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Review

Assessing the Interlinkage between Biodiversity and Diet through the Mediterranean Diet Case

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ABSTRACT

The adoption of healthy and sustainable diets and the transition to sustainable food systems is of principal importance in order to counteract the double burden of climate change and noncommunicable diseases. The Mediterranean diet (MD) has been widely recognized as a biodiversity and healthy nutrition resource to support sustainable development and food security. This study explored biodiversity in terms of food plants species, subspecies, varieties, and races, and also addressed food plant diversity differences between the MD and Western-type consumption patterns. It was funded by the EU BioValue Project, aiming to promote the integration of underutilized crops into the food value chains. Using a 2-stage scheme, data were selected from MEDUSA and Euro+Med databases (including 449 species, 2366 subspecies, varieties, and races). Furthermore, 12 countries from North Africa and Europe were classified in 2 groups according to their subregional attributes and their traditionally most prevalent dietary pattern (MD or Western-type diets). Statistical analysis showed that the mean of the majorly cultivated food plants in the MD was significantly higher than its counterpart in the Western diet. Furthermore, no statistical difference was detected in the averages of native food plants between the MD group and the Western diet group, implying that the higher diversity in food plants observed in the MD seems to be attributed to crop utilization rather than crop availability. Our findings indicated the interlinkage between biodiversity and prevailing dietary patterns and further underlined that biodiversity could constitute a prerequisite for dietary diversity and hence nutrition security. In addition, this study demonstrated that diets and nutrition should be approached in a broader way within the context of both agro-food and ecological systems.

Keywords: biodiversity, food plants, prevailing dietary pattern, Mediterranean diet, Western diet, sustainable food systems

Introduction

The question of how to feed people and provide adequate and healthy food to eliminate hunger and malnutrition constitutes a crucial social challenge [1], since the world population is steadily increasing and it is expected to rise from 7.7 billion worldwide in 2019 to around 9.7 billion by 2050, and up to 10.9 billion by the end of the century [2,3]. Food and Agriculture Organization (FAO) estimates showed that agro-food production will have to increase by almost 50% in order to accomplish consumers' requirements and satisfy the increasing demand, especially for meat and processed meat products [4]. This constant population growth may be considered as an underlying threat to sustainable development because it stresses natural resources through overexploitation, intensive farming, and land fragmentation [5]. Besides feeding the population, the current agro-food system has also been considered as a major driver of environmental degradation and climate change [6–8]. Agricultural production occupies approximately 40% of the global land, whereas livestock and livestock-feed production represent 75% of all agricultural land [2,9]. Subsequently, agricultural land expansion and the associated extensive usage of inputs, such as irrigation, fertilizers, and pesticides, may result in fragmentation of habitats, natural resources depletion, and environmental degradation. In addition, food production constitutes the principal consumer of fresh water and accounts for up to 30% of global greenhouse gas (GHG) emissions [10–13]. Awuchi et al. [14] provided an analytical report on the environmental impacts

Abbreviations: CBD, Convention on Biological Diversity; FSN, Food security and nutrition; GHG, Greenhouse gas; MD, Mediterranean diet; NUPs, Neglected and underutilized plant species; SFS, Sustainable food system.

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of the agro-food industry, noting that these impacts in terms of environmental pressures may obstruct agro-food production, especially in the future.

Intensified management practices in the agro-food businesses together with the overexploitation of inputs may endanger the conservation of the terrestrial ecosystems and have severe impacts on biodiversity [15–19]. It has been argued that biodiversity is declining partially due to several drivers associated with the current conventional agriculture, such as intensification, monocropping, and the use of chemicals, among others [20]. According to the Article 2 of the Convention on Biological Diversity (CBD), biological diversity is defined as "*the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems*" [21]. Wood and Lenne [22] also defined agrobiodiversity as "*the diversity of living organisms, including animals, plants, bacteria, etc., used in agriculture.*" Both definitions noted that the quantitative measurement of food plant species and subspecies within a particular food system comprises a strong indicator of biodiversity [22].

Although intensification in agricultural production systems can substantially increase yields and at the same time reduce the area of the cultivated land, there is a high risk for biodiversity loss due to fertilizer and pesticide pollution [19]. Agricultural expansion and intensification may increase evapotranspiration [23], which in turn can reduce the amount of freshwater runoff and aquifer recharge [24,25], putting extra pressure on ecosystems and biodiversity. Furthermore, irrigated agriculture may decrease the availability of water in surrounding rivers and lakes and generate trade-offs between ecosystems regarding the usage of freshwater [26,27], whereas excessive use of fertilizers contributes to water bodies eutrophication and the subsequent degradation of aquatic ecosystems [27]. Livestock, and especially meat production, has also been associated with natural ecosystems degradation and biodiversity decline because it constitutes a water and land-intense sector and also accounts for higher GHG emissions per unit of energy or protein than other foods [13,19]. Future expansion and intensification in agro-food production practices will put extra burden, especially in biodiverse regions [28]. On the other hand, the production of plant foods accounts for lower GHG emissions compared with animal foods, denoting that a shift toward plant-based diets could help preserve biodiversity [8,29].

In an effort to address biodiversity decline, the great majority of the world's governments adopted the Global Strategic Plan for Biodiversity 2011–2020 and its 20 Aichi Biodiversity Targets, a 10-y framework for action designed by the CBD, to safeguard biodiversity [30]. Unfortunately, none of these targets were fully met, whereas the Fifth Global Biodiversity Outlook 5, published in September 2020, reported limited progress [31]. The Post-2020 Global Biodiversity Framework will be presented for consideration in December 2022, aiming to restrain biodiversity loss by 2030 and achieve recovery by 2050 [32]. Within the framework of the EU Green Deal, the European Commission published the EU Biodiversity Strategy for 2030 in order to protect natural ecosystems after recognizing "the multiple benefits of biodiversity for society and, more broadly, for life on earth" [33].

There is a great body of literature linking food consumption and diet with both human health and environmental sustainability [12, 34–37]. Dietary guidelines have to combine the health-nutrition aspect with the environmental aspect for providing food for all in a healthy and sustainable way [9,36]. Toward a more sustainable dietary option, the traditional MD addresses both health and environmental issues because recent evidence showed that plant-based dietary patterns with low consumption of animal foods contribute to health maintenance and can help mitigate biodiversity degradation [2,38,39] compared to Western dietary patterns. In particular, the Med Diet 4.0 framework evaluated the MD as a food consumption pattern with sustainability outcomes, incorporating the following components: *1*) well-established major health and nutrition benefits, prevention of chronic diseases, decrease in public health costs, and overall improvement of well-being; *2*) low environmental impacts and biodiversity conservation, reduction of pressure on natural resources, and climate change mitigation; *3*) local economic returns, sustainable territorial development, reduction in rural poverty, and food waste and food loss reduction; *4*) high social and cultural food value and identity, social interaction, and consumer empowerment [2,8,40].

In light of biodiversity decline, this study sought to investigate biodiversity in terms of food plants species, subspecies, varieties, and races and address food plant diversity differences between the MD and Western-type consumption patterns. In particular, this study explored whether the dietary pattern that traditionally prevails in the country of reference (MD or Western-type diets) is influenced by biodiversity in food plants (including species, subspecies, varieties, and races). To the best of our knowledge, this is the first study to explore the biodiversity of the MD at the plant species, subspecies, variety, and race level within the Mediterranean basin. Therefore, the cultivation status of 449 food plant species and their 2366 related subspecies, varieties, and races was investigated within 12 countries in the Mediterranean region and the rest of Europe, out of which 6 countries traditionally present a greater adherence to the MD, whereas the remaining 6 countries have adopted a Western-type dietary pattern. The research was funded by the EU BioValue Project, aiming to promote the integration of underutilized crops into the food value chains.

Sustainability in the food sector

Sustainable food systems and sustainable diets.

Modern food systems have to compromise the increasing food demand due to global population growth while competing for resources [36]. This dual challenge forces dietary interventions and nutrition programs to move from the traditional nutrients-health approach to a new one that puts on the table sustainable development and its sociocultural, environmental, and economic aspects [2,41]. To enhance the sustainability of the food systems and achieve food security, there has been a concerted effort to broad the sustainability perspective along 3 axes, emphasizing the transition from *1*) the production approach to a more holistic food system approach, *2*) the environmental approach to an integrated and wider approach incorporating both the sociocultural and economic perspective as well, and *3*) the "global availability" perspective of food security to a new perspective encompassing the dimensions of food accessibility, nutrition, and stability to the individual level [42,43].

According to the 2014 High Level Panel of Experts on Food Security and Nutrition Report, a sustainable food system (SFS) is the "food system that ensures food security and nutrition (FSN) for all in such a way that the economic, social, and environmental bases to generate FSN for future generations are not compromised" [43,44]. Therefore, the concepts of FSN and SFS seem to be interrelated and the existence of "food security and nutrition for all, worldwide" over time can only be achieved within the frames of a sustainable food system [45]. The sustainability concept includes a time dimension to ensure that its environmental, sociocultural, and economic aspects will interact with the dimensions of food security (i.e., food availability, access, utilization, and stability).

The necessity for the transition to sustainable diets has been widely discussed and fostered within the context of sustainable food systems. Numerous studies underline that diets that exploit the physical constraints of an environment with finite resources stress the biodiversity and produce unnecessary gas emissions that disrupt environmental quality and conservation [46–49]. Furthermore, current food consumption is characterized by a global shift from basic plant-based food components toward higher-value foods (i.e., meat, dairy) and more processed food items, resulting in increasing rates of diet-related chronic diseases (i.e., cardiovascular disorders, diabetes) and overweight and obesity [35,50]. Modern food industries through marketing strategies have substantially influenced consumers' food choice by directing their preferences toward food products without considering their seasonality or promote less healthy foods, highly polluting with low nutritive value [51,52].

A universal healthy reference diet can be defined as a plant-based diet that mostly includes fruits and vegetables, whole grains, nuts, pulses, and unsaturated fatty acids; low quantities of fish products and white meat; negligible quantities of red meat, processed meat, added sugar, refined grains, and starchy vegetables [36,53]. Well-documented evidence showed that plant-based dietary patterns with low quantities of animal source foods promote a mutual beneficial co-existence of both individual's health improvement and environmental safety [54–60]. In spite of the healthy reference diet, FAO and Biodiversity International defined sustainable diets as "those diets with low environmental impacts which contribute to food and nutrition security and to healthy live for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible and economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources" [61]. Lairon [62] also introduced a 6-factor model to describe sustainable diets, comprising the following 6 dimensions as *1*) food security and accessibility, *2*) healthy food, *3*) respect for environment and biodiversity, *4*) fair trade, *5*) locality/seasonality, and *6*) protection of culture, heritage, and skills.

The MD: health impacts

Following a debate on how food systems and diets should be oriented toward a more sustainable perspective, the MD has been widely recognized as a sustainable dietary pattern [52,63–65]. Originally, the MD has been described as the dietary pattern adopted by populations of olive tree-growing areas around the Mediterranean basin (Albania, Algeria, Bosnia, Croatia, Cyprus, Egypt, France, Gibraltar, Greece, Israel, Italy, Lebanon, Libya, Morocco, Malta, Monaco, Montenegro, Palestinian territory, Slovenia, Spain, Syria, Turkey, and Tunisia) [66,67]. The traditional MD is a mainly plant-based diet and it is based on the consumption of *1*) minimally refined plant foods (fruits, vegetables, breads and other cereals, potatoes, beans, nuts and seeds), *2*) minimally processed, seasonally fresh, and locally cultivated foods, *3*) fresh fruits as typical dessert, with sweets containing sugars or honey for a few times per wk, *4*) a high intake of olive oil (especially virgin and extra-virgin olive oil) comprising the principal source of fat, *5*) a moderate intake of dairy products (mostly cheese and yogurt), *6*) up to 4 eggs per wk, *7*) fish and poultry in low to moderate amounts and red meat in low amounts, and *8*) wine during meals, in moderate amounts [68]. However, it should be noticed that there is no single MD, and different countries in the Mediterranean regions may have their own diets, varying in some elements but also presenting a common base (for instance, in all the Mediterranean countries, the most common source of dietary lipids is monounsaturated fat [69]). Besides the balance of foods in the dietary pyramid, the MD is also associated with regular consumption of home-cooked meals, meals as social events, low temperature cooking methods, reduced snacking, fasting, owning a vegetable garden, using traditional foods and recipes, and a post-lunch nap [70,71]. Furthermore, the MD pattern is also characterized by a balanced consumption of diverse foods, promoting locally produced and consumed plants with seasonal character [71,72].

Since 2010, UNESCO has recognized the Mediterranean diet as an Intangible Heritage of the Humanity, stating that it "constitutes a set of skills, knowledge, practices and traditions ranging from the landscape to the table" [73]. This UNESCO confirmation highlighted the social dimension of the food culture, which is irrelevant to the nutritional pyramid and concerns the enhancement of social interactions, the conservation of traditional activities, and the way in which foods are produced, cooked, and consumed [52,73,74]. The MD is more than just the composition and distribution of a bundle of foods consumed by individuals and societies; rather, it has been incorporated into the MD the concept of lifestyle, as determined by local, social, cultural, and socioeconomic influences [75].

A great body of the literature emphasized the health benefits associated with the adherence to the MD, noting that it seems to protect from cardiovascular diseases [52,75,76–79], the metabolic syndrome and obesity [80,81], diabetes [82], hypertension [75,83], and various types of cancer [84]. However, despite the certain health benefits of the MD, recent evidence underlined a significant decline in MD adherence in the Mediterranean basin, mainly attributed to socioeconomic changes and emerging new lifestyles that put at risk the preservation and transmission of the MD to future generations [71,85–88]. In a thorough review, Obeid et al. [67] explored MD adherence among populations in the Mediterranean basin and showed that individuals living in the Mediterranean countries seem to have altered their nutritional habits and their dietary principles, shifting away from the traditional MD plant-based diet. However, the authors noted that there are variations among groups with different sociodemographic characteristics and/or lifestyle factors, which may affect the estimation of MD adherence scores. A significant body of the recent literature in the field reported moderate scores in MD adherence [67,88,89,90–92], sounding the alarm for subsequent health and environmental impacts and rendering necessary the design and the implementation of various strategies directed to the promotion of the MD and its healthier and more sustainable plant-based dietary patterns [88].

The MD: biodiversity and environmental impacts

As a traditional sustainable dietary pattern, the MD exerts a lower environmental impact and has a better ecological footprint compared to Western diets [2] because it is associated with lower GHG emissions, water consumption, land use, and energy requirements [71]. Despite a noticeable increase in interventions and actions to support biodiversity, the food system comprises a major driver of biodiversity decline as a consequence of pressures on natural resources, GHG emissions, and eutrophication [8,19].

In a thorough review, Bôto et al. [93] examined the environmental dimension of the MD after assessing various environmental indicators. The authors came to the conclusion that the MD had a lower environmental impact compared to Western-type diets, and showed a Carbon Footprint between 0.9 and 6.88 kg CO_2/d per capita, a Water Footprint between 600 and 5280 m^3/d per capita, and an ecological footprint between 2.8 and 53.42 m^2/d per capita [93]. Aleksandrowicz et al. [54] also found that shifting from Western to sustainable diets could decrease more than 70% of GHG emissions and land use and up to 50% of water usage. These results were also supported by a significant body of the recent literature, noting that high adherence to the MD pattern was linked with lower GHG emissions and resources consumption (land, water, energy) [65,94–96]. Using data on dietary consumption patterns from a group of European Mediterranean pioneer countries and a group of EU28 countries, Castaldi et al. [97] explored adherence to the MD to global GHG emission reduction targets. The authors noted that the GHG emissions associated with the ideal MD pattern are in accordance with the planetary GHG emissions climate targets. However, they underlined that the analysis of the actual food consumption patterns in the Mediterranean region indicates that the dietary habits significantly diverged from the ideal MD health and environmental objectives, since emissions were up to 4.46 kg CO_2eq capita^{-1} d^{-1} [97].

The MD has also been acknowledged as one of the most prominent sustainable dietary patterns with a significant contribution to biodiversity protection [65,72,74,98,99]. In a recent study, Belgacem et al. [8] explored the pressures of the MD, the European diet, and the Western diet on biodiversity in terms of land and water usage, GHG emissions, and eutrophication impact indicators. The authors indicated the link between dietary patterns and biodiversity and underlined that the plant-based MD had the lowest values of biodiversity indicators compared with the other 2 dietary patterns. On the other side, Vega Mejía et al. [100] indicated that the Western diet is based on agricultural production methods that harm ecosystems, increase the use of fossil fuels, and increase GHG emissions. In particular, processed foods in the Western dietary pattern have a high environmental cost since they emit high levels of GHGs, accelerate land-use change to support agriculture and intensive livestock activities, and necessitate large amounts of water and agrochemicals.

The pressures on resources and the emissions of GHGs vary according to the food consumed. In particular, meat and dairy foods have the largest carbon, water, and ecological footprint. They account for 14% of the GHGs produced by human activities because of the large quantity in animal feed resources required [101]. For instance, poultry meat produces 4000 g/kg of CO_2, whereas seasonal vegetables produce 815 g/kg of CO_2. Similarly, vegetables and fruits require less than 1000 L of water and about 3 m^2/kg, whereas beef needs about 19,000 L and 144 m^2/kg [52,101]. Several recent studies also demonstrated that the contribution of animal products (meat, poultry, dairy, egg, and fish) constituted the greatest contributor to GHG emissions [19,65,96,102].

Rationale and Methodology

Rationale

Farmers have a crucial role in utilizing biodiversity for crops' adaptation to various and changing environments of production. At the same time, they face competing pressures to increase yield efficacy and produce more food while restoring, conserving, and enhancing biodiversity in their farms. Farmers are more likely to pursue their interests by cultivating available food crop species and also respond to consumers' preferences and needs in order to sell their yield and increase profitability. This interaction between producer decision and consumer demand can help increase the market's efficiency by creating added value to agricultural products, increasing consumer's satisfaction, and providing a greater share of consumer price to farmers [103]. Thus, a farmer's decision to grow a particular crop species is highly associated with the utilization of that crop by consumers, and hence the prevalence of that specific dietary pattern within a specific geographic region.

However, to date, no previous study has explored the association between dietary patterns and agrobiodiversity at plant species, subspecies, varieties, and races level. As there is no direct method to investigate the relationship between dietary patterns and food plants, we developed the following set of arguments: 1) if a food plant species (x) has been cultivated in a geographic unit (y), then the latter's population has consumed this food plant species (x) as part of their diet; 2) if in the geographic unit (y), diet (z) is more prevalent compared to other dietary patterns, then the food plant (x) is utilized in diet (z); 3) if the geographic unit, in which dietary pattern (z_1) is prevalent, includes, on average more food plant species compared to the geographic unit in which dietary pattern (z_2) is prevalent, then based on the previous argument, diet (z_1) utilizes a more diverse mix of food plant species compared to dietary pattern (z_2).

Data selection

This study employed a 2-stage data selection scheme. First, a filtered search on the MEDUSA plant database was performed to collect species used as food and food additives over the period January to February 2022. The MEDUSA database has been developed at the Mediterranean Institute of Chania as an integrated and coordinated project of the MEDUSA network, aiming to identify the native and naturalized plants of the Mediterranean region that are currently or potentially useful to people. The MEDUSA network information includes details on plants' conservation status and their potential utilization as alternative minor crops, geography, habitat description and usage. The classes of usage may encompass food, food additives, animal food, bee plants, food for useful invertebrates, materials, fuels, social uses, vertebrate poisons, nonvertebrate poisons, medicines, environmental uses, and gene sources. Furthermore, the MEDUSA network provides a regional information system covering scientific plant names and authority, vernacular names, chemical data, trade, marketing and distribution, and references to literature sources [104]. All this information has been incorporated to the up-to-date online MEDUSA database designed to overcome inconsistencies in the taxonomy and usage of regional plants. In addition, it provides a solid basis for projects oriented to explore methods for the socioeconomic, health and nutrition development of rural areas in the Mediterranean region under sustainable management systems that will evaluate the usage and conservation of plant resources in the area [104,105]. The Mediterranean countries that participate in the MEDUSA project are: Greece, Turkey, Syria, Lebanon, Cyprus, Egypt, Tunisia, Algeria, Morocco, Malta, Portugal, Spain, France, and Italy. In the context of the present research, the data included the list of food crops attained after the application of 2 filters concerning usage (i.e., "food" and "food additive"). All the displayed species were categorized in a separate Excel file, resulting to an overall of 449 species. Supplemental Table 1 presents in detail the species and their usage as edible plants.

Second, the Euro+Med plant database was employed to select information on the geographical location of different species, subspecies, varieties, and landraces (https://europlusmed.org, consulted from March to April 2022). The search for each species resulted in all the subspecies, varieties, and races that were available on the database in the regions of Europe and the Mediterranean basin. In particular, each taxonomic subdivision's page revealed its geographic distribution, the nativity status, and the cultivation status within Europe and the Mediterranean basin. For instance, if a variety is majorly cultivated in Greece, the map of the country is marked with yellow color, whereas for native but not cultivated varieties, the map of the country is pictured in green color.

The aforementioned approach was adopted for all the 449 species obtained from the MEDUSA database on a species-by-species basis. The results were registered in a matrix that included food plant species, subspecies, varieties, and races in the rows and the chosen countries in the columns. An entry of 1 in (i_1, j_1) indicated that species i_1 is native to country j_1, while an entry of 2 in (i_1, j_2) implied that the species i_1 is majorly cultivated in country j_2. This procedure resulted in the identification of an asymmetric matrix of size (2815×12). Therefore, 449 species and 2366 subspecies, varieties, and races were examined in this study. Finally, the overall number of cultivated species was obtained through summation. A table was constructed to indicate dietary region (Western/Mediterranean), country (name of the country), and number of majorly cultivated and native species, subspecies, varieties, and races, respectively (Supplemental Table 2). Figure 1 summarizes the data sources and the data selection process.

For the purposes of the present study, we selected 12 countries from North Africa and Europe (N=12), out of which 6 countries (Greece, Italy, Malta, Morocco, Algeria, and Lebanon) are geographically included in the Mediterranean basin and their populations traditionally show a greater adherence to the MD pattern [66,67,106]; the remaining 6 countries (Belgium, Switzerland, Germany, Austria, Denmark, and Sweden) follow a Western-type diet [86,107,108]. The selection of the countries was random to avoid selection biases. In addition, the Mediterranean region was further distinguished into Western Mediterranean, Central Mediterranean, and Eastern Mediterranean regions, whereas the Western-diet region was classified into Mediterranean borders, Central European, and Northern European regions. Because there is no direct method to investigate the relationship between dietary pattern prevalence and biodiversity, we expect that there is a more diverse mix of food plants in the selected countries in the Mediterranean basin compared with the 6 Central-Northwestern European countries. Besides, as Mattavelli et al. [109] note, "it is important to associate the term 'Mediterranean diet' not only with the food quality and meal composition, but also with a particular way of cooking, eating and more." The MD includes a variety of traditions and lifestyle factors that characterize countries in the Mediterranean basin and reinforce the cultural identity in the region [109,110]. All

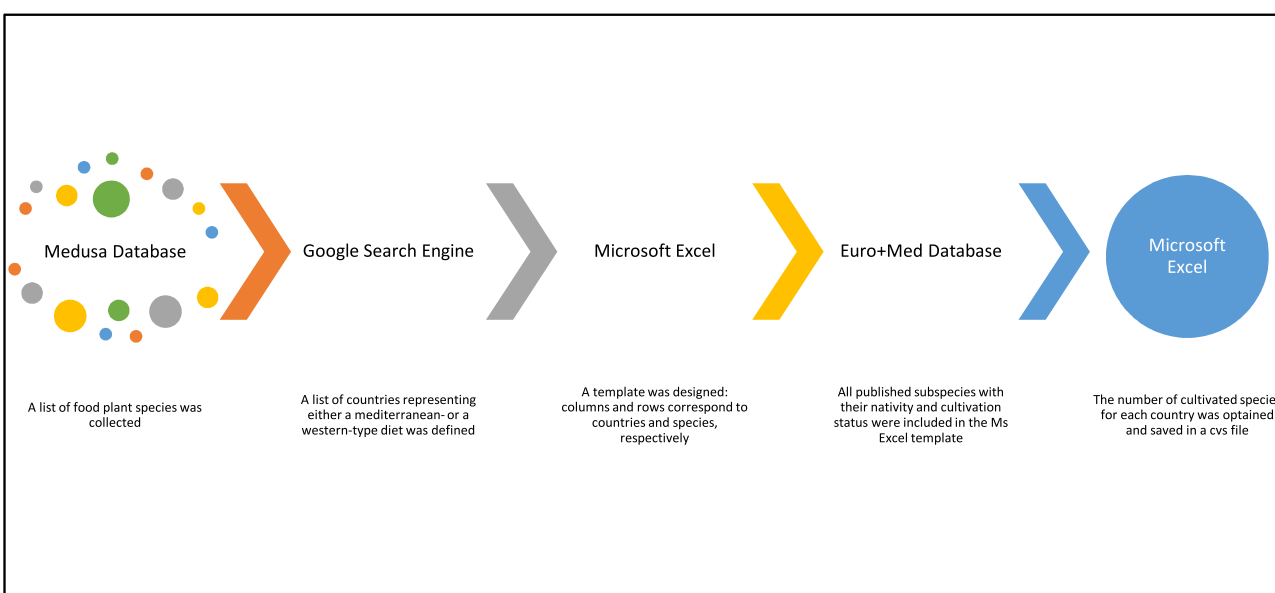

FIGURE 1. Data selection process.

these factors that construct the frame of the MD extend beyond dietary patterns, and for this reason the MD has been inscribed since 2013 in the Representative List of the Intangible Cultural Heritage of Humanity Countries in the Mediterranean basin [109,110]. Table 1 demonstrates the dietary and subregional attributes of the selected countries.

Statistical analysis

This study investigated potential differences in the mean number of majorly cultivated and native food plant species, subspecies, varieties, and races between countries in which the Mediterranean diet constitutes the basic dietary pattern and countries in which a Western-type diet is the most prevalent among their population. Thus, an independent samples t-test was applied to compare the means of 2 independent groups and determine whether there is statistical evidence that the associated population means are significantly different [111]. The independent samples t-test is defined as:

$$H_0 : \mu_1 = \mu_2 \quad (1)$$

$$H_1 : \mu_1 \neq \mu_2 \quad (2)$$

where μ_1 and μ_2 are the population means for group 1 and group 2, respectively. The null hypothesis tests that the population means from 2 independent groups are equal. In case the null hypothesis H_0 is rejected ($P < 0.05$), then the population means are not equal and the alternative hypothesis H_1 is accepted.

To perform the independent samples t-test, there are several assumptions that should be considered [112]:

- Assumption 1: The dependent variable should be measured on a continuous scale (i.e., interval or ratio level). In the context of the present study, the dependent variable meets Assumption 1 since it describes the number of majorly cultivated food plant species, subspecies, varieties, and races.
- Assumption 2: The independent variable should consist of 2 categorical, independent groups. In the context of the present study, the independent variable is a dichotomous indicator representing 2 distinct and independent subsamples; the group of countries in which the MD is the most prevalent dietary pattern, and the group of countries with a Western-type diet culture (West).
- Assumption 3: The independence of observations assumption states that there is no relationship between the observations in each group or between the groups themselves. In the context of the present study, the independence of observations is confirmed because each country is classified to a specific category according to the prevalent dietary pattern among its population (i.e., either Mediterranean-type or Western-type).
- Assumption 4: The dependent variable should be approximately normally distributed for each category of the independent variable. To assess potential departures from normality, the Shapiro-Wilk test was employed, which comprises the most appropriate procedure for small sample sizes (N<50) [113]. This test was adopted to examine the following hypothesis:

$$H_0 : \textit{the data are normally distributed}, \quad (3)$$

$$H_1 : \textit{the data are not normally distributed} \quad (4)$$

In case $P < 0.05$, assumption of normality is violated, implying that the data are not normally distributed.

- Assumption 5: The Levene's test for homogeneity of variances was applied to check for equality of variances. In case data does not meet this assumption, the independent samples t-test is not a suitable statistical test. The Levene's test for homogeneity of variances is defined as follows:

$$H_0 : \sigma_1^2 = \sigma_2^2 \quad (5)$$

$$H_1 : \sigma_1^2 \neq \sigma_2^2 \quad (6)$$

In case $P < 0.05$, the null hypothesis is rejected, and the variances are not equal. Once all the assumption tests are verified, we, in accordance with the requirements of the independent samples t-student test, may accomplish this procedure as previously described.

Results

The number of majorly cultivated and native food plants (species, subspecies, varieties, and races) in selected countries was considered a proxy for the food plant diversity in dietary patterns. Data elaboration showed that Italy had the most diverse cuisine in both majorly cultivated and native food plants compared to the rest countries of our sample, whereas Denmark presented the lowest diversity in food plants (Figure 2). The group of the Mediterranean countries had a higher average of both majorly cultivated (29.33 compared with 19.17) and native food plants (1508.83 compared with 1198.17) than the "Western diet" group. In the Mediterranean sample, Algeria and Greece, and Algeria, Lebanon, and Malta were ranked below-the-average in terms of diversity in majorly cultivated and native food plants, respectively. Furthermore, biodiversity in majorly cultivated food plants was lower in Belgium, Denmark, and Sweden compared to the other selected countries.

The Shapiro-Wilk test application showed that the numbers of both majorly cultivated and native food plants are normally distributed for both dietary groups (Table 2). In addition, the

TABLE 1
Prevalent dietary pattern and subregional selection

Diet	Mediterranean diet			Western diet		
Region	**Western med**	**Central med**	**Eastern med**	**Bordering med**	**Central EU**	**Northern EU**
Countries	Morocco	Italy	Greece	Belgium	Germany	Denmark
	Algeria	Malta	Lebanon	Switzerland	Austria	Sweden

EU, European Union; Med, Mediterranean.

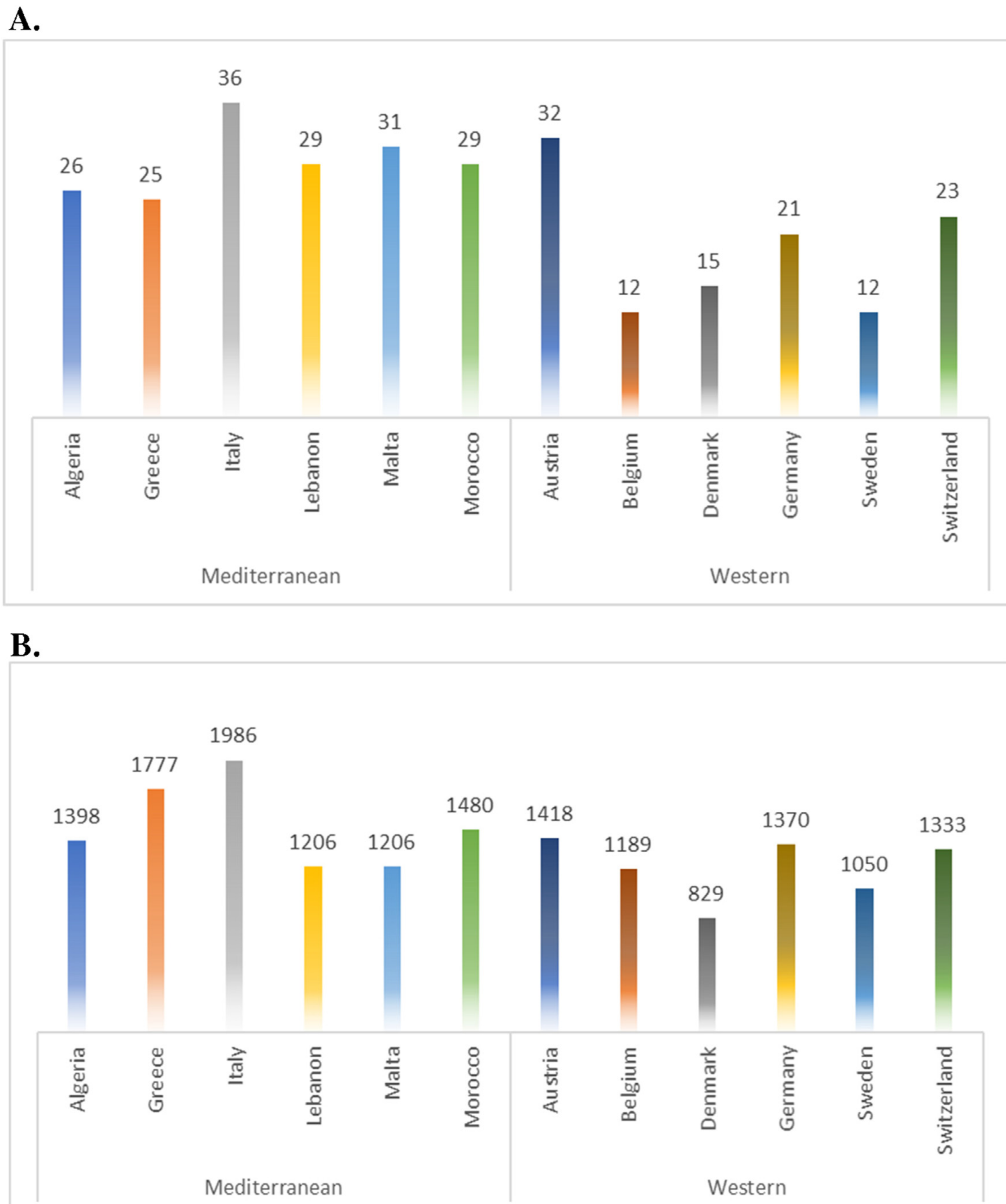

FIGURE 2. (A) Number of majorly cultivated food plants (species, subspecies, varieties, and races); (B) Number of native food plants (species, subspecies, varieties, and races) in the selected countries.

Levene's test application indicated that the variances are equal, and the homogeneity of variances assumption is not violated (Table 3).

TABLE 2
Shapiro-Wilk test application – normality assumption

Variable	Diet	S-W statistic	*P*
Number of majorly cultivated food plants	**Mediterranean**	0.929	0.573
	Western	0.896	0.354
Number of native food plants	**Mediterranean**	0.902	0.387
	Western	0.911	0.440

After the verification of the normality and the homogeneity of variances assumptions, the application of the independent samples t-test showed that the mean of majorly cultivated food plant species, subspecies, varieties, and races in the MD sample was significantly higher than its counterpart in the Western diet sample (29.33 compared with 19.17, $t = -2.856$, $P < 0.05$) (Table 4). Therefore, it seems that the countries that traditionally show a higher adherence to the MD support biodiversity in food plant cultivation to a greater extent compared to the "Western diet" countries. The analysis procedure also indicated that there is no statistical difference in the averages of native food plants between the MD group and the Western diet group (1508.83

TABLE 3
Levene's test application – homogeneity of variances assumption

Variable		F	P
Number of majorly cultivated food plants	**Equal variances assumed**	3.259	0.101
	Equal variances not assumed	—	—
Number of native food plants	**Equal variances assumed**	0.817	0.387
	Equal variances not assumed	—	—

compared with 1198.17, t = 1.964, $P > 0.05$), and the 2 groups include similar means of native food plants (species, subspecies, varieties, and races) (Table 4). This implies that although countries with a higher adherence to the MD present similar diversity in native food plants compared with the countries having adopted Western-type diets, the utilization of the available food crops seems to differ between the 2 clusters. Thus, this higher diversity in food plants observed in the MD countries seems to be attributed to crop utilization rather than crop availability.

Discussion

Our findings further emphasized the increased agricultural biodiversity in the Mediterranean region and the higher diversity in food plants species subspecies, varieties, and races in the MD, supporting a great body of recent studies that has linked sustainable diets, and especially the MD, with biodiversity [2,8,19,74,93,96,98]. The Mediterranean basin is characterized by high biodiversity attributed to its location at the intersection of Africa and Eurasia, its topographical diversity, and several social, political, ecological, and climatic factors [114,115]. Furthermore, the MD, as a plant-based dietary pattern, presents high agrobiodiversity resulting from the adaptation of plants brought from different geographical locations that became indigenous and further diverged into cultivars [72]. Approximately one-third of the foodstuffs used for feeding the population is originated from the Mediterranean basin [116].

Implications for farmers

Although biodiversity enables agricultural systems to evolve, the genetic diversification of food crops is continually decreasing. It has been reported that only 10% of the variety of cultivated crops in the past are still being grown in farm systems, and many local varieties have been replaced by a small number of genetically improved nonnative varieties [117]. In particular, Vavilov had identified over 80 cultivated crops, mostly cereals, pulses, fruit trees, and vegetables, in a previous study [118,119]. Today, only 30 plant species, including major staple crops, provide 95% of dietary energy or protein used for human nutrition [120], whereas food systems rely on just 3 crops (rice, wheat, and maize) to cover more than 50% of consumers' plant-derived calories [121]. Although the Mediterranean basin is considered a biodiversity center for many cultivated food crops, the current industrial farming approach is putting at risk agricultural biodiversity and food diversity in the area. Food value chains have favored farms that can provide large quantities of a single product, but this shift of agricultural production to monocropping systems has destroyed the habitat of diverse species in previous mixed-farming systems. In addition, the increasing demand in agricultural water and fertilizers, and pest outbreaks, which may increase with climate change, put extra burdens in agro-ecosystems and food security [119,122]. According to the Bioversity International, intensive agricultural systems constitute a major driver of global and local biodiversity loss, water pollution, and soil degradation, and also fail to provide access to balanced and healthy diets to all consumers [121].

Recent innovations in the agricultural production systems have moved toward the development and the adoption of more sustainable approaches to offset the severe impacts of intensified agriculture, protect biodiversity, and reinforce environmentally resilient agro-food systems. In a thorough review, Dong notes that "such efforts are making a paradigm shift in agriculture value chains" [123]. Furthermore, maintaining and fostering diversity in agricultural production is crucial for the transition to sustainable food systems. Policies to preserve agricultural biodiversity should motivate farmers to adopt alternative farming practices that will support sustainable agricultural production. Policy measures and interventions might include economic incentives (e.g., loans, subsidies) to farmers for converting to sustainable production techniques and training programs that will inform them how to effectively adopt environmentally friendly agricultural practices. Agricultural diversification approaches can enhance biodiversity, pollination, and pest control, and also regulate resources without compromising crop yields [124]. Agricultural cooperatives and farmer's unions could also have a vital role in disseminating knowledge on sustainable agricultural practices to producers. In particular, agricultural consultants could act as opinion leaders for convincing farmers to use sustainable agricultural production methods.

TABLE 4
Independent samples t-test application – differences in food plant diversity between MD and Western diet

Variable	T	P	Lower 95% CI of difference	Upper 95% CI of difference
Number of majorly cultivated food plants	-2.856	0.017	-18.098	-2.235
Number of native food plants	1.964	0.078	-41.748	663.081

MD, Mediterranean diet.

Implications for consumers and food marketing

Today's food systems are under pressure to meet the increasing population's nutrition demand. Dietary diversification is considered necessary for providing nutritional efficiency to consumers and helping them avoid micronutrient malnutrition resulting from monotonous diets [125]. Although monocropping production systems have raised both food production and energy intake, reliance on a few major crops for population feeding has led to micronutrient deficiencies [126]. This study showed that the MD pattern offers a higher diversity in majorly cultivated food plant species subspecies, varieties, and races compared to the Western-type diets. More specifically, 29 majorly cultivated food plants on average are grown in the Mediterranean countries of our sample, whereas the mean of the majorly cultivated food crops in the other European countries is about 19. The MD, as the most prevalent dietary pattern in the Mediterranean region, offers a higher food plant diversification to meet consumers' requirements for the recommended intakes of nutrients. With respect to the diversity in native food plants, no statistical difference was detected in the averages of the native food plants between the "MD" countries and the "Western diet" countries, indicating that this higher food plant diversity in the MD pattern seems to be more strongly associated with crop utilization rather than crop availability.

Despite the extensive food plant usage in local Mediterranean economies, agro-food production is substantially affected by environmental degradation and climate change, overexploitation of resources, and monoculture. To mitigate the environmental impacts and the pressures on resources, it is necessary to adopt improved crops and new food plant species, which could adjust to actual or future climate and augment the stability of agro-ecosystems [127]. Furthermore, the increasing demand for healthy and sustainable food, the adoption of the MD pattern from new generations and its transmission to other geographic regions makes crucial the sustainable management of plant genetic resources [128–130]. Libiad et al. [127] noted that the introduction of neglected and underutilized plant species (NUPs) in the agro-food systems would benefit both consumers and producers and would also contribute to biodiversity preservation. The usage of NUPs with resistance to pests and adaptation ability to difficult environmental conditions could provide cultivation alternatives for poor and degraded soils [131]. Furthermore, several studies underlined the importance of the domestication and cultivation of NUPs, especially for supporting the household income of marginalized farmers in local economies [132,133]. Several studies have highlighted the increased demand for diversity and novelty in foods and consumers' awareness of NUPs because of their richness in micronutrients, vitamins, and proteins [127,134]. Following modern trends in food markets, domesticated wild edible plants and vegetable local landraces are used in sustainable cultivation systems for the production of functional foods [128,130,135,136]. These novel and high added-value food products create new market opportunities, especially for small-scale farms, and stimulate consumers' interest on their functional attributes [130,137,138].

Therefore, the reinforcement of the demand for such commodities through the appropriate marketing channels could help consumers adopt more diverse and healthy food consumption patterns, and could also motivate producers to explore alternative cultivation opportunities to ensure sustainability in agricultural production systems. Recent studies showed a trend of reduced adherence to the MD across all countries in the Mediterranean region [71,85]. Socioeconomic changes and new lifestyles have significantly altered food habits and food consumption patterns. Nutrition and public health scholars should design appropriate intervention strategies to inform consumers on the benefits of the sustainable diets in order to enhance the consumption of plant-based functional foods and plant-based meals. Besides the production of novel functional foods, the food industry should invest on the production and promotion of novel meals. For instance, plant-based snacks in school cafeterias and the installation of vending machines with healthy plant-based food products could help reinforce adherence to MD patterns in children and adolescents. In addition, the supply of healthy meals and snacks in workplace canteens could affect adults' food choices and urge their engagement with a more sustainable lifestyle.

Study limitations and directions for future research

Although the present study employed a 2-stage selection scheme to include data from 2 large and valid databases, there are still some limitations in data availability that should be reported. First, our data set lacked information on restraints in food plant accessibility due to limitations in the food value chain (e.g., price increases, losses throughout the value chain, cultivation practices, seasonal shortages). Future research should take into consideration these parameters to provide a broader picture of the relationship between biodiversity and diet in the agro-food system. Further research might also elaborate data on food plants market and trade, and explore whether food imports and exports can influence food choices and the adoption of sustainable eating habits. Second, we investigated the association between biodiversity and diet using the prevailing dietary patterns and the subregional characteristics of 6 Mediterranean countries and 6 countries of the rest of the European region. Data expansion to a larger geographic area could enhance the validity of our findings and describe the relationship between diet and biodiversity with greater accuracy.

Concluding remarks

To further support previous studies, our findings underlined the higher agricultural biodiversity in the Mediterranean region and the higher diversity in food plants species subspecies, varieties, and races in the MD compared with Western-type dietary patterns. The statistical analysis underpinned that this higher food plant diversity in the MD pattern seems to be more strongly associated with crop utilization rather than food plant availability in the Mediterranean region. Therefore, this study notes that biodiversity could constitute a prerequisite for dietary diversity, and hence nutrition security. Furthermore, the analysis demonstrated that nutrition and diets should be approached with a broader and more integrated view due to the interlinkages between the agro-food system and the prevailing dietary patterns. It is also implied that adopting a more diverse diet in today's modern society could support the establishment of a more biodiverse rural environment and mitigate the adverse effects of climate change in the long run. Given the well-documented benefits of the sustainable food systems, reaching any biodiversity target will require a combination of initiatives to include all involved agents. Since biodiversity is strongly related with both human and environmental health, nutrition interventions, environmental preservation strategies and public health protection measures should involve multi-stakeholder partnership in order to make food systems sustainable along the entire food chain, "from farm to fork," and also protect ecosystems as a whole. Strengthening agricultural practices to conform with sustainable agroecosystem practices protects the right of all to have access to nutritious, adequate, and affordable food, whereas, at the same time, protects the right of all to live and develop themselves within environmentally healthy and safe places.

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The authors' responsibilities were as follows—all authors: contributed to conceiving and designing the study; KM: supervised the study, directed, contextualized and had primary responsibility for final content; ER: extended the paper to additional dimensions and drafted the extended paper; AA, GY: extracted and analyzed the data and drafted the relative to data parts; GB: took responsibility for the integrity of the data, the accuracy of the data analysis and editing; and all authors: read and approved the final manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.advnut.2023.03.011.

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