# Bioclimatic characterisation of the Mediterranean region: future climate projections for Spain, Italy and Tunisia

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**Abstract:** *The present study provides a meteorological and bioclimatic characterisation of three Mediterranean areas: Spain, Italy and Tunisia. This includes, on the one hand, an evaluation of the past climate using meteorological data collected from 1931 to 1994. On the other hand, the future climate characterisation has been constructed for each study area, under the projected A1B emission scenario for the 2081 to 2100 period. Three Bioclimatic Indices are used to compare the annual and seasonal climate from these past periods through to these future periods: the Ombrothermic Index, the Continentality Index and the Thermicity Index. A clear tendency toward semicontinentality in the Mediterranean basin is observed, and higher thermicity is expected in the future. The Ombroclimatic Index, and especially the seasonal indices, is the most helpful of these Bioclimatic Indices, showing that the southern Mediterranean areas would be the most vulnerable to climate change.*
**Keywords:** *bioclimatic indices, climate change, future projections, Mediterranean region.*

**Riassunto:** *Il presente studio fornisce una caratterizzazione meteorologica e bioclimatica di tre aree del Mediterraneo: Spagna, Italia e Tunisia. Dapprima è stata realizzata una valutazione del clima utilizzando dati meteorologici raccolti dal 1931 al 1994, quindi una simulazione futura per ogni area di studio, secondo lo scenario di emissione A1B previsto per il periodo 2081-2100. Sono stati utilizzati tre indici bioclimatici per rapportare il clima annuale e stagionale reale del passato a quello potenziale del futuro: l'Indice Ombrotermico, l'Indice di Continentalità e quello di Termicità. I risultati hanno evidenziato una chiara tendenza verso la semicontinentalità nel bacino del Mediterraneo mentre una maggiore termicità è prevista in futuro. L'indice ombro climatico, insieme a quelli stagionali, risultano essere i più utili, dimostrando che le zone del sud del Mediterraneo sarebbero le più vulnerabili ai cambiamenti climatici.*
**Parole chiave:** *indici bioclimatici, cambiamento climatico, scenari futuri, Bacino Mediterraneo.*

## 1. INTRODUCTION

The Mediterranean region is a transition area between the temperate climate of central Europe and the arid climate of northern Africa. The Mediterranean climate is characterised by cool, wet winters and hot, dry summers, with these regions coming under the dominant influence of subtropical anticyclones in the summer and experiencing strong cyclonic activity in the winter. The seasonality and variability of the rainfall are two of the main attributes of the Mediterranean climate (Gasith and Resh, 1999). The annual rainfall can also vary markedly from year to year in some regions. According to Lionello *et al.*, (2006), the Mediterranean Sea is an important source of moisture and energy for storms. The moderating ocean influence keeps winter tem-peratures mild. Moreover, the high pressure and the descending motions lead to dry conditions, especially over the southern Mediterranean.

Warming trends and spatially variable changes in rainfall are a reality that can affect the composition and functioning of natural and managed ecosystems (Osborne *et al.*, 2000; Alcamo *et al.*, 2007; Food and Agriculture Organization (FAO) of the United Nations 2007; Giorgi and Lionello, 2008). Both natural ecosystems and biodiversity can have serious difficulties in adapting to climate change, and agro-ecosystems and their crop yields can be seen to be notably reduced.

Bioclimatic Indices can also be used to study the influence of the climate on the distribution and biological development of plant species. The most detailed world-climatic classification available at the moment is that developed by Rivas-Martínez and collaborators (Rivas-Martínez, 1997; Rivas-Martínez and Loidi, 1999; Rivas-Martínez and Rivas-Sáenz, 2008). This classification is based on the use of different Bioclimatic Indices, which relate climate

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to the distribution of the living species, and at the same time, allow separation of the Mediterranean climates from the temperate climates. The detailed knowledge of the vegetation distribution patterns of the Earth and of the modifications to the composition and biological development of the potential natural vegetation that arises from climatic, edaphic, geographic and anthropogenic factors, make it possible to recognise bioclimatic and vegetation boundaries with great accuracy and objectivity (Fernández-González *et al.*, 2005; Rivas-Martínez and Rivas-Sáenz, 2008).

Climate change, whether driven by natural or human forcing, can lead to changes in the likelihood of the occurrence or strength of extreme weather and climate events or both. In this sense, the elaboration of future climate projections under different greenhouse emission scenarios can be considered such as an useful tool to know both the possible global or regional climatic expressions and their relevance for future climate change (Intergovernmental Panel on Climate Change, IPCC, 2013).

One of the most comprehensive reviews of climate change projections over the Mediterranean region was by Giorgi and Lionello (2008), which was based on the latest and most advanced sets of global and regional climate-model simulations. According to their study, changes in the general atmospheric circulation, such as sub-tropical high-pressure cells or shifts in the locations of mid-latitude storm tracks, can profoundly modify the climate characteristics of the Mediterranean. Indeed, several studies have reported that significant and great warming in southern and central Europe under different greenhouse gas emission scenarios is expected in the future, while decreasing trends in the rainfall patterns have been detected, mainly for the wet period (Ulbrich *et al.*, 2006; Giorgi and Lionello, 2008; Vergni and Todisco, 2011). As a consequence, some Mediterranean areas might manifest particular sensitivity to future global climate change.

In the present study, a meteorological and bioclimatic characterisation of different Mediterranean areas is presented: southern-central Spain, southern-central Italy, and northern-central Tunisia. Three Bioclimatic Indices are used to compare the annual and seasonal climates from the past and through the future periods. Finally, an evaluation and discussion of the potential influences of climate change on Mediterranean species is carried out, above all from an agricultural point of view.

## 2. MATERIALS AND METHODS

### 2.1 Study area

The main characteristics of the sites considered in the present study are shown in Tab. 1. The criteria used for the selection of the meteorological stations were the following: time periods long enough to yield reliable estimations of the parameters; and representative geography and altitude of the three macro-areas studied. It is important to consider that the term macro-area used in this study refers to the southern-central regions of both Spain and Italy, and to the northern-central region of Tunisia. The latitudinal gradient through the Mediterranean basin covers a large geographical area, from 43°05' N, of Perugia-Sant'Egidio, Italy, to 33°52' N, of Djerba Mellita, Tunisia. In terms of the longitude, the study areas cover from 18°21' E of Santa Maria di Leuca, Italy, to 06°20' W of Cáceres, Spain. The range of altitude is from 3 m a.s.l. of Gabes, Tunisia, to 702 m a.s.l. of Albacete, Spain.

### 2.2 Meteorological data

*2.2.1 Past climate*

Daily meteorological data used for the construction of the meteorological and bioclimatic characterisation of each study macro-area were obtained from the Spanish Meteorological Agency (Agencia Estatal de Meteorologia; AEMET) for the Spanish sites, the Italian National Meteorological and Climatological Centre (Centro Nazionale di Meteorologia e Climatologia Aeronautica; CNMCA) for the Italian sites, and the Tunisian National Institute of Meteorology (NIM) for the Tunisian sites. The meteorological data were provided for the different time periods in the past, which depended on the dataset available for each site (Tab. 1). The meteorological parameters considered in the present study were first calculated as average values for the time periods of each study site. Secondly, through the combination of the data of the different locations within each country, the average meteorological values for these Spain, Italy and Tunisia macro-areas were obtained.

The meteorological variables were arranged into three groups: (i) monthly; (ii) three-monthly, or seasonal; and (iii) annual. These provided the mean (Tmean, °C), maximum (Tmax, °C), and minimum (Tmin, °C) temperatures and the cumulative precipitation (Pacp, mm).

For the seasonal analysis, the meteorological variables were grouped as follows: December, January and February (DJF; winter season); March, April and May (MAM; spring season); June, July and

| Site | Coordinates | Altitude (m a.s.l) | Time period | Number of years |
|---|---|---|---|---|
| **Spain** | | | | |
| Toledo | 39°53'N, 04°02'W | 515 | 1931-1994 | 64 |
| Cáceres | 39°28'N, 06°20'W | 394 | 1931-1994 | 64 |
| Ciudad Real | 38°59'N, 03°55'W | 628 | 1931-1994 | 64 |
| Albacete | 38°57'N, 01°51'W | 702 | 1961-1994 | 34 |
| Córdoba | 37°50'N, 04°50'W | 90 | 1951-1994 | 44 |
| San Javier | 37°47'N, 00°48'W | 4 | 1942-1994 | 53 |
| Jaén | 37°46'N, 03°47'W | 510 | 1951-1994 | 44 |
| Sevilla | 37°25'N, 05°52'W | 34 | 1952-1994 | 43 |
| Granada | 37°08'N, 03°38'W | 690 | 1951-1994 | 44 |
| Almería | 36°50'N, 02°21'W | 21 | 1934-1994 | 61 |
| Málaga | 36°39'N, 04°28'W | 5 | 1931-1994 | 64 |
| **Italy** | | | | |
| Perugia-Sant'Egidio | 43°05'N, 12°30'E | 208 | 1951-1994 | 44 |
| Pescara | 42°26'N, 14°12'E | 10 | 1951-1994 | 44 |
| Roma | 41°48'N, 12°35'E | 129 | 1951-1994 | 44 |
| Foggia | 41°26'N, 15°33'E | 57 | 1959-1994 | 36 |
| Capo Palinuro | 40°01'N, 15°16'E | 184 | 1951-1994 | 44 |
| Santa Maria di Leuca | 39°49'N, 18°21'E | 104 | 1951-1994 | 44 |
| Lamezia Terme | 38°58'N, 16°19'E | 216 | 1976-1994 | 19 |
| Messina | 38°12'N, 15°33'E | 59 | 1951-1994 | 44 |
| Palermo | 38°11'N, 13°06'E | 21 | 1951-1994 | 44 |
| **Tunisia** | | | | |
| Tunis-Carthage | 36°05'N, 10°14'E | 4 | 1951-1994 | 44 |
| Jendouba | 36°29'N, 08°48'E | 144 | 1951-1994 | 44 |
| Kairouan | 35°04'N, 10°06'E | 68 | 1951-1994 | 44 |
| Sfax El-Maou | 34°43'N, 10°41'E | 23 | 1951-1994 | 44 |
| Gafsa | 34°25'N, 08°49'E | 314 | 1951-1994 | 44 |
| Gabes | 33°47'N, 10°12'E | 3 | 1951-1994 | 44 |
| Djerba Mellita | 33°52'N, 10°46'E | 4 | 1951-1994 | 44 |

**Tab. 1** - Main geographical characteristics and data collection periods for each study site.
*Tab. 1 - Caratteristiche geografiche e periodo considerato per ciascuna area di studio.*

August (JJA; summer season); September, October and November (SON; autumn season).

*2.2.2 Future climate*

The future climate characterisation of the study areas is based on the future climate change projections over the Mediterranean region obtained by Giorgi and Lionello (2008), under the A1B emission scenario for the 2081 to 2100 period. According to the IPCC (2007), the A1B emission scenario assumes a future world of very rapid economic growth, a global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Moreover, the A1B scenario includes the balanced use of fossil and non-fossil energy sources, and can thus be considered as an intermediate future scenario in terms of greenhouse gas emissions. This is also because it is in the middle of the entire IPCC scenario range, with B1 closer to the low end of the range ($CO_2$ concentration, ca. 550 ppm by 2100), A2 to the higher end of the range ($CO_2$ concentration, ca. 850 ppm by 2100), and the A1B emission scenario to the middle of the range ($CO_2$ concentration, ca. 700 ppm by 2100). Given that the future world will change in ways that are difficult to forecast, the use of an intermediate emission scenario can be considered appropriate. The IPCC examined different climate variables and statistics, such as mean changes and changes in variability and extremes for surface climate variables, as well as circulation patterns. Even in the Fifth Assessment Report of the IPCC (2013), interconnections between climate phenomena, their regional expressions and their relevance for future regional climate change are examined, showing also global and regional patterns of climate change computed under different future emissions scenarios.

For a more accurate analysis, Giorgi and Lionello (2008) divided the Mediterranean area into a number of sub-regions. In the present study, the projections used were those obtained for the western Mediterranean (28° N to 44° N; 9.5° W to

10.5° E) and central Mediterranean (28° N to 46° N; 10.5° E to 20.5° E) sub-regions. Giorgi and Lionello (2008) estimated their future projections for temperature and precipitation changes for the period 2081 to 2100 by using the average period from 1961 to 1980 as reference. The average surface warming projected under the A1B emission scenario for the 2081 to 2100 period (with reference to the 1961-1980 period) was 3.1 °C for the winter months, 3.7 °C for the spring months, 4.9 °C for the summer months, and 4.1 °C for the autumn months in the western Mediterranean sub-region, and 3.2 °C for the winter months, 3.1 °C for the spring months, 4.4 °C for the summer months, and 3.8 °C for the autumn months in the central Mediterranean sub-region. The precipitation decreases across all of the seasons, by 11% in the winter months, by 22% in the spring months, by 34% in the summer months, and by 18% in the autumn months in the western Mediterranean sub-region, and by 7% for the winter months, by 11% for the spring months, by 27% for the summer months, and by 12% for the autumn months in the central Mediterranean sub-region. The projections obtained for the western Mediterranean sub-region were used to construct the meteorological variables needed to characterise the future climate of the Spanish and Tunisian sites, while the projections obtained for the central Mediterranean sub-region were used to construct the meteorological variables needed to characterise the future climate of the Italian sites. The monthly maximum temperature, minimum temperature and precipitation for the 2081 to 2100 period were estimated by applying the Giorgi and Lionello (2008) projections, by summation/ multiplication of the proportional parts of the monthly changes proposed by Giorgi and Lionello (2008) to the average data of the 1961 to 1980 period, for each study site. This approach has been recently applied in a previous study (Aguilera *et al.*, 2014) and can be considered appropriate to homogeneously compare the hypothetical future climate behavior in the macro-areas under study. Finally, the three-monthly and annual meteorological variables for each macro-area were calculated.

In the construction of the Bioclimatic Diagrams, the monthly mean temperatures and cumulative precipitation were used (Rivas-Martínez and Loidi, 1999; Rivas-Martínez and Rivas-Sáenz, 2008). By definition, the Mediterranean macrobioclimate is an extratropical macrobioclimate that is characterised by at least two consecutive dry months during the summer (the warmest period of the year) (Rivas-Martínez and Loidi, 1999). A month is defined as dry if the precipitation (mm) is less than twice the mean temperature (°C). Thus, through the use of the Bioclimatic Diagrams, the dry period for each time period and study area was estimated. Moreover, the areas between the intersections of the lines of temperature and precipitation can provide information about the intensity of this period.

### 2.3 Bioclimatic data

The different Bioclimatic Indices were calculated for each study area for both of the time periods (Rivas-Martínez and Loidi, 1999; Rivas-Martínez and Rivas-Sáenz, 2008), as follows:

(i) Ombrothermic Index (Io; mm/°C): Io = (Pp/Tp); where Pp is the total annual precipitation (mm) and Tp is 10-fold the sum of the monthly mean temperatures (°C). The seasonal Io was also calculated: $Io_1$, for the winter season; $Io_2$, for the spring season; $Io_3$, for the summer season; Io4, for the autumn season.

(ii) Continentality Index (Ic; °C): Ic = Tmax' - Tmin'; where Tmax' is the mean of the mean temperatures of the warmest month of the year (°C), and Tmin' is the mean of the mean temperatures of the coldest month of the year (°C).

(iii) Thermicity Index (It; °C): It = (T + m + M) ×10; where T is the mean of the annual mean temperatures (°C), m is the mean of the minimum mean temperatures of the coldest month of each year (°C), and M is the mean of the maximum mean temperatures of the coldest month of each year (°C).

The values obtained for the different Bioclimatic Indices were used for the bioclimatic classification of each study area for both the past period and the future period (see the Worldwide Bioclimatic Classification of Rivas-Martínez and Rivas-Sáenz, 2008).

## 3. RESULTS

For the data in the past, the mean data for each location were derived from the available data, given in Tab. 1. Overall, these ranged from data collected from 1931 to 1994, with mean past periods of 53 years for Spain (during 1931-1994), 40 years for Italy (during 1951-1994), and 44 years for Tunisia (from 1951-1994). The data in the future were the estimated mean data under the projected A1B emission scenario for the period 2081 to 2100 (see Methods).

| Meteorological characteristic | Spain | | Italy | | Tunisia | |
|---|---|---|---|---|---|---|
| | past | future | past | future | past | future |
| **T** (°C) | 16.3 | 20.2 | 16.1 | 19.6 | 18.7 | 23.1 |
| **Pp** (mm) | 408 | 347 | 720 | 638 | 381 | 287 |
| **Tmax** (°C) | 33.2 (Jl) | 38.0 (Jl) | 29.2 (Jl) | 33.3 (Jl) | 33.9 (A) | 38.4 (A) |
| **Tmin** (°C) | 3.4 (J) | 6.5 (J) | 5.5 (J) | 8.8 (J) | 6.2 (J) | 9.7 (J) |

**Tab. 2** - Mean annual meteorological characteristics for the past and the future periods for all of the study areas.
*Tab. 2 - Medie annuali delle principali variabili meteorologiche nei periodi passati e futuri per ciascuna area di studio.*

### 3.1 Meteorological analysis

In the future, the annual mean temperature would be higher than 19.5 °C in all of the study areas, and particularly in the Tunisian area, where it would reach over 23 °C (Tab. 2). In both periods of the study, the coldest month of the year is January. In the past, the mean January temperatures were between 3.4 °C and 6.2 °C. However, in the future, these would range from 6.5 °C to 9.7 °C. The warmest month of the year in the Spanish and Italian study areas is July. For Spain, the mean of the mean maximum July temperatures could change from 33.2 °C in the past, to 38.0 °C in the future, while in Italy, this could change from 29.2 °C in the past, to 33.3 °C in the future. In central and northern Tunisia, the warmest month of the year is August, which showed a mean of its mean maximum temperatures of 33.9 °C in the past, and this would be 38.4 °C in the future.
The total annual precipitation will be particularly lower in the future. The highest decrease in percentage value is projected for the Tunisian area, followed by the Spanish and the Italian areas. In Tunisia, a decrease of 25% could be expected in the future, as compared to the past. The mean of the total annual precipitation in the Spanish area could be 15% lower in the future than in the past. In Italy, where it normally rains more, there would be a difference of 11% in the means of the total annual precipitation between the past and future study periods.
The seasonal analysis indicates that the greatest changes in the seasonal mean maximum and minimum temperatures would be expected in both summer and autumn, for all of the study areas (Fig. 1a, b, 2a, b, 3a, b). In the future, for the Spanish and Tunisian study areas, the mean of the mean maximum temperatures could be higher than 36 °C in the summer, and between 27 °C and 30 °C in the autumn. In the Italian study areas, the mean of the mean maximum temperatures could be over 32 °C in the summer, and around 25 °C in the autumn. The mean of the mean minimum temperatures in Spain and Italy would be around 22 °C in the summer, and about 17 °C in the autumn. A large increase in the mean of the mean minimum temperatures is projected for the Tunisian area, where this would be around 26 °C in the summer and 20 °C in the autumn.
For the mean seasonal precipitation, the highest

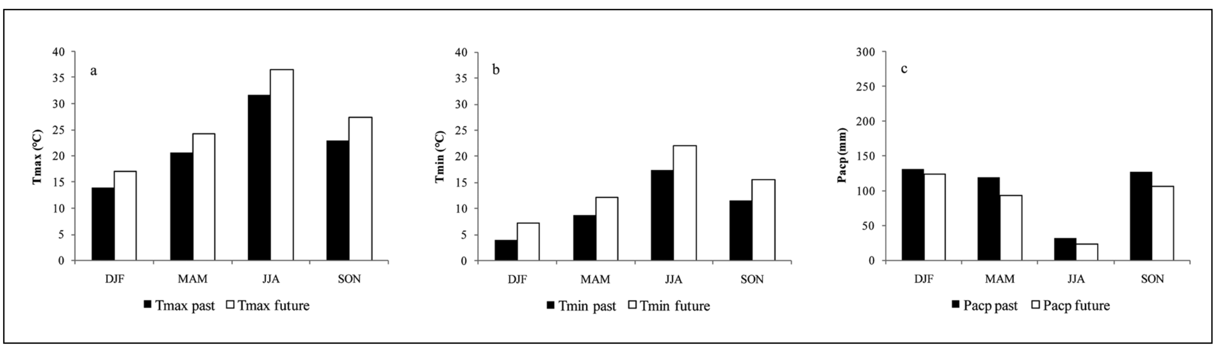


**Fig. 1** - Seasonal meteorological characteristics for the past and future in the Spain study area. (a) Tmax, mean of the mean maximum seasonal temperatures; (b) Tmin, mean of the mean minimum seasonal temperatures; (c) Pacp, mean of the mean seasonal cumulative precipitations; DJF, winter season; MAM, spring season; JJA, summer season; SON, autumn season.
*Fig. 1 - Caratteristiche meteorologiche stagionali per il passato e il futuro nell'area di studio Spagnola. (a) Tmax, media delle temperature massime medie stagionali; (b) Tmin, media delle temperature minime medie stagionali; (c) Pacp, media delle precipitazioni cumulate stagionali medie; DJF, stagione invernale; MAM, stagione primaverile; JJA, stagione estiva; SON, stagione autunnale.*

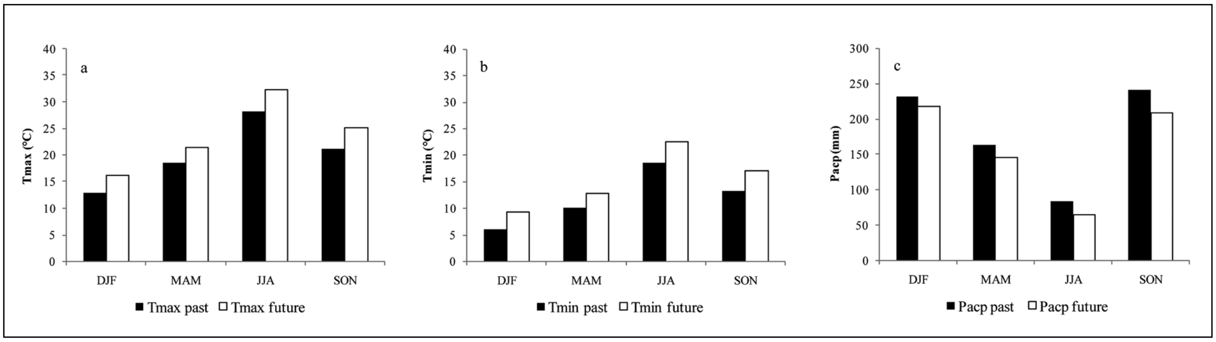


**Fig. 2** - Seasonal meteorological characteristics for the past and future in the Italy study area. (a) Tmax, mean of the mean maximum seasonal temperatures; (b) Tmin, mean of the mean minimum seasonal temperatures; (c) Pacp, mean of the mean seasonal cumulative precipitations; DJF, winter season; MAM, spring season; JJA, summer season; SON, autumn season.
*Fig. 2 - Caratteristiche meteorologiche stagionali per il passato e il futuro nell'area di studio Italiana. (a) Tmax, media delle temperature massime medie stagionali; (b) Tmin, media delle temperature minime medie stagionali; (c) Pacp, media delle precipitazioni cumulate stagionali medie; DJF, stagione invernale; MAM, stagione primaverile; JJA, stagione estiva; SON, stagione autunnale.*

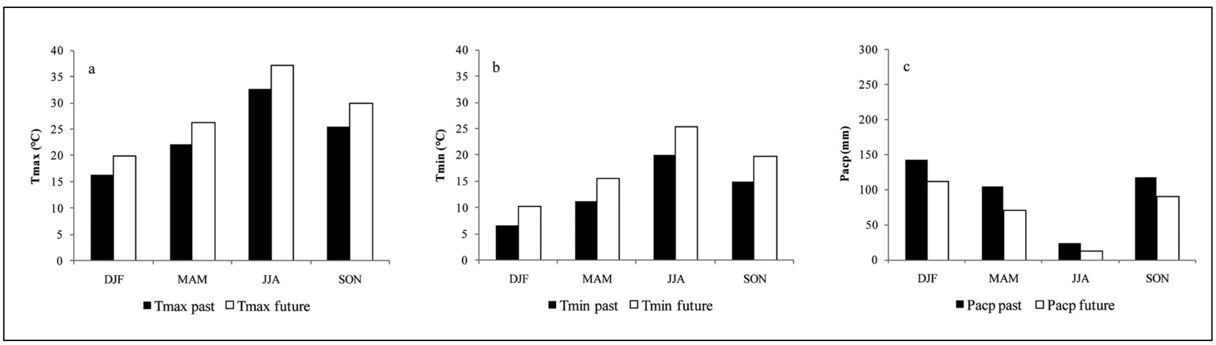


**Fig. 3** - Seasonal meteorological characteristics for the past and future in the Tunisia study area. (a) Tmax, mean of the mean maximum seasonal temperatures; (b) Tmin, mean of the mean minimum seasonal temperatures; (c) Pacp, mean of the mean seasonal cumulative precipitations; DJF, winter season; MAM, spring season; JJA, summer season; SON, autumn season.
*Fig. 3 - Caratteristiche meteorologiche stagionali per il passato e il futuro nell'area di studio Tunisia. (a) Tmax, media delle temperature massime medie stagionali; (b) Tmin, media delle temperature minime medie stagionali; (c) Pacp, media delle precipitazioni cumulate stagionali medie; DJF, stagione invernale; MAM, stagione primaverile; JJA, stagione estiva; SON, stagione autunnale.*

decreases from the past to the future are generally projected for spring and autumn. In Spain, the future mean precipitation for these two seasons would be around 20% less than the past (decrease of 22% in the spring, and 17% in the autumn) (Fig. 1c). For the Italian areas, autumn would be the season with the greatest decrease in the mean seasonal precipitation (decrease of 15%), followed by the summer (decrease of 12%) (Fig. 2c). Spring would be the season with the greatest decrease in the mean seasonal precipitation in the Tunisian area (decrease of 32%), followed by the winter (decrease of 22%) (Fig. 3c).
The Bioclimatic Diagrams constructed for each study area over the past and future time periods are shown in Fig. 4. Significant differences in the monthly means of the mean temperatures and cumulative precipitation are not observed between the past and future study periods for these three macro-areas (Tab. 3). However, the dry period could begin earlier and it would be longer lasting and more intense in the future. In the past, the dry period in the Spanish study area spanned from the second half of May to the end of September. In the future, the dry period should start earlier, in the second half of April, and end later, in the middle of October. In Italy, the dry period in the past was from the second half of May to the first of September, while in the future this would widen to the first half of May to the middle of September. Finally, the dry period in the Tunisian study area was the longest in the past, from the second half of April to the first

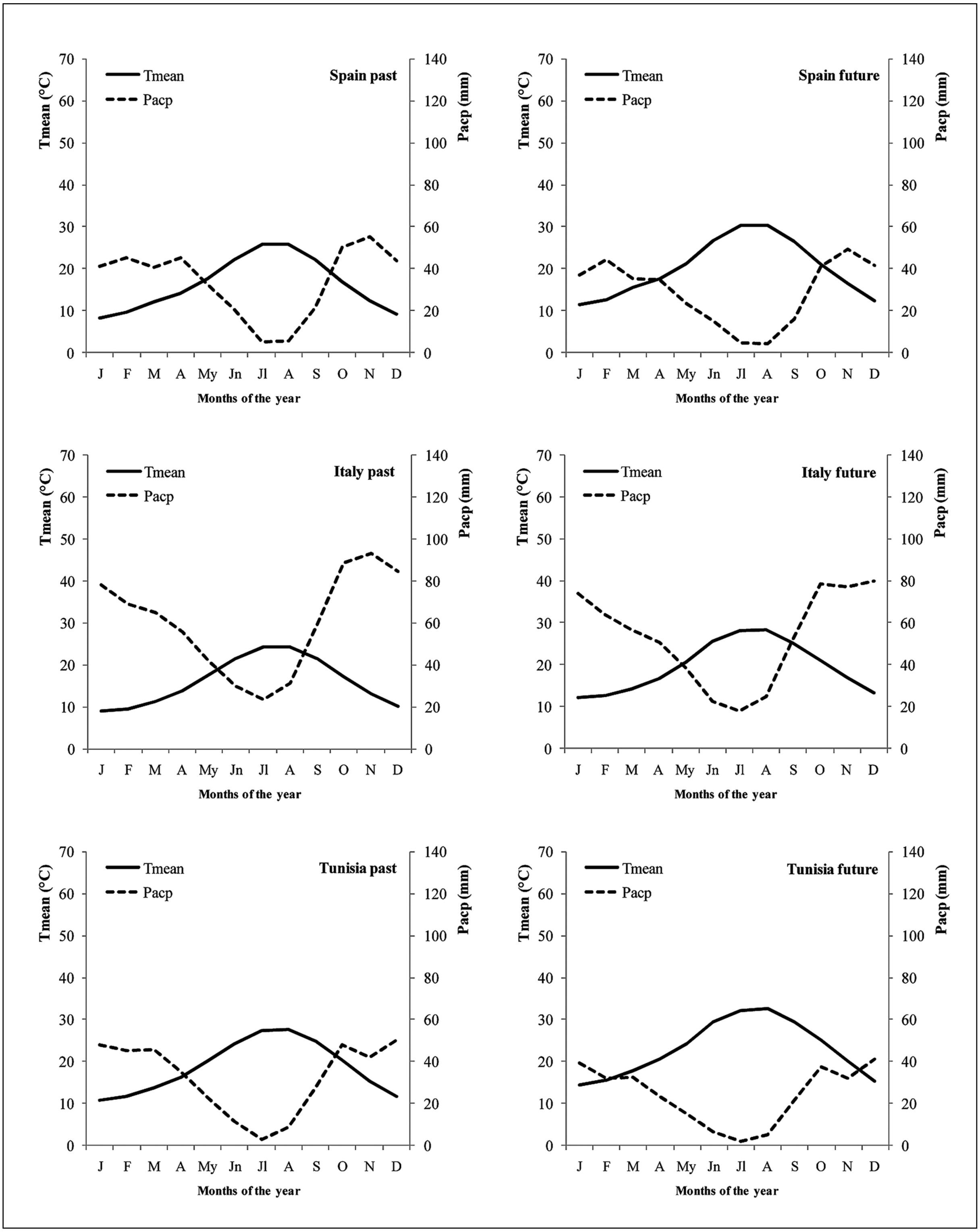


**Fig. 4** - Bioclimatic diagrams for the past and future periods for Spain, Italy and Tunisia. Tmean, mean of the mean monthly temperatures; Pacp, mean of the mean monthly cumulative precipitations; J, January; F, February; M, March; A, April; My, May; Jn, June; Jl, July; A, August; S, September; O, October; N, November; D, December.
*Fig. 4 - Diagrammi bioclimatici per i periodi passati e futuri per la Spagna, Italia e Tunisia. Tmean, media delle temperature medie mensili; Pacp, media delle precipitazioni cumulate mensili medie; J, Gennaio; F, Febbraio; M, Marzo; A, Aprile; My, Maggio; Jn, Giugno; Jl, Luglio; A, Agosto; S, Settembre; O, Ottobre; N, Novembre; D, dicembre.*

| Metereological characteristic | Spain | | Italy | | Tunisia | |
|---|---|---|---|---|---|---|
| | t-value | p | t-value | p | t-value | p |
| **Tmean** (°C) | 1.405 | 0.173 | 1.465 | 0.157 | 1.589 | 0.126 |
| **Pacp** (mm) | -0.768 | 0.450 | -0.714 | 0.482 | -1.182 | 0.249 |

**Tab. 3** - Statistical results for the t-tests to compare the mean of the mean monthly temperatures and cumulative precipitations between the past and future study periods.
*Tab. 3 - Risultati statistici dei trend tests per comparare i valori medi mensili delle temperature medie e delle precipitazioni cumulate tra i periodi passati e futuri.*

half of October, and in the future it could cover almost all of the year, from the middle of February to the end of November.

### 3.2 Bioclimatic analysis

In central and southern Spain, a mean annual Io of 2.1 mm/°C was obtained for the past, which corresponds to a dry ombrotype horizon; in the future, this could change to semiarid, with a mean annual Io of 1.4 mm/°C (Tab. 4). The seasonal Io analysis shows that the ombrotype horizons would change for all of the seasons. From the past to the future, the ombrotype horizon in the winter ($Io_1$) would change from subhumid to dry (see Tab. 4 for seasonal Io means). The spring ($Io_2$) in the past was dry in the Spanish area, while semiarid could be expected in the future. The summer ($Io_3$) would change from arid to hyperarid in the future, and the autumn ($Io_4$) would pass from a dry to a semiarid horizon.
In central and southern Italy, in the past, the mean annual Io was 3.7 mm/°C, which corresponds to a subhumid ombrotype horizon (Tab. 5). In the future this would change to dry, with a mean annual Io of 2.7 mm/°C. As in the Spanish study macro-area, the ombrotype horizons would change for all of the seasons. From the past to the future, the ombrotype horizon in the winter ($Io_1$) could change from humid to subhumid, while for the spring ($Io_2$) and the autumn ($Io_4$), the change from subhumid to a dry horizon is projected (see Tab. 5 for seasonal Io means). The summer (Io3) would change from semiarid to arid in the future.
In Tunisia, the mean annual Io of 1.7 mm/°C in the past, which corresponds to a semiarid ombrotype horizon, would change to an arid level in the future, with a mean annual Io of 1.0 mm/°C (Tab. 6). As in the Spanish study macro-area, winter ($Io_1$) was subhumid in the past, with a dry horizon expected in the future, and spring ($Io_2$) would change from dry to semiarid in the future (see Tab. 6 for seasonal Io means). From the past to the future, the ombrotype horizon in the autumn ($Io_4$) would remain at a semiarid level, although with a lower index value. Summer ($Io_3$) would be the most arid season in Tunisia, and its past arid ombrotype horizon is expected to be hyperarid in the future, and very close to ultrahyperarid.
A future increase in the Continentality Index is expected for all of the study areas. The past

| Bioclimatic characterisation | Study period | |
|---|---|---|
| | Past | Future |
| **Ombrotype horizon** (mm/°C) | | |
| Io | Dry (2.1) | Semiarid (1.4) |
| $Io_1$ | Subhumid (4.8) | Dry (3.4) |
| $Io_2$ | Dry (2.7) | Semiarid (1.7) |
| $Io_3$ | Arid (0.4) | Hyperarid (0.2) |
| $Io_4$ | Dry (2.5) | Semiarid (1.7) |
| **Continentality** (°C) | | |
| Ic (type; subtype) | Oceanic; Semicontinental attenuated (17.5) | Oceanic; Semicontinental pronounced (19.1) |
| **Thermal type** (°C) | | |
| It | Hot (329.6) | Hot (430.0) |

Io, Ombrothermic Index; $Io_1$, Ombrothermic Index for winter; $Io_2$, Ombrothermic Index for spring; $Io_3$, Ombrothermic Index for summer; $Io_4$, Ombrothermic Index for autumn; Ic, Continentality Index; It, Thermicity Index

**Tab. 4** - Bioclimatic characterisation of the Spanish study area for the past and future.
*Tab. 4 Caratterizzazione bioclimatica dell'area di studio Spagnola nei periodi passati e futuri.*

| Bioclimatic characterisation | Study period | |
|---|---|---|
| | Past | Future |
| **Ombrotype horizon** (mm/°C) | | |
| Io | Subhumid (3.7) | Dry (2.7) |
| $Io_1$ | Humid (8.2) | Subhumid (5.7) |
| $Io_2$ | Subhumid (3.8) | Dry (2.8) |
| $Io_3$ | Semiarid (1.2) | Arid (0.8) |
| $Io_4$ | Subhumid (4.7) | Dry (3.3) |
| **Continentality** (°C) | | |
| Ic (type; subtype) | Oceanic; Euoceanic attenuated (15.8) | Oceanic; Semicontinental attenuated (17.0) |
| **Thermal type** (°C) | | |
| It | Hot (338.7) | Hot (439.2) |

Io, Ombrothermic Index; $Io_1$, Ombrothermic Index for winter; $Io_2$, Ombrothermic Index for spring; $Io_3$, Ombrothermic Index for summer; $Io_4$, Ombrothermic Index for autumn; Ic, Continentality Index; It, Thermicity Index

**Tab. 5** - Bioclimatic characterisation of the Italian study area for the past and future.
*Tab. 5 - Caratterizzazione bioclimatica dell'area di studio Italiana nei periodi passati e futuri.*

| Bioclimatic characterisation | Study period | |
|---|---|---|
| | Past | Future |
| **Ombrotype horizon** (mm/°C) | | |
| Io | Semiarid (1.7) | Arid (1.0) |
| $Io_1$ | Subhumid (4.2) | Dry (2.5) |
| $Io_2$ | Dry (2.1) | Semiarid (1.1) |
| $Io_3$ | Arid (0.3) | Hyperarid (0.1) |
| $Io_4$ | Semiarid (1.9) | Semiarid (1.2) |
| **Continentality** (°C) | | |
| Ic (type; subtype) | Oceanic; Euoceanic attenuated (16.7) | Oceanic; Semicontinental attenuated (17.6) |
| **Thermal type** (°C) | | |
| It | Hot (403.6) | Hot (519.5) |

Io, Ombrothermic Index; $Io_1$, Ombrothermic Index for winter; $Io_2$, Ombrothermic Index for spring; $Io_3$, Ombrothermic Index for summer; $Io_4$, Ombrothermic Index for autumn; Ic, Continentality Index; It, Thermicity Index

**Tab. 6** - Bioclimatic characterisation of the Tunisian study area for the past and future.
*Tab. 6 - Caratterizzazione bioclimatica dell'area di studio Tunisina nei periodi passati e futuri.*

semicontinentality of central and southern Spain would change from attenuated (Ic, 17.5 °C) to pronounced (Ic, 19.1 °C) in the future. In the Italian and Tunisian study areas, the continentality subtype could be modified from euoceanic attenuated in the past (Ic, 15.8 °C, 16.7 °C, respectively), to semicontinental attenuated in the future (Ic, 17.0 °C, 17.6 °C, respectively).
Similarly, compared to the past, a higher thermicity is expected for all of the study areas in the future (see Tables 4, 5, 6 for It means). Although all of their thermal types would remain at a hot level in the future, as compared to the past, there would be notable increases in the mean It values, which could be 29% to 30% higher than those in the past.

## 4. DISCUSSION

Increases in the mean annual temperatures and decreases in the total annual precipitation are both expected in the future for the Mediterranean region (Giorgi and Lionello, 2008). Over the last decades, the higher levels of greenhouse gases in the atmosphere have evidently been changing the climate of the Earth (Lieth, 1994; IPCC, 2007). One of the main consequences might be alterations in the physiological behaviour of woody plant species with winter to spring flowering (Hartmann and Porlingis, 1957; Linsley-Nokes *et al.*, 1995; Myking and Heide, 1995; Wielgolaski, 1999; Rodríguez-Rajo *et al.*, 2003; Gómez-Casero *et al.*, 2007; Aguilera and Ruiz Valenzuela, 2009; Orlandi *et al.*, 2014). Given also the close relationships between plant biological development and environmental conditions, this means that detailed seasonal and bio-meteorological analyses for the characterisation of the future climate are needed.

In the present study, numerous seasonal changes from the past weather conditions are seen for several sites through the Mediterranean area, in terms of the projected future climate. Although the characterisation of the hypothetical future climate in the study areas was based in a simple approach, could be useful to inform us on climate changes that could be expected in the future. Summer and autumn would be the most vulnerable seasons for temperature warming. In all of the study sites, there would be appreciable increases in the maximum and minimum temperatures compared to the past. Several authors have detected a slightly greater increase in the maximum temperatures regarding the minimum temperatures in central Mediterranean areas (Brunetti *et al.*, 2006; Bartolini *et al.*, 2012). Nevertheless, other studies highlighted as the increasing trends detected in the maximum and minimum temperatures during the last decades were nearly identical (Vose *et al.*, 2005) or also that, despite the spatio-temporal variability, minimum temperatures are increasing at a faster rate than the maximum temperatures for many parts of the world (Easterling *et al.*, 1997; Vergni and Todisco, 2011). In any case, the increase in both the maximum and minimum temperatures is clear.

The development processes in buds that release trees in temperate zones from their winter dormancy, and that thus trigger the onset of growth, are mainly regulated by temperature (Aron, 1983; Fernández-Escobar *et al.*, 1992; Wielgolaski, 1999; Jato *et al.*, 2002; Menzel *et al.*, 2006). Similarly, but conversely, fruit species require low-temperature exposure (chilling) for normal and abundant budburst to occur in late winter (Couvillon, 1995). However, under a warmer future scenario, the levels of chilling might not be sufficient to regulate this dormancy phenomenon.

In Mediterranean species such as the olive (Olea europaea L.), the release of the floral bud dormancy occurs when the olive trees have been exposed to a long enough period of chilling temperatures (Pinney and Polito, 1990; Rallo and Martin, 1991; Fernández-Escobar *et al.*, 1992). The general increase in the minimum temperatures could produce incomplete chilling periods, which can delay the release of this floral bud dormancy, and consequently, this might have detrimental effects on the subsequent flowering (Martin *et al.*, 1994; Barranco *et al.*., 2008).

For the mean seasonal total precipitation, the greatest decreases are projected for spring and autumn. The data from the present study agree with previous studies carried out in different regions of Italy, where records show decreasing trends in the precipitation, mainly for the wet period (Todisco and Vergni, 2008; Capra and Pavanelli, 2010; Capra *et al.*, 2013). Nevertheless, these data from the present study are not in agreement with the data reported by Sabaté *et al.*, (2002), who defined a generalised increase in rainfall throughout the Mediterranean region. This difference will mainly be due to the climate scenarios used or to the future time period considered.

Several studies have demonstrated that when water deficit occurs during inflorescence development, many different flowering parameters are reduced, including inflorescence numbers, flower numbers, perfect flower numbers, and pollen production (Cuevas and Polito, 2004; Gómez-Casero *et al.*, 2004; Ogaya and Peñuelas, 2007; Aguilera and Ruiz Valenzuela, 2012; Oteros *et al.*, 2012; Rapoport *et al.*, 2012). Moreover, correct fruit maturation depends on the autumn rainfall, as has been observed in typical Mediterranean species such as olive (Lavee, 1994; Orlandi *et al.*, 2012) and holm oak (*Quercus ilex* L.; Ogaya and Peñuelas, 2007). Consequently, a lower rainfall regime during these phenological periods might seriously affect fruit production.

The use of the Bioclimatic Indices in the present study is successful, and these indicate that future increases in the continentality levels could be expected in all of these study areas. The Continentality Index, which represents the yearly thermal mean interval, shows a clear tendency toward semicontinentality in the Mediterranean basin. The same is seen for the Thermicity Index. As expected, warming of the different study areas is evident, and thus higher thermicity has been projected for the future. These increases in both the continentality and the thermicity levels will be related to the increases in the greenhouse gas concentrations in the atmosphere. It is important to consider that the future projections obtained in the present study were realised using the middle of the full IPCC greenhouse gas forcing scenario range (IPCC, 2007). Thus, the climate change projected under the worst hypothetical scenario would have devastating effects on the distribution and development of bio-organisms.

The Ombroclimatic Index can be considered as the most helpful of these Bioclimatic Indices, given its relationship with the aridity levels (Rivas-Martínez and Loidi, 1999). In particular, the seasonal Ombroclimatic Indices have been stressed as being a valuable tool to analyse the climate in more detail. In central and southern Spain, all of the seasons showed high variations, with a clear tendency towards extreme scenarios. The same would be expected in Tunisia, where the climate would be more arid in the future. Seasonal changes have been observed in central and southern Italy too, where less humid horizons are expected.

In general, the season that could show the greatest variations would be summer, and mainly in southern Mediterranean areas. Water deficit during the summer period has been recognised as one of the most important stresses that limits plant-species distributions and their growth throughout the Mediterranean region (Mooney, 1983). The Bioclimatic Diagrams generated in the present study indicate that in the future the dry periods should begin earlier, and they should last longer and be more intense. The results in this study agree with those reported in previous studies, where general increases in the frequency, intensity and duration of droughts has been detected for several Mediterranean zones, such as Greece (Livada and Assimakopoulos, 2007), Italy (Todisco and Vergni, 2008; Capra *et al.*, 2013), Jordan and Portugal (Cancelliere and Rossi, 2003). The dry period could also begin in the spring season. Water stress during these months can result in partially developed flowers, with malfunctioning or absent pistils, which will thus not be able to form fruits and seeds, which might have a negative and direct effect on vegetation and crop productivity (Martin *et al.*, 1994; Rapoport *et al.*, 2012).

According to Vergni and Todisco (2011), the decrement in the pluviometric regime might significantly reduce the natural water supply during the dry period, when the water need is maximal. The contemporary occurrence of the maximum evapotranspiration demand with negative trends in precipitation will have important consequences on the agricultural water balance (Mendicino and Versace, 2007; Vergni and Todisco, 2011). Increasing crop water requirements would be expected, and thus there will be greater demand for irrigation water.

In the context of climate change, the less drought-resistant species are likely to have serious problems for their adaptation to the new environments (Ogaya and Peñuelas, 2007). Lower water availability for the vegetation can negatively influence fruit development and seed formation. The number of reproductive structures might decrease, and the recruitment of new individuals might be drastically reduced (Borchert *et al.*, 1989; Ogaya and Peñuelas, 2007).

From an agronomic point of view, the presented scenarios in the different Mediterranean study areas would increase the problems of plant cultivation, above all in those species that carry out their phenological cycles during the summer months. The notable increase in the tendencies of temperature together with the lower rainfall patterns during the final part of spring, in summer, and in the first part of autumn would result in great problems during the fundamental vegetative and reproductive phases. This would include adverse effects on pollination, fruit setting and fruit maturation across a lot of plant species in the Mediterranean area. The consequences could affect quantitative and qualitative aspects, such as an increase in fruit falling percentages and fruit disease, and a decrease in the organoleptic characteristics of typical Mediterranean products, such as olive oil. However, not all species should be adversely affected. In western and central Mediterranean Europe, the wine quality improvement observed in the last few decades will be partially due to an increase of temperature and to a decrease in precipitation (Dalu *et al.*, 2013).

These potential climate change scenarios suggest the need for potential changes in the plant varieties grown, and also in the traditional aspects of regional agronomies. Comparisons between grapevine varieties have shown that different adaptations to climate change can occur, in terms of mean yields and yield variability (Bindi *et al.*, 1996). In this sense, genetic selection to obtain new plant cultivars with improved commercial qualities and drought resistance represents a necessary agronomic practice.

## 5. CONCLUSIONS

A clear tendency towards semicontinentality in the Mediterranean region has been observed, and higher thermicity is expected in the future. The Ombroclimatic Index can be considered as the most helpful of the Bioclimatic Indices studied in the present paper, given its relationship with the aridity levels. A notable increase of the aridity levels in southern Mediterranean areas is detected. Summer and autumn would be the most vulnerable seasons to temperature warming. For the mean seasonal total precipitation, the greatest decreases are generally projected for spring and autumn. The Bioclimatic Diagrams generated in the present study indicate that in the future, the dry periods might begin earlier, and they would last longer, and be more intense. Although a simple procedure was used to characterise the future climate in the study areas, it could be considered as an useful approach to inform us on climate changes that could be expected in the future. Combined with the context of climate change, most of the Mediterranean species would be likely to have serious problems in terms of their adaptation to the presented future scenarios, and there would be the need to obtain new plant varieties as part of the necessary agronomic practices.

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