Chapter 1

A Systematic Review: Polyphenol Contents in Stressed-Olive Trees and Its Fruit Oil

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Additional information is available at the end of the chapter

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Abstract

Olive oil includes high amounts of phenols and polyphenols. Through health benefits to humans, the antioxidant role of polyphenols that contain more than two phenolic hydroxyl groups has been well proven. Of those polyphenols, oleuropein, hydroxytyrosol, catechin, chlorogenic acids, hesperidin, nobiletin, and isoflavones are major compounds. Along with the present study, (1) the uses and biological roles of polyphenols have not been limited to their physiological roles to human health; their physiological roles for plant and aromatic values for plant are also evaluated; (2) possible roles of major components in response to environmental stressors are discussed; (3) bibliometric analysis of studies concerned with polyphenols in olive fruit oil has been done to evaluate the research trends concerned with polyphenol in olive fruit oil, considering the main theme of the studies. The study is concluded with highlights, limitation, and future outlooks.

Keywords: olive fruit oil, olive leaves, polyphenol, Turkey, *Olea europaea* L., plant stress physiology

1. Introduction

Stress is a difficult concept to be described in biology. Briefly described in various forms, it is defined as the power (potential) that brings damage to living things. This damage is the result of the degradation of metabolism. As a result, it can cause a reduction in the growth and productivity of a plant or plant organ or even death. Stress severity is within very wide limits ranging from stress-free (optimal conditions favoring for the sustainability of the plant) to moderate and severe stress. But in nature, a completely stress-free environment is not possible for any living organisms, not only for plants. In addition to stress severity, duration of the stress is also essential. In a short period of stress, the reaction of the plant may not emerge. What we mean here is that the visible reaction for growth or development of the plant may not be measured or observed. We should not ignore the endogenous invisible changes in metabolites. Stress degree depends on the plant species. That is, a stress factor that causes severe stress in a plant species may cause moderate stress or zero stress in another species. The degree of stress also depends on the amount of energy that affects the change in metabolic events in living systems. While whole or some parts of a plant (seeds, dormant seeds and dormant cells) may be tolerant to stress, some parts (meristem tissues, succulent organs, young seedlings) are susceptible to stress [1].

In the present chapter, we have mainly focused on the two subtopics for phenolic content. For the first subtopic, we have discussed about the stress physiology, mainly considering abiotic stress and, in the second subtopic, a bibliometric analysis associated with phenolic contents in fruit, which are edible and consumed parts of the plant. So, the first subtopic can be considered as the contents used for plant health itself; the second one can be considered as the contents used for people health.

1.1. A brief outlook on Turkey and Mediterranean region with emphasis on olive orchards

Olive belonging to the Oleaceae family is represented with many genera, and some of the genera have been devoted to produce oil. They are related to *Olea* genus and are usually found in subtropical and tropical climate regions, on the world's middle belt and where Mediterranean climate dominates. *Olea europaea* L. distributes in Upper Mesopotamia including the Southeastern Anatolian Region and South Asia [2]. Approximately 97% of world olive tree and olive production belongs to Mediterranean countries [3].

According to the data extracted from the Food and Agriculture Organization of the United Nations [4], with respect to the world area harvested for olives, world olive production, ranking for top producer countries and Turkey, was documented from 1961 to 2018. In 1961, area harvested for olive was reported to be 2,608,804 ha. The highest value was 10,650,068 ha in 2016, and the lowest value was recorded in 1966 with 2,578,098 ha (**Figure 1**).

For the data about olive production, the lowest quantity was documented in 1962 with a value of 5,410,901 tonnes, and highest quantity was about 22,025,129 tonnes in 2013 (**Figure 2**). In **Figure 3**, top olive-producing countries were represented. Spain was top producer with a remarkable quantity as 9,276,100 according to the data extracted for 2013. **Figure 4** illustrates the yield and production of olives for Turkey, indicating an increasing trend in parallel with the worldwide values.

1.2. Polyphenols versus phenols

Phenolic compounds are the most common secondary metabolites in the plant kingdom. Phenolic compounds are rarely found in bacteria, algae and fungi. Bryophytes are regular producers of polyphenols, including flavonoids, and all of the polyphenols are found in vascular plants. It is estimated that approximately 2% of all carbons photosynthesized by plants are transformed into flavonoids or closely related compounds [5].

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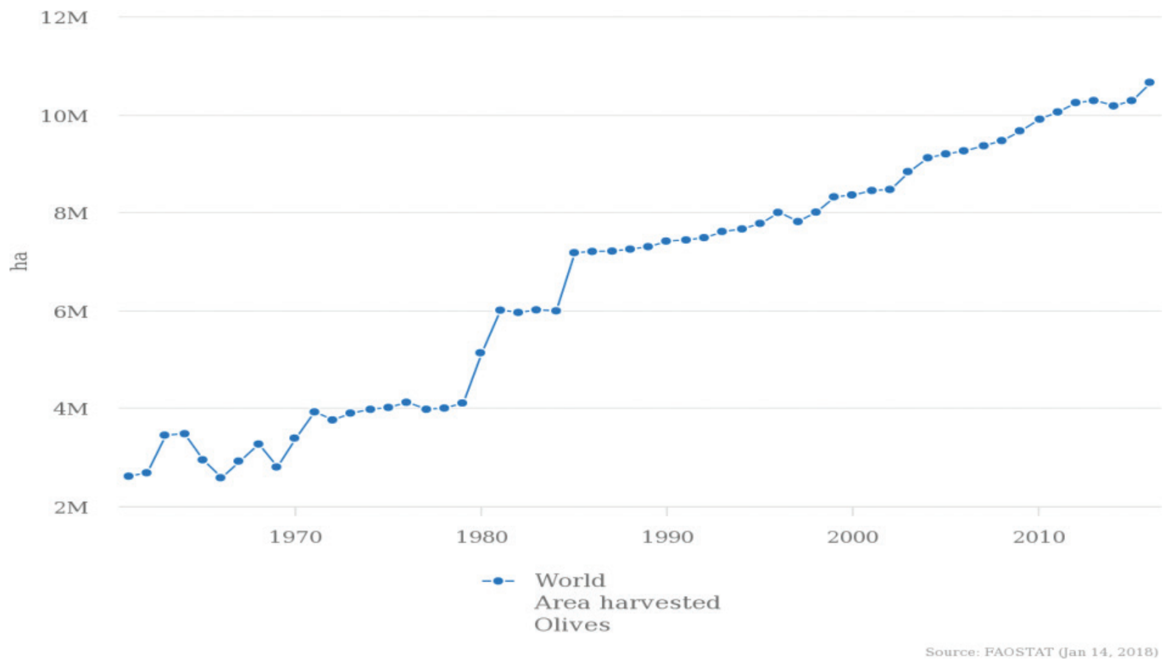

Figure 1. World area harvested for olives (ha).

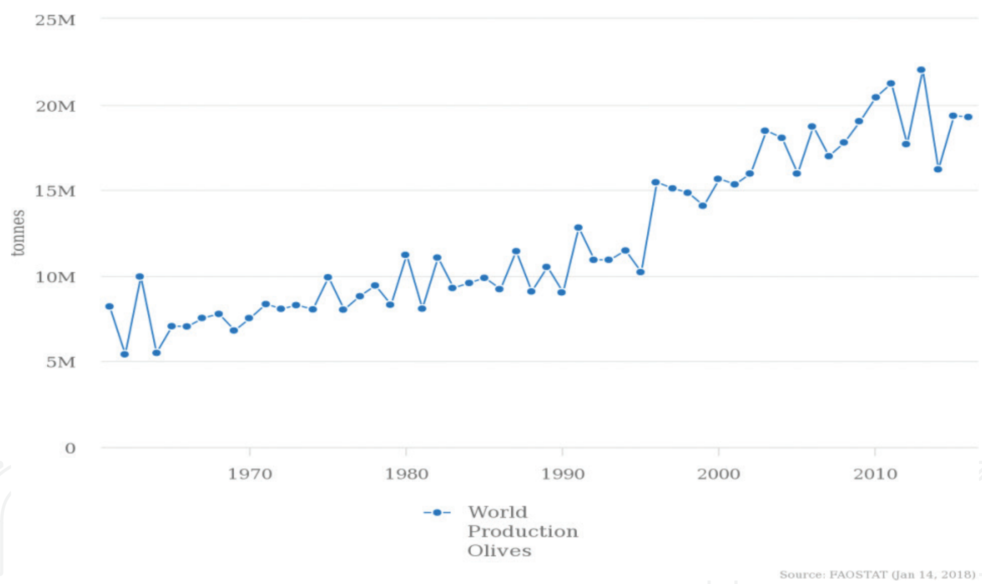

Figure 2. World olive production (tonnes).

The structure of the secondary metabolite of a certain plant is quite complex: (I) the contents of secondary metabolites specifically vary according to the tissue and organ; (II) may also differ between the developmental stages of the plant, for example, the organs important for survival and reproduction have the highest and strongest secondary metabolites; and (III) may also differ between plant individuals and populations. These secondary metabolites are divided into various groups according to biosynthesis pathways and structural properties [6].

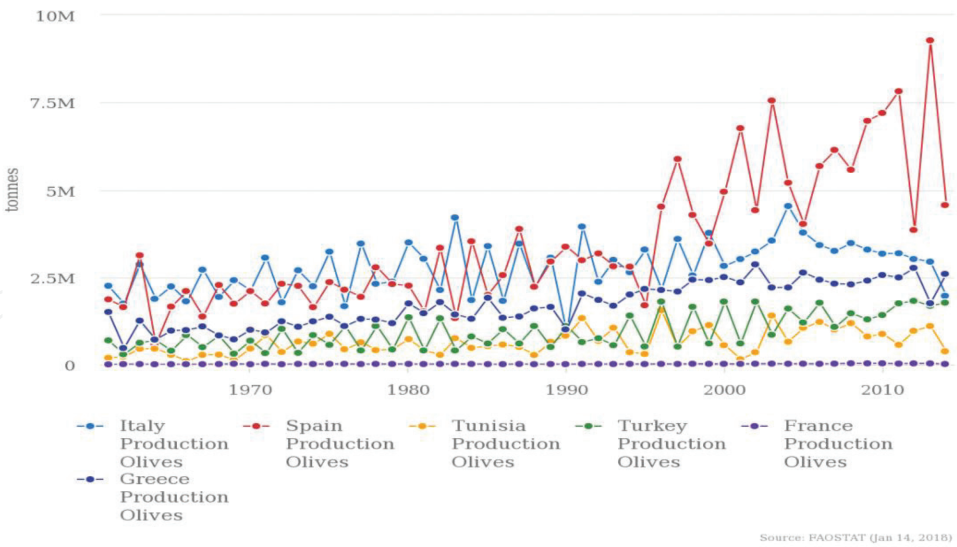

Figure 3. Ranking for top producer countries.

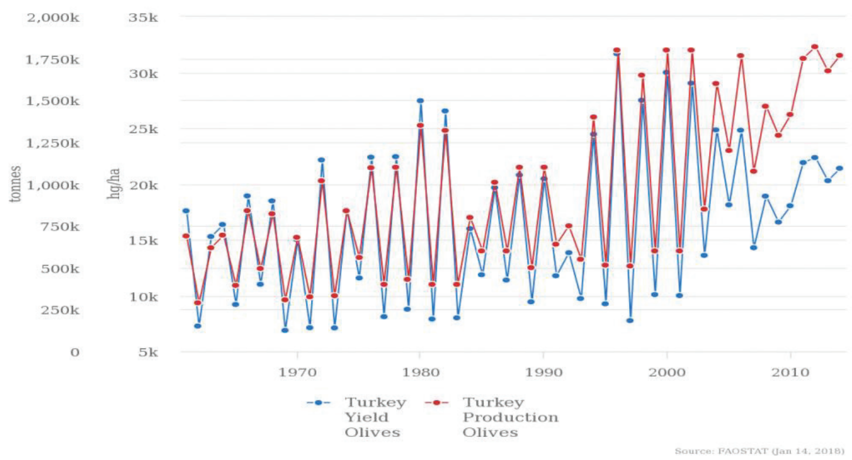

Figure 4. Yield and production values for Turkey.

Before going further, we should simply describe the difference between "phenol" and "polyphenol" terms. Can the terms phenol and polyphenol be used for the same purpose or meaning? In general, with respect to the definition of plant phenolic, phenol is a chemical term that defines a phenyl ring bearing one or more hydroxyl substituents. Polyphenol can be used to describe natural products having at least two phenyl rings carrying one or more hydroxyl substituents including functional derivatives (e.g., esters and glycosides), but such a definition in the context of plant phenolic is unsatisfactory because phenolic carotenoid 3-hydroxyisorenetin, which is a terpenoid, and female sex hormone estrone are also defined under this definition [7].

1.3. What about possible potential roles of phenolic compounds against environmental stress conditions?

Plants face adverse growth conditions during their lifetime such as drought, salinity, cold, low temperature and high temperature. Environmental stress factors can disrupt cellular structures and weaken important physiological functions of the plant. Drought, salinity and low temperature stress can cause osmotic stress, resulting in loss of turgor in plants. Disruption in the stability of the cell membrane, loss of activity or denaturation of proteins and excessive accumulation of the reactive oxygen species rather than optimal content for the essential physiological plants are of the consequences of stress conditions. As a result, photosynthesis inhibition, metabolic dysfunction, damage to cellular structures, growth retardation, loss of yield and early senescence can occur [8]. These undesirable conditions can delay the growth and development of the plant, decrease the productivity and cause the plant to die depending on the severity and duration of the stress. The response of the plant to stress conditions is dynamic, and as a response against unfavorable conditions, plants exhibit mechanisms such as regulation of metabolism and gene expression for the physiological and morphological adaptation of the plant [8, 9].

Phenolic compounds are secondary metabolites which are derivatives of pentose phosphate, shikimate and phenylpropanoids pathways in plants [10]. These compounds, which are one of the most common groups of phytochemical groups in plants, have important physiological and morphological importance in plants. These compounds play an important role in growth and proliferation by providing protection against pathogens and predators [11].

The interaction of plants with their own and biotic and abiotic surroundings has been a driving force in the emergence of certain natural products. In this context, plants are thought to accumulate phenolic material in the tissues of plants as a common response to adverse environmental conditions in the course of their spread and adaptation to the earth. Plant phenolics are thought to play an important role as defense compounds in situations where environmental stresses such as high light, low temperature, pathogenic infections, herbivores and nutrient deficiencies may lead to increased production of free radicals and other oxidative species. Increasing scientific studies and evidence showed that plants respond to biotic and abiotic stress factors by increasing the sweeping capacity of reactive oxygen species. The induction of gene expression of the secondary metabolism with biotic and abiotic stress is mediated by the integration of signaling molecules such as salicylic acid, jasmonic acid and their derivatives [12–14].

1.4. Phenolic profile of olive leaves, fruit and fruit oil

Olive leaves are rich in bioactive compounds, especially polyphenols. The reason of high concentration of polyphenols has been attributed to the long periods of sunlight and attack of many pathogens and insects to olive leaves in Mediterranean region. As a defense mechanism to cope with those stressors, a large quantity accumulation or storage of polyphenols has been reported in the canopy leaves. However, the production, accumulation or secretion of the fatty acids and polyphenols are not only consequences of exogenous factors but also endogenous factors of the plant itself such as cultivar and age of plant [15–19]. Of those compounds, oleuropein, hydroxytyrosol, tyrosol, chlorogenic acid, caffeic acid, p-coumaric acid, verbascoside, gallic acid, ellagic acid, epicatechin, quercitrin, kaempferol, luteolin, luteolin-7-o-glucoside, luteolin-4′-o-glucoside, quercetin, quercetin-7-o-rhamnoside, rutin and apigenin-7-o-glucoside are of the phenolic alcohols, phenolic acids, flavonoids, and secoiridoids analyzed in olive leaves [15, 17, 20–24].

In the Mediterranean region, olive fruit is the prevalent crop as a source of oil. The phenolics in oil composition are considered to contribute to the antioxidant properties [25, 26]. The olive fruits were reported to possess phenolic alcohols, phenolic acids, flavonoids and secoiridoids including oleuropein, ligstroside, demethyloleuropein, hydroxytyrosol, tyrosol, chlorogenic acid, verbascoside, luteolin-7-o-glucoside, luteolin, quercetin-3-o-rhamnoside, cyanidin-3-o-glucoside, cyanidin-3-o-rutinoside and apigenin-7-o-glucoside [27, 28].

There is a negligible number of some secondary metabolites in olive oil, and most of the secondary metabolites are composed of phenolic compounds. Of those compounds, α-tocopherol, oleuropein, hydroxytyrosol, tyrosol, caffeic acid, ferulic acid, p-coumaric, vanillic acid, apigenin, luteolin, pinoresinol, 1-acetoxypinoresinol, oleocanthal and oleacein have been reported in olive oils. As expected, the quantity and quality of the compounds are not stable corresponding to the developmental stage or environmental fluctuations. In short, multivariate interactions of endogenous and exogenous factors are predictive factors on the phenolics. For example, increases in number of phenolic compounds have been recorded from the green to the spotted stages of maturation, and then it decreases until maturity [29]. In this context, Guo et al. [26] suggested that the optimal harvest time for each olive variety may contribute to obtain the highest phenolic content.

1.5. Do polyphenol contents vary with the plant age, cultivation and storage conditions, harvesting times or biotic and abiotic stress factors?

This section can be considered as core of the present chapter. Not all but some studies concerned with polyphenol profile under different conditions or in different developmental stages are briefly summarized. Initially, we should emphasize that nothing stays as its former form. As a simple law of physics, when there is an action, there is a reaction. Any simple change deviating from the present situation of the plant itself or any deviation from optimal growth conditions of the plant—note that plants differ according to the their optimal growth conditions—cause changes in the biochemistry and physiology of the plant. There will always be change even sometimes statistical analysis states no differences between the experimental and control groups of the study. We should note that the change may not be in the measured parameters of the complex-structured whole plant. Plants are open system—not localized in a vacuumed media—and are continuously interacted with their surrounding conditions. This interaction is about the abiotic and biotic environmental conditions. It should not be ignored that the changes in metabolites of the plant might be consequences of the ontogenetic stages of plant itself. In this section, we will briefly represent some studies regarding with external or exogenous applications on the phenolic profile of the olive leaves and fruit oil.

On the hypothesis that the olive trees are exposed to water stress during summer, Petridis et al. [30] conducted a study to determine the effects of water deficit stress for 2 months on in total phenol content, oleuropein and hydroxytyrosol in the leaves of four olive cultivars. As expected and documented in previous studies, water stress triggered the biosynthesis of phenolic compounds, suggesting the possible antioxidant roles of phenolics, but the hydroxytyrosol content declined with the progression of water stress. We should note that the term "phenolic content" means total of thousands of components acting together. The general idea on protective role is that an increase is an indicator of possible antioxidant activity but any decline in any compounds under stress conditions may also be considered as antioxidant agent since synergistic or antagonistic interaction of compounds decides the protective roles. Unless individual activity of isolated pure compounds themselves is not tested, measurement of any individual in total phenolics pool using mass spectrometric analytical techniques may not be certain explanation for protective role of the compound.

Cetinkaya [31] examined the effects of tree age, cultivar and irrigation on flavanol content of two olive cultivar leaves (Kilis Yağlık and Gemlik). The study was designed as a 12-month observation under two irrigation conditions (irrigated and nonirrigated) using two cultivars differing in age. What achieved in the study was cultivar “Kilis Yağlık” contained more flavanols than cultivar “Gemlik”. The age effect was not found to be significant, but nonirrigated conditions lead to higher content of flavanols, which were the possible stress defensive strategies of the plant. Considering the variations of flavanol by months, the content increased from flowering stages to harvest time of olive. Based on the study, we can conclude that flavanols are not only important for their preventive roles versus stress conditions but also important for developmental stages of olive.

Çetinkaya and Kulak [32] proposed the relationship between total phenolics, total flavonoid and oleuropein in different aged (9 and 65 years old) olive (*Olea europaea* L.) cultivars (Kilis Yağlık). Young trees exhibited higher phenolics and oleuropein content, while the higher total amounts of flavonoids were obtained in old trees.

Cetinkaya et al. [33] conducted a 12-month field manipulation irrigation experiment in two olive cultivars. The cultivars were exposed to irrigation and nonirrigation (April–September) and natural climate conditions of the region (October–March). The highest total phenolic contents were produced in cultivar “Kilis Yaglik” in February under natural conditions of the region, but irrigation regimes did not cause any statistical significance changes. The lowest phenolic content was found in cultivar “Kilis Yaglik” in August under irrigated conditions, while nonirrigation treatment increased the content. This decline may be explained with the defense-related functions of phenolic compounds. Moreover, the lowest content of flavonoids was determined in spring for both cultivars (in April for cultivar “Gemlik” and in May for cultivar “Kilis Yaglık”), whereas the highest content was observed in summer. The contents were remained at high levels for both cultivars during autumn. Those results propose the hypothesis that the increase in flavonoid content in summer could be induction of their biosynthesis in leaves to ensure a protection against stress induced by ultraviolet irradiations since the flavonoid roles against ultraviolet irradiation stress have been well documented [14, 34, 35].

Changes in phenolic compounds of *Olea europaea* cultivars contrasting in salt tolerance was reported by Rossi et al. [36]. The accumulation of phenolics was correlated with the content of sodium. Salt-sensitive cultivar (Leccino) had higher concentration of phenolic in their root, stem and old leaves, but salt-tolerant cultivar (Frantoio) exhibited higher concentration in their new leaves. The concentration of phenolics doubled under high salt stress in new leaves of salt-tolerant cultivar. On the other hand, phenolic content in new leaves of salt-sensitive remained stable by increasing salt stress. Of the phenolic compounds, kaempferol concentration was found to be higher in new leaves of salt-sensitive cultivar but lower in old leaves of the cultivar. Quercetin concentration was reported to be so low that it was below the detection threshold, and it increased in salt-tolerant cultivar with increases in salt stress. Salt-tolerant cultivars exhibited more abundant phenolic compounds, which were subsequently increased with the increase in salt stress in new and old leaves. The phenolic compounds in salt-sensitive cultivars, in which leaves accumulated more sodium, were reported to be stable or depleted with salt stress for new leaves. In the same study, genes responsive to phenylpropanoid metabolic pathway were correlated with biosynthesis of phenolic compounds. As a result, upregulation of the pathway was observed for the salt-sensitive cultivars and vice versa.

In one more study by Petridis et al. [37], salinity-induced changes in phenolic compounds in leaves and roots of four olive cultivars (*Olea europaea* L.) were monitored. Accordingly, severe salt stress triggered accumulation of total phenolic compounds (TPC) in leaves, but moderate salt stress level induced formation of TPC in roots. Of the quantified phenolic compounds, oleuropein was reported to be major compound in both leaves and roots, suggesting the possible protective roles against salt stress.

As an exogenous factor, Stanković et al. [38] examined the ecological variability of the phenolic compounds of *Olea europaea* L. leaves from natural habitats and cultivated conditions. In this context, samples from wild-spread regions (Tunisia, Malta and Montenegro) and from cultivated conditions (France and Serbia) were scanned for their total phenolic content, flavonoid content and antioxidant properties. As expected result, polyphenol content and antioxidant properties were found to be habitat dependent. Interesting output of the research was that samples from cultivated plants exhibited higher total quantity of phenols and flavonoids, but the values associated to antioxidant properties were higher in samples from natural habitats. The researchers deduced that natural habitats contained metabolites with high antioxidant activity, proposing that those substances may be active players for adaptation of the plants against stress conditions. Using mass spectrometric technologies for profiling the individual compounds with their quantities may contribute more to increase our understanding of important roles of polyphenolic compounds as a response to the changing environmental conditions.

Higher total quantity of phenols and flavonoids in young plants of four Tunisian olive cultivars (Chetoui, Ouslati, Jarboui and Meski) grown under water deficit conditions for two months were determined but the quantity differed according to the cultivars. Furthermore, cultivar with high content of phenolic and flavonoid exhibited important antiradical activity under water deficit [39].

Aparicio et al. [40] reported the effects of saline condition (0 and 200 mM NaCl for 12 weeks) on physiological properties of six olive genotypes. Out of the tested cultivars, total quantity of phenolics of four cultivars increased with increase in salt stress. The preventive roles of phenolic compounds as compatible organic solutes and as molecular antioxidants through their free radical scavenging abilities have been re-reported [41].

1.6. How do phenolic compounds exhibit antioxidative properties in plants? Which parts of phenolics are used to combat with free radicals?

Reactive oxygen species (ROS) production, which damages the cellular structure, is a common result of stress at the cellular level [42]. The prominence of the phenol compounds is that the hydroxyl group has an inhibitory potential for free radicals. Therefore, an increase in this compound means an increase in an antioxidative activity. ROS production is normally detoxified by a number of antioxidants including phenolics and antioxidant enzymes [43]. In addition to the free radical scavenger roles, phenolics also act as a radiation-absorbing filter limiting chlorophyll excitation for photosynthesis under adverse conditions [44]. Depending on the decrease of water content in leaf tissues, protective mechanisms involving the synthesis of phenolic compounds are triggered and then neutralized by absorption of radiation and conversion to blue fluorescence [45].

In the presence of suitable functional groups (hydroxyl and carboxyl), phenolic compounds have the ability to chelate iron and copper ions. Plants with a content of tannins were documented to possess capability to tolerate the high concentrations of manganese in a soil through chelation of these ions [46, 47]. Posmyk et al. [48] suggested the roles of peroxidases and phenolic compounds in defense reaction in response to the oxidative stress mediated by copper ions.

1.7. The remarkable changes of phenolic compounds during alternation: a prominent compound, "chlorogenic acid"

Alternate bearing or irregular bearing is of the major unfavorable attribute decreasing crop production and consequently results in significant economic loss in some years. The phenomenon of alternate bearing is described as the processes associated with the plants (both deciduous and evergreen trees) bearing an irregular crop year after year, usually heavy yields which are followed by light ones [49], proposing a biennial cycle (sorted as "on" and "off" year) of fruit production. High yield in "on" year and little or no yield in "off" year are representatives of the alternation. In order to understand and reveal the underlying mechanisms for alternate bearing, a number of physiological, biochemical and molecular studies have been carried out [50–54]. The quality and subsequently the aromatic value or bio-efficacy of the oil or table olives have been well documented to be related to the content and pattern of phenolic compounds of the fruit. The phenolic contents are not only strongly influenced by cultivar and stage of the maturation but also by plant genetic structure and alternate bearing phenomenon [52]. Profiling the polyphenolic content and composition is also essential physiological basis for enlightening this phenomenon. In this context, Mert et al. [21] monitored the quantitative seasonal changes in the leaf phenolic content related to the alternate-bearing patterns of olive (*Olea europaea* L. cv. Gemlik). In this context, oleuropein, chlorogenic acid, caffeic acid, 3-hydroxycinnamic acid, scopolin and p-coumaric acid concentration in leaves were investigated. Significant differences in concentration of the measured phenolic compounds in 2008 (off year) and 2009 (on year) were reported. The higher concentration of chlorogenic and p-coumaric acids during "on" year was determined, and lower levels of other phenolic compounds were reported and vice versa for the "off" year samples. In general, higher levels of phenolic compounds were measured during the dormant season. Also, the central role of chlorogenic acid in alternation has been identified, exhibiting 3–4 times greater concentration in fruit-bearing years once compared to the non-fruit-bearing period [55–57]. The chlorogenic acid concentration in old season leaves exhibited dramatically variations between seasons [58].

2. A bibliometric analysis of olive fruit oil

The research questions of this section are as follows. Along with the present study, (i) what are the research trends concerned with polyphenol in olive fruit oil, considering the main theme of the studies? (ii) What is the spatial distribution of the researches? Do the Mediterranean countries mostly conduct studies or not, considering the attributes influential on the performing the studies? (iii) How far Turkey is away from worldwide studies regarding with polyphenol contents in olive fruit oil? To answer these questions, we performed a bibliometric analysis using VOSviewer v.1.61 (Centre for Science and Technology Studies) program.

2.1. Methods

2.1.1. Data source

The data were retrieved from online version of Scopus database on December 7, 2017, which indexed 37.956 major journals across many different scientific disciplines. The Scopus is considered as most comprehensive and reliable bibliographic source. Thus, the Scopus database was used to identify research articles on the topic of polyphenols. All records with the term "polyphenols" in the "article title, abstract and keywords" were retrieved. Accordingly, 47,821 documents containing the word "polyphenols" were recorded. The search was then restricted for publications that contain the words "olive or *Olea europaea* and fruit oil" in the title and abstracts. The inclusion criteria were all relevant available scientific publications in field of polyphenols in olive fruit oil. The search was conducted on December 7, 2017. The documents published during the period of 1995–2017 were included. After assessment literature in the title and abstract of all documents, duplicated articles, errata and undefined documents were excluded. No language limitation was considered. Finally 434 documents were analyzed. Workflow for the present study was illustrated in **Figure 5**.

Furthermore, VOSviewer v.1.61 (Centre for Science and Technology Studies) was used to construct bibliometric diagrams for visualization of co-citation, co-occurrences extracted from the title and abstract fields of the articles. Co-citation is described as any two items (authors) that have been jointly cited by another item (author). Hence, the more co-citations two items received correspond to the more likely they are related.

2.2. Results

2.2.1. Co-occurrence network of terms and country rankings

Figure 6 shows the co-occurrence of terms that occurred in the title and abstract fields. After inclusion of some limitations, the most relevant terms were displayed in **Figure 6**. Three main clusters were identified as the first cluster (red), the second cluster (blue) and the third cluster (green). To conclude, the clusters are found to be associated with (i) the first cluster (red), biochemistry of olive fruit oil; (ii) the second cluster (blue), genetics concerned with diversity of olive; and (iii) the third cluster (green), agricultural applications concerned with irrigation treatments for yield. In **Figure 7**, the co-occurrence terms that appeared in Turkish-originated

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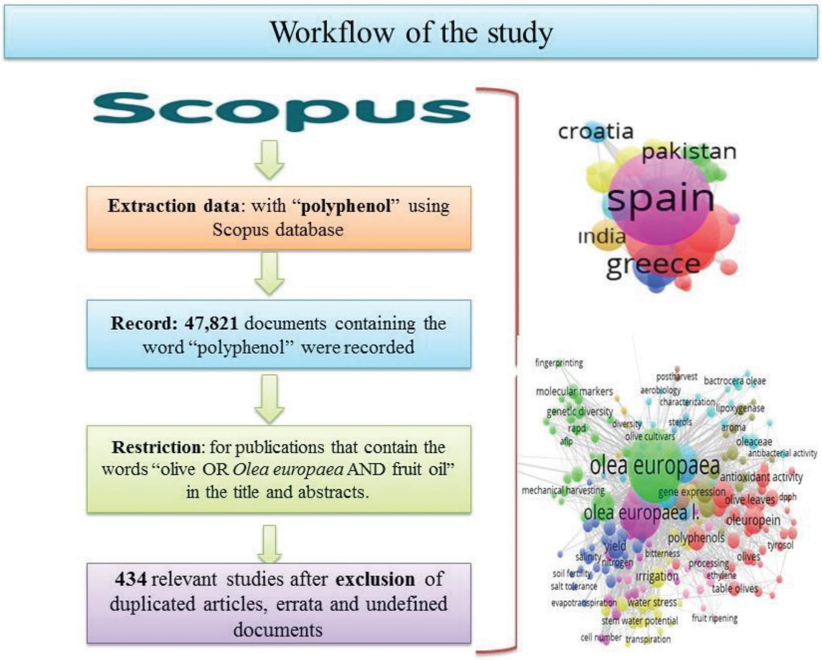

Figure 5. Workflow for the present study.

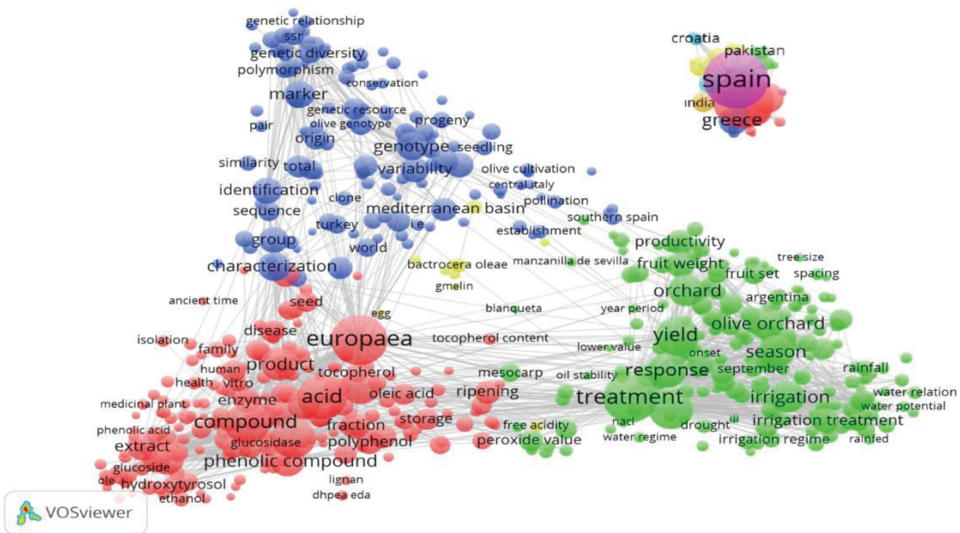

Figure 6. Co-occurrence network of terms occurred in the title and abstract of the documents on polyphenol contents and olive fruit oils between 1995 and 2017. Four clusters were identified and displayed in different colors.

studies are shown. Three clusters were also identified. The first cluster (green) and second cluster (blue) were related to biochemistry of olive fruit oil including phenolics and fatty acid composition, and the third cluster (red) was associated with genetics concerned with diversity of olive and its cultivars. To conclude that the worldwide trend for olive studies is not only limited to profile, the biochemical or nutritional composition of olives but also exogenous agricultural practices for yielding higher oil content. For Turkish studies, the works are mainly concentrated on monitoring or profiling the phenolic and fatty acid composition

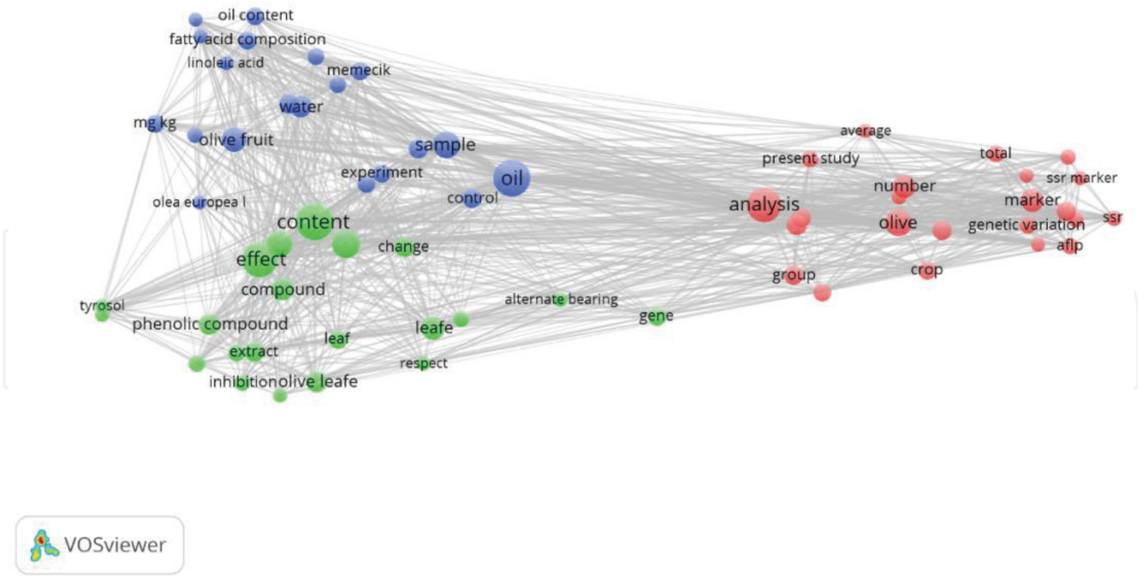

Figure 7. Co-occurrence network of terms occurred in the title and abstract of the documents on polyphenol contents and olive fruit oils between 2001 and 2017. Three clusters were identified and displayed in different colors. The terms were retrieved from Turkish studies.

with their total yield. We should also note that the extracted documents were mostly limited to the agricultural and biological sciences. Furthermore, the genetic studies in Turkey are concomitant with the worldwide studies. Of the publishing countries, as expected Mediterranean countries—Spain, Italy, Tunisia, Greece, Turkey and France—were predominant countries. Olive tree is a typical Mediterranean plant grown in Marmara, Aegean, Mediterranean and South East Anatolian regions of Turkey and important oil sources for Mediterranean countries, fulfilling 90% of the world olive oil production. Spain, Italy, Greece, Tunisia and Turkey are of the important producer and stakeholders of olive oils [59].

2.2.2. Contributions of keyword by authors

The simple keyword extraction provides raw information about the research topics, but they are assigned to documents to represent the core content of their papers. In this regard, keyword analysis can be used to determine the progress the research frontiers associated with a knowledge [60], proposing the gap of keyword analysis in polyphenol studies in olive fruit oils. Herewith the core results, this section should be considered as the most important contribution of the manuscript [61]. Co-occurrence and author keywords might be considered as one of the factors to provide information on polyphenol studies in olive fruit oils. **Figures 8** and **9** represent the core content of the studies for worldwide and Turkey-centered studies, respectively. For the worldwide studies (**Figure 8**), the researches on molecular approaches (molecular markers, genetic diversity, RAPD, AFLP methods), biochemical approaches (polyphenol content, olive leaves, table olive, processing for quality and antioxidant activity), stress physiology (irrigation, water stress, salinity, salt tolerance, water potential and transpiration) were performed. For Turkey-centred studies (**Figure 9**), the studies are mostly concentrated on polyphenol content and fatty acid composition. For molecular studies, some cultivars have been compared with wild cultivars using molecular markers.

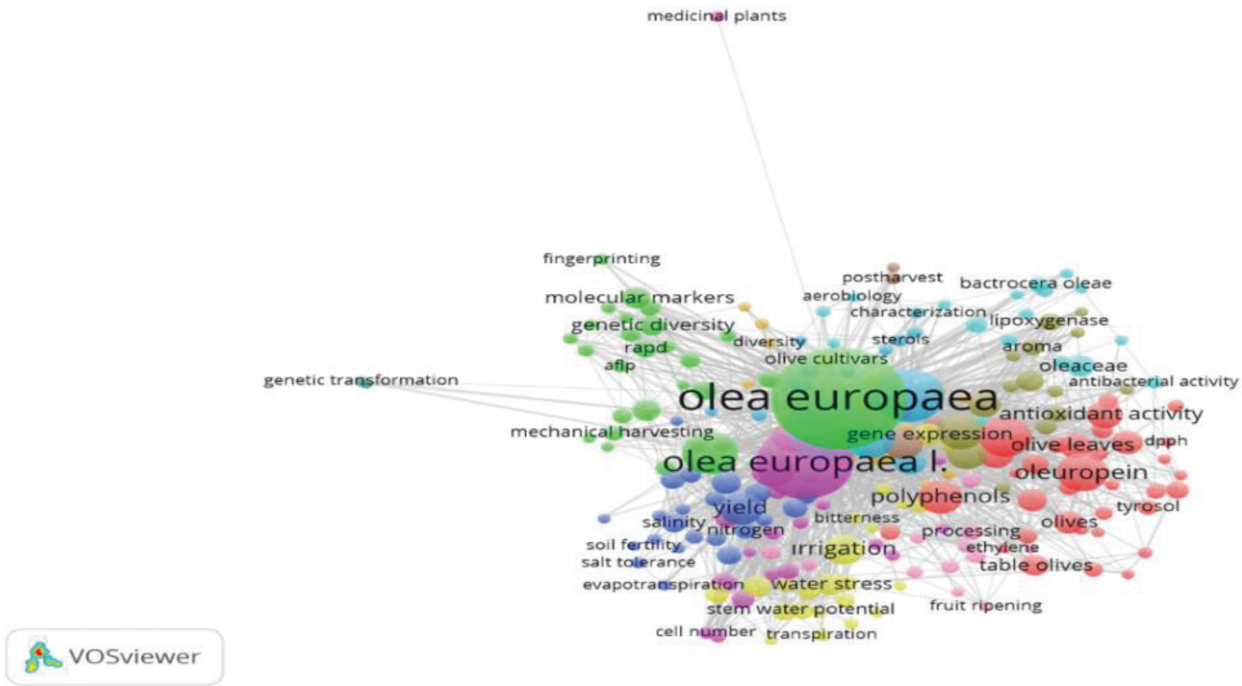

Figure 8. Co-occurrence network of keywords occurred in the title and abstract of the documents on polyphenol contents and olive fruit oils between 1995 and 2017. Thirteen clusters were identified and displayed in different colors.

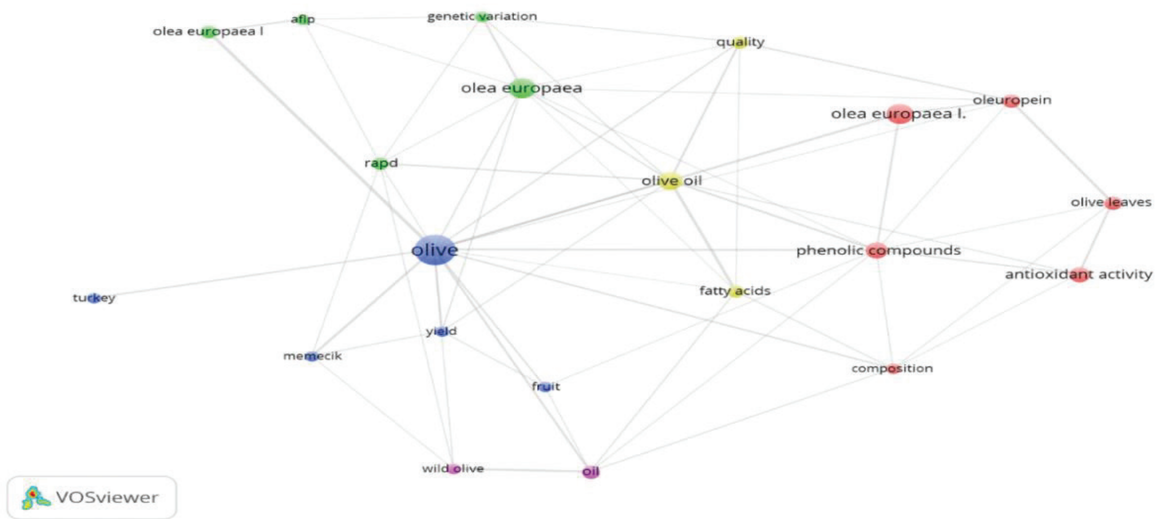

Figure 9. Co-occurrence network of keywords occurred in the title and abstract of the documents on polyphenol contents and olive fruit oils between 2001 and 2017. Five clusters were identified and displayed in different colors. The keywords were retrieved from Turkish studies.

2.3. Future outlook

In this section, we focused on the gaps and gave suggestions for future studies associated polyphenols for Turkish olive cultivars:

1. Polyphenol content and patterns of the olive cultivars and wild ones might be documented in order to point out the aromatic value.
2. Biotic and abiotic stress-tolerant cultivars might be monitored in response to the probable sharp and extreme environmental conditions.
3. Exogenous stressors (water stress, salt stress, etc.) might be applied to enhance the stress tolerance and increase the essential secondary metabolites.
4. Stressed olive cultivar extracts might be tested for their plausible biological activities.

2.4. Highlights of the study

Along with the present study, we have illustrated a schema as studies regarding to (i) the current state knowledge of polyphenol studies or profiling the changes in polyphenolic components in Turkish olive cultivars, (ii) pointing out the stages of development of the studies, (iii) presenting assessments for the significance of the studies performed and (iv) giving suggestions for the key areas for further work.

2.5. Limitations of the study

Although this is the first study—up to our best survey—to present the most comprehensive and specific view of available research on for polyphenol content of olive fruit oil from the largest existing database using VOSviewer program, we have several limitations in this study. (1) We only extracted data from SCOPUS, and so documents in nonindexed plant journals have not been considered. (2) The search was then restricted for publications that contain the words *olive or Olea europaea and fruit oil* in the title and abstracts. (3) Hence some publications might not contain polyphenol and olive fruit oil-related terms in the publication title and abstracts, so it is possible that not all publications for polyphenol content of olive fruit oil were identified.

3. Conclusions

We can list the main conclusions of the review as follows:

1. The content and pattern of the polyphenolic compounds are dynamic, not constant. They exhibit variations with the genetic structure, alternate bearing or irregular bearing, plant age, cultivation and storage conditions, harvesting times or biotic and abiotic stress factors.
2. Upregulation of the phenolic biosynthesis pathway was observed for the salt-sensitive cultivars and vice versa, deciphering the plausible defense roles of phenolics under stress conditions.
3. The roles of phenolic compounds in defense mechanism have been well documented. Neutralizing the effects of oxidative stress and chelating heavy metals are the major mechanisms to combat stress factors but in the presence of suitable functional groups.

4. Chlorogenic acid was of the outstanding compounds in response to the alternation phenomenon.

5. According to the co-occurrence network of terms and country rankings, the worldwide trend for olive studies is not only limited to profile the biochemical or nutritional composition of olives but also exogenous agricultural practices for yielding higher oil content. For Turkish studies, the works are mainly concentrated on monitoring or profiling the phenolics and fatty acid composition with their total yield.

6. Of the publishing countries, as expected Mediterranean countries—Spain, Italy, Tunisia, Greece, Turkey and France—were predominant countries.

7. Even though there are some limitations of the present study, we pointed the stages of the development of the olive studies but only for phenolics, giving suggestions for the key areas for further works.

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