***Moringa oleifera*: Potential areas of cultivation on the Iberian Peninsula**

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Abstract

***Moringa oleifera* is a tree native to the southeast of the Himalaya that, by its characteristics, spread through southern Asia. Although the species is considered of tropical climate, its presence as native in Indian Kashmir, between 1,200 and 1,800 meters of altitude, is an indication that the tree could have a greater climatic range. Today, *Moringa oleifera* is a panecuatorial species, has widely spread throughout America, from the southern part of the US to northern Chile and Argentina. In Spain, moringa is beginning to grow in the subtropical zone of the peninsula and the Canary and Balearic Islands.**

Its multiple uses make moringa an attractive crop in different fields of food, human or animal, also in cosmetics, biofuels and pharmaceuticals.

The aim of this study is to determine possible areas of cultivation on the Iberian Peninsula. For that reason we have compiled information about the climatic requirements of the species for its suitable development; we have validated this data with that provided by the AEMET "Iberian Climate Atlas", using ArcGis v. 10; and we have placed this information on a map.

Keywords: *Moringa oleifera*, bioclimate, frost, agroclimatic conditions

INTRODUCTION

Moringa oleifera is a tree which belongs to the monogeneric family *Moringaceae*, with thirteen species distributed throughout Africa, Madagascar and India.

Known since ancient times for its nutritional and medicinal properties and its oil, *Moringa oleifera* was distributed since ancient times from India to Africa and to Southeast Asia and the Philippines. With the arrival of the Spaniards in the Philippines, and the exchange of plants by the Nao de Manila (Pacheco, 2006), moringa was introduced into America and Europe. There is evidence that in the eighteenth century *M. oleifera* was brought to the Iberian Peninsula, as quoted in the List of Plants of the Royal Botanical Garden of Madrid 1796 (Gomez Ortega, 1796). Today, moringa is cultivated and growing naturally in at least seventy countries of tropical and subtropical regions of the world, mostly in underdeveloped regions.

Cultivation of moringa is spreading and its possible introduction into new biogeographic regions is being studied. For example, in Europe, it is being introduced in the Mediterranean biogeographic regions, in the south of the Iberian Peninsula and the Balearic Islands, and Macaronesian, in the Canary Islands. This paper focuses on the Spanish part of the western Mediterranean region.

All parts of the plant are used in some way. Its stems, flowers, fruits and seeds are edible and have high percentages of protein, vitamins and minerals. It is used as food for both people and animals (mammals, birds and fish) and as a nutritional supplement.

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The seed of *M. oleifera* contains 35% of high quality oil, with a content of oleic acid similar to olive oil. In addition, the "cake" obtained after pressing the seeds is used in depuration and water purification thanks to the natural flocculent power of their seeds; this is an effective and inexpensive method (Jahn et al., 1986; Sutherland et al., 1989); it is also used as fertilizer and animal feed. When feeding mammals, moringa generates significant yield increases in both weight gain and milk production (Sánchez, 2004).

Its low density wood is used as firewood and to make charcoal; the pulp may be used for paper and for bioethanol

Moringa oleifera is an oleaginous tree of a very fast growth. In the first year of life, moringa may exceed four meters in height (Prabhakar, 2008); and it can easily regrow. It spreads easily, also by seed and by vegetative material. If the tree is derived from seed, it may live for 20 years; but if it comes from cutting, the average age is only 10-15 years. When cultivated at very high densities, the life span is only four or five years before it is replanted. In India annual varieties have been obtained that allow its cultivation in temperate climates (Falasca and Barnabas, 2008).

M. oleifera is considered a species of light. Lack of light can cause losses of 30% of young seedlings (Sánchez et al., 2006). In Sudan, Jahn (1986) made a study providing data on germination and more favorable growth under half shade conditions, with 86% of seed germination and 20 cm size of suckers at 75 days after planting, compared to 78% of germination at full light and 11 cm of growth of suckers during the same period.

M. oleifera grows and develops well in tropical and subtropical climates. In its area of origin, and where it has been introduced, the plant grows in areas where the average temperature is between 12.6 and 40 °C, withstanding high temperatures till 48 °C (Roloff, 2009). Regarding its cold hardiness, *M. oleifera* grows in the USDA hardiness zones: 9b to 12, it resists light frosts down to -3 °C, but is seriously affected when temperatures drop below -5 °C, even for one night (Bertoni, 1927; NRC, 2006). In Spain, Sanchez Lorenzo-Cáceres (2004) considers that its cultivation as an ornamental plant could be in the hardiness zone 11 (Tmin of 4-10 °C), which means that moringa could be introduced for other purposes than shown, in the subtropical zone of the Iberian Peninsula and in places with light frosts.

According to Köppen-Geiger climate classification, the southwestern region of the Himalayas, where *Moringa oleifera* is native, has the following climates: hot steppe (BSh), subtropical hot-summer (Cfa), dry-summer subtropical (Csa) and subtropical-dry winter (Cwa) (OCHA, 2015). Except for the latter, the first three are found on the Iberian Peninsula. In the region of Kashmir, the plant is found between 1,200 and 1,800 meters elevation (Khuroo, 2011), the same height as in Oaxaca (Mexico) (Jahn, 1986) making it possible to find seed varieties that are suited to the climates of the Iberian Peninsula.

In its habitat, the average annual temperatures have large fluctuations. According to the literature, during the coldest months, moringa resists few and light frosts, between -1 °C and -3 °C; while during the warmest months, it resists 38 °C to 48 °C. However, its optimum growth is between 25 and 35 °C. According to Radovich (2011), the average annual minimum temperature, which the plant tolerates is 15 °C.

According to Muhl et al. (2011), temperature is the key factor that influences the growth and productivity of *M. oleifera*. These authors conducted several studies of the plant and proved that the growth is favored by increasing temperatures and that the plant can adapt to lower temperatures. This can be important for establishing plantations in colder climates. In these colder climates there is the possibility of cultivating moringa in greenhouses.

M. oleifera cultivation can start when night temperature exceeds 15 °C (Prabhaka, 2008). If the average temperature is below 14 °C, moringa cannot bloom or germinate, and can only be reproduced by vegetative material (Garcia Roa, 2003). With daily average temperatures below 20 °C the plant does not grow (Radovich, 2011).

The annual rainfall in the region of origin of *M. oleifera* ranges from 500 up to 2,200 mm (Roloff, 2006), while in arid and semiarid areas of Arabia and Ethiopia where it also grows, rainfall can be down to 300 mm. The moringa tree is resistant to drought; in areas

with subtropical climate *M. oleifera* can tolerate up to six months of dry season if the annual rainfall reaches 500 mm. It can be planted in areas where rainfall varies from 500-1,500 mm (Parrotta, 2000). When cultivated for fodder production, it needs at least 800 mm of precipitation (Broin, 2010).

Objective of the study

The aim of the present work is to define the areas bioclimatically suitable for *M. oleifera* cultivation on the Iberian Peninsula and the Balearic Islands, either as a forage crop or for production of pods and seeds.

Like with other crops, moringa dissemination and cultivation is determined by the vital requirements of the plant and by climatic boundaries of the region where one wants to cultivate it.

MATERIALS AND METHODS

To carry out this study we used the application ArcMap and ArcCatalog from ARCGIS 10 software. The first application is oriented to building application maps, edit geographic information layers and to analyze spatial data; and the second one manages the files that store the geographic data.

The data that have been used are: maps of annual and monthly mean temperatures, maps of maximum average temperatures, monthly and annual, maps of monthly and annual mean minimum temperature, and maps of number of days of frost. All data, in digital format (.TIFF), were used to prepare the "Iberian Climate Atlas" (2011), based on the results of climatological normals from the period 1971-2000. These data were provided by the Spanish State Meteorological Agency (AEMET, 2011).

From the recompilation of available information regarding the moringa distribution range, both under natural and cultivated conditions, the following limiting factors were obtained:

- *Moringa oleifera* does not survive at temperatures above 48 °C;
- Moringa is especially sensitive to low temperatures. This is the most limiting factor for its distribution. During the coldest months, it can only withstand a few frosts of short duration and low intensity;
- On the Iberian Peninsula and the Balearic Islands, the months in which the lowest temperatures are reached are from December to February. For these months, the risk of frost according to Emberger criteria, and the number of frost days were studied:
 - Emberger criteria: if the average minimum temperature exceeds 7 °C, the risk of light frost is low; if it is between 3 and 7 °C frosts are likely to happen. A subdivision with a value of 5 °C was made in order to define more precisely the possible areas of plant introduction. Average minimum temperatures below 3 °C mean that frosts are definitely going to occur, so this range is not considered for moringa cultivation. To evaluate the risk of frost, we applied the Emberger criteria with the values of 3, 5 and 7 °C as the minimum average temperatures during the three winter months. Values lower than 3 °C mean that frost is very likely to occur; hence, these values were put aside. Between 3 and 7 °C, frosts are likely to happen. These areas are subdivided into two: above or below 5 °C; areas with values above 5 °C are better suited for moringa. In frost-free areas, > 7 °C, the plant can thrive.
 - The factor "number of days of frost" aims to ensure that the plant will not perish by persistent risk of frost. The higher the number of frost days, the higher the risk that these frosts will be persistent. Regions without frost, or with only sporadic frost (1 to 5 days), are the best. Areas with intermediate frost (from 6-20 days) present a risk. If more than 20 days of frost are registered, the zone is excluded.
 - To discard areas with low temperatures, the maps with the Emberger criteria and the number of frost days were superimposed.

- The average annual isotherm of 15 °C marks the limit of life for moringa. Areas that do not exceed this value will be put aside.
- Growth of moringa occurs when the average monthly temperature reaches 20 °C. Areas with at least four months $T \geq 20$ °C are selected. This ensures that the seed harvest cycle is completed or that at least three forage crops are obtained.
- Need for watering: from the literature we have collected, the common limiting values of precipitation for woodland persistence. These are: 300 mm (below this level trees cannot grow), 500 mm (below this limit, trees have some limitations; above it, there are no problems). The isohyet of 800 mm marks the limit of irrigation needs for forage (Broin, 2010) and above the isohyet of 1,500 mm, the rain will damage flowers and will affect fruiting (Garavito, 2010). These values are not reached in the study area.

Based on these data we started to draw the maps as shown in the following section.

RESULTS

Only very few and very small zones reach an average temperature above 48 °C. So, we considered that there is no limitation by high temperatures.

Figure 1.a) shows the areas, where the average annual temperature is above 15 °C, which means that the plant is expected to grow.

Figure 1.b) shows areas, where the number of months in which $T_{med} \geq 20$ °C is 4 or more, securing the minimum time required to reach pod harvest.

Figure 1. a) Annual isotherm $T = 15$ °C. Figure 1.b) N° of months that $T_{med} \geq 20$ °C is 4 or more.

Figure 2: Potential growing areas for moringa with regard to temperature.

Combining both figures, Figure 2 is obtained, which provides the potential growing areas for moringa with regard to heat.

Figure 3 is obtained by overlaying the maps of the Emberger criteria and the number of frost days. Figure 3 shows the possible growing areas depending on the duration and intensity of frost. Regions without frost or occasional frosts (1-5 days) are preferred. Areas with intermediate frost (6-20 days) are a risk, and more than 20 frost days, are considered excluded.

By combining Figures 2 and 3, Figure 4 is obtained. The latter classifies the potential growing areas of moringa based on the temperature conditions in two categories, annual and perennial, and these are ranging from marginal to optimal.

Figure 3. Potential growing areas in response to cold obtained by combining Emberger criteria and days of frost.

Figure 4. Classification of potential growing areas.

Figure 5.a) shows a map of rainfall for the crop ranges on the Iberian Peninsula that have been defined for moringa. Combining these ranges with the areas defined in Figure 4, Figure 5.b) is obtained. In this figure, the areas where irrigation is required are defined in Table 1, either for use of moringa as forage or for seed production.

Figure 5. a) Isohyets on the Iberian Peninsula. b) Isohyets in the potential growing areas.

Table 1. Irrigation requirements for use of moringa as forage crop or for seed production.

	Pp (mm)	Seeds	Forage
$Pp \leq 300$	Watering required	Watering required
$300 < Pp \leq 500$	Watering recommended	Watering required
$500 < Pp \leq 800$	No watering required	Watering required
$800 < Pp$	No watering required	No watering required

DISCUSSION

We have been working with the help of data obtained from the "Climate Atlas of the Iberian Peninsula", covering the period 1971-2000. Due to the effect of global warming, during the past three decades the average temperature has been rising 0.5 °C per decade (Pérez, 2010). This fact can modify the maps presented here leading to an increase of the areas, where it is possible to introduce the moringa tree.

The precipitation data used here were those derived from tropical or subtropical conditions. No information is available on the precipitation requirements of moringa under temperate climate conditions.

CONCLUSIONS

The potential growing area for *Moringa oleifera* on the Iberian Peninsula and Balearic Islands has been defined. Moringa can grow on more than 40% of this land area. Out of this 40% surface area, 70 % would be suitable for growing moringa as annual crop and the rest, about 70,000 km², would be suitable to grow permanent moringa crops, either as fodder or for seed production.

Moringa oleifera is a crop of great interest for introduction into the semi-arid regions of southern Andalusia and the Mediterranean coast, where the cultivation of this crop could increase the profitability of these lands. With the aim to produce leaves and pods for human consumption, some trials have been conducted in Almeria in greenhouses with good results.

Growing moringa as forage crop, it is necessary to consider irrigation as mandatory in all areas. Also if moringa is grown to produce seeds, irrigation will be necessary in almost all areas. Only in zones like the eastern half of the province of Cadiz, moringa could grow without irrigation.

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