subasi, 2020). The linoleic acid content was reported for *C. abyysinica* seeds; 6.9-8.5% (Warwick et al., 2003), 9% (Yaniv et al., 1998), 8.2% (Oliveira et al., 2013), and for *C. hispanica* seeds; 5.4-8.4% (Warwick et al., 2003). The available studies show that the fatty acid composition of *Crambe* varies greatly depending on the origin, genotype, and climatic conditions of the growing areas. Moreover, the oil composition of *C. tataria* and *C. orientalis* is found to be less than 3% palmitic acid, palmitoleic acid, heptadecanoic acid, cis-10- heptadecenoic acid, stearic acid, arachidic acid, 8,11-eicosadienoic acid, behenic acid, 13z 16z-docosadienoic acid, lignoceric acid and nervonic acid.

Principal Component Analysis Biplot of the Samples According to Fatty Acid Compounds

The biplot (PCAbiplot) format is used to represent a data source with a few components that best reflect the data's variance. It allows to zoom out on the data and see the relationships among the variables that make up the data. There is a positive correlation among the lines that are in the same direction and close to each other, while there is a negative correlation among the opposite and distant lines. PCAbiplot on correlations was performed to visualize the effect of locations and the species (Fig. 2). The experimental groups were separately discriminated with principal component analysis on correlations. In terms of the seed oil components, clear discrimination was revealed on the plotted scores, where component 1 and component 2 accounted for 52.1% of the total variance. The first axis and second axis explained 37.5% and 14.6% of the total variance, respectively. As seen in the figure, PCAbiplot indicates that erucic acid was negatively correlated with gondoic acid and oleic acid.

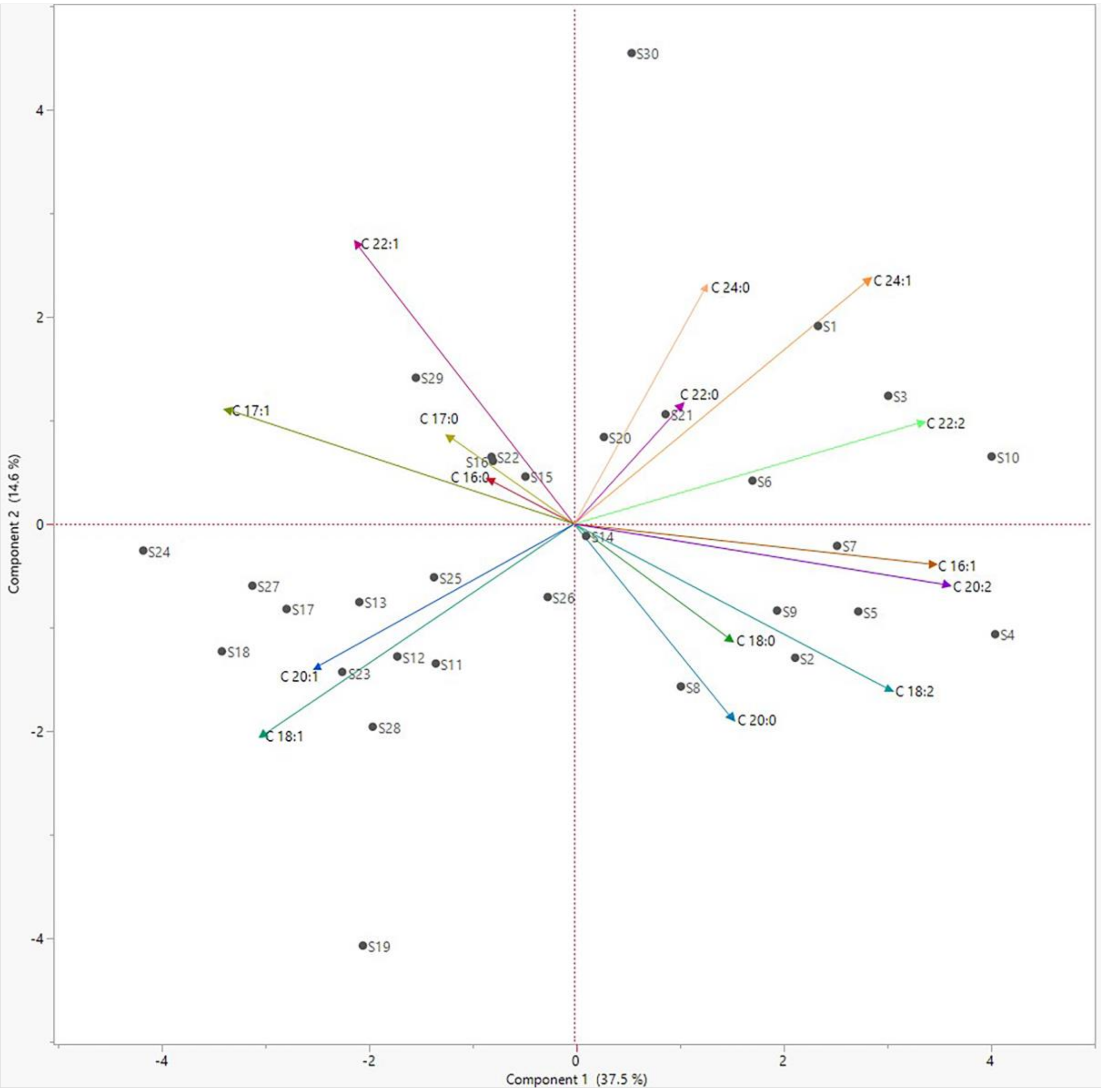

Figure 2. Principal component analysis on correlations of the samples according to fatty acid compounds (C 16:0 (Palmitic acid), C 16:1 (Palmitoleic acid), C 17:0 (Heptadecanoic acid), C 17:1 (cis-10-Heptadecenoic acid), C 18:0 (Stearic acid), C 18:1 (Oleic acid), C 18:2 (Linoleic acid), C 20:0 (Arachidic acid), C 20:1 (Gondoic acid), C 20:2 (8,11-Eicosadienoic), C 22:0 (Behenic acid), C 22:1 (Erucic acid), C 22:2 (13z 16z-docosadienoic acid), C 24:0 (Lignoceric acid), C 24:1 (Nervonic acid)).

Şekil 2. Aksesyonlardaki yağ asitlerinin korelasyona bağlı temel bileşen analizi, (C 16:0 (Palmitik asit), C 16:1 (Palmitoleik asit), C 17:0 (Heptadecanoic asit), C 17:1 (cis-10-Heptadecenoic asit), *C 18:0 (Stearik asit), C 18:1 (Oleik asit) C 18:2 (Linoleik asit), C 20:0 (Araşidik asit), C 20:1 (Gondoik asit), C 20:2 (8,11-Eikosadienoik), C 22:0 (Behenik asit), C 22 :1 (Erusik asit), C 22:2 (13z 16z-dokosadienoik asit), C 24:0 (Lignoserik asit), C 24:1 (Nervonik asit)).*

Heat Map for the Samples According to Main Fatty Acid Compounds

The changes in fatty acid components were structured using a heat map. According to the heat map (Fig. 3), the fatty acids were visualized under the samples. The differences among treatments can be observed easily with the help of the heat map. For instance; the highest erucic acid content was noted on S30, the highest gondoic acid content was noted on S-17 and the highest oleic acid content was noted on S-19. The differences can be observed clearly among the samples.

CONCLUSIONS

Crambe is an alternative plant for the production of biofuels, especially biodiesel, among the renewable energy sources instead of fossil fuels in our world threatened by global warming and climate change. Increasing genetic variability and discovering genotypes that are better suited to different environmental conditions can be beneficial, as future agriculture will have to adapt to climate change.

Table 2. Fatty acid compounds of Crambe accessions collected from different collection sites
Çizelge 2. Farklı bölgelerden toplanan Crambe aksesyonlarının yağ asidi bileşenleri

Fatty Acid Compounds (Yağ Asidi Bileşenleri)				C 16:0	C 16:1	C 17:0	C 17:1	C 18:0	C 18:1	C 18:2	C 20:0	C 20:1	C 20:2	C 22:0	C 22:1	C 22:2	C 24:0	C 24:1
Retention Time (min) *(Çıkış Zamanı (dakika))*				13.12	13.76	14.55	14.73	15.07	15.86	16.96	17.43	18.58	19.52	20.92	21.92	23.45	24.16	25.59
Sample No *(Örnek No)*	Accessions *(Aksesyonlar)*	Taxon *(Takson)*	Organ *(Organ)*								Area % *(Alan %)*							
S1	K-1	*C. tataria*	fruit	2.22	0.37	0.03	0.07	0.52	17.16	12.53	0.03	24.82	1.12	5.88	29.06	0.75	0.17	1.14
S2	K-2	*C. orientalis*	fruit	2.32	0.37	0.02	0.03	0.81	17.77	12.75	1.15	22.47	0.95	0.46	31.34	0.66	0.02	1.05
S3	K-3	*C. orientalis*	fruit	2.43	0.41	0.03	0.07	0.55	14.92	12.25	1.22	21.89	0.94	0.45	32.97	0.80	0.27	1.25
S4	K-4	*C. tataria*	fruit	2.31	0.44	0.05	0.08	1.47	16.49	12.89	1.13	23.85	1.25	0.42	27.51	0.67	0.20	1.40
S5	K-5	*C. tataria*	fruit	2.60	0.43	0.05	0.08	0.78	19.91	13.39	1.07	25.69	1.13	0.40	27.12	0.72	0.22	1.30
S6	K-6	*C. orientalis*	fruit	2.32	0.36	0.04	0.06	0.53	17.57	12.30	0.95	27.66	1.07	0.41	31.22	0.54	0.28	1.37
S7	K-7	*C. tataria*	fruit	2.12	0.40	0.02	0.08	0.50	15.25	17.56	-	20.35	0.98	0.29	25.60	0.39	0.13	0.88
S8	K-8	*C. tataria*	fruit	2.33	0.37	0.03	0.07	0.62	20.59	13.20	0.86	27.02	1.10	0.31	29.16	0.39	0.11	1.06
S9	K-9	*C. orientalis*	fruit	2.65	0.43	0.02	0.02	0.63	19.05	13.63	0.99	22.88	0.97	0.35	30.87	0.43	0.11	1.18
S10	K-10	*C. tataria*	fruit	2.45	0.41	0.03	0.05	0.62	18.16	12.86	1.17	22.62	1.29	0.43	29.72	1.03	0.29	1.43
S11	N-1	*C. orientalis*	fruit	2.43	0.30	0.05	-	0.60	22.68	10.55	0.88	25.62	0.64	0.31	34.55	0.36	0.11	0.19
S12	N-1	*C. orientalis*	seed	2.58	0.27	0.04	-	0.67	24.90	9.54	0.87	26.30	0.56	0.32	32.80	0.28	0.10	0.74
S13	N-2	*C. orientalis*	fruit	2.42	0.31	-	-	0.55	20.15	10.61	0.92	25.60	-	0.37	37.47	0.29	-	0.69
S14	N-2	*C. orientalis*	seed	2.37	0.31	0.04	-	0.57	19.44	10.57	1.14	25.13	0.81	0.45	37.20	0.45	0.14	0.89
S15	N-3	*C. orientalis*	fruit	2.65	0.36	0.03	-	0.48	20.71	9.78	0.88	25.57	0.63	0.32	36.82	0.43	0.16	1.02
S16	N-3	*C. orientalis*	seed	2.64	0.37	0.04	-	0.49	19.90	9.31	0.78	25.97	0.61	0.31	38.07	0.38	0.13	1.00
S17	N-4	*C. orientalis*	fruit	2.06	0.17	0.03	-	0.43	21.60	8.32	0.66	28.33	0.62	0.21	36.51	0.23	-	0.70
S18	N-4	*C. orientalis*	seed	1.90	0.09	-	-	0.86	21.76	8.13	0.52	27.77	0.39	0.22	36.42	0.16	-	0.44
S19	N-5	*C. tataria*	fruit	3.04	0.28	-	-	0.59	28.46	12.88	0.84	28.02	0.59	0.08	24.67	0.17	-	0.38
S20	N-6	*C. orientalis*	seed	2.06	0.20	-	-	0.54	20.38	9.67	0.82	24.75	0.86	-	34.67	0.56	0.17	1.59
S21	N-7	*C. orientalis*	fruit	2.77	0.37	0.04	-	0.46	17.30	11.17	0.78	25.39	0.69	0.53	35.39	0.75	0.14	1.25
S22	N-7	*C. orientalis*	seed	2.94	0.37	0.45	-	0.46	18.04	11.39	0.76	26.87	0.74	0.21	36.31	0.44	0.09	0.90
S23	N-8	*C. orientalis*	fruit	2.76	0.28	-	-	0.46	22.66	10.21	0.63	27.32	0.57	0.23	34.10	0.24	-	0.52
S24	N-8	*C. orientalis*	seed	2.66	0.16	-	-	0.41	22.82	9.92	-	26.16	-	0.20	34.49	0.15	-	0.47
S25	N-9	*C. orientalis*	fruit	2.48	0.31	-	-	-	22.70	10.96	0.93	25.02	0.61	0.37	34.87	0.34	0.10	0.62
S26	N-9	*C. orientalis*	seed	2.53	0.32	0.04	-	0.68	22.58	11.15	1.04	24.02	0.66	0.46	34.87	0.40	0.15	0.73
S27	N-10	*C. orientalis*	fruit	2.59	0.23	-	0.60	0.52	21.95	9.71	0.79	26.86	0.70	0.23	34.63	0.29	-	0.70
S28	N-10	*C. orientalis*	seed	2.42	0.30	-	-	0.46	24.37	10.35	0.71	26.89	0.59	0.20	32.67	0.28	-	0.50
S29	M-1	*C. orientalis*	fruit	2.48				0.67	19.48	9.48	0.48	23.83	0.63	0.43	33.40	0.26	0.24	1.17
S30	M-1	*C. orientalis*	seed	2.87	0.29			0.53	15.85	9.89	0.45	18.97	0.51	0.42	44.68	0.41	0.23	2.11

C 16:0 (Palmitic acid), C 16:1 (Palmitoleic acid), C 17:0 (Heptadecanoic acid), C 17:1 (cis-10-Heptadecenoic acid), C 18:0 (Stearic acid), C 18:1 (Oleic acid), C 18:2 (Linoleic acid), C 20:0 (Arachidic acid), C 20:1 (Gondoic acid), C 20:2 (8,11-Eicosadienoic), C 22:0 (Behenic acid), C 22:1 (Erucic acid), C 22:2 (13z 16z-docosadienoic acid), C 24:0 (Lignoceric acid), C 24:1 (Nervonic acid)

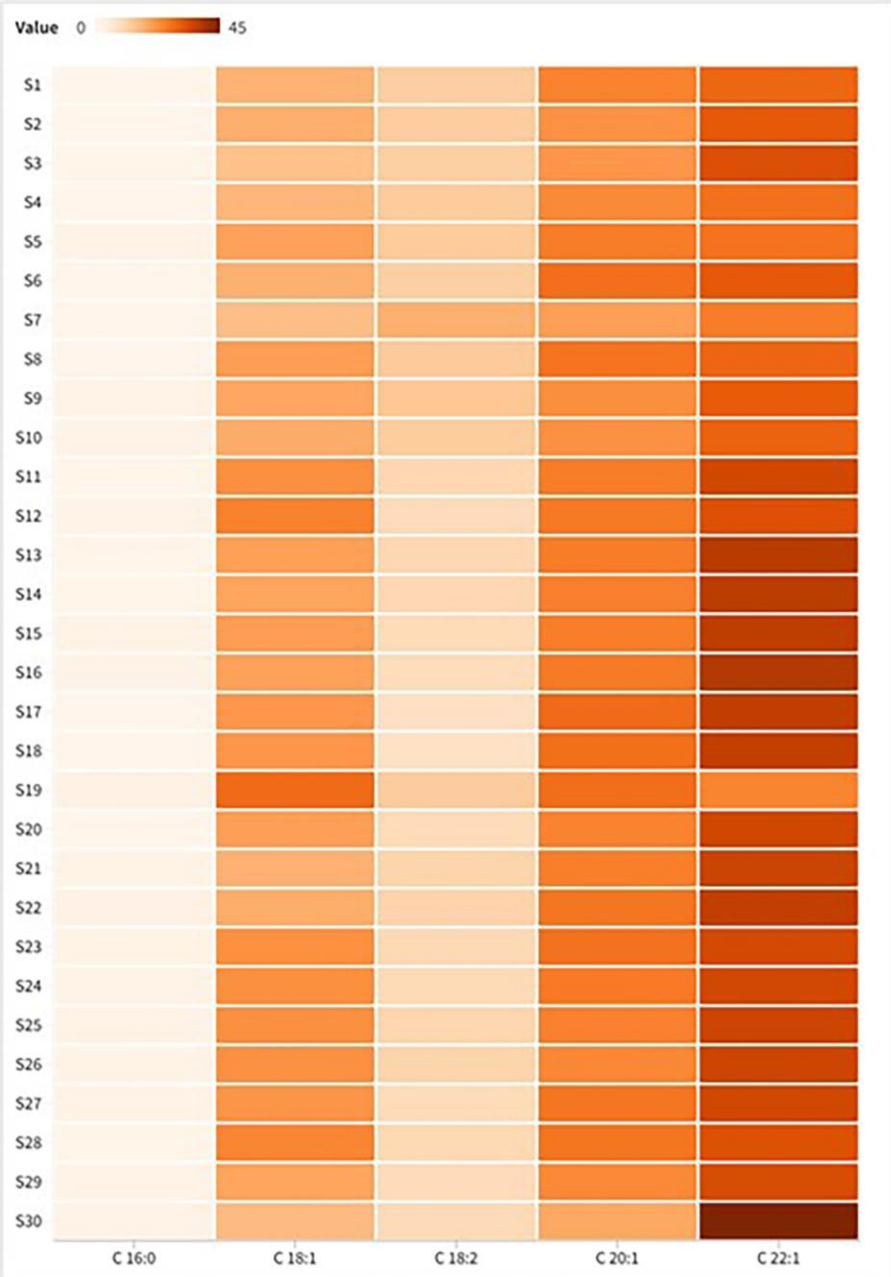

Figure 3. Heatmap for the fatty acids of Crambe samples (Value=%)
Şekil 3. Crambe örneklerinin yağ asitleri bakımından ısı haritası (Değer=%)

Crambe is one of the important genera for industrial uses of its oil. It is a cost-effective oil plant compared to many others. In the study, different Crambe plants were collected at various locations in the Central Anatolian and Mediterranean regions, the species were identified and the seed and fruit oil composition were evaluated. As a result of the identification, two different species, *C. orientalis* and *C. tataria*, were determined. However, the amount of erucic acid of both species was lower than the annual *C. abyssinica*, which is cultivated in different parts of the world. This is due to the varieties improved for the higher amount of erucic acid demanded by the industry, in addition to the genetic species characteristic of *C. abyssinica*. *Crambe*, which has a high production potential due to its natural presence in Türkiye, is not well-known commercially. In recent years, increasing awareness around the world about agriculture and the environment has led to an intensification of studies on this plant. Since it is a crop that can be grown taking advantage of winter and spring rainfall, it has good potential as an alternative oil crop for industrial purposes in those regions that oppose the increase in drought. Different species of Crambe, stand out with their biodegradable feature, and the determination of morphological and quality characteristics of these species have gained importance in this respect. Further studies are recommended to focus on studies aimed at achieving the higher levels of erucic and gondoic acid required by the industry and examining the yield and quality of Crambe species in different regions.

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Author's Contributions

The contribution of the authors is equal.

Statement of Conflict of Interest

The authors have declared no conflict of interest.

REFERENCES

Adamsen FJ, Coffelt TA 2005. Planting date effects on flowering, seed yield, and oil content of rape and crambe cultivars. Industrial Crops and Products 21(3): 293-307.

Arslan Y, Subaşı İ, Keyvanoğlu H 2015. Crambe (*Crambe hispanica* subsp. *abyssinica*) Genotiplerinin Bazı Bitkisel Özelliklerinin Belirlenmesi. Tarla Bitkileri Merkez Araştırma Enstitüsü Dergisi 24 (1): 16-23.

Ayaz FA, Glew RH, Millson M, Huang HS, Chuang LT, Sanz C, Hayırlıoglu-Ayaz S 2006. Nutrient contents of kale (*Brassica oleraceae* L. var. *acephala* DC.). Food Chemistry 96(4): 572-579.

Bondioli P, Folegatti L, Lazzeri L, Palmieri S 1998. Native *Crambe abyssinica* oil and its derivatives as renewable lubricants: an approach to improve its quality by chemical and biotechnological processes. Industrial Crops and products 7: 231-238.

Comlekcioglu N, Karaman S, Ilcim A 2008. Oil composition and some morphological characters of *Crambe orientalis* var. *orientalis* and *Crambe tataria* var. *tataria* from Turkey. Natural Product Research 22: 525-532.

Costa E, Almeida MF, Alvim-Ferraz C, Dias JM 2019. The cycle of biodiesel production from *Crambe abyssinica* in Portugal. Industrial Crops and Products 129: 51-58.

Davis PH, Miller RR, Tan K 1965. Flora of Turkey and the Aegean Islands. Vol. 1-9.

Dolya VS, Shkurupii EN, Kaminskii NA, Magerya ED 1977. Oils of the seeds of nine species of the genus *Crambe*. Chemistry of Natural Compounds 13: 14-16.

Falasca SL, Flores N, Lamas MC, Carballo SM, Anschau A 2010. *Crambe abyssinica*: An almost unknown crop with a promissory future to produce biodiesel in Argentina. International Journal of Hydrogen Energy 35: 5808-5812.

Fontana F, Lazzeri L, Malaguti L, Galletti S 1998. Agronomic characterization of some *Crambe abyssinica* genotypes in a locality of the Po Valley. European Journal of Agronomy 9: 117-126.

Genesys 2021. Genesys Global Portal on Plant Genetic Resources. www.genesys-pgr.org. (Accessed 05.09.2021).

Glaser LK 1996. *Crambe*: an economic assessment of the feasibility of providing multiple-peril crop insurance. Washington, DC: Economic Research Service for the Risk Management Agency.

Google Earth Pro 7.3.4.8248. 2021. Turkey. Borders and labels; places layers. http://www.google.com/earth/index.html. (Accessed 15.09.2021).

Hebard A 2016. Successful commercialization of industrial oil crops. In Industrial Oil Crops, AOCS Press 343-358.

Kikukawa H, Sakuradani E, Nishibaba Y, Okuda T, Ando A, Shima J, Shimizu S, Ogawa J 2015. Production of cis-11-eicosenoic acid by *Mortierella fungi*. Journal of Applied Microbiology 118(3): 641-647.

Köybaşı Ö, Tansı LS 2008. Çukurova Koşullarında Bazı *Crambe* Türlerinin Verim ve Yağ Oranlarının Saptanması. Çukurova Üniversitesi Fen Bil Enstitüsü Tarla Bitkileri Ana Bilim Dalı, Yüksek Lisans Tezi, 69 sy.

Mastebroek HD, Wallenburg SC, Van Soest LJ 1994. Variation for agronomic characteristics in *Crambe* (*Crambe abyssinica* Hochst. ex Fries). Industrial Crops and Products 2: 129-136.

Mattos C, Andrade J, NL TM, da Cunha Veloso MC, Folly ED (2021). Acaricidal Properties of Bio-Oil Derived from Slow Pyrolysis of *Crambe abyssinica* Fruit Against the Cattle Tick *Rhipicephalus microplus* (Acari: Ixodidae). Frontiers in Physiology 12: 768522-768522.

Miller RW, Earle FR, Wolff IA, Jones Q 1965. Search for new industrial oils. XIII. Oils from 102 species of *Cruciferae*. Journal of the American Oil Chemists' Society 42: 817-821.

Morimoto K, Tojima H, Haruta T, Suzuki M, Kakemi M 1996. Enhancing effects of unsaturated fatty acids with various structures on the permeation of indomethacin through rat skin. Journal of Pharmacy and Pharmacology 48(11): 1133-1137.

Mridula D, Barnwal P, Singh KK 2015. Screw pressing performance of whole and dehulled flaxseed and some physico-chemical characteristics of flaxseed oil. Journal of Food Science and Technology 52(3): 1498-1506.

Nelson LA, Grombacher A, Baltensperger DD 1993. G93-1126 *Crambe* Production.

Oliveira L, Da Silva MJRE, Journal PQ 2013. Comparative study of calorific value of rapeseed, soybean, jatropha curcas and *Crambe* biodiesel. Renewable Energy and Power Quality Journal 1: 679-682.

Oplinger ES, Oelke EA, Kaminski AR, Putnam DH, Teynor TM, Doll JD, Kelling KA, Durgan BR, Noetzel DM 1991. *Crambe*: alternative field crops manual. University of Wisconsin and University of Minnesota. St. Paul, MN. 55108.

Qi W, Tinnenbroek-Capel IE, Salentijn EM, Zhang Z, Huang B, Cheng J, Shao H, Visser RG, Krens FA, Van Loo EN 2018. Genetically engineering *Crambe abyssinica*-A potentially high-value oil crop for salt land improvement. Land Degradation & Development 29(4): 1096-1106.

Rogério F, da Silva TR, dos Santos JI, Poletine JP 2013. Phosphorus fertilization influences grain yield and oil content in *Crambe*. Industrial Crops and Products 41: 266-268.

Rudloff E, Wang Y 2011. *Crambe*. In: Wild crop relatives: Genomic and breeding resources. Springer 97-116.

Stefanoudaki E, Kotsifaki F, Koutsaftakis A. 1999. Classification of virgin olive oils of the two major Cretan cultivars based on their fatty acid composition. Journal of the American Oil Chemists' Society 76(5): 623-626.

Subasi I 2020. Seed fatty acid compositions and chemotaxonomy of wild *Crambe* (Brassicaceae) taxa in Turkey. Turkish Journal of Agriculture Forestry 44: 662-670.

Tansı S, Yaniv Z, Kahraman SJPNT-S 2003. Çukurova Koşullarında *Crambe* spp'nin Kültürü Olanakları ile Kalitesinin Belirlenmesi Üzerine Bir Araştırma. 63.

Warwick SI, Gugel RKJGR, Evolution C 2003. Genetic variation in the *Crambe abyssinica*-*C. hispanica*-*C. glabrata* complex. Genetic Resources and Crop Evolution 50: 291-305.

Wazilewski WT, Bariccatti RA, Martins GI, Secco D, de Souza SN, Rosa HA, Chaves LI 2013. Study of the methyl *Crambe* (*Crambe abyssinica* Hochst) and soybean biodiesel oxidative stability. Industrial Crops and Products 43: 207-212.

Yaniv Z, Elber Y, Zur M, Schafferman D 1991. Differences in fatty acid composition of oils of wild *Cruciferae* seed. Phytochemistry 30: 841-843.

Yaniv Z, Shabelsky E, Schafferman D, Granot I, Kipnis T 1998. Oil and fatty acid changes in Sinapis and *Crambe* seeds during germination and early development. Industrial Crops and Products 9: 1-8.