






Article

Coriander (*Coriandrum sativum* L.) from Alentejo (South Portugal)—Ethnobotany and Potential Industrial Use

Orlanda Póvoa ^{1,*}, Noémia Farinha ^{1,*}, Violeta Lopes ², Alexandra M. Machado ³
and Ana Cristina Figueiredo ³

- ¹ VALORIZA—Centro de Investigação para a Valorização de Recursos Endógenos, Instituto Politécnico de Portalegre, Praça do Município 11, 7300-110 Portalegre, Portugal
- ² Banco Português de Germoplasma Vegetal (BPGV), Instituto Nacional de Investigação Agrária e Veterinária, Quinta de S. José, S. Pedro de Merelim, 4700-859 Braga, Portugal; violeta.lopes@iniav.pt
- ³ Centro de Estudos do Ambiente e do Mar (CESAM Lisboa), Faculdade de Ciências da Universidade de Lisboa (FCUL), Biotecnologia Vegetal, DBV, C2, Campo Grande, 1749-016 Lisboa, Portugal; ialexam@gmail.com (A.M.M.); acsf@fc.ul.pt (A.C.F.)
- * Correspondence: opovo@ippportalegre.pt (O.P.); nfarinha@ippportalegre.pt (N.F.); Tel.: +351-268628528 (O.P. & N.F.)

Abstract: Coriander is a medicinal and aromatic plant (MAP) traditionally cultivated and used in Alentejo, Portugal. However, few publications are available about its ethnobotanical applications. Four independent ethnobotanical surveys were carried out: throughout the region (2002–2003), in three villages (2013), and in city markets (2007 and 2022). Coriander was the most common fresh cultivated MAP (75% of the total area) and also the most representative MAP fresh herb in city markets. The leaves, mostly, were used fresh or frozen or transformed in *piso*. Some of the recipes have agro-industrial potential, such as *piso* and aromatized olive oil. Coriander essential oils (EOs) were isolated by hydrodistillation from aerial parts with inflorescence emergence (APIs) and from fruits, and fatty acids (FA) by solvent extraction from the fruits. Gas chromatography and gas chromatography-mass spectrometry analysis showed EOs dominated by *n*-decanal (21–24%), 2-*trans*-decanal (12–18%) and *n*-nonane (10–17%) in APIs, and linalool dominance (73–78%) in the fruits. Petroselinic acid (32–55%) was the dominant fatty acid. A literature survey on conventional and nonconventional extraction techniques showed a constancy in the dominant compounds isolated, highlighted *piso* as a home-made green-extraction procedure, but also reflected the relevance of coriander as a MAP with diverse industrial potential uses.

Keywords: ethnobotany; traditional recipes; local markets; medicinal and aromatic plants (MAP); essential oils; fatty acids; extraction procedures



Citation: Póvoa, O.; Farinha, N.; Lopes, V.; Machado, A.M.; Figueiredo, A.C. Coriander (*Coriandrum sativum* L.) from Alentejo (South Portugal)—Ethnobotany and Potential Industrial Use. *Foods* **2024**, *13*, 929. <https://doi.org/10.3390/foods13060929>

Academic Editor: Jayanta Kumar Patra

Received: 29 January 2024
Revised: 13 March 2024
Accepted: 15 March 2024
Published: 19 March 2024



Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

The term ethnobotany was introduced in 1895 by the American botanist John Harshberger and at the end of the 19th century, ethnobotany began to emerge as a science, offering a whole new field for pharmaceutical research [1–3]. Ethnobotany can be described in several contexts such as the study of the relationship between plants and humans since the term “ethno” refers to the study of people and “botany” to the investigation of plants [1–3].

Humans have used plants and natural products in general with a traditional understanding that dates back thousands of years. Ancient societies made extensive use of plants as spices or as the primary ingredients in food preparations. Plants were also the primary therapeutic agents used by humans until the middle of the 19th century, and their value in medicine is still acknowledged today as sources of bioactive compounds for the development of drugs and health-promoting products [1–3]. Recent studies focusing on the US market show that herbal dietary supplements sales surpassed USD 10 billion for the first time in 2020 [4–7].

The United Nations Sustainable Development Goals (UNSDG) represent a vision of a peaceful, fairer, and sustainable world. The third UNSDG is “Good Health and Well-Being” [8], which aims to enhance health by using health-enhancing plants and environmentally friendly practices in the food industry. Future dietary habits will be influenced by the advances made today since they may lead to the creation of plant-based goods with useful features that improve human health. The World Health Organization (WHO) reported that almost 80% of the global population depends on traditional medicine. WHO emphasized the significance of investigating medicinal plants for potential benefits to health (i.e., safety, efficacy, dose, clinical trials, toxicity, drug interaction, and therapeutic use). There is huge interest in aromatic plants as phytoconstituent-rich sources for nutraceuticals, innovative foods, and medications due to advancements in clinical nutrition. Due to their potential to improve health, interest in essential oils and plant-based active ingredients has grown [9,10].

The global demand for Medicinal and Aromatic Plants (MAPs) is on the rise, predominantly fueled by natural habitats as primary sources. In 2021, the European Union (EU) imported over 227 thousand tons of MAPs, with more than 50% originating from developing countries. Consequently, developing countries have emerged as pivotal suppliers of MAPs to Europe. From 2017 to 2021, the aggregate import volume of aromatic and MAPs into Europe exhibited an average annual growth rate of 3% [11,12].

Coriandrum sativum L. (coriander, family Umbelliferae or Apiaceae) is one of the oldest spices used also for its therapeutic properties. The origin of this MAP is the eastern Mediterranean and it's grown in Europe, Africa, and Asia. All coriander parts are used as aromatic agents and/or as traditional medicines in different civilizations. Coriander leaves (cilantro or Chinese parsley) and coriander fruit (seed) are used in curry meat dishes, puddings, bread, soups, poultry, fish, and seafood dishes, or even to mask unpleasant odors in some foods. *C. sativum* contains high levels of vitamin B12, folate, vitamin C, vitamin A, and phenolics [2,9,13–16]. Due to its antimicrobial and antioxidant properties, coriander is used as an alternative food preservative [9,13–15].

In addition to coriander seasoning qualities, its nutritional and biological properties can be highlighted, including digestive, antioxidant, antimicrobial, hypoglycaemic, antihyperlipidemic, analgesic, anti-inflammatory and anticonvulsant activities, among others. These properties are due to the presence of several classes of phytoconstituents like carotenoids, tannins, phenolic acids, flavonoids, coumarins and terpenes [3,9,17–20]. Coriander roots and seeds contain bioactive phytochemicals (i.e., gallic acid, thymol, and bornyl acetate). Linalool is the main leaf volatile constituent responsible for several coriander therapeutic traits. Other active ingredients in coriander include essential oils, fatty acids, tocopherols, and sterols. Varieties, genotypes, ecotypes, planting season and condition, plant part, growth stage, harvesting period, and extraction method all affect the yields and compositions of these components. Both coriander aerial parts and seeds provide solvent extracts, water-soluble compounds, fixed oils, and essential oils. Coriander essential oil ranks second highest in the global annual production [9].

Coriander benefits can be extended to related fields, such as the cosmetics, agricultural and food industries. Due to its everyday use and medicinal properties, coriander is a highly interesting functional food [16,18].

Located at the south of the Tagus River, Alentejo is one of the seven territorial units of Portugal. It is a territory of particular interest for its morphology, flourishing vegetation, and history, having been a meeting area among different civilizations, Phoenicians, Celts, Greeks, Romans, Arabs, Jews and Christians. *Açorda* traditional recipes were a gift from the presence of the Arabs in Alentejo' lands.

Coriander is used as a folk plant in the south of the Tagus River, where is one of the most popular and extensively grown aromatic and food seasoning species, giving a distinctive flavor to this region's traditional cuisine. Most commonly, Portuguese from the North of the Tagus River, dislike its taste and aroma. Coriander is not commonly used in recipes in the northern areas of Portugal, such as Beira Baixa and Beira Litoral, where it

is used in just 2.8% and 2.1% of recipes, respectively. On the other hand, in the southern region of Portugal, coriander leaves are used in 8.6% of Estremadura recipes, 13.4% of Algarve recipes, 14.3% of Ribatejo recipes, and 18.4% of Alentejo recipes [21]. Nowadays, the use of coriander in food seasoning is also recommended to reduce salt [22].

At the end of the 20th century and the first decade of the 21st century, ethnobotanical studies were carried out in line with the dynamics of MAP research in the Iberian Peninsula [1,23–28]. Alentejo is characterized by an ethnic plurality and a rich ethnobotanical knowledge, although the available information is fragmentary, widely dispersed, and often guarded in oral popular culture.

The main goal of this study was to compile the findings from multiple initiatives carried out at the Escola Superior Agrária de Elvas/Instituto Politécnico de Portalegre (ESAE/IPP), with an emphasis on the agronomic features of the most widely utilized species as well as the gathering and preservation of traditional Alentejo recipes. To identify MAP species of commercial relevance, numerous surveys were conducted at both indoor and outdoor marketplaces, and interviews were conducted with local MAP producers. Notably, coriander emerged as a significant MAP plant. The ethnobotanical data was complemented with other significant qualities, such as the essential oil profile and total fatty acid composition, in addition to a survey on the advancements in coriander extraction technologies, with the goal of locally potentiating improved coriander varieties.

2. Materials and Methods

2.1. Ethnobotanical Surveys: Food Seasoning with Coriander in Alentejo Region

2.1.1. Surveys Conducted in 2002 and 2003

During 2002 and 2003, 28 semi-structured interviews were carried out throughout the Alentejo region (Figure 1), with the goal of collecting coriander regional landraces and data on its ethnobotanical uses [29–31]. The survey questionnaire, included in Supplementary Materials Table S1, was carried out within project Agro 34 [32].

2.1.2. Surveys Conducted in 2013

The ethnobotanical survey conducted in 2013, benefiting from the experience of the previous surveys, focused on gathering the frequency of use of eight categories of food seasoning recipes [*açorda*, Fabaceae (beans, chickpea, pea), fish, fish soup, meat, *migas*, *pisso* and rice]. Concrete food recipes with coriander were also registered. The surveys were carried out in three Alentejo villages, selected to calculate the representativeness of coriander use in a population of known size. The three villages were chosen based on their location in three different subregions of Alentejo.

Considering the 2011 population census [33], a total of 24 interviews (1.4% of the inhabitants) were carried out in Alegrete (North Alentejo), 20 interviews (1.2% of the inhabitants) in Santa Catarina (Alentejo Litoral) and 21 interviews (2.2% of the inhabitants) in Vale de Vargo (Baixo Alentejo) (Figure 1), making an average of 1.6% inhabitants interviewed in the 3 villages. Since each household was only surveyed once, the actual representation was higher given that the typical family size in the area is larger than one member. The survey questionnaire is included in Supplementary Materials Table S2.

The plants mentioned in the recorded recipes and recipe citations, were botanically identified. The species employed in the recipes were divided into three categories, large, medium, and small amounts, according to the used quantities.

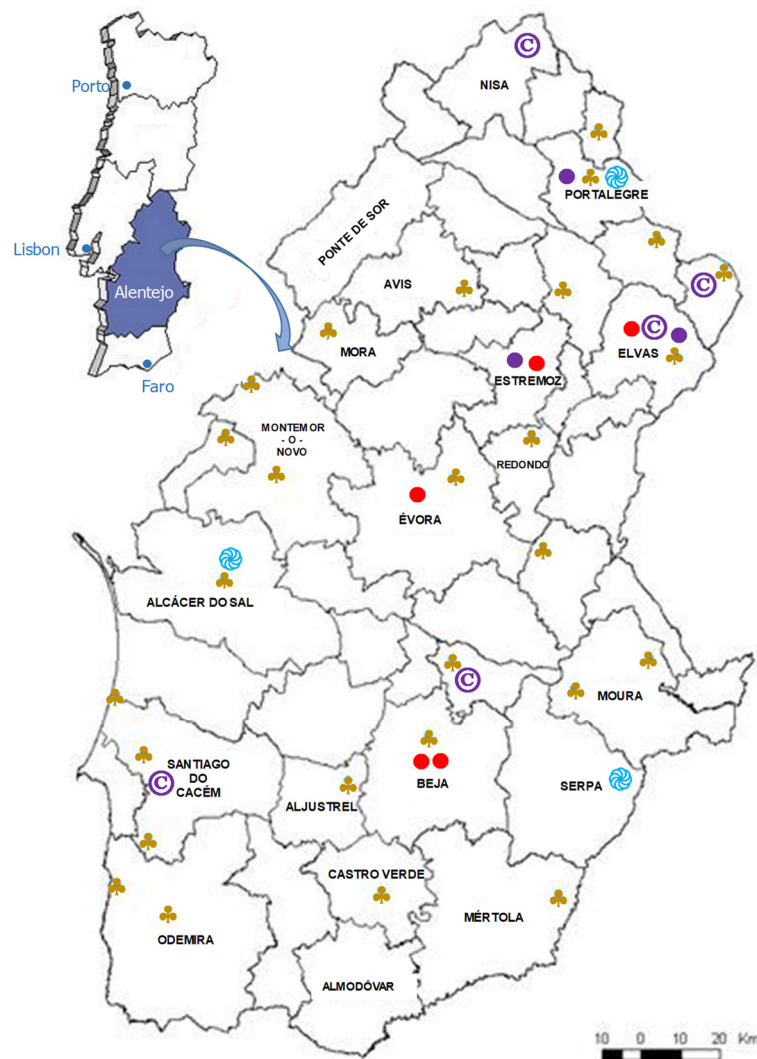


Figure 1. Ethnobotanical surveys in the Alentejo region during 2002–2003 (☘) and 2013 (☘). Mainland Portugal in the top left corner with Alentejo region evidenced in blue. Arrow indicates detail of Alentejo municipalities. Visited markets in 2007 (●) and 2022 (●). Geographic origin of coriander landraces used in chemical characterization analysis (©).

2.2. Ethnobotanical Surveys: Coriander Representativeness on Local Markets

The Alentejo region is divided into three subregions: Alto Alentejo, whose administrative center is the city of Portalegre; Central Alentejo, whose administrative center is the city of Évora; and Baixo Alentejo, whose administrative center is the city of Beja.

Every subregion's administrative center was included in the surveys of city markets: Portalegre (2022 surveys), Évora (2007 surveys) and Beja (2007 surveys). Furthermore, 2 important cities in the region were included in the survey collection: Elvas, in 2007 and 2022 surveys, and Estremoz in 2007 and 2022 surveys, Figure 1. The data collection in the cities markets, both in 2007 and 2022 surveys, included all of the MAP sellers present in the marketplaces.

2.2.1. Surveys Conducted in 2007

From December 2006 to March 2007, 5 markets in the Alentejo region were visited, interviewing 33 MAP producers in the indoor markets of Beja (8 producers), Elvas (2 producers), and Évora (4 producers), and in the outdoor markets of Beja (9 producers) and Estremoz (10 producers).

This study gathered information on MAP with commercial interest (list of MAPs sold) and species agronomic features (cultivated area for each MAP), such as the number of sowing dates per year, number of plants cuts per year, provenance of the seed (landrace or acquired), the importance of obtaining new varieties and the most important features for a new variety. The survey was included within Project Agro 522 [34]; the questionnaire is included in Supplementary Materials Table S3.

2.2.2. Surveys Conducted in 2022

The 2022 surveys were carried out to continue assessing the information about the MAP species with commercial interest in the Alentejo region markets [35]. The survey took place in the markets of Elvas, Portalegre and Estremoz, based on two visits (autumn 2020 and spring 2022). The survey included recorded data regarding sellers of dried wild plants and imported spices; however, since coriander is a cultivated species, always sold fresh, only the information pertaining to sellers of fresh vegetables was included in this study to facilitate comparisons with surveys conducted in 2007. Thus, a total of 28 MAP sellers (4 from Elvas, 11 from Portalegre and 13 from Estremoz) were considered. Two localities are shared by the 15-year interval local market surveys.

The list of MAP sold, the origin of the plants (cultivated or wild), the type of plant (fresh, dried, potted) and the packaging (bulk, plastic, paper, other) were recorded. The survey questionnaire is included in Supplementary Materials Table S4.

2.3. Chemical Characterization of Coriander Accessions

The chemical characterization of selected accessions was performed by evaluating their essential oils (EOs) and total fatty acid composition, Table 1.

Except for samples obtained from the wild collection, the remaining *C. sativum* plant materials were obtained from the experimental fields of Escola Superior Agrária de Elvas/Instituto Politécnico de Portalegre (ESAE/IPP). Representative material was deposited at the Banco Português de Germoplasma Vegetal (BPGV) under each own accession number. The plant material was obtained for two consecutive years (2013 and 2014). The sampling details for each of the analyzed plant materials, and their origin, are provided in Table 1, and detailed in Supplementary Material Figure S1.

The aerial parts of the coriander with inflorescence emergence were collected in the agronomic essay and transported in paper bags, inside a thermal box, directly from the field to the FCUL laboratory. The coriander fruits were obtained from the agronomic trial field of ESAE/IPP, sown on 30 November 2014, with harvesting in June 2015, when they were fully ripe. The samples were transported in paper bags to the laboratory. Subsequently, they were mechanically threshed and stored in paper bags at room temperature until they were sent to the chemical analysis laboratory at FCUL on 30 November 2015.

Table 1. *Coriandrum sativum* accessions studied codes, BPGV accession number, collection site, plant part studied, EO and fatty acids yields.

Sample Code	BPGV Accession	Accession Origin: Municipality/District	Plant Part	Yield (% <i>v/v</i>)
Essential oil Analysis				
Cs_1_API_14	BPGV08514	Elvas, Portalegre	APIs	0.04
Cs_16_API_14	BPGV19284	Vidigueira, Beja	APIs	0.05
Cs_32_API_14	BPGV28149	Campo Maior, Portalegre	APIs	0.05
Cs_TP_API_14		Commercial variety	APIs	0.04
Cs_1_F_14	BPGV08514	Elvas, Portalegre	Fruits	0.46
Cs_16_F_14	BPGV19284	Vidigueira, Beja	Fruits	0.39
Cs_26_F_13	BPGV08524	Santiago do Cacém, Setúbal	Fruits	0.25
Cs_31_F_14	BPGV19293	Campo Maior, Portalegre	Fruits	0.25
Cs_31_F_14_w	BPGV19293	Campo Maior, Portalegre	Fruits	0.14
Cs_32_F_14	BPGV28149	Campo Maior, Portalegre	Fruits	0.37
Cs_TP_F_14		Commercial variety	Fruits	0.40

Table 1. Cont.

Sample Code	BPGV Accession	Accession Origin Municipality/District	Plant Part	Yield (% <i>w/w</i>)
Fatty Acids Analysis				
Cs_1_1_F_14	BPGV08514	Elvas, Portalegre	Fruits	0.8
Cs_1_2_F_14	BPGV08514	Elvas, Portalegre	Fruits	0.9
Cs_1_3_F_14	BPGV08514	Elvas, Portalegre	Fruits	1.2
Cs_16_1_F_14	BPGV19284	Vidigueira, Beja	Fruits	1.2
Cs_16_2_F_14	BPGV19284	Vidigueira, Beja	Fruits	0.7
Cs_16_3_F_14	BPGV19284	Vidigueira, Beja	Fruits	0.8
Cs_31_F_14_w	BPGV19293	Campo Maior, Portalegre	Fruits	0.8
Cs_32_1_F_14	BPGV28149	Campo Maior, Portalegre	Fruits	1.5
Cs_32_2_F_14	BPGV28149	Campo Maior, Portalegre	Fruits	1.1
Cs_32_3_F_14	BPGV28149	Campo Maior, Portalegre	Fruits	1.2
Cs_33_F_14_w	BPGV19649	Campo Maior, Portalegre	Fruits	0.7
Cs_Santo_1_F_14		Commercial variety	Fruits	1.0
Cs_Santo_2_F_14		Commercial variety	Fruits	0.9
Cs_Santo_3_F_14		Commercial variety	Fruits	1.5
Cs_TP_1_F_14		Commercial variety	Fruits	0.5
Cs_TP_2_F_14		Commercial variety	Fruits	0.8
Cs_TP_3_F_14		Commercial variety	Fruits	0.5

In the accession code, the two first letters stand for the species name, followed by sample number, plant part and collection year. APIs: Aerial parts with inflorescence emergence. F: Fruits. TP and Santo: Designations of commercial varieties. When the sample was obtained from wild collection the sampling year is followed by letter w. BPGV: Banco Português de Germoplasma Vegetal.

2.3.1. Essential Oils Isolation and Analysis

The EOs of 11 samples were obtained by hydrodistillation (HD), using a Clevenger apparatus [36], and analyzed by Gas Chromatography (GC) and Gas Chromatography-Mass Spectrometry (GC-MS) for component quantification and identification [37–47], respectively, according to Machado et al. [48], as fully detailed in Supplementary Material Section S2.3.

2.3.2. Fatty Acids Isolation and Analysis

Total fatty acids of 17 samples were isolated, using a Soxhlet apparatus. After transesterification to fatty acid methyl esters (FAMES), GC and GC-MS analyses were run as fully detailed in Supplementary Material Section S2.3. Except for the fruits obtained from the wild plants (Cs_31_F_14_w and Cs_33_F_14_w), the remaining data on total fatty acids is presented as an average of each three samples obtained for each plant material, Table 1.

2.4. Numeric Data Statistical Treatment

The data statistical treatment of all of the ethnobotanical surveys was carried out using Excel [49] spreadsheets, with the creation of lists of cited species and calculations of citation frequencies.

The relationship between the various samples was evaluated using the EOs' and fatty acids percent composition, through cluster analysis using the Numerical Taxonomy Multivariate Analysis System (NTSYS PC software, version 2.2, Exeter Software, Exeter University, Exeter, UK) [50]. The sequential agglomerative hierarchical nested cluster analysis was chosen as the agglomerative clustering method. The effect of different scales of identification was eliminated by standardizing the percent composition data matrix. The correlation coefficient was chosen as the measure of sample similarity for the cluster analysis, and the cluster definition was carried out using the unweighted pair group method with arithmetical averages. The correlation degree was assessed according to Pestana and Gageiro [51] as very high [0.90, 1.00], high [0.70, 0.90], moderate [0.40, 0.70], low [0.20, 0.40], and very low (<0.20).

3. Results and Discussion

3.1. Ethnobotanical Surveys: Food Seasoning with Coriander in Alentejo Region

3.1.1. Surveys Conducted in 2002–2003

During this survey, 62 coriander recipes or recipe names expressively naming plants were recorded, including 23 complete recipes. Among popular recipes three traditional ones stood out, *açorda*, a traditional Alentejo bread soup with fish, or codfish, and egg, seasoned with coriander, pennyroyal (*Mentha pulegium* L.) or hart’s pennyroyal (*M. cervina* L.), *migas*, a meat side dish based on Alentejo bread seasoned with coriander, and *piso*, a more fluid or spread preparation, made from coriander, pennyroyal or hart’s pennyroyal, garlic, olive oil and salt.

Most people used coriander more than once a week, an extremely common usage. Primarily the leaves, but also the tender stems were used fresh or frozen or transformed in *piso* similarly to pennyroyal [27]. The most popular recipes were *açorda* (traditional bread recipe) and fish, but with a broad utilization on salads, omelets, meats, infusions, etc. [31].

3.1.2. Surveys Conducted in 2013

Based on the 2013 ethnobotany survey, the four most important coriander recipe categories were: *açorda*, fish, rice, and Fabaceae (mostly beans) (Table 2). A total of 63 citations of coriander usage as a spice, including 51 complete recipes were recorded.

Table 2. Food categories from 2013 surveys in Alegrete, Santa Catarina, and Vale de Vargo, arranged by order of importance in the sum of the 3 villages.

Recipe Type	Alegrete	Santa Catarina	Vale de Vargo	Total 3 Villages
<i>Açorda</i> *	20	20	20	60
Fish	18	20	13	51
Rice	16	20	15	51
Fabaceae	11	18	17	46
Fish soup	18	19	7	44
Meat	18	11	8	37
<i>Piso</i> *	16	15	1	32
<i>Migas</i> *	2	6	0	8
Total	119	129	81	329

* *Açorda*, *migas*, and *piso*: traditional recipes detailed in Section 3.1.1.

The average representativeness of these results was 1.6% (considering the number of inhabitants interviewed in the total population of the villages in the 2011 census).

3.1.3. Surveys Conducted in 2002–2003 and 2013

This section includes the results of the concrete examples of coriander recipes from the 2013 surveys, with descriptive text (part 7 of the survey, Table S2), as well as the recipe descriptions from the 2002–2003 surveys. The studies considered a total of 125 recipes or recipe names in all; of these, the majority (36) were recipes of beans and other Fabaceae, followed by *açorda* (29) (Table 3).

Table 3. Representativeness of the food categories from the 2002–2003 and 2013 surveys recipes, arranged by order of importance in the sum of the 2 surveys.

Recipe Type	Surveys		
	2003	2013	Total
Fabaceae	19	17	36
<i>Açorda</i> * and <i>migas</i> *	24	5	29
Fish	7	19	26
Other recipes	8	16	24
Meat	4	6	10
Total	62	63	125

* *Açorda*, and *migas*: traditional recipes detailed in Section 3.1.1.

Plants from 14 botanic families were mentioned. The most cited botanic families were Apiaceae (coriander), Amaryllidaceae (garlic, onion), Oleaceae (olive), Poaceae (wheat, rye, corn, rice), Fabaceae (bean, brad bean, chickpea), Solanaceae (potatoes) (Figure 2).

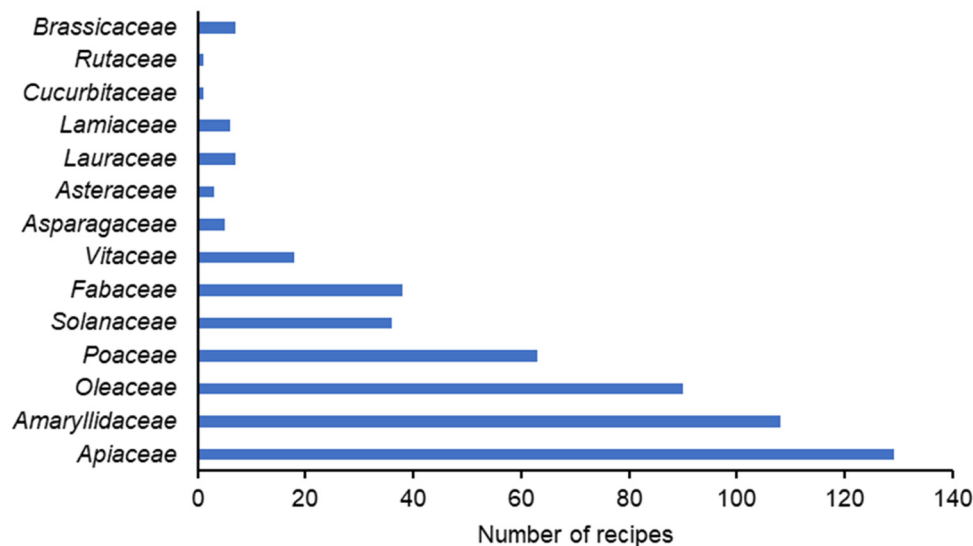


Figure 2. Representativeness of plant species botanic families on coriander traditional recipes. 2002–2003 and 2013 surveys.

Taking into account the results of both surveys (2002–2003 and 2013), 512 references to plant species were found in the recipes; these references accounted to 24 plant species, belonging to 14 botanical families (Figure 3). Twelve species, as *Triticum aestivum* L. (wheat, in bread and flour), *Oryza sativa* L. (rice), *Solanum tuberosum* L. (potato) and *Phaseolus vulgaris* L. (bean) were consumed in large amounts, being the most representative in the recipes. Four plant species were consumed in average amounts, including *Allium cepa* L. (onion) and *Olea europaea* L. (olive, as olive oil and olives). Spices were consumed in small amounts, of which the most representative were *Coriandrum sativum* L. (coriander), *Allium sativum* L. (garlic), *Vitis vinifera* L. (vine, vinegar) and *Mentha pulegium* L. (pennyroyal) (Figure 3).

These surveys were also valuable for assessing the genetic erosion of the species [29] and the collection of germplasm to continue the ESAE/IPP coriander plant breeding program [30].

The survey's results obtained in 2013 were like those from 2002–2003 regarding the main families and species used in traditional coriander recipes, supporting the key findings from Póvoa et al. [27,31]. *Açorda* (with *Triticum aestivum* bread) appears as the most cited recipe, both in 2002/2003 surveys and 2013 surveys. Considering the recipes with plants as major constituents, coriander rice (*Oryza sativa*), stewed beans (*Phaseolus vulgaris*), stewed chickpea (*Cicer arietinum*) and stewed broad bean (*Vicia faba*) were also very frequently mentioned, in both surveys, which confirms the Mediterranean nature of this cuisine.

3.2. Coriander Representativeness on Local Markets

3.2.1. Surveys Conducted in 2007

The MAP producers from Évora indoor market had the highest average area dedicated to MAP production (about 6000 m²), followed by Elvas indoor market (about 2500 m²). Most of the remnant producers cultivated their MAP on small plots (less than 1000 m²). The number of sold MAP species by producer varied from 3 to 6 (Figure 4).

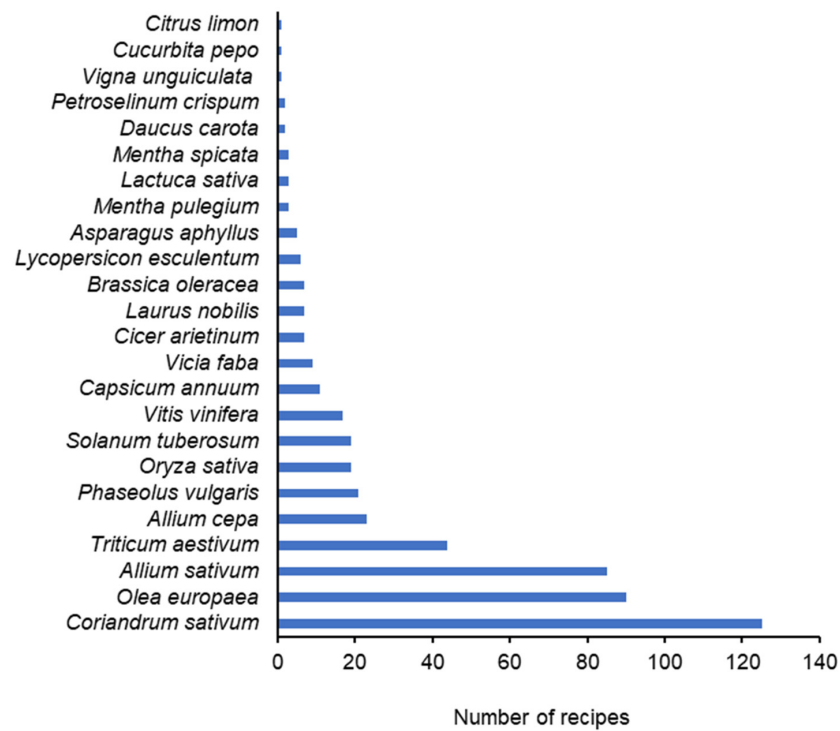


Figure 3. Representativeness of plant species on coriander traditional recipes. 2002–2003 and 2013 surveys.

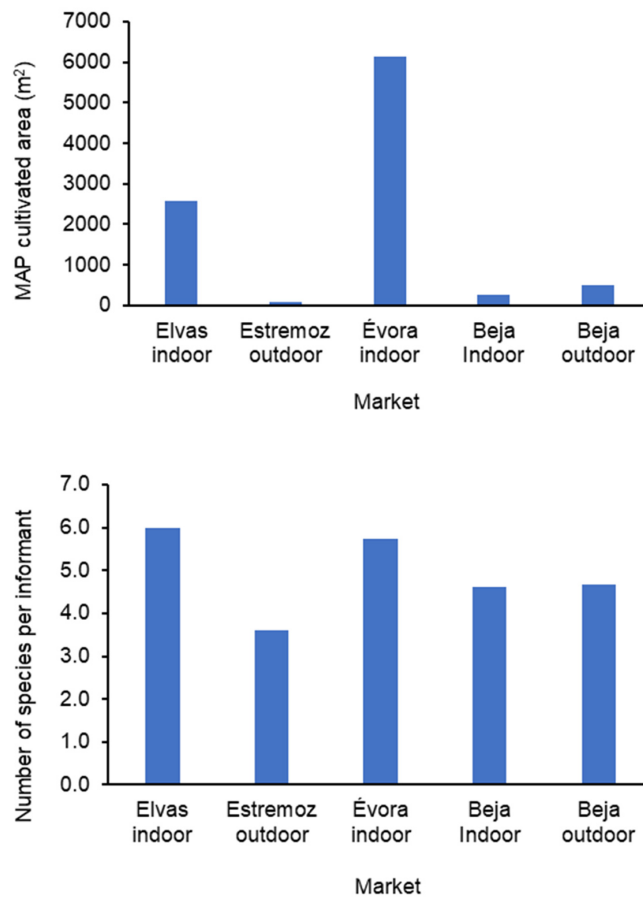


Figure 4. Cultivated area (up) and number of plant species (bottom) from MAP producers on Elvas, Estremoz, Évora and Beja markets (2007 surveys).

All of the interviewed MAP producers cultivated coriander (Figure 5). Parsley (*Petroselinum crispum* (Mill.) (Mill.) Fuss) and mint (*Mentha spicata* L.) were also very common cultivated species, but with lesser incidence. Considering the percentage of total MAP cultivated area, coriander clearly dominates (about 75%), which coincides with the official statistics from the Portuguese government [52] giving 71% of the MAP cultivated area to coriander (Figures 6 and 7).

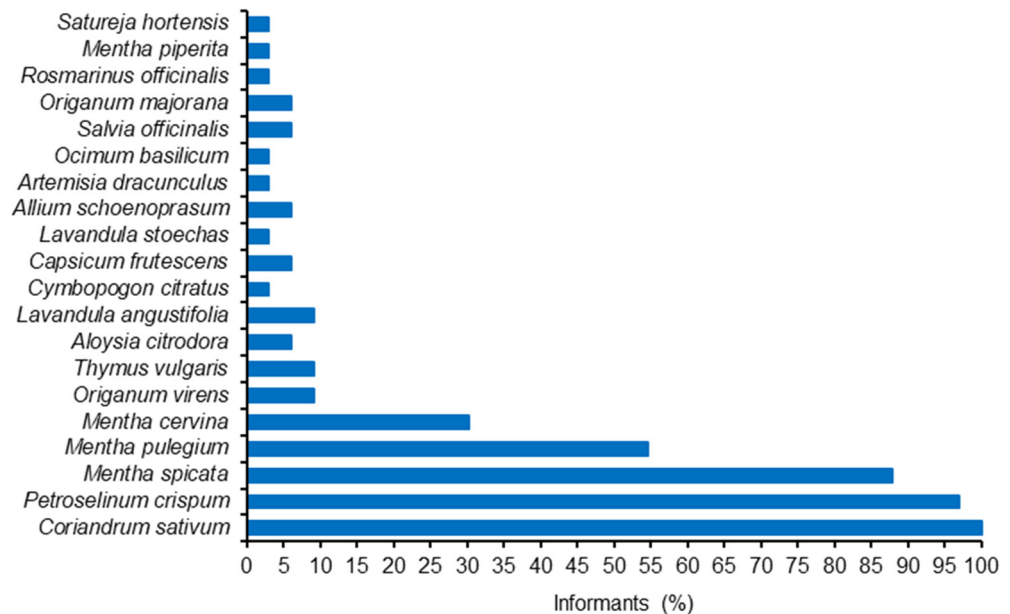


Figure 5. Cultivated MAP species and % informants who cultivate each species (2007 surveys) according to MAP producers in Elvas, Estremoz, Évora and Beja markets.

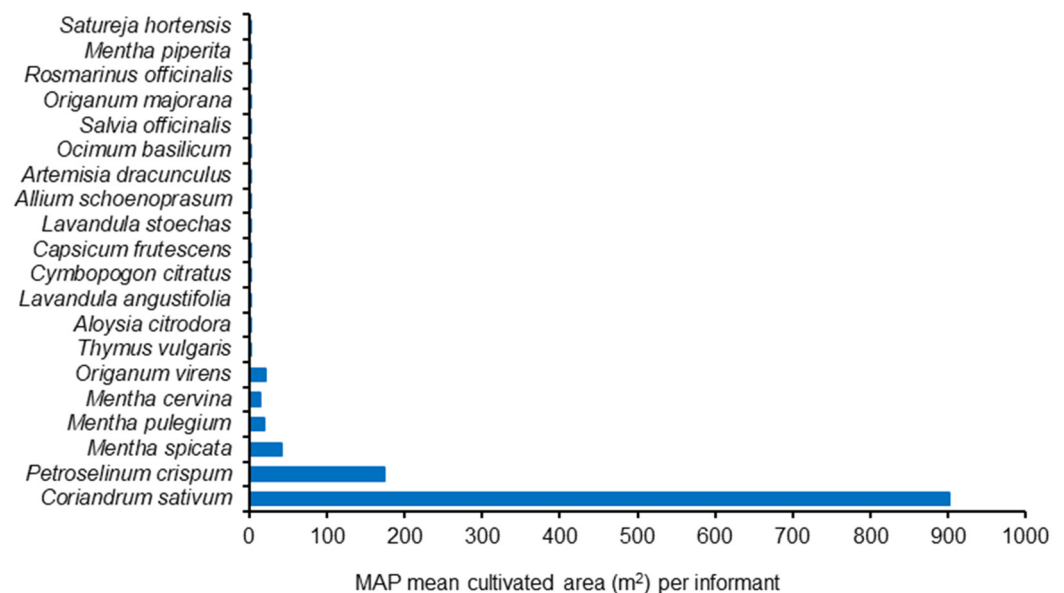


Figure 6. Mean cultivated area (m²) per informant for each MAP species (2007 surveys) according to MAP producers in Elvas, Estremoz, Évora and Beja markets.

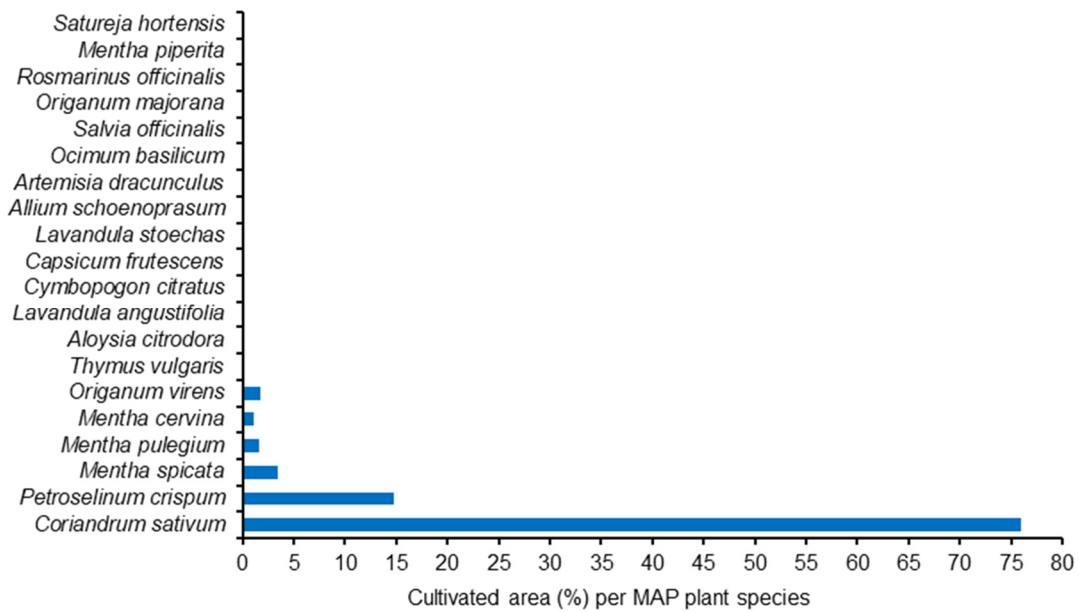


Figure 7. Cultivated area (%) for each MAP species (2007 surveys) according to MAP producers in Elvas, Estremoz, Évora and Beja markets.

Most of the interviewed MAP growers considered that it was important to have a coriander traditional varieties (landraces) conservation program, however, most cultivate using purchased seeds. The informants didn't recognize the importance of developing new coriander varieties (52%) (Figure 8). The most important features for coriander plant breeding programs were biomass yield, flavor, and late flowering (Figure 9).

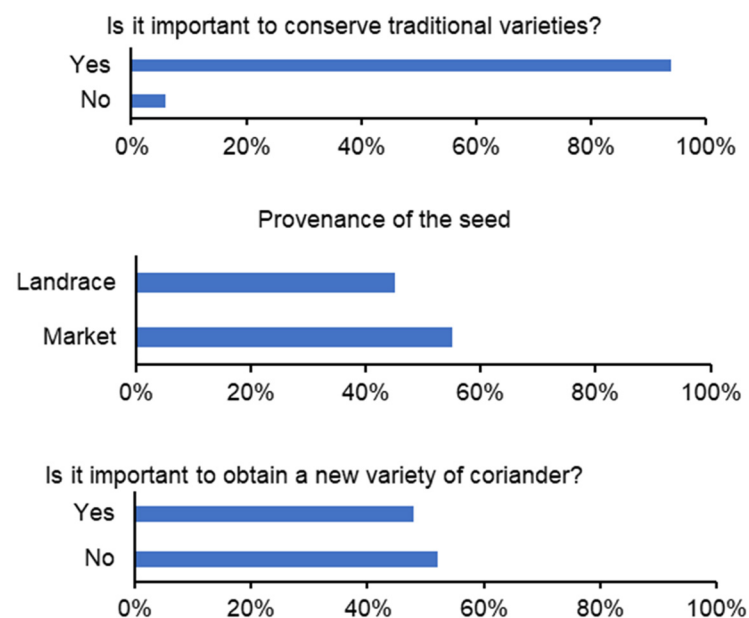


Figure 8. The importance of traditional varieties conservation (**top**), provenance of the seeds (**middle**) and the importance of the development of new varieties (**bottom**) (2007 surveys) according to MAP producers in Elvas, Estremoz, Évora and Beja markets.

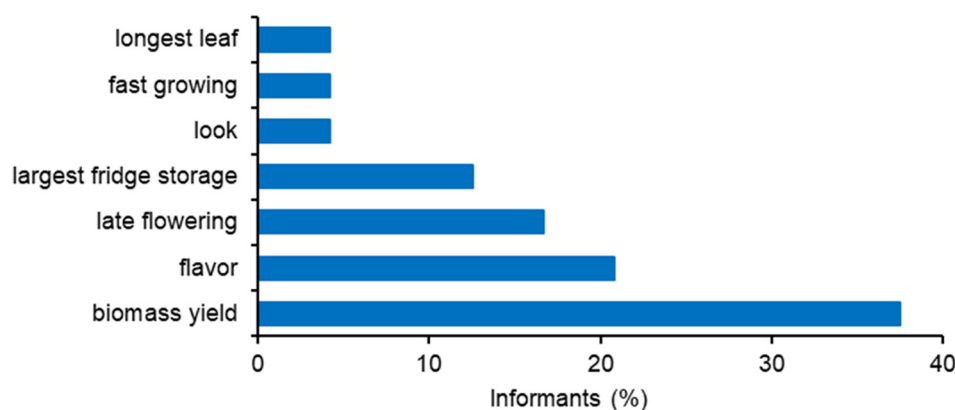


Figure 9. Most important coriander features for plant breeding programs (2007 surveys), according to MAP producers in Elvas, Estremoz, Évora and Beja markets.

3.2.2. Surveys Conducted in 2022

Four sellers were found in the Elvas market, which sold 11 fresh MAP species, 16 dry species, of which 10 from the wild collection. In the Portalegre market there were 11 vendors of 17 fresh MAP species, 35 dried species, of which 23 were from the wild. In the Estremoz market there were 13 sellers of 33 fresh MAP species in bulk or potted (in nursery plant containers), 75 dried species, of which 31 were from the wild.

The cultivated MAP species represented 66% of the total marketed species, while wild collected species represented 34%. A total of 69 MAPs collected from the wild were identified in the 3 markets (unpublished results from the authors).

Most cultivated MAPs were marketed fresh (54%), in bulk (44%), potted (35%) or in plastic bags (28%). Considering the cultivated fresh MAP sector, most of the plants were sold in bulk (97.5%), with a total of 17 species. Coriander (*Coriandrum sativum*) represented 17% of the observed species, parsley (*Petroselinum crispum* (Mill.) Nyman ex A. W. Hill) with 17% and spearmint (*Mentha spicata* L.) with 16% were also very frequent (Figure 10).

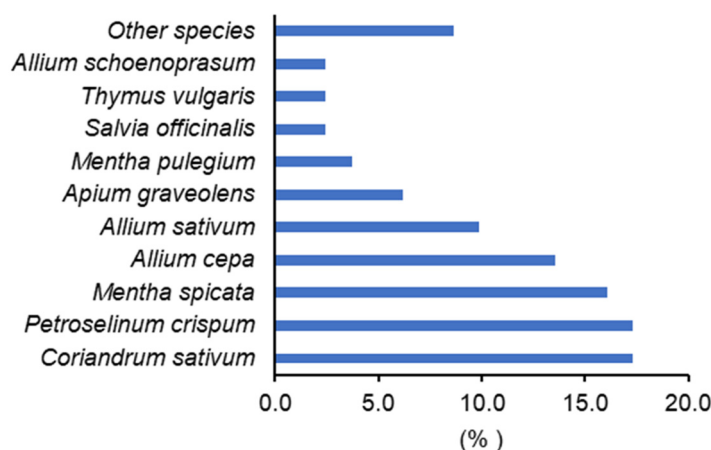


Figure 10. Representativeness of the fresh cultivated medicinal and aromatic plants (MAP) in the markets of Elvas, Estremoz and Portalegre (2022 surveys).

There were species simultaneously on the list of cultivated and wild species, such as laurel (*Laurus nobilis* L.), linden (*Tilia platyphyllos* Scop.), pennyroyal (*Mentha pulegium* L.), and oregano (*Origanum vulgare* spp. *virens* Hoffmanns. et Link.). In addition to the wild harvest, they were also grown for sale in bulk or in pots (unpublished results from the authors).

The survey should be carried out in other marketplaces to complete the list of commercialized MAPs.

3.2.3. Surveys Conducted in 2007 and 2022

Coriander appears in the 2 ethnobotanic surveys as the most representative MAP species in the Alentejo region markets, concerning the fresh plant sector, which justified the continuity of the plant breeding program developed at ESAE/IPP.

3.3. Coriander Aerial Parts and Fruits Essential Oils

The yields of the EOs isolated from *C. sativum* aerial parts with inflorescence emergence (APIs) ranged from 0.04% to 0.05% (*v/w*), whereas the fruits EOs yields ranged from 0.1% to 0.5%, Table 1.

There were fifty-five compounds identified in the APIs EOs and forty-four in the fruits EOs, for a total identification percentage >94%. Table 4 lists the relative amounts of all of the identified compounds on each EO, with their elution order in the DB-1 column.

Table 4. Percentage composition of the EOs isolated by hydrodistillation, from *Coriandrum sativum* aerial parts with inflorescence emergence (APIs) and fruits (F). For samples codes, see Table 1.

Peak #	Components	RI	APIs				Fruits						
			Cs_1_API_14	Cs_16_API_14	Cs_32_API_14	Cs_TP_API_14	Cs_1_F_14	Cs_16_F_14	Cs_26_F_13	Cs_31_F_14	Cs_31_F_14_w	Cs_32_F_14	Cs_TP_F_14
1	<i>n</i> -Hexanal	756					t	t	t	t	t	t	t
2	<i>n</i> -Octane	800	0.7	1.0	0.5	1.2							
3	<i>cis</i> -3-Hexen-1-ol	868	t	0.2	0.1	t							
4	<i>cis</i> -2-Hexen-1-ol	882	t	0.1	0.1	t							
5	<i>n</i> -Hexanol	882	t	0.1	t	t							
6	<i>n</i> -Heptanal	897	t	t	t	t	t	t	0.1	0.1	t	t	t
7	1-Nonene	899	t	t	t	t							
8	<i>n</i> -Nonane	900	15.1	9.9	11.0	17.2	t	t	t	0.1	t	t	t
9	<i>trans</i> -2-Nonene *	900	t	t	t	t							
10	α -Thujene	924					t	t	0.1	0.1	0.1	t	t
11	α -Pinene	930	0.5	0.4	0.4	0.6	4.6	3.3	3.0	8.7	6.2	3.6	4.1
12	Camphene	938					0.5	0.4	0.3	0.5	0.4	0.4	0.4
13	<i>n</i> -Heptanol	952	t	t	t	t	t	t	t	t	t	t	t
14	Sabinene	958	t	t	t	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.2
15	1-Octen-3-ol	961	t	t	t	t	t	t	t	t	t	t	t
16	β -Pinene	963	t	t	t	t	0.4	t	0.4	0.9	0.6	0.3	0.4
17	3-Methyl nonane	970	t	t	t	t							
18	2-Pentyl furan	973					t	t	0.1	t	t	t	t
19	<i>n</i> -Octanal	973	3.0	2.6	2.1	2.8	t	t	0.1	t	t	t	t
20	β -Myrcene	975					0.8	0.8	1.3	1.6	1.3	0.7	0.8
21	α -Phellandrenene	995					t	t	t	t	t	t	t
22	<i>n</i> -Decane	1000	1.2	0.6	0.7	0.8							
23	α -Terpinene	1002					t	t	0.1	0.1	0.1	t	0.1
24	<i>p</i> -Cymene	1003	t	t	t	t	0.9	1.1	1.1	0.6	1.0	1.2	1.6
25	β -Phellandrene	1005					0.1	0.1	0.1	0.1	0.2	0.1	0.1
26	Limonene	1009	t	t	t	0.1	1.4	1.4	1.4	1.6	1.3	1.2	1.4
27	<i>cis</i> - β -Ocimene	1017					t	t	0.2	0.2	0.2	t	t
28	<i>trans</i> - β -Ocimene	1027	t	t	t	t	t	t	0.3	0.3	0.3	t	t
29	γ -Terpinene	1035	t	t	t	0.1	4.8	6.2	4.4	4.3	8.3	7.3	5.7
30	<i>trans</i> -Sabinene hydrate	1037					t	t	t	t	t	t	t
31	<i>cis</i> -Linalool oxide	1045					t	0.3	t	0.1	t	t	0.1
32	<i>n</i> -Octanol	1045	0.4	0.3	0.3	0.4	t	t	t	t	t	t	t
33	<i>trans</i> -Linalool oxide	1059					t	t	0.1	t	t	t	0.1
34	Terpinolene	1064					0.3	t	0.2	0.3	0.3	0.3	0.3
35	<i>n</i> -Nonanal	1073	0.9	1.0	1.0	1.0							
36	Linalool	1074	0.2	0.5	0.2	0.1	77.9	75.7	78.0	73.3	73.4	73.7	77.7
37	1-Octen-3-yl acetate	1086	t	t	t	t							
38	<i>n</i> -Undecane	1100	0.2	t	0.1	0.1							
39	Camphor	1102					2.9	4.3	2.1	2.3	1.9	3.9	2.7
40	Citronellal	1121						t	0.1	0.6	0.9	0.1	t
41	2- <i>trans</i> -Nonenal	1124	0.1	0.2	0.2	0.1						t	
42	Borneol	1134					0.3	t	0.6	t	0.1	0.1	0.1
43	Terpinen-4-ol	1148					0.2	0.3	0.3	0.2	0.2	0.4	0.3
44	<i>n</i> -Nonanol	1148	0.3	0.5	0.4	0.3							
45	α -Terpineol	1159					0.3	0.4	0.3	0.2	0.2	0.3	0.3
46	4- <i>cis</i> -Decenal	1163	0.2	0.3	0.2	0.2							
47	<i>n</i> -Decanal	1180	23.0	20.9	21.0	24.1	0.1	0.1	0.4	0.5	0.3	0.2	0.2
48	Pulegone	1207	t	t	t	t	0.1	t	0.1	0.1	t	t	0.1
49	Citronellol	1207	t	t	t	t	0.1	t	0.1	0.5	0.6	0.1	t
50	Geraniol	1236					2.0	3.0	2.0	0.8	0.6	3.3	1.4
51	2- <i>trans</i> -Decenal	1236	12.2	17.9	16.1	13.1							
52	2- <i>trans</i> -Decen-1-ol *	1256	9.2	9.8	8.8	7.5							
53	<i>n</i> -Decanol	1259	6.7	6.5	6.0	7.1	t	t	0.1	0.1	0.1	t	t
54	<i>n</i> -Undecanal	1288	4.0	4.2	4.2	3.2							
55	Myrtenyl acetate	1290					t	t	0.1	0.1	t	0.1	t

Table 4. Cont.

Peak #	Components	RI	APIs				Fruits						
			Cs_1_API_14	Cs_16_API_14	Cs_32_API_14	Cs_TP_API_14	Cs_1_F_14	Cs_16_F_14	Cs_26_F_13	Cs_31_F_14	Cs_31_F_14_w	Cs_32_F_14	Cs_TP_F_14
56	2-trans-Undecenal	1323	1.9	3.7	3.2	1.6							
57	2-trans-Undecen-1-ol *	1325	0.7	1.2	1.0	0.5							
58	Citronellyl acetate	1343					t	t	t	0.1	t	t	t
59	Neryl acetate	1353					t	t	t	t	t	t	t
60	n-Undecanal	1366	0.5	0.6	0.5	0.4							
61	Geranyl acetate	1370					1.3	1.1	1.8	1.0	0.8	0.8	1.6
62	n-Dodecanal	1397	4.3	3.2	3.8	3.8	t	t	0.1	t	t	t	t
63	2-trans-Dodecenal	1446	5.3	5.4	5.3	5.1	0.3	t	0.2	0.2	0.2	0.2	t
64	2-trans-Dodecen-1-ol	1448	1.1	1.2	1.1	1.0							
65	n-Dodecanol	1468	0.2	0.2	0.2	0.2							
66	α-Amorphene	1476	0.1	t	t	t							
67	n-Tridecanal	1499	0.4	0.3	0.3	0.4							
68	2-trans-Tridecen-1-ol	1574	0.4	0.2	0.4	0.4							
69	n-Tetradecanal (=miristaldehyde)	1596	0.7	0.6	0.9	0.7							
70	α-Cadinol	1626	0.1	t	t	t							
71	cis-9-Tetradecenal *	1647	2.9	2.7	3.4	2.9							
72	n-Pentadecanal	1688	0.1	0.1	0.1	0.1							
73	11-Pentadecenal *	1735	0.5	0.4	0.4	0.5							
74	Hexadecanoic acid (=palmitic acid)	1908	t	t	t	t							
75	Phytol acetate 2	2101	0.1	t	t	t							
76	Methyl linoleate	2101	0.1	t	t	t							
77	n-Nonadecanal *	2102	t	t	t	t							
78	Petroselinic acid	2128					t	t	t	t	t	t	t
79	n-Eicosanal	2200	0.1	t	0.1	t							
	% Identification		97.4	96.8	94.1	97.7	99.5	98.7	99.9	99.9	99.9	98.6	99.7
	Grouped components												
	Monoterpene hydrocarbons		0.5	0.4	0.4	0.9	14.0	13.5	13.2	19.6	20.6	15.4	15.1
	Oxygen-containing monoterpene hydrocarbons		0.2	0.5	0.2	0.1	85.1	85.1	85.6	79.3	78.7	82.8	84.4
	Sesquiterpene hydrocarbons		0.1	t	t	t							
	Oxygen-containing sesquiterpene hydrocarbons		0.1	t	t	t							
	Oxygen-containing diterpene hydrocarbons		0.1	t	t	t							
	Fatty acids		t	t	t	t	t	t	t	t	t	t	t
	Fatty acid derivatives		79.2	84.0	81.0	77.4	0.4	0.1	1.0	0.9	0.6	0.4	0.2
	Others		17.2	11.7	12.4	19.3	t	t	0.1	0.1	t	t	t

Peak #: Peak number. RI: In-lab calculated retention index relative to C₈–C₂₃ n-alkanes on the DB-1 column. t: traces (t < 0.05%). * Identification based on mass spectrum only. Percentages in bold: dominant compounds relevant for each cluster.

n-Decanal (21–24%), 2-trans-decenal (12–18%), n-nonane (10–17%), and 2-trans-decen-1-ol (8–10%) were the dominant components (≥10%) of APIs EOs. The fruits EOs were characterized by linalool dominance (73–78%), followed, in much lower amounts, by α-pinene (3–9%) and γ-terpinene (4–8%).

As detailed in Figures S2 and S3, agglomerative cluster analysis, based on the chemical composition of all coriander EOs analyzed, corroborated the qualitative and quantitative differences between APIs and fruits EOs. Interestingly, for both the APIs and the fruits EOs, there was some consistency in the observed groupings. With a very high degree of correlation, Cs_1 paired with Cs_TP both in API and fruits EOs, as well as Cs_16 with Cs_32. In the fruits EOs, Cs_31_F_14 paired with that from wild collection, Cs_31_F_14_w, Figure S1.

The yields, as well as the general composition of both API and fruits EOs agree with what was reported for this species EOs, isolated both from plants grown in Portugal or in other countries, as described by Machado et al. [48]. Most commonly, coriander aerial parts EOs are dominated, in variable amounts, by 2-trans-decenal, n-decanal, 2-trans-dodecenal, 2-trans-decen-1-ol, among other components as detailed in references in Machado et al. [48]. More consistently, the fruits EOs are dominated by linalool, most published data being within ISO specifications (65–78%) [48,53].

3.4. Coriander Fruits Fatty Acids

The yields of the fatty acids isolated from *C. sativum* fruits ranged from 0.6% to 1.3% (*w/w*), Table 5.

Table 5. Percentage composition of the fatty acids isolated using a Soxhlet apparatus, from *Coriandrum sativum* fruits (F), after transesterification to fatty acid methyl esters (FAMES). For samples codes, see Table 1.

Peak #	FAMES	Fatty Acids	Formula	C:D	ω	Cs_1_F_14	Cs_16_F_14	Cs_31_F_14_w	Cs_32_F_14	Cs_33_F_14_w	Cs_Santo_F_14	Cs_TP_F_14	
1	Methyl dodecanoate (=Methyl laurate)	Dodecanoic acid (=lauric acid)	C ₁₂ H ₂₄ O ₂	C12:0		t	t	t	t	t	t	t	
2	Methyl tridecanoate	Tridecanoic acid (=tridecylic acid)	C ₁₃ H ₂₆ O ₂	C13:0		t	t	t	t	t	t	t	
3	Methyl tetradecanoate (=methyl myristate)	Tetradecanoic acid (=myristic acid)	C ₁₄ H ₂₈ O ₂	C14:0		7.6	17.5	6.5	4.2	4.1	5.6	4.9	
4	Methyl pentadecanoate	Pentadecanoic acid (=pentadecylic acid)	C ₁₅ H ₃₀ O ₂	C15:0		t	t	t	t	t	t	t	
5	Heptadecenoic acid methyl ester	<i>cis</i> -10-Heptadecenoic acid	C ₁₇ H ₃₂ O ₂	C17:1 <i>cis</i> -10	ω 7	t	t	t	t	t	t	t	
6	Methyl <i>cis</i> -9-hexadecenoate (=methyl palmitoleate)	<i>cis</i> -9-Hexadecenoic acid (=palmitoleic acid)	C ₁₆ H ₃₀ O ₂	C16:1 <i>cis</i> -9	ω 7	t	t	t	t	t	t	t	
7	Methyl hexadecanoate (=methyl palmitate)	Hexadecanoic acid (=palmitic acid)	C ₁₆ H ₃₂ O ₂	C16:0		19.2	29.7	27.3	12.9	22.3	14.7	12.0	
8	Methyl heptadecanoate (=methyl margarate)	Heptadecanoic acid (=margaric acid)	C ₁₇ H ₃₄ O ₂	C17:0		t	t	t	t	t	t	t	
9	Methyl <i>cis,cis</i> -9,12-octadecadienoate (=methyl linoleate)	(9Z,12Z)-9,12-Octadecadienoic acid (=linoleic acid, grape seed oil)	C ₁₈ H ₃₂ O ₂	C18:2 <i>cis</i> -9, <i>cis</i> -12	ω 6	16.7	14.0	7.6	19.1	12.3	18.3	19.2	
10	Methyl <i>cis</i> -6-octadecenoate (=methyl petroselinic acid)	(6Z)-Octadec-6-enoic acid (=petroselinic acid)	C ₁₈ H ₃₄ O ₂	C18:1 <i>cis</i> -6	ω 12	45.6	31.5	45.1	55.3	54.1	54.7	55.4	
11	Methyl <i>cis</i> -9-octadecenoate (=methyl oleate)	(9Z)-Octadec-9-enoic acid (=oleic acid)	C ₁₈ H ₃₄ O ₂	C18:1 <i>cis</i> -9	ω 9	t	t	t	t	t	t	t	
12	Methyl octadecanoate (=methyl stearate)	Octadecanoic acid (=stearic acid)	C ₁₈ H ₃₆ O ₂	C18:0		3.9	4.6	8.1	2.7	1.7	2.8	2.1	
13	Methyl eicosanoate (=methyl arachidate)	Eicosanoic acid (=arachidic acid)	C ₂₀ H ₄₀ O ₂	C20:0		t	t	t	t	t	t	t	
% of identification						93.1	97.3	94.6	94.2	94.5	96.2	93.6	
Fatty acids ratio													
Petroselinic acid:Myristic acid						(C18:1 <i>cis</i> -6):(C14:0)	6.1	1.8	6.9	13.1	13.2	9.8	11.6
Petroselinic acid:Palmitic acid						(C18:1 <i>cis</i> -6):(C16:0)	2.4	1.1	1.7	4.3	2.4	3.8	4.8
Petroselinic acid:Linoleic acid						(C18:1 <i>cis</i> -6):(C18:2)	2.7	2.3	5.9	2.9	4.4	3.0	2.9
Petroselinic acid:Stearic acid						(C18:1 <i>cis</i> -6):(C18:0)	2.7	2.3	5.9	2.9	4.4	3.0	2.9
Average extract yield (% w/w)						1.0	0.9	0.8	1.3	0.7	1.1	0.6	

Peak #: Peak number. C:D: where C is the number of carbon atoms in the fatty acid and D is the number of double bonds in the fatty acid. ω : Number of carbons from the methyl end to the first carbon in the double bond of the fatty acid, according to Omega nomenclature. t: traces ($t < 1\%$).

Thirteen fatty acids were identified in the fruit's extracts, with a total percentage of identification >93%. The relative amounts of all fatty acids identified are listed in Table 5, following their elution order in the DB-1 column.

Petroselinic acid (32–55%) was the dominant fatty acid in coriander extracts, followed by palmitic acid (12–30%), Table 5. Despite the high correlation (Scorr > 0.84), hierarchical clustering, based on the fatty acid composition showed sample Cs_16 separated from the remaining six, even more correlated samples (Scorr > 0.92), Figures S4 and S5, due to the lower amount of petroselinic acid (32%). This clustering is also supported by the relation between fatty acids ratios in Table 5.

The European Commission (EU) decided to approve coriander seed oil as a novel food ingredient in food supplements in 2014, with a maximum daily intake of 600 mg [54]. This

decision specifies a petroselinic acid content of 60–75%, followed by linoleic (12–19%), oleic acid (8–15%) and palmitic acid (2–5%).

According to Uitterhaegen et al. [55] petroselinic acid may represent 31–75% of the fatty acid profile. These authors compared the quality of fatty acid composition of coriander Soxhlet extracted oil and twin-pressed oil, and they found an average value of 73% of petroselinic acid with both extraction procedures, which is consistent with previous reported data [56,57].

The petroselinic acid percentages obtained in the present study were within the lowest range reported in the literature [55–57], and somewhat below EU specifications [54], namely in oleic acid content which was found only in trace amounts. This may be due to diverse operative conditions pre-extraction (with, or without grinding, for instance), in extraction type and analysis (without, or with solvent and temperature, and or solvent type, and extraction time), or other factors, such as the ripening stage of the fruits, or coriander variety. In addition, the analytical chromatographic procedure can also induce some variations, as in some studies instead of FAMES analysis, derivatizing agents were used. Thus, it would be important to test for each coriander variety, the effects of the fruit's maturity state, the significance of grinding the fruit, or not, before extraction, and the various types of extraction, such as cold-pressed, without or with solvent, extraction with hot solvent, extraction with different types of solvent, time of extraction, and diverse analytical conditions in order to better respond to and evaluate the reason for these differences.

3.5. Advances in Coriander Extraction Methods

The relevance of coriander on itself (fresh or dry, whole, or ground), and of its bioactive rich extracts, is supported on several dedicated standards and monographs [53,58–61]. In addition, coriander is an interesting plant species as being an example of the same plant providing very different bioactive compounds according to the plant part used for extraction (aerial parts or fruits, also named seeds), or, for the same plant part (fruits), according to the methodology of extraction.

An ideal extraction procedure would be highly efficient, rapid, easy to apply, sustainable, and non-destructive. Nowadays, there is a wide range of extraction techniques for recovering diverse bioactive compounds, which fall into two categories, conventional and nonconventional techniques, with their corresponding advantages and disadvantages. The former include maceration, soaking, Soxhlet extraction, water percolation, solid–liquid extraction with organic solvents, or distillation procedures. These techniques require a considerable extraction time, with the possibility of thermal degradation of thermolabile bioactive compounds or they use organic solvents such as *n*-hexane, which despite allowing good recovery of lipid compounds, have some drawbacks, such as toxicity to humans and the environment [62–65]. Therefore, in recent years several nonconventional techniques have been explored to minimize these limitations, such as microwave-assisted extraction, ultrasound-assisted extraction, pulsed electric field extraction, ohmic heating, enzyme digestion, subcritical water extraction, supercritical carbon dioxide extraction, or the use of natural deep eutectic solvents (NADES) [64,66,67].

Despite the existence of other types of extracts, coriander is mostly known for its essential oil (EO) obtained from either the aerial parts or fruits, and for its vegetable oil (oil), extracted from the fruits. In both cases, these extracts result from different, but conventional, techniques. An EO can only be isolated by one of two procedures, by either steam-, hydro- or dry- distillation of any plant part, or, from the epicarp of citrus fruits, by a mechanical process without heating, designated cold-pressing. The main advantage of obtaining an EO by distillation is using only water as solvent, although at high temperatures. A vegetable oil is either obtained by solvent extraction or by mechanical pressing, without, or with heating. These two types of extracts have very different compositions, and thus also diverse biological properties. For this reason, EO and oil should not be used as synonyms, nor should these designations be attributed to other types of extracts. Another advantage of

both the EO and oil from coriander is that their main compositions are well established internationally, thus allowing the assessment of their quality [53,54].

Aroma is a fundamental food characteristic that is decisive in consumer perception and acceptance. *C. sativum* is an aromatic herb frequently used as a food additive and flavor enhancer, as a spice and condiment. In addition to culinary applications, coriander is also used in traditional medicine, cosmetics, and the food industry [62,68,69]. The characteristic aroma and pleasant flavor of coriander is due to volatile components isolated from the seeds (fruit), or from the aerial parts, as an EO. The fruits EO, with the oxygen-containing monoterpene, linalool as the main component, is applied in medicine as a carminative or as a flavoring agent to mask the bitter taste of other preparations [70,71]. Despite the aerial parts of coriander not being as well studied as the seeds, aliphatic aldehydes, and alcohols, such as *trans*-2-decenal, decanal, *trans*-2-dodecenal and 2-decen-1-ol, were the dominant compounds in the fresh herb EO, responsible for the characteristic aerial parts' odor [68,69].

Although in lower amounts than other oil-rich fruits or seeds, the lipid components of coriander fruits (seeds) are thought to contribute to the development of distinctive aromas and flavors during ripening, since they are regarded as the precursors of several of the fruit's volatile odor principles. Thus, fatty acids, sterols, and tocopherols can be found in the seeds lipidic fraction (oil), with petroselinic acid as the major fatty acid identified followed by linoleic acid. Identification of the fatty acids in coriander leaves indicated a dominance of polyunsaturated fatty acids, with α -linolenic as predominant, followed by linoleic, heptadecenoic and palmitic acids [14].

In addition to essential oils (terpenes rich), and oil (fatty acids rich), by using other extraction procedures, different compounds can be isolated from coriander seeds or aerial parts (leaves and stems). Condensed tannins and flavonoids were identified in the methanolic seed extract, and flavonoids, phenolic acids and polyphenols were found in the leaves and stems [3,72].

Although not providing an EO, subcritical water extraction was compared with hydrodistillation and Soxhlet extraction in volatile oil isolation from the seeds, with the former yielding a volatile oil that was more concentrated in valuable oxygenated components, despite the lower extraction efficiency. This technique is based on the use of water, at temperatures between 100 °C and 374 °C and at a pressure high enough to maintain the liquid state. With this technique, polar compounds are extracted at lower extraction temperatures of water and nonpolar at higher extraction temperatures. Therefore, by controlling the polarity of the solvent by adjusting the temperature, terpenes may be extracted selectively according to their structural properties [62,70,73]. Song and Ko [73] also reported that subcritical water extraction has reduced the time necessary for extraction compared to methanol, hexane, hot water and hydrodistillation, making it an applicable technique for extracting terpenes from seeds. This method's main advantages over conventional extraction procedures include shorter extraction times, higher-quality extracts, less extraction agent costs, and being an environmentally friendly technique [70,74].

Supercritical fluid extraction was another extraction technique studied as an alternative method to hydrodistillation and steam distillation to overcome hydrolysis and thermal degradation in coriander seeds. Studies reported that the volatile oil obtained by supercritical CO₂ extraction provided a higher yield when compared to the other techniques used, namely Soxhlet-dynamic headspace, solvent extraction, steam distillation and hydrodistillation. Linalool represented the main compound, regardless of the extraction procedure used, as opposed to the other components which differed in accordance with the isolation technique. These findings revealed a marked influence of the method applied on the composition of the minor compounds [71]. Abbas et al. [75] reported coriander aerial parts essential oil yield isolated by hydrodistillation was a little higher than the extract obtained by supercritical fluid extraction. However, when compared to the essential oil obtained by hydrodistillation, the extract obtained by supercritical fluid extraction had a higher biological potential due to the presence of a larger number of bioactive compounds.

The microwave assisted hydrodistillation method is another technique that can be used to obtain volatile oil from coriander seeds. This method is recognized as environmentally friendly given its shorter extraction time, reduced energy consumption, which results in lower costs, environmental compliance, improved heat flow and lower solvent consumption. Briefly, the microwave waves are converted into thermal energy, which leads to the heating of the solvent and the sample in the microwave oven, resulting in a faster extraction process. A comparative study on the extraction of essential oil from coriander seeds performed by hydrodistillation and microwave-assisted hydrodistillation showed that the yield was very similar between both processes, 0.31% and 0.33%, respectively. Most of the identified compounds were found in both extracts, with linalool as the dominant one. It was also noticed that microwave-assisted hydrodistillation gave the highest oxygenated monoterpenes content, although the number of identified compounds was lower [64].

As an example of a non-invasive technique, headspace-solid phase microextraction was used to characterize the volatiles present in coriander aerial parts. Among the various compounds, the content of aldehydes was dominant, mostly represented by *trans*-2-tetratecenal, followed by alcohols, hydrocarbons, and esters [76].

Scandar et al. [67], used several natural deep eutectic solvents (NADES) as additives in coriander hydrodistillation. The use of choline chloride (ChCl)-urea enhanced the extract yield compared to the other tested NADES and to water. There were not many variations among extracts composition (except for those obtained with the NADES acidic ChCl-citric acid, which evidenced a possible impact on the final extract composition).

Interestingly, some common recipes can be considered green-extraction procedures, and methods of preserving the obtained product. This is true for the *pisto*, one of the most recorded recipes in this study. In *pisto*, olive oil serves as the green-solvent in a home-made vegetable oil-extraction of coriander active principles. Consumers can directly use this extract as an aromatized olive oil or spread.

The potential applications of coriander could target different areas, most notably its fruits essential oil, with preservative properties due to the antibacterial activity of its compounds, with environmentally friendly features as well as being a biodegradable agent suitable for food preservation. Coriander essential oil has also been recognized as a safe flavoring and/or preservative ingredient in food products, by the Food and Drug Administration [2,77].

Given the aforementioned biological properties of its constituents, coriander could also be considered a promising functional food contributing to the promotion of healthy living, in the actual context of ageing and lifestyle-related diseases [16]. The lipidic fraction obtained from the seeds can also be applied in different industries, such as the plastic industry, due to petroselinic acid content, which can be used as a plastic lubricant during the manufacturing of nylons [78].

The growing demand for improved phytochemicals extraction that are valuable to the food, pharmaceutical, agricultural and cosmetics industries, has led to the development of several extraction techniques suited to the specific compounds to be obtained. Coriander phytochemicals extraction comprise an important and growing area of research, contributing towards the valorization of this medicinal and aromatic plant.

4. Conclusions

This study combined three different approaches (namely ethnobotany, chemical analysis, and a literature survey) with the aim of contributing to the selection of coriander enhanced varieties to be made available for producers.

Ethnobotanical studies were essential to understand the use of coriander by the population and for which purposes, as well as which varieties are nowadays in use by producers. These results were used to publish a book with the traditional recipes, cultivation, and plant breeding results [79], to return to the people their knowledge, valuing and allowing it to be used for future generations.

The most interesting coriander features for the development of a new variety were fresh biomass yields, flavor, and late flowering. These findings were taken into account for the coriander breeding program, leading to the submission of four coriander varieties to the Portuguese National Varieties Catalogue in 2022 [30].

The chemical analysis allowed understanding how these varieties perform, in terms of essential oil and oil production. The literature survey confirmed the potential of this species, and that the optimization of extraction techniques may help meet the demands of producers and industry.

In view of the growing food, therapeutic and agricultural interest in coriander, the obtained findings may contribute to the selection of varieties with greater resistance to biotic and abiotic stress, and enhanced amounts of bioactive compounds.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/foods13060929/s1>, Table S1. Survey questionnaire used during 2003 in 28 coriander landraces origins across Alentejo region (see Figure 1). Table S2. Survey questionnaire used during 2013 in the villages of Alegrete, Santa Catarina and Vale de Vargo (see Figure 1). Table S3. Survey questionnaire used during 2007 in Beja, Elvas and Évora indoor markets and Beja and Estremoz outdoor markets. Table S4. Survey questionnaire used during 2022 in the markets of Elvas, Estremoz and Portalegre (see Figure 1). Figure S1. *Coriandrum sativum* vegetative aerial parts with inflorescence emergence (A) and fruits, with detail of the field trial with plant material at full ripening stage (B,C). Figure S2. Dendrogram obtained by cluster analysis of the EOs from *C. sativum* vegetative aerial parts and fruits, based on correlation and using the unweighted pair group method with the arithmetic average. For the samples' codes in each of cluster I and II, see Table 1. Figure S3. Representative gas chromatography profiles of the EOs from *C. sativum* vegetative aerial parts and fruits. Figure S4. Dendrogram obtained by cluster analysis of the fatty acids from *C. sativum* fruits, based on correlation and using the unweighted pair group method with the arithmetic average. For the samples' codes, see Table 1. Figure S5. Chromatographic profile of the fatty acid from coriander fruits, analyzed in the form of FAMES.

Author Contributions: O.P., N.F., V.L., A.M.M. and A.C.F., conceived and designed research, conducted the experiments and wrote the manuscript: All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by national funds through the Fundação para a Ciência e a Tecnologia, I.P. (Portuguese Foundation for Science and Technology) by the project UIDB/05064/2020 (VALORIZA—Research Centre for Endogenous Resource Valorization), CESAM UIDP/50017/2020+UIDB/50017/2020+LA/P/0094/2020 and PDR2020-7.8.4-FEADER-042741. The study was partially funded by the European Union and the Portuguese Ministry of Agriculture, the Ocean, Environment and Landscape Planning through the AGRO program (Agro 34 for 2002–2003 field missions and Agro 522 for 2007 markets survey), Interreg V-A Espanha-Portugal (POCTEP) project 0665_COOP4PAM_4_P (2022 surveys).

Institutional Review Board Statement: The Ethics Committee of the Instituto Politécnico de Portalegre emitted a positive statement for 2022 surveys (document SC/2020/1775, 12 November 2020).

Informed Consent Statement: Not applicable to 2002–2003, 2007 and 2013 surveys.

Data Availability Statement: The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Acknowledgments: The authors wish to thank all the people in the Alentejo region that shared their coriander landraces seeds, as well as their knowledge. Thanks are due to Fundação para a Ciência e a Tecnologia/Ministério da Ciência, Tecnologia e Ensino Superior (FCT/MCTES) for the financial support to CESAM UIDP/50017/2020+UIDB/50017/2020+LA/P/0094/2020.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Camejo-Rodrigues, J.; Ascensão, L.; Bonet, M.A.; Vallès, J. An ethnobotanical study of medicinal and aromatic plants in the Natural Park of “Serra de São Mamede” (Portugal). *J. Ethnopharmacol.* **2003**, *89*, 199–209. [[CrossRef](#)]
2. Silva, F.; Domingues, F.C. Antimicrobial activity of coriander oil and its effectiveness as food preservative. *Crit. Rev. Food Sci. Nutr.* **2017**, *57*, 35–47. [[CrossRef](#)] [[PubMed](#)]
3. Sahib, N.G.; Anwar, F.; Gilani, A.H.; Hamid, A.A.; Saari, N.; Alkharfy, K.M. Coriander (*Coriandrum sativum* L.): A potential source of high-value components for functional foods and nutraceuticals—A review. *Phytother. Res.* **2013**, *27*, 1439–1456. [[CrossRef](#)] [[PubMed](#)]
4. Mitchell, C.A.; Dever, J.T.; Gafner, S.; Griffiths, J.C.; Marsman, D.S.; Rider, C.; Welch, C.; Embry, M.R. The Botanical Safety Consortium: A public-private partnership to enhance the botanical safety toolkit. *Regul. Toxicol. Pharmacol.* **2022**, *128*, 105090. [[CrossRef](#)] [[PubMed](#)]
5. Peron, G.; Hošek, J. Plants: From Farm to Food and Biomedical Applications. *Appl. Sci.* **2022**, *12*, 2803. [[CrossRef](#)]
6. Rahman, I.U.; Afzal, A.; Iqbal, Z.; Ijaz, F.; Ali, N.; Shah, M.; Sana, U.; Bussmann, R.W. Historical perspectives of ethnobotany. *Clin. Dermatol.* **2019**, *37*, 382–388. [[CrossRef](#)] [[PubMed](#)]
7. Pranskuniene, Z.; Bajoraite, R.; Simaitiene, Z.; Bernatoniene, J. Home Gardens as a Source of Medicinal, Herbal and Food Preparations: Modern and Historical Approaches in Lithuania. *Appl. Sci.* **2021**, *11*, 9988. [[CrossRef](#)]
8. United Nations. Transforming our World: The 2030 Agenda for Sustainable Development. 2015–2030 Agenda for Sustainable Development. United Nation. 2015. Available online: <https://sustainabledevelopment.un.org/> (accessed on 24 July 2023).
9. Ramadan, M.F. *Handbook of Coriander (Coriandrum sativum): Chemistry, Functionality, and Applications*, 1st ed.; CRC Press: Boca Raton, FL, USA, 2023; p. 590. [[CrossRef](#)]
10. Zuzarte, M.; Girão, H.; Salgueiro, L. Aromatic Plant-Based Functional Foods: A Natural Approach to Manage Cardiovascular Diseases. *Molecules* **2023**, *28*, 5130. [[CrossRef](#)] [[PubMed](#)]
11. Centre for the Promotion of Imports from Developing Countries (CBI). What Is the Demand for Natural Ingredients for Health Products on the European Market? Netherlands Enterprise Agency. 2022. Available online: <https://www.cbi.eu/market-information/natural-ingredients-health-products/what-demand> (accessed on 18 February 2024).
12. Nurzynska-Wierdak, R. Chemical Diversity, Yield, and Quality of Aromatic Plants. *Agronomy* **2023**, *13*, 1614. [[CrossRef](#)]
13. Al-Khayri, J.M.; Banadka, A.; Nandhini, M.; Nagella, P.; Al-Mssallem, M.Q.; Alessa, F.M. Essential Oil from *Coriandrum sativum*: A review on Its Phytochemistry and Biological Activity. *Molecules* **2023**, *28*, 696. [[CrossRef](#)]
14. Laribi, B.; Kouki, K.; M’Hamdi, M.; Bettaieb, T. Coriander (*Coriandrum sativum* L.) and its bioactive constituents. *Fitoterapia* **2015**, *103*, 9–26. [[CrossRef](#)]
15. Ramkumar, T.R.; Karuppusamy, S. Plant Diversity and Ethnobotanical Knowledge of Spices and Condiments. In *Bioprospecting of Plant Biodiversity for Industrial Molecules*; Chapter 12; Upadhyay, S.K., Singh, S.P., Eds.; John Wiley & Sons: West Sussex, UK, 2021; pp. 231–260. [[CrossRef](#)]
16. Prachayasittikul, V.; Prachayasittikul, S.; Ruchirawat, S.; Prachayasittikul, V. Coriander (*Coriandrum sativum*): A promising functional food toward the well-being. *Food Res. Int.* **2018**, *105*, 305–323. [[CrossRef](#)]
17. Kaur, H.; Patel, R.; Kaur, J. Ethnobotanical Knowledge of Umbelliferae Family: A Review. *Int. J. Pharm. Sci. Invent.* **2023**, *12*, 45–54.
18. Souza, A.; Rodrigues, A.R.P.; Ribeiro, M.N.; Antunes, V.C. A study on the consumption of coriander (*Coriandrum sativum* L.) and consumers’ perception of its functional properties. *Res. Soc. Dev.* **2022**, *11*, 1–11. [[CrossRef](#)]
19. Kajal, A.; Singh, R. *Coriandrum sativum* seeds extract mitigate progression of diabetic nephropathy in experimental rats via AGEs inhibition. *PLoS ONE* **2019**, *14*, e0213147. [[CrossRef](#)]
20. Mahleyuddin, N.N.; Moshawih, S.; Ming, L.C.; Zulkifly, H.H.; Kifli, N.; Loy, M.J.; Sarker, M.M.R.; Al-Worafi, Y.M.; Goh, B.H.; Thuraisingam, S.; et al. *Coriandrum sativum* L.: A Review on Ethnopharmacology, Phytochemistry, and Cardiovascular Benefits. *Molecules* **2022**, *27*, 209. [[CrossRef](#)]
21. Dias, A.S.; Dias, L.S. Herbs and spices in traditional Portuguese culinary: A preliminary picture. In *VIII International Symposium of Ethnobotany 2010 Proceedings*; Faculty of Pharmacy, University of Lisbon and Friends, the University for Peace Foundation: Lisbon, Portugal, 2011; ISBN 978-989-20-2789-0:595-602. Available online: <http://hdl.handle.net/10174/3828> (accessed on 24 July 2023).
22. Lopes, A.; Teixeira, D.; Calhau, C.; Pestana, D.; Padrão, P.; Graça, P. *Ervas Aromáticas: Uma Estratégia para a Redução de sal na Alimentação dos Portugueses*; DGS: Lisbon, Portugal, 2015; pp. 3–17. ISBN 978-972-675-223-3. Available online: <https://repositorio-aberto.up.pt/bitstream/10216/82620/2/116245.pdf> (accessed on 22 November 2023).
23. Carvalho, A.M.; Pardo-de-Santayana, M.; Morales, R. Traditional knowledge of basketry practices in a Northeastern Region of Portugal. In *Proceedings of the Fourth International Congress of Ethnobotany (ICEB 2005)*, Istanbul, Turkey, 21–26 August 2006; Available online: <http://hdl.handle.net/10198/915> (accessed on 24 July 2023).
24. Dias, A.S.; Dias, L.S. Herbs and spices in traditional recipes of Alentejo (Portugal). In *Proceedings of the Fourth International Congress of Ethnobotany (ICEB 2005)*, Istanbul, Turkey, 21–26 August 2005; Ertug, Z.F., Ed.; Ege Yayinlari: Istanbul, Turkey, 2006; pp. 63–69. Available online: <http://hdl.handle.net/10174/1355> (accessed on 24 July 2023).
25. Moreira, C.; Farinha, N.; Póvoa, O. Preliminary Study of Coriander’s (*Coriandrum sativum* L.) Ethnobotany and Variability in the Alentejo Region. *Rev. Fitoter.* **2005**, *5*, 196–201. Available online: <https://www.researchgate.net/publication/375863433> (accessed on 22 November 2023).

26. Santos, S.; Correia, A.I.D.; Figueiredo, A.C.; Dias, L.S.; Dias, A.S. The use of herbal remedies in urban and rural areas of the Setubal Peninsula (Portugal): A study among elders. In Proceedings of the Fourth International Congress of Ethnobotany (ICEB 2005), Istanbul, Turkey, 21–26 August 2005; Ertug, Z.F., Ed.; Ege Yayinlari: Istanbul, Turkey, 2006; pp. 197–201. Available online: <http://hdl.handle.net/10174/1356> (accessed on 24 July 2023).
27. Póvoa, O.; Ribeiro, G.; Rodrigues, L.; Lobato, P.; Monteiro, P.; Monteiro, A.; Moldão-Martins, M. Effect of storage time on physico-chemical characteristics of *Mentha pulegium* L. and *Mentha cervina* L. Piso Food Sauce. *Acta Hort.* **2009**, *826*, 193–200. [[CrossRef](#)]
28. Lopes, E.; Farinha, N.; Póvoa, O. Characterization and evaluation of traditional and wild coriander in Alentejo (Portugal). *Acta Hort.* **2017**, *1153*, 77–84. [[CrossRef](#)]
29. Póvoa, O.; Lopes, V.; Barata, A.M.; Farinha, N. Monitoring Genetic Erosion of Aromatic and Medicinal Plant Species in Alentejo (South Portugal). *Plants* **2023**, *12*, 2588. [[CrossRef](#)] [[PubMed](#)]
30. Farinha, N.; Churra, M.; Paulo, M.; Lopes, E.; Barata, A.; Lopes, V.; Figueiredo, A.C.; Serrano, C.; Póvoa, O. Plant breeding of *Coriandrum sativum* from landraces collected in Alentejo (Portugal). *Acta Hort.* **2023**, *1358*, 57–64. [[CrossRef](#)]
31. Póvoa, O.; Farinha, N.; Dias, S.S. Levantamento Etnobotânico Sobre Coentros e Poejos no Alentejo. 2012. Available online: <http://hdl.handle.net/10400.26/4598> (accessed on 3 July 2023).
32. Farinha, N.; Póvoa, O. Participação da Escola Superior Agrária de Elvas no Projecto AGRO 34 “Etnobotânica, o Uso e a Gestão das Plantas Aromáticas e Medicinais e a sua Utilização Sustentável como Contributo para a Valorização do Meio Rural”. 2005. Available online: <https://www.researchgate.net/publication/375828496> (accessed on 25 November 2023).
33. Dinis, S.C.B. Recolha de Conhecimentos Etnobotânicos Aplicados ao Tratamento de Animais em três Aldeias do Alentejo. 2014. Available online: <https://comum.rcaap.pt/handle/10400.26/9773> (accessed on 9 June 2023).
34. Monteiro, A.; Póvoa, O.; Pereira, J.; Afonso, E. Conservação de germoplasma, produção e utilização dos taxa *Mentha pulegium*, *Mentha cervina* e *Thymbra capitata*. In *Relatório final do Projecto AGRO 522*; Instituto Superior de Agronomia, Universidade de Lisboa: Lisboa, Portugal, 2008. [[CrossRef](#)]
35. Póvoa, O.; Paulo, M.; Rodrigues, F.; Churra, M.; Santana, C.; Conceição, L.; Farinha, N. Orégãos do Alentejo. In *Do campo ao prato*; IPP: Portalegre, Portugal, 2022; ISBN 978-989-8806-59-8.
36. Council of Europe; European Pharmacopoeia Commission; European Directorate for the Quality of Medicines & Healthcare. European Directorate for the Quality of Medicines. In *European Pharmacopoeia*, 7th ed.; Council of Europe, European Directorate for the Quality of Medicines and Healthcare: Strasbourg, France, 2010; p. 241.
37. *ISO 7609:1985*; Essential Oils-Analysis by Gas Chromatography on Capillary Columns-General Method. ISO: Geneva, Switzerland, 1985.
38. Santos, P.M.; Figueiredo, A.C.; Oliveira, M.M.; Barroso, J.G.; Pedro, L.G.; Deans, S.G.; Younus, A.K.M.; Scheffer, J.J.C. Essential Oils from Hairy Root Cultures and from Fruits and Roots of *Pimpinella anisum*. *Phytochemistry* **1998**, *48*, 455–460. [[CrossRef](#)]
39. Figueiredo, A.C.; Sim-Sim, M.; Barroso, J.G.; Pedro, L.G.; Santos, P.A.G.; Fontinha, S.S.; Schripsema, J.; Deans, S.G.; Scheffer, J.J.C. Composition of the Essential Oil From the Liverwort *Marchesinia mackaii* (Hook.) S. F. Gray Grown in Portugal. *J. Essent. Oil Res.* **2002**, *14*, 439–442. [[CrossRef](#)]
40. Figueiredo, A.C.; Barroso, J.G.; Pais, M.S.S.; Scheffer, J.J.C. Composition of the Essential Oils from Leaves and Flowers of *Achillea millefolium* L. ssp. *millefolium*. *Flavour Fragr. J.* **1992**, *7*, 219–222. [[CrossRef](#)]
41. Ascensão, L.; Figueiredo, A.C.; Barroso, J.G.; Pedro, L.G.; Schripsema, J.; Deans, S.G.; Scheffer, J.J.C. *Plectranthus madagascariensis*: Morphology of the Glandular Trichomes, Essential Oil Composition, and Its Biological Activity. *Int. J. Plant Sci.* **1998**, *159*, 31–38. [[CrossRef](#)]
42. Santos, P.A.G.; Figueiredo, A.C.; Lourenço, P.M.L.; Barroso, J.G.; Pedro, L.G.; Oliveira, M.M.; Schripsema, J.; Deans, S.G.; Scheffer, J.J.C. Hairy Root Cultures of *Anethum graveolens* (dill): Establishment, Growth, Time-Course Study of Their Essential Oil and Its Comparison with Parent Plant Oils. *Biotechnol. Lett.* **2002**, *24*, 1031–1036. [[CrossRef](#)]
43. Faria, J.M.S.; Sena, I.; Moiteiro, C.; Bennett, R.N.; Mota, M.; Figueiredo, A.C. Nematotoxic and Phytotoxic Activity of *Satureja montana* and *Ruta graveolens* Essential Oils on *Pinus pinaster* Shoot Cultures and *P. pinaster* with *Bursaphelenchus xylophilus* in vitro Co-cultures. *Ind. Crops Prod.* **2015**, *77*, 59–65. [[CrossRef](#)]
44. Faria, J.M.S.; Rodrigues, A.M.; Sena, I.; Moiteiro, C.; Bennett, R.N.; Mota, M.; Figueiredo, A.C. Bioactivity of *Ruta graveolens* and *Satureja montana* Essential Oils on *Solanum tuberosum* Hairy Roots and *Solanum tuberosum* Hairy Roots with *Meloidogyne chitwoodi* Co-cultures. *J. Agric. Food Chem.* **2016**, *64*, 7452–7458. [[CrossRef](#)] [[PubMed](#)]
45. Salgueiro, L.R.; Vila, R.; Tomi, F.; Figueiredo, A.C.; Barroso, J.G.; Cañigüeral, S.; Casanova, J.; Proença da Cunha, A.; Adzet, T. Variability of Essential Oils of *Thymus caespititius* from Portugal. *Phytochemistry* **1997**, *45*, 307–311. [[CrossRef](#)]
46. Cavaleiro, C.; Salgueiro, L.; Barroso, J.G.; Figueiredo, A.C.; Pedro, L.G.; Fontinha, S.S.; Bighelli, A.; Casanova, J.; Looman, A.; Scheffer, J.J.C. Composition of the Essential Oil of *Juniperus cedrus* Webb & Berth. Grown on Madeira. *Flavour Fragr. J.* **2002**, *17*, 111–114.
47. Figueiredo, A.C.; Moiteiro, C.; Rodrigues, M.C.S.M.; Almeida, A.J.R.M. Essential Oil Composition from *Cryptomeria japonica* D. Don Grown in Azores: Biomass Valorization from Forest Management. *Nat. Prod. Commun.* **2021**, *16*, 1934578X211038431. [[CrossRef](#)]
48. Machado, A.M.; Lopes, V.; Barata, A.M.; Póvoa, O.; Farinha, N.; Figueiredo, A.C. Chemical Variability of the Essential Oils from Two Portuguese Apiaceae: *Coriandrum sativum* L. and *Foeniculum vulgare* Mill. *Plants* **2023**, *12*, 2749. [[CrossRef](#)]

49. Microsoft. *Microsoft Excel 2016*; Microsoft Corporation: Redmond, WA, USA, 2016.
50. Rohlf, J.F. *NTSYS-pc, Numerical Taxonomy and Multivariate Analysis System*; Version 2.1; User Guide and Exeter Publishing Setauket: New York, NY, USA, 2000.
51. Pestana, M.H.; Gageiro, J.N. *Análise De Dados Para Ciências Sociais: A Complementaridade do SPSS*; Edições Sílabo: Lisboa, Portugal, 2000.
52. Gabinete de Planeamento e Políticas. *As Plantas Aromáticas Medicinais e Condimentares*, Portugal Continental 2012. Ministério da Agricultura e do Mar. 2013. Available online: https://www.gpp.pt/images/GPP/O_que_disponibilizamos/Publicacoes/Estudo_PAM_final.pdf (accessed on 24 January 2024).
53. *ISO 2255:1996*; Coriander (*Coriandrum sativum* L.), whole or ground (powdered). Last Reviewed and Confirmed in 2018. ISO: Geneva, Switzerland, 2018.
54. *2014/155/EU*; The Publications Office of the European Union, Commission Implementing Decision of 19 March 2014 Authorising the Placing on the Market of Coriander Seed Oil as a Novel Food Ingredient under Regulation (EC) No 258/97 of the European Parliament and of the Council (notified under document C (2014). Official Journal of the European Union, L 85, 21.3.2014, p. 13–14. The Publications Office of the European Union: Luxembourg, 1689.
55. Uitterhaegen, E.; Nguyen, Q.H.; Sampaio, K.A.; Stevens, C.V.; Merah, O.; Talou, T.; Rigal, L.; Evon, P. Extraction of Coriander Oil Using Twin Screw Extrusion: Feasibility Study and Potential Press Cake Applications. *J. Am. Oil Chem. Soc.* **2015**, *92*, 1219–1233. [[CrossRef](#)]
56. Ramadan, M.F.; Mörsel, J.-T. Oil composition of coriander (*Coriandrum sativum* L.) fruit-seeds. *Eur. Food Res. Technol.* **2002**, *215*, 204–209. [[CrossRef](#)]
57. Sriti, J.; Aidi Wannes, W.; Talou, T.; Mhamdi, B.; Hamdaoui, G.; Marzouk, B. Lipid, fatty acid and tocol distribution of coriander fruit's different parts. *Ind. Crops Prod.* **2010**, *31*, 294–300. [[CrossRef](#)]
58. *ISO 3516:1997*; ISO and Oil of Coriander Fruits (*Coriandrum sativum* L.). Last Reviewed and Confirmed in 2023. ISO: Geneva, Switzerland, 2023.
59. European Pharmacopoeia (Ph. Eur.) 10th Edition-European Directorate for the Quality of Medicines & HealthCare-EDQM. Available online: <https://www.edqm.eu/en/> (accessed on 8 November 2023).
60. Instituto Nacional da Farmácia e do Medicamento. *Farmacopeia Portuguesa 9.0*; Autoridade Nacional do Medicamento e Produtos de Saúde: Lisboa, Portugal, 2008.
61. European Medicines Agency: EMA/HMPC/180400/2018. *European Union Herbal Monograph on Species Digestivae*; EMA: Amsterdam, The Netherlands, 2022; Available online: <https://docplayer.net/234480337-European-union-herbal-monograph-on-species-digestivae.html> (accessed on 22 November 2023).
62. Pavlič, B.; Vidović, S.; Vlačić, J.; Radosavljević, R.; Zeković, Z. Isolation of coriander (*Coriandrum sativum* L.) essential oil by green extractions versus traditional techniques. *J. Supercrit. Fluids* **2015**, *99*, 23–28. [[CrossRef](#)]
63. Grosso, C.; Ferraro, V.; Figueiredo, A.C.; Barroso, J.G.; Coelho, J.A.; Palavra, A.M. Supercritical carbon dioxide extraction of volatile oil from Italian coriander seeds. *Food Chem.* **2008**, *111*, 197–203. [[CrossRef](#)]
64. Ghazanfari, N.; Mortazavi, S.A.; Yazdi, F.T.; Mohammadi, M. Microwave-assisted hydrodistillation extraction of essential oil from coriander seeds and evaluation of their composition, antioxidant and antimicrobial activity. *Heliyon* **2020**, *6*, e04893. [[CrossRef](#)] [[PubMed](#)]
65. Kaanin-Boudraa, G.; Brahmi, F.; Wrona, M.; Nerín, C.; Moudache, M.; Mouhoubi, K.; Madani, K.; Boulekbache-Makhlouf, L. Response surface methodology and UPLC-QTOF-MSE analysis of phenolic compounds from grapefruit (*Citrus × paradisi*) by-products as novel ingredients for new antioxidant packaging. *LWT* **2021**, *151*, 112158. [[CrossRef](#)]
66. Mouhoubi, K.; Boulekbache-Makhlouf, L.; Madani, K.; Freidja, M.L.; Silva, A.M.; Cardoso, S.M. Microwave-assisted extraction optimization and conventional extraction of phenolic compounds from coriander leaves: UHPLC characterization and antioxidant activity. *North Afr. J. Food Nutr. Res.* **2023**, *7*, 69–83. [[CrossRef](#)]
67. Scandar, S.; Zadra, C.; Lanari, D.; Marcotullio, M.C. Boosting the essential oil yield of *Coriandrum sativum* L. using choline chloride-based NADES: An optimized and systematic study employing response surface methodology (RSM). *Ind. Crops Prod.* **2024**, *208*, 117920. [[CrossRef](#)]
68. Shahwar, M.K.; El-Ghorab, A.H.; Anjum, F.M.; Butt, M.S.; Hussain, S.; Nadeem, M. Characterization of coriander (*Coriandrum sativum* L.) seeds and leaves: Volatile and non volatile extracts. *Int. J. Food Prop.* **2012**, *15*, 736–747. [[CrossRef](#)]
69. Kumar, S.; Ahmad, R.; Saeed, S.; Azeem, M.; Mozūraitis, R.; Borg-Karlson, A.K.; Zhu, G. Chemical composition of fresh leaves headspace aroma and essential oils of four Coriander cultivars. *Front. Plant Sci.* **2022**, *13*, 820644. [[CrossRef](#)] [[PubMed](#)]
70. Eikani, M.H.; Golmohammad, F.; Rowshanzamir, S. Subcritical water extraction of essential oils from coriander seeds (*Coriandrum sativum* L.). *J. Food Eng.* **2007**, *80*, 735–740. [[CrossRef](#)]
71. Msaada, K.; Taarit, M.B.; Hosni, K.; Salem, N.; Tammar, S.; Bettaieb, I.; Hammami, M.; Limam, F.; Marzouk, B. Comparison of different extraction methods for the determination of essential oils and related compounds from coriander (*Coriandrum sativum* L.). *Acta Chim. Slov.* **2012**, *59*, 803–813. [[PubMed](#)]
72. Sriti, J.; Talou, T.; Faye, M.; Vilarem, G.; Marzouk, B. Oil extraction from coriander fruits by extrusion and comparison with solvent extraction processes. *Ind. Crops Prod.* **2011**, *33*, 659–664. [[CrossRef](#)]
73. Song, E.J.; Ko, M.J. Extraction of monoterpenes from coriander (*Coriandrum sativum* L.) seeds using subcritical water extraction (SWE) technique. *J. Supercrit. Fluids* **2022**, *188*, 105668. [[CrossRef](#)]

74. Rodríguez-Meizoso, I.; Marin, F.R.; Herrero, M.; Señorans, F.J.; Reglero, G.; Cifuentes, A.; Ibáñez, E. Subcritical water extraction of nutraceuticals with antioxidant activity from oregano. Chemical and functional characterization. *J. Pharm. Biomed. Anal.* **2006**, *41*, 1560–1565. [[CrossRef](#)]
75. Abbas, A.; Anwar, F.; Ahmad, N.; Shahid, M.; Al-Mijalli, S.H.; Yaseen, M.; Farooq, S.; Iqbal, M. Characterization of bioactives and nutra-pharmaceutical potential of supercritical fluid and hydro-distilled extracted coriander leaves essential oil. *Dose-Response* **2022**, *20*, 15593258221130749. [[CrossRef](#)]
76. Wei, S.; Lyu, J.; Wei, L.; Xie, B.; Wei, J.; Zhang, G.; Li, J.; Girão, H.; Salgueiro, L.; Yu, J. Chemometric approaches for the optimization of headspace-solid phase microextraction to analyze volatile compounds in coriander (*Coriandrum sativum* L.). *LWT* **2022**, *167*, 113842. [[CrossRef](#)]
77. Falleh, H.; Jemaa, M.B.; Saada, M.; Ksouri, R. Essential oils: A promising eco-friendly food preservative. *Food Chem.* **2020**, *330*, 127268. [[CrossRef](#)] [[PubMed](#)]
78. Kassahun, B.M. Unleashing the exploitation of coriander (*Coriander sativum* L.) for biological, industrial and pharmaceutical applications. *J. Agric. Sci. Res.* **2020**, *8*, 552–564.
79. Póvoa, O.; Farinha, N.; Lopes, E.; Mendes, J.P.; Pereira, L. *Coentros do Alentejo—Conservação do Conhecimento Tradicional e dos Recursos Genéticos*; C3i do Instituto Politécnico de Portalegre/77'83 Atelier de Design: Portalegre, Portugal, 2014; ISBN 978-989-8806-00-0.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.