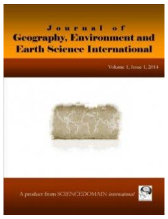

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Agroclimatic Zoning for Amaranth (*Amaranthus caudatus*) Using a Geographical Information System in Argentina

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Authors' contributions

This work was carried out in collaboration between all authors. Author SF designed the study, wrote the protocol, and wrote the first draft of the manuscript. Authors SP managed the literature searches and wrote the last draft of the manuscript and author MAB drew the maps. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The aim of the present paper was to define the agro-climatic suitability of the Argentinean semiarid and subhumid regions to produce grains from *A. caudatus*.
Study Design: Agro climatic zonation utilizing Arc-Gis 9.3.
Place and Duration of Study: Buenos Aires, Argentina. June 2013 to November 2014.
Methodology: Based on international bibliography, the authors outlined an agro-climatic zoning model for amaranth in Argentina. To define its agro-climatic suitability, the average climatic data of all the meteorological stations (1981-2010) were analyzed. The requirements, limits and bio-meteorological tolerance and conditions for this species were evaluated, considering the climatological characteristics of the native regions around the world where it is successfully

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cultivated. To obtain the maps, a series of previously interpolated bioclimatic variables were used. The agro-climatic indices, which determine different classes of suitability, were integrated in a Geographic Information System to create thermal and moisture regions. The maps elaborated (frost-free days, annual rainfall, annual temperature and average temperature during growing period), were superimposed to determine the agroclimatic zoning.

Results: Nine classes of agroclimatic suitability under three different climatic conditions were delineated: humid, subhumid and semiarid. Agro-climatic zoning identifies areas with different potential yields, as per their environmental conditions. This is an innovative work, made by the implementation of a Geographic Information System that can be updated by further incorporation of complementary information.

Conclusion: Because of its low hydric requirements, amaranth is a promising dry land crop for farmers in subhumid and semiarid areas of Argentina. Its cultivation would also be recommendable in optimal, very suitable and suitable areas under humid climate on moderately-highly saline soils and moderately alkaline soils, so as not to displace the traditional crops of Humid Pampas. This model may be applied in any part of the world, using the agroclimatic limits presented in this paper.

Keywords: Amaranth; bioclimatic requirements; agroclimatic zoning; subhumid to semiarid climate; Argentina.

1. INTRODUCTION

Amaranthus caudatus originated in the Andes, probably as a hybrid between the wild *Amaranthus hybri*dus L. subsp. *quitensis* (Kunth) [1] and the cultivated *Amaranthus cruentus* L. (originated in Central America). *Amaranthus caudatus* is synonymous with: *A. sanguineus* L. (described and named in 1763); *A. caudatus* L. *var. alopecurus* (in 1849), *A. mantegazzianus* Presserini (in 1865) and *A. edulis Spegazzini* (in 1917) [2]. *A. caudatus* has been cultivated in America for more than 10,000 years [3] and it is known commonly as amaranth, kiwicha, Inca wheat, cat-tail, etc. Amaranth was "rediscovered" in the 80´s, when the USA National Academy of Sciences started researching the crop because of its high nutritional value and agronomic potential [4]. According to the World Health Organization (WHO), amaranth seeds are highly nutritious because they are rich in proteins with an amino acid composition ideal for human diets [5,6]. The consumption of seeds has been shown to decrease blood pressure and increase poly-unsaturated acids in the organism [7]. The oil, rich in squalene, is used in the cosmetic and pharmaceutical industries [8]. Another by-product is "milk of amaranth", which is an inexpensive option for lactose-intolerant patients [9]. The production scales worldwide are not sufficient to reach the goal of large-scale industrialization. Thus, the market is restricted to a small number of consumers.

A. caudatus is a species native to Argentina. The cultivation of amaranth for grain was traditionally carried out by indigenous people in the provinces of Jujuy (Purmamarca, Humahuaca), Salta (Pampa Grande), Tucumán and Catamarca [10]. However, it practically disappeared and could only be found in small plots near the farmers´ house and associated with corn, typically with isolated plants within the maize field. The situation has changed recently because, as a result of its high nutritional value and adaptability to diverse environmental conditions, it is being promoted as an alternative crop. It is now cultivated in the Semiarid Pampas Region, the Argentine Northwest (NOA) and the North Patagonian Region [10,11]. Producers have also sprung up in the provinces of Córdoba, San Luis, and Santa Fe, in the Reconquista town. Assays with germplasm from different parts of America have been carried out, with yields of 143 - 1530 kg/ha [12]. In the Comarca de los Siete Pueblos (Medium Valley of Rio Negro), in the neighborhood of Luis Beltrán, amaranth is also being produced [13]. Nonetheless, amaranth is still not a well-known crop in Argentina: it is used in the northwest (a region that belonged to the Southern part of the Inca Empire) and it is commercialized mainly in markets and stores dedicated to natural products. According to the National Service of Hygiene and Agro-alimentary Quality (SENASA), in 1988, 114 kg of certified organic amaranth were assigned to the internal market; during 1998 the offer increased to 1604 kg and in the year 2000, it dropped to 468 kilos [14]. Argentina also exports small amounts of amaranth: in 1996, 23 tons were exported to Germany, and during the years 2000 and 2001 small volumes were exported to Brazil [14]. The yields obtained through the Amaranth Project, an enterprise that is executed in the province of La Pampa, fluctuated from 0.8 to 3 ton/ha. In normal conditions (i.e. without drought and in good sanitary conditions) the yields achieved are in the 1.8 to 2.3 ton/ha range. Other assays done by the University of La Plata and by the University of Santiago del Estero resulted in yields of 3.0-4.5 ton/ha and 1.5-2.2 ton/ha, respectively.

It is recommended that amaranth should be sown in the semiarid regions of Argentina in the period extending from the first two weeks of November to the end of December. It can be consociated with corn in the borders or between rows to protect the cultivar and diversify the production. In these regions, the cultivation cycle reaches 170 days and the crop is harvested when the seed contains 50% moisture. [10] estimated that more than 50 million hectares are potentially useful for the cultivation of amaranth under semiarid conditions. All of them are located in the north of Patagonia. However, at present, nobody has studied the agroclimatic zoning for this crop in Argentina. The aim of the present paper was to define the agroclimatic suitability of the Argentinean semiarid and subhumid zones to produce grains from *A. caudatus*.

2. MATERIALS AND METHODS

2.1 Area under Study

The studied area was the Argentine Republic. The country borders to the North with Bolivia and Paraguay; to the South with Chile and the Atlantic Ocean; to the East with Brazil, Uruguay and the Atlantic Ocean and to the West with Chile. As a result of its vast territory, Argentina presents exceptional climatic diversity. Various geographic factors influence the climatic characteristics of the different regions. One of these is latitude: the Argentine Republic is characterized by its great latitudinal development: 21°46' in the North to 55°58' S in Cabo de Hornos, in the South. The extreme eastern limit of the country is located at 53°38'W, in the town of Bernardo de Irigoyen.

2.2 Ecological Requirements

Amaranth is capable of growing in a wide range of weather conditions and in different soil and agricultural systems. It is also suitable for both intensive and extensive cultivation [15]. According to [16] *A. caudatus* can grow in regions with diverse climate conditions: Tropical wet and dry (Aw), Desert or arid (Bw), Steppe or semiarid (Bs), Subtropical humid (Cf), Subtropical dry summer (Cs) and Subtropical dry winter (Cw).

The dispersal area for this species extends from Ecuador to the north of Argentina, and it grows in temperate zones and in the Inter-Andean Valleys, from sea level up to 3000 m [12]. However, in the Andes Mountains the major part is grown at altitudes between 1,500 and 3,600 m. Near Lima, Peru, commercial varieties are being successfully cultivated at sea level. Traditionally, amaranth has been cultivated within 30° latitude of the Equator. However, if the strains selected initiate flowering in spite of longer day-lengths (photoperiod) compared to the tropics, it can grow in higher latitudes. According to [17] the latitudinal limit is 47°S. Nonetheless, it is not well-known outside the highland regions of Ecuador, Peru, Bolivia, and Northwestern Argentina.

The crop develops adequately with annual precipitations that vary from 400-2000 mm, and it is resistant to water deficit periods [18]. Although water requirements are in the 400-800 mm range, decent production levels can be reached with 250 mm. According to [16] the optimal precipitation range is from 800 to 2300 mm. The species requires acceptable amounts of precipitation to germinate and flower, but, after it is established, it can tolerate periods of drought. Crops have also been observed in areas with 1000 mm of annual precipitation [19]. The crop adapts well in low to medium atmospheric humidity. Since it is a C_4 plant, it uses only 3/5 of the water required by a C_3 plant to produce the same amount of biomass [20]. In fact, grain amaranths have set seed in areas that receive as little as 200 mm. Their moisture demand is estimated to be equivalent to that of sorghum, or about half of corn. The C_4 photosynthetic cycle allows for rapid growth at high temperatures and in drought conditions, where C_3 plants would be severely affected [21].

During the dry season, the leaf transpiration rate is inordinately high. Usually, the crop requires frequent watering, dependant on the particular growth stage and the capacity of the soil to retain moisture. Under water stress conditions, amaranth can extract water from as deep as 1.5 m. The maximum radical depth is registered between the beginning of the flowering stage and its completion. The average water requirement for amaranth can be as high as 2673 m^3 ha^{-1}, according to studies done in North Dakota, USA [22].

For germination, temperatures should be in the 15 to 17°C range, and the optimal temperature for this phase is 35°C. The base temperature for growth has been estimated in 8°C [17]. In general, all the species belonging to the *Amaranth* genus grow when the average temperature exceeds 15°C, and the optimum temperatures are in the 24–28°C range [23]. They thrive in environments with high luminosity [4] and are very sensitive to cold. In fact, in the branching period they can tolerate only 4°C, with 35 to 40°C as the maximum temperature [17]; [19].

Although amaranth is more tolerant to cold than most grains, it cannot survive frost. When temperatures are below 4°C, frost can damage the crop irreversibly and production can be lost completely. If the frost takes place during the formation of the inflorescence, a phenomenon called "Panicle Hanging" occurs, by which the basal part of the panicle is damaged, but not the inflorescence in itself. Consequently, if the plant is recovered it grows decumbently. If temperatures decrease during the flowering stage, the resulting plant is sterile because the stamen and ovaries are damaged. Empty grains are obtained when temperatures are low during the period of grain filling. Conversely, a frost at harvest time is useful to dry out the plants, thus facilitating mechanical harvesting [24].

Since amaranth is photoperiod-sensitive, most species will flower when day lengths are shorter than 12 hours, although there are cultivars that flower at day lengths ranging from 12 to 16 hours [16]. The vegetative stage can fluctuate from 90 to 240 days. In most biotypes, the seeds mature in 120-180 days; however, in higher latitudes, it may require 300 days [24].

Amaranth performs well in soils that contain varying levels of nutrients, although loose, sandy soils with high humus content are ideal. It prospers in a wide range of pH, from 4.3 to 8.5 [16]. There are genotypes that tolerate alkaline soils with pH as high as 8.5. In addition, some genotypes can endure salinity. According to [25] *Amaranthus* species are characteristically tolerant to acid soils, aluminum toxicity and salinity (>8 mmhos cm^{-1}).

2.3 The Agroclimatic Zoning

To satisfy a plant´s physiological requirements, minimum and maximum climate conditions should be met for each particular species. [26] defined an "ideal temperature", which is the range between these two values and represents the energetic level that plants need for their physiological complex to work efficiently. Beyond such limits they are negatively affected. When moisture conditions are considered adequate, the "length of growing period" refers to the number of days, within the period, with temperatures above base temperature [27].

Agro-climatic zoning identifies areas with different potential yields, according to the environmental conditions. To establish potential growing areas for amaranth, the requirements, limits and bio-meteorological tolerance and conditions had to be determined. First, the climatological characteristics of native areas and the regions of successful cultivation around the world were taken into consideration. Afterwards, the resulting bio-climatic indicators were extrapolated to the Argentine lands. It was mandatory to consider growth aspects such as development and death chances by excess or deficiency. To design the agroclimatic zoning model, the references presented in Table 1 were taken into account.

In order to define the agro-climatic fitness of this culture in Argentina, we worked with the weather data collected by all meteorological stations around the country in the 1981-2010 Period. In parallel, an agro-climatic inventory was performed based on information of available climatic statistics and agro-climatic derived values. When all the information was gathered, the data were evaluated. From the available database, geographical limits were mapped for the different variables that define aptitude classes: optimal zone, very suitable, suitable and non-suitable.

2.4 GIS Analysis

A Geographic Information System (GIS) analysis was employed to generate an agroclimatic suitability map for amaranth production in Argentina. To obtain the maps, a series of previously interpolated bioclimatic variables were used. These were processed with the GIS tool of the Arc-GIS 9.3 program. Climatic interpolations were made using the "Interpolate to Raster" tool, within the "3D Analyst" extension of the GIS of the some program, following the Ordinary Kriging interpolation method. Agroclimatic suitability mapped variables were obtained from multivariable integration geo-processing, using the "Raster Calculator" tool of the "Spatial Analyst" extension of the same program. The moisture regions were determined using annual isohyets. Areas were classified as non-suitable, suitable, very suitable and optimal. The moisture limits are presented in Table 1. Frost-free days were also mapped. These had to be above 150 to ensure the growing period for amaranth. To analyze thermal regions, the 10°C annual average isotherm was considered, which generally demarcates the suitable and the unsuitable areas within the country. Afterwards, the average temperature during the growing period was analyzed (November to April in the South Hemisphere). As shown in Table 1, if the average temperature registered in the area was <15°C, it was classified as non suitable, suitable in the 15-20°C range, very suitable from 20-24°C and optimal >24°C.

The maps pertaining to annual rainfall, frost-free days, annual temperature and temperature of growing period were superimposed, and thus the agroclimatic suitability map was obtained. Nine classes were identified, and Table 2 shows the agroclimatic indices that define each class. In order to distinguish the classified areas with different grades of agro-climatic fitness, we include Argentina's political map, with the toponomy of the provinces (Fig. 1).

3. RESULTS AND DISCUSSION

3.1 Moisture Regions

Fig. 2 shows the moisture regions. The isohyets show the humidity trend along the E-W gradient due to the "Atlantic" influence. The optimal areas have humid climate and comprise the east, the north and Northeast of Argentina (NEA), including most of the Buenos Aires province. Another region with similar characteristics occupies part of the Northwest (NOA) of our country, from the Salta province to Tucuman. In this situation, the "Atlantic" influence together with the latitudinal factor, generate a "closed island" that receives more precipitation than the surrounding areas.

Very suitable areas present subhumid climate and cover the west of the eastern optimal areas and surround the optimal area of the NOA, from the north of the country to the south of Buenos Aires province. A similar area can be found towards the west of Patagonian region, called Andean Patagonian Forest, and Tierra del Fuego province. Suitable areas are characterized by semiarid climate and cover almost all the Patagonian coast, from the south of San Matías gulf to the province of Santa Cruz. The other zone defined as suitable is located east of the Andean Patagonian Forest. The suitable area that is latitudinally most comprehensive surrounds the very suitable area from the north of Argentina to the south of the province of Buenos Aires and the east of Rio Negro.

In the Argentine plains, the rainfall events are determined by a series of conflicting air masses. The northern and central territories of Argentina receive not only humid winds from the South Atlantic Anticyclone but also dry winds from the Patagonian region. The latter differ in relative strength, according to the season. During the warm season, warm winds dominate the territory, bringing plentiful rainfall until desiccation in the west. In the cooler seasons, and due to the increase in the strength of the southern dry winds, a large part of Argentina lacks rain, except for the eastern regions. As a result, the northeast and central east (temperate pampas) regions of Argentina are humid environments and the rainfalls are distributed evenly. South of the Colorado River, the masses of humid air come from the south pacific Anticyclone. Southerly winds always dominate the Patagonian territory. Annual precipitation ranges from western territory to more than 2,000 mm in the area of Andean Patagonian forest to 150 mm in the driest parts of Patagonia.

Table 1. References considered for the design of the agroclimatic zoning model for Amaranth

Ecological requirement	Suitable range	Very suitable range	Optimal range	Reference
Rainfall	> 250 mm			[16]
Humid regime	> 800 mm	> 800 mm	> 800 mm	[16]
Subhumid regime	400-800 mm	400-800 mm	400-800 mm	[18]
Semiarid regime	250-400 mm	250-400 mm	250-400 mm	[16]
Frost-free days	> 150 days	> 150 days	> 150 days	[24]
Temperature				
Average annual	>10°C	>10°C	>10°C	[17]
Average growing period	>15°C			[17]
	15-20°C	20-24°C	>24°C	[23]

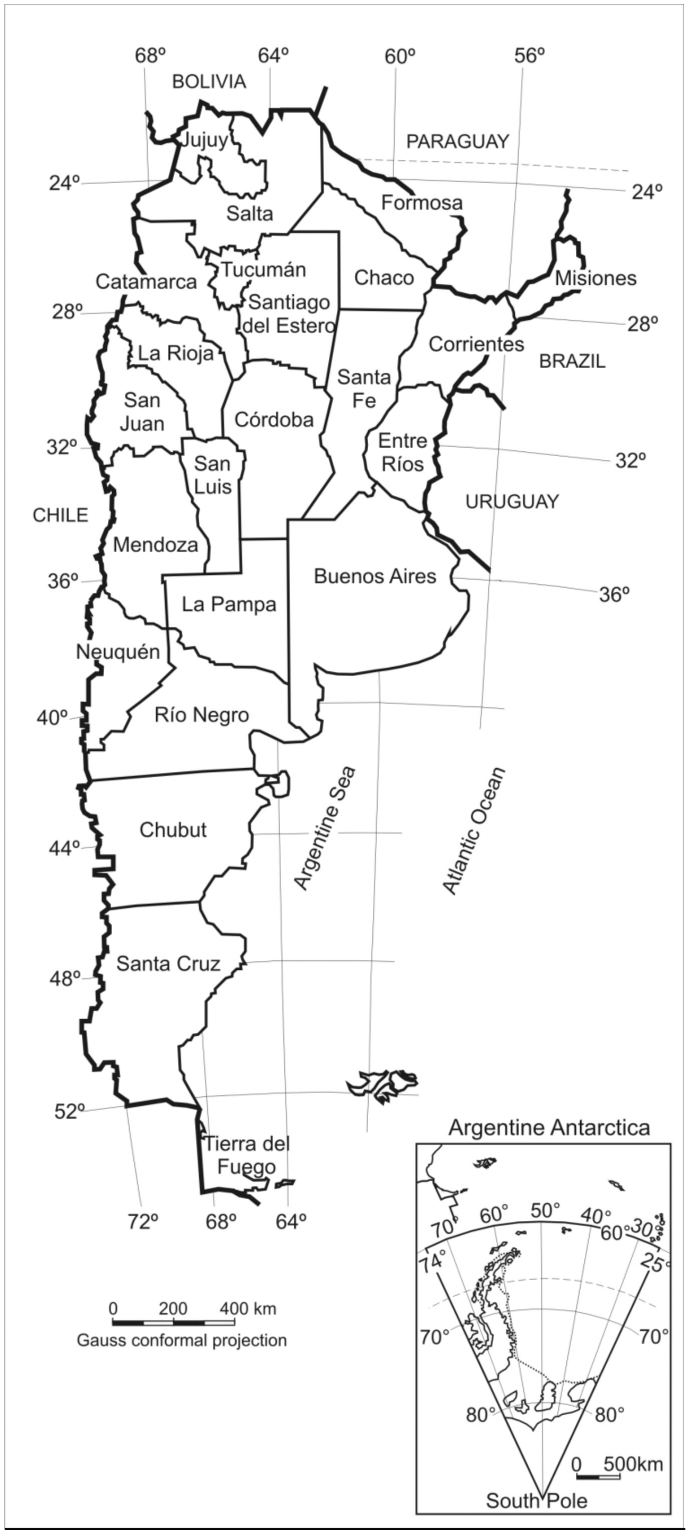

Fig. 1. Argentina's political map

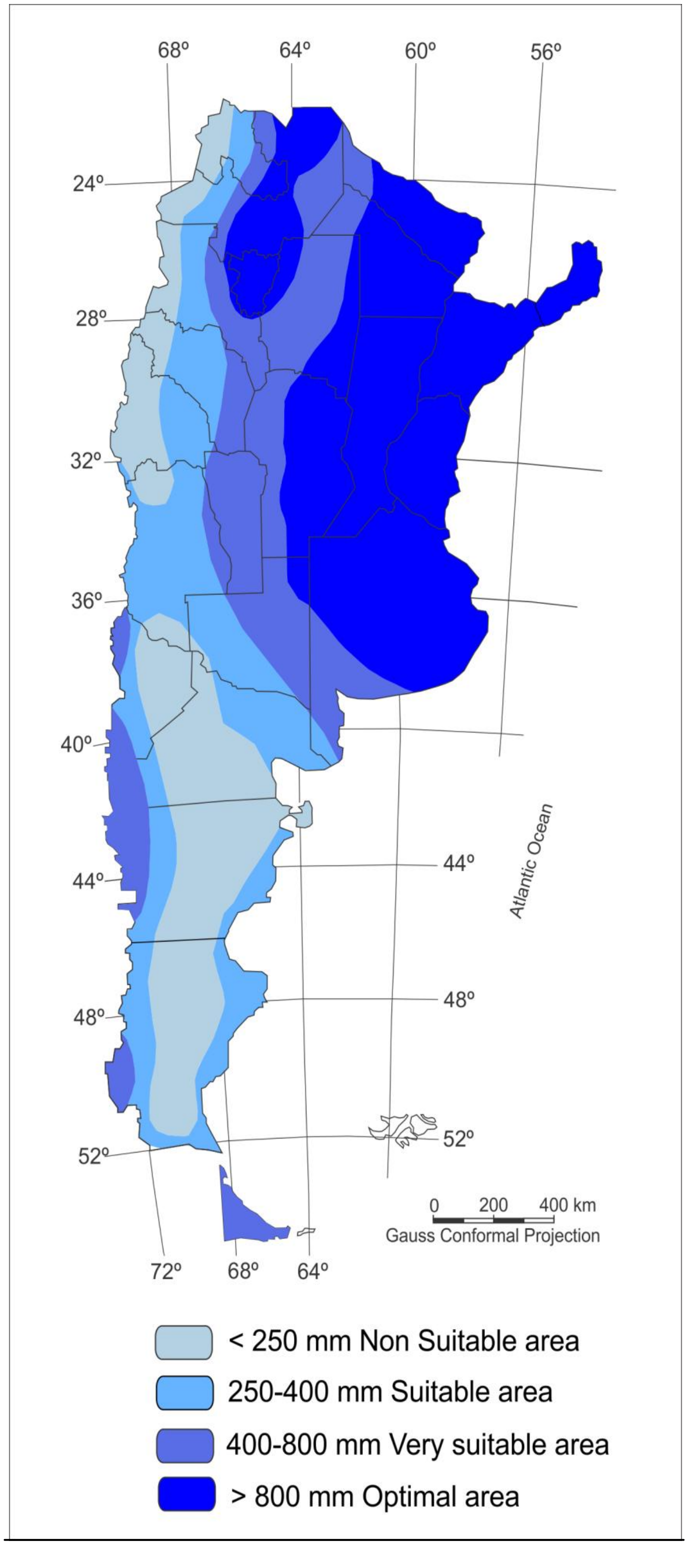

Fig. 2. Annual rainfall

Table 2. Classes of agroclimatic suitability and limits for each class

	Annual rainfall	Frost-free days	Annual temperature	Temperature growing period
Optimal area	> 800 mm	>150 days	>10°C	> 24°C
Very suitable humid regime	> 800 mm	>150 days	>10°C	20-24°C
Suitable area humid regime	> 800 mm	>150 days	>10°C	15-20°C
Very suitable area subhumid regime	400-800 mm	>150 days	>10°C	> 24°C
Suitable area subhumid regime	400-800 mm	>150 days	>10°C	20-24°C
Very suitable area semiarid regime	250-400 mm	>150 days	>10°C	> 24°C
Suitable area semiarid regime	250-400 mm	>150 days	>10°C	15-24°C
Suitable area complementary irrigation	< 250 mm	>150 days	>10°C	15-20°C
Non suitable area	< 250 mm	< 150 days	< 10°C	<15°C

3.2 Frost-free Days

Each year occurrence of the first frost in autumn and the last frost in spring causes damage to the crops in different climatic regions. Information on the probable dates of frost free days helps farmers in avoiding or reducing the damages caused by frost. In Argentina there is great dispersion of mean dates of first and last frost (approximately 30 days). This means that the first frost or last frost may occur 30 days before or 30 days after the mean date. This great dispersion is due to the combined effect of the great asynchronous variability of temperature and the scarce thermal tension in the time in which frosts occur. This happens because there is easy entrance of polar air masses in the South-North direction and little annual thermal amplitude since Argentina is under maritime influence. The frost-free reach a maximum of 360 days in the northeast of Argentina and diminish towards the southwest. The increase in the length of frost period is associated with an increase in the number of frost days. Fig. 3 presents the regions where frost-free days surpass 150 days. These guarantee the appropriate conditions for the growing period of amaranth, which consists of five consecutive months without frost.

3.3 Thermal Regions

The annual average isotherms divide the country into three great thermal areas: tropical, where the average annual temperature is above 20°C; temperate, between the 20°C and 10°C isotherms and, lastly, cold, where the mean temperature is below 10°C. In Fig. 4, the average annual temperature above 10°C can be observed. The suitable area comprises practically the entire country and it has temperate and tropical climates. The non-suitable areas are exceedingly cold for the development of amaranth and cover the west of Patagonia, from the province of Neuquén to the south (Rio Negro, Chubut and Tierra del Fuego). Another non suitable area appears in the northwest of the country, covering part of the provinces of Jujuy, Salta and Catamarca.

In Fig. 5, the average temperature of the growing period is represented (November to April in south hemisphere). It can be observed that the isotherms in the plains follow the path of the terrestrial parallels, from the east to west, and are well spaced among them. Upon reaching the Andes mountains, they display an inflection towards the north, due to the altitude factor, which is very noticeable for the 15 and 20°C isotherms. Further inflections can be appreciated near mountain ranges: the Pampas mountains in the center of the country divert the 24° isotherm towards the N, while the Tandilia and Ventania hills in the province of Buenos Aires deflect the 20°C isotherm. The south of the Buenos Aires province has a cooler climate than the rest of the province during the warm semester owing to the ocean effect and the Malvinas cold current. The center of this province also has the same characteristic but due to the altitude factor, as was previously stated.

When the temperature is above 24°C, the optimal area covers northeast, north and part of the center of the country. In the 20 to 24°C range, there is a very suitable area circumscribed by the one described above and that also covers part of the northwest, west and the entire center of the country. This area includes the center of the province of Buenos Aires, and it reaches higher latitude to the west, encompassing the south of Buenos Aires province and Rio Negro. In the range of 15-20°C, four regions were delineated: one of them covers the center of Buenos Aires province and a second one the west of San Juan and Mendoza, part of Neuquén and the east and the center of Patagonia. One small region appears to the south of province of Buenos Aires and the east of Rio Negro, in the vicinity of the Rio Negro estuary that leads to the

Atlantic Ocean. Finally, the fourth region is located in the NOA, covering part of Jujuy, Salta and Catamarca provinces. Marginal areas appear to the west of Patagonia and in the NOA, in the sector denominated “Puna”.

3.4 Agroclimatic Zoning

Fig. 6 shows the agroclimatic zoning for amaranth. The map generated by the GIS software provided nine different levels of suitability for this crop. To the east of the 800 mm isohyet three areas under humid regime were classified: an optimal area to the North, a very suitable one at the center and a suitable area in the South.

The optimal area encompasses the north of the country and the NEA, extending to the provinces of Entre Rios, center of Santa Fe and north of Cordoba. An additional optimal area is situated in the NOA and covers part of the provinces of Salta, Jujuy, Tucumán, Santiago del Estero and Catamarca. Very suitable areas under humid regime can be found in the center of the province of Buenos Aires. Suitable areas under humid regime cover the center and the south of Buenos Aires province.

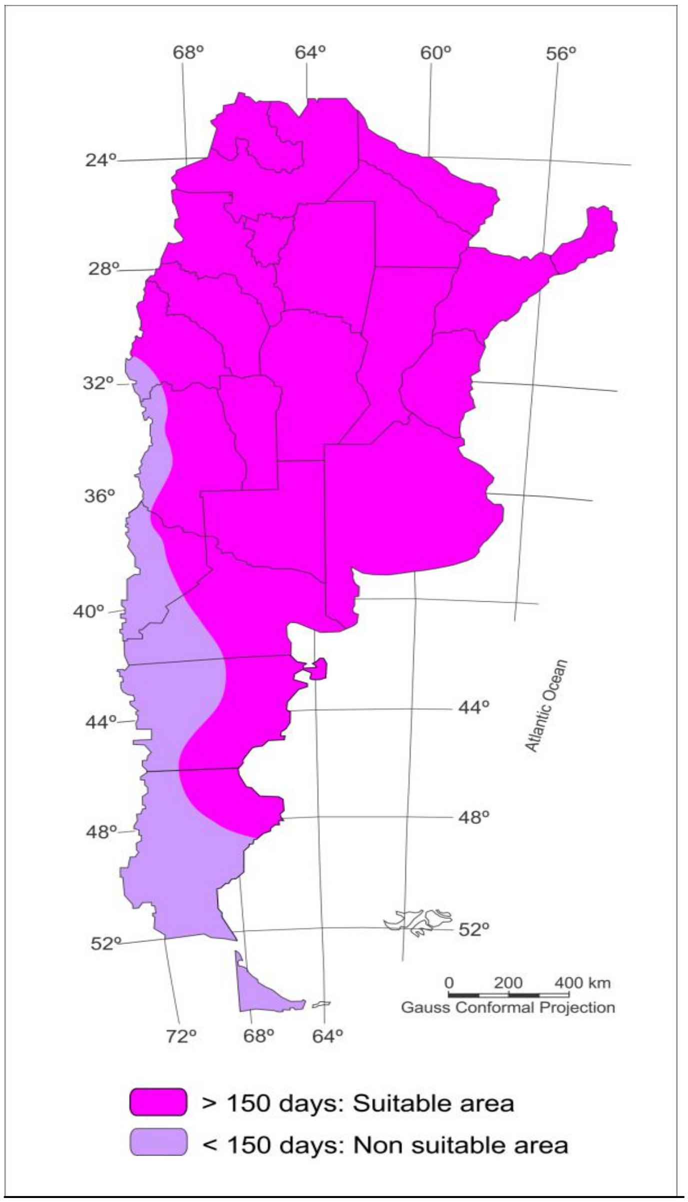

Fig. 3. Frost-free days

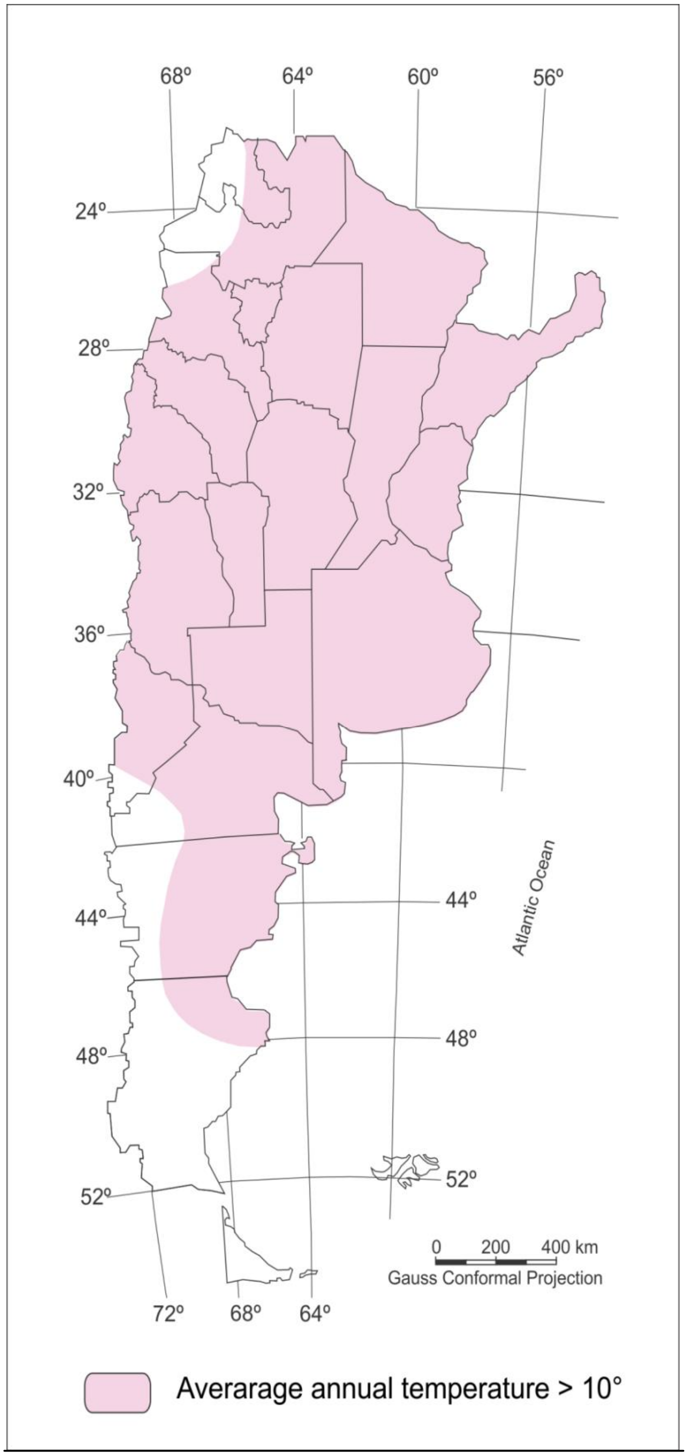

Fig. 4. Average annual temperature above 10°C

In the 400 and 800 mm range, two suitable areas and one very suitable area were identified, both under subhumid regime. The very suitable area under subhumid regime is located between the two optimal areas, including the north of Cordoba, east of La Rioja and Catamarca and north of San Luis. One Suitable area under subhumid regime appears in the center of the country covering half of the province of Cordoba, San Luis, the east and the center of La Pampa, east of Mendoza and southwest of Buenos Aires. The remaining suitable area is located in the northwest, comprising part of provinces of Salta, Jujuy, Tucumán and Catamarca.

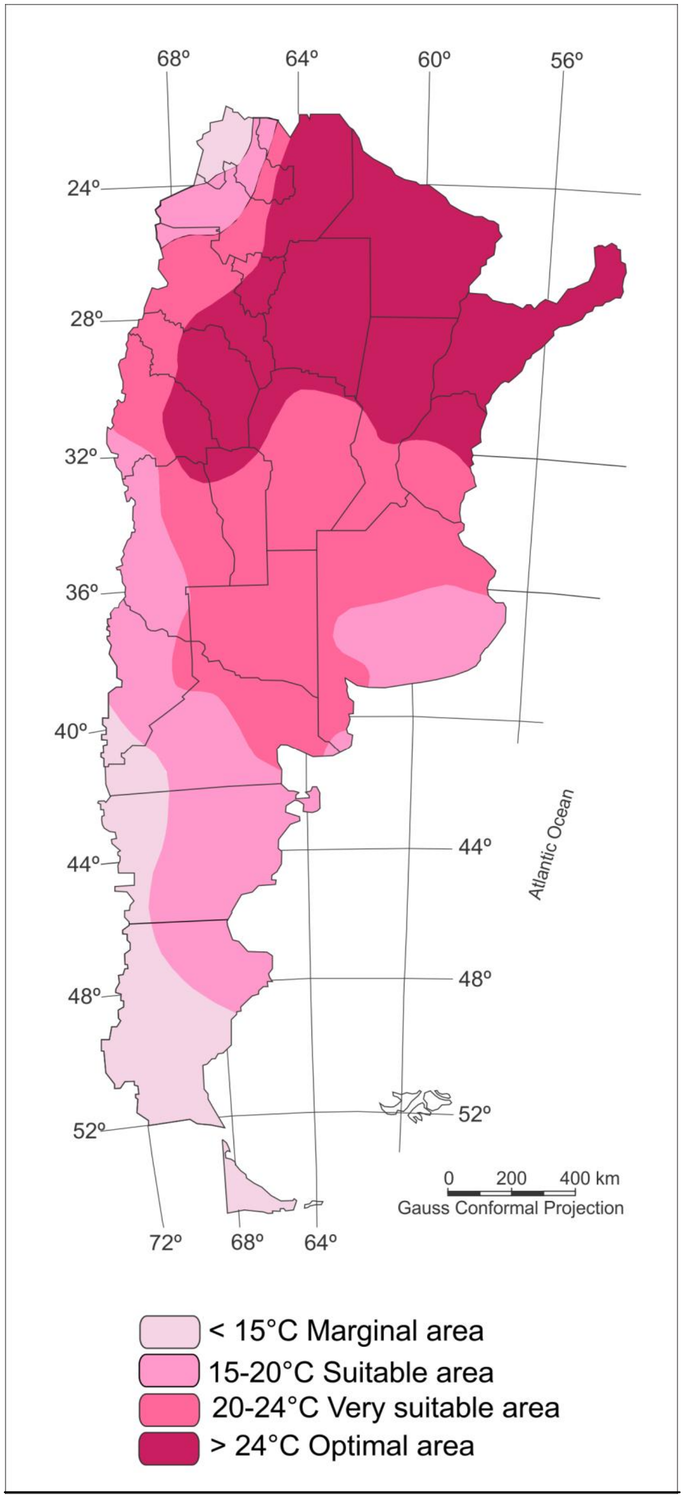

Fig. 5. Average temperature of the growing period

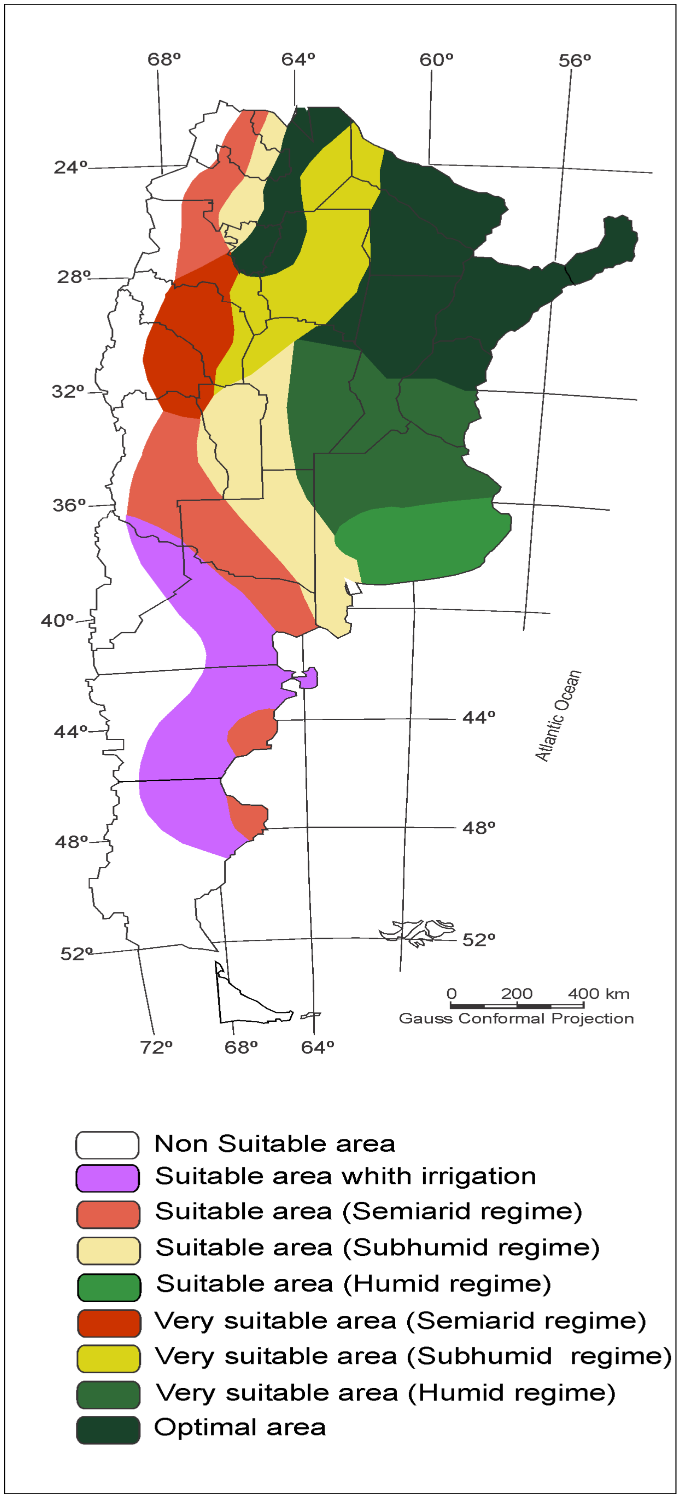

Fig. 6. Agroclimatic zoning for Amaranth

Between 250 – 400 mm the following areas were determined: one very suitable area and multiple suitable areas, all under semiarid regimes. A very suitable area under semiarid regime covers part of Catamarca, La Rioja, San Juan, North of Mendoza and northwest of San Luis. There are two regions that can be classified as suitable area under semiarid regime: One of them covers the northwest of country with the provinces of Jujuy, Salta and Catamarca and the other, located in the center of the country, comprises part of the provinces of Mendoza, Rio Negro, La Pampa and the south of Buenos Aires. In the coastal region, there are two areas with the same aptitude: one in Rio Negro and another in Santa Cruz, located north and south of San Jorge gulf, respectively. The suitable area with irrigation covers the Patagonian sector from the south of Mendoza until Santa Cruz province.

Amaranth is not currently grown extensively in Argentina, but it appears to be adaptable to other non-Andean regions in our country. The existence of a large area with agroclimatic suitability has been established. Also, it has potential in the long term as a grain crop alternative. The suitable areas in Argentina stretch to 49° south Latitude. However, according to [17] this crop only reaches 47°L. Discover life [28] indicates that the species can be found in Argentina at different latitudes: 25°S and 64.5´W (Salta); 34°S and 64´W; 36°S and 60° W (Buenos Aires). However, the same reference indicates that the species can be located at higher latitudes: 43°49´S and 172.6° E (New Zealand in the south Hemisphere); 55°N and 125°W (Canada); 64°70´N and 24°46´E (Suomi) and 63°3´N and 13.3°E (Sweden), all in the north Hemisphere. These facts confirm that it could be sown up to the latitude presented in the agroclimatic suitability map.

The model would best be validated by performing long term geographic trials involving multiple sites and actually observing where the crop gets grown by producers, but this would imply lengthy and costly field work which can be avoided by using GIS technology. The extensive agricultural activity that constitutes the main source of exports in Argentina is developed east of the 800 mm isohyet and under humid climate conditions. This region is comprised by the plains of Humid Pampas. In this area, there is rainfall mainly in the summer months, although there are also droughts during the winter. As a whole, this region has a pleasant climate. It lies well outside the tropics and is moderated by the east Atlantic influences. Although the optimal area presents these moisture conditions, and there are very suitable and suitable areas under humid regime, the cultivation of amaranth crop should be undertaken in moderately to highly saline soils (with EC > 8 mmhos cm^{-1}) and moderately alkaline soils (with pH 8.5), so as not to compete with soils used for traditional crops.

Above all, in certain subhumid and semiarid areas where farmers have few options because of limited rainfall, drought-tolerant amaranth is particularly appropriate. For amaranth production, the most suitable areas for cultivation are those located on regions with subhumid and semiarid climate (very suitable and suitable under subhumid and semiarid regime, suitable under subhumid and semiarid regime), because diseases and plagues are rarer than in regions optimal, very suitable and suitable with humid climate. However, these zones have soils susceptible to eolic erosion, periods with climate-induced water shortage and untimely droughts that would demand special handling. If the cost-benefit analysis is favorable, the farmer can implement this culture in suitable areas with complementary irrigation. In this area, there should also be special handling of the soils due to the strong winds from the west. In this region, there are large variations in temperatures not only through the year, but also from day to night. Summers are usually warm, but winters are cold and with light snowfall. The natural vegetation can be described as typical of semi-desert.

To cultivate amaranth in Argentina at great scale, the following problems would have to be solved: scarce production, absence of seedbeds, lack of adequate labs to determine the quality of amaranth, lack of machinery and equipment adapted to the different production steps, and the dearth in development of processes and products destined for human and animal consumption and for non-food uses. It is important to highlight that the agro-climatic suitability map should not be regarded as definitive with respect to individual applications. It only provides the foundation for future studies, at a higher cartographic scale, which will furnish accurate regional guidance for the planting of this crop. The suitability map can be used to select the regions for future field research with amaranth, and to aid industries in determining the best areas for its production.

4. CONCLUSION

Nine classes of agroclimatic suitability under three different climatic conditions were delineated: humid, subhumid and semiarid. This species can grow as an alternative crop in subhumid and semiarid regions of Argentina. The cultivation of amaranth would also be recommendable in optimal, very suitable and suitable areas under humid climate on moderately-highly saline soils and moderately alkaline soils, so as not to displace the traditional crops of plains of Humid Pampas. The presented model can be used in any part of the world, employing the same agroclimatic indices presented in this paper.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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