Agricultural Sciences, 2015, 6, 1048-1057
Published Online September 2015 in SciRes. http://www.scirp.org/journal/as
http://dx.doi.org/10.4236/as.2015.69100

Potential for Growing *Salvia hispanica* L., Areas under Rainfed Conditions in Mexico

Genovevo Ramírez-Jaramillo[1], Mónica Guadalupe Lozano-Contreras[2*]

[1]Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP)-Centro de Investigación Regional Sureste, Programa para el Desarrollo de los Trópicos, Mérida, México
[2]Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP), Campo Experimental Mocochá, México
Email: *lozano.monica@inifap.gob.mx

Received 12 August 2015; accepted 22 September 2015; published 25 September 2015

Abstract

The *Salvia hispanica* L. is an endemic species Mexican plant, which relevance relies upon its properties as a natural source of omega 3 (α-linolenic acid), soluble and insoluble fibers, proteins, plus some other significant nutritional components. Due to the growing relevance generated by this crop, it became necessary to characterize its physical environment, as well as the natural factors related with its cultivation nationwide, aiming to find those most suitable for its production under rainfed conditions, looking forward to provide the basis to make a decision regarding where to target the agriculture promotion of such cropland. The software used for data process and analysis was the Arc/View 3.3 version. Thus, the crop requirements were recognized in order to analyze those most suitable for chia development in each one of its selected variables in the study hereby. The regionalization and mapping aimed to detect both the optimal and suboptimal potential areas for such crop were carried out, afterwards. It was finally determined that Mexico holds a total of 2,512,359 hectares with an optimal or high cultivation potential, whereas the areas with a medium or suboptimal potential are close to 3,658,089 hectares, which can be set under rainfed conditions.

Keywords

Potential, Rainfed Conditions, Chia

1. Introduction

The chia (*Salvia hispanica* L.) is an endemic species Mexican plant, and its usage has been documented since pre-Hispanic times [1]. It has been mentioned, in accordance to several codex, that tributes ranging from 5 to 15

*Corresponding author.

How to cite this paper: Ramírez-Jaramillo, G. and Lozano-Contreras, M.G. (2015) Potential for Growing *Salvia hispanica* L., Areas under Rainfed Conditions in Mexico. *Agricultural Sciences*, **6**, 1048-1057. http://dx.doi.org/10.4236/as.2015.69100

thousand tones were received, on a yearly basis, from the conquered lands in Tenochtitlan, the capital of the Aztec empire [2]; the seed was also used as an offering to the Aztec gods. Nevertheless, due to its religious utilization, such offerings were banned by the Spaniards because of its close association with religion, but replaced for some other species demanded by the conquerors (wheat, barley, rice, etc.) [3]. The *Salvia hispanica* L. plant was sown through 2013 in three different states of the Mexican Republic: Jalisco (17,739 ha), Puebla (336 ha) and Sinaloa (80 ha), for a total of 18,155 ha with a production output of 8431.89 tones, with an average yield of 0.47 t/ha, a $3449.24 USD average rural price, plus a production value ranging over 478 million pesos [4]. The relevance of this crop relies upon its properties as a natural source of omega 3 (α-linolenic acid), soluble and insoluble fiber, protein, as well as some other relevant nutritional compounds, such as vitamins, minerals and natural antioxidants [5]-[7].

The *Salvia hispanica* L. is a Mesoamerican native species that has its greater genetic diversity along the slope of the Pacific Ocean [8]. It is more specifically reported as an annual herbaceous native plant from the mountains located in the western and central areas of Mexico [9].

A large group of species genetically known as chia exists, including *Salvia polystachya* (chia, tepechia or chinetlacolo) and *Salvia hispanica*; the *Hyptis suaveolens* commercial chia (fat or large chia), is produced from it. Some of the most common usages given to chia include the preparation of food and drinks, the mixture of its flour with corn and amaranth, and as medicine against fever, diarrhea, and constipation, as well as to regulate bile secretion; chia oil is also used as a handcrafting material to improve paintings quality. It has been considered as a marginalized cultivation since the colonial era, being currently cultivated at a small scale in the states of Morelos, Puebla, Guerrero and Jalisco; there is currently a lack of a formal program for either the collection or preservation of such species [10]. Yet, despite the importance of chia cultivation, there have not been nowadays many studies aimed to explain what the best geographical areas to produce *S. hispanica* in Mexico are.

An increase on the demand of *Salvia hispanica* L. in the international market, the improvement of average farm prices, as well as the limited availability of raw materials, raised the necessity by the government authorities, industry, individual entrepreneurs and the social sector to enlarge the cultivation area for this species. Due to the growing relevance of chia cultivation in Mexico, in addition to the need to rescue such species for the feeding of the Mexican population, it was necessary to have both its physical environment and its natural factors characterized nationwide, throughout the location of the most suitable areas for its production under rainfed conditions, providing the basis to make a decision to guide the promotion for its cultivation.

2. Materials and Methods

The study was carried out at the laboratory of Geographic Information Systems (GIS) from INIFAP Southeast Regional Research Center, throughout the program for the development of the tropics located in the city of Merida, Yucatan, Mexico during the year 2013.

The delimitation of the production potential is based upon the search for agroecological requirements and their respective spatial query on existing maps, taking into account the climatic, topographic and soil variables, in addition to their intersections.

2.1. Agro-Ecological Requirements Determination

Crops distribution is currently marginalize by climate limits worldwide, either by default or by an excess of the vital needs for the individuals within different biotypes. Right from the moment the planting is performed, the plants are submitted to the climate components asynchronous variations, having those turned into the most determinant factors for the success of any given crop [11]-[17].

The particular needs and requirements of such crops are most commonly described in ranges, being usually reported by species or even genotype. The result of the diagnosis shall rely on the intervals taken into account; as a result, if optimal values are considered, the resultant potential areas may indeed provide a better yield and cultivation profitability.

The following criteria were considered to determine the potential areas for *S. hispanica* cultivation under rainfed conditions: Those where all of the appropriate variables interacting with each other were considered as the most suitable for an optimal development; those where the correct climatic and soil characteristics interaction prevailed, despite some restrictions, were considered as suboptimal; finally, those considered as inadequate for the mechanical settlement of chia cultivations were reported, too. Potential areas were determined taking into account only those opened for cultivation; as a result, their potential is even higher nationwide [18]-[23]. Altitude, soil, temperature and annual rainfall levels were also taken into account in addition to climate, in order to have the optimal, suboptimal and inadequate chia cultivation areas defined (**Table 1**).

2.2. Identification or Regionalization of Potential Chia Cultivation Areas

The Arc/View version 3.3., software—developed by the American company ESRI, was the program used for data process and analysis. Geo-referenced data can be represented with it, as well as the analysis of characteristics and distribution patterns for such data, looking forward to have it reported, afterwards [24]. All of the Arc/View activity took place within the project parameters, which were a collection of related documents controlled during the Arc/View session.

Projects may contain as many as five different views, tables, charts, layouts (or printouts) and scripts. The names of all of the documents contained in an Arc/View project were displayed through the Project window; then, a project had the status of all of these documents properly organized and stored; next, the project decided how and where such documents were meant displayed, keeping the document selection active and with the appearance of the application window defined, which is the same as making a quick picture of the Arc/View status at the moment of saving it. The project information was further stored in an ASCII format file, always with an *. Apr. Extension. Arc/View was mainly a maps vector generator.

The procedure was performed in Arc/View 3.3 (**Figure 1**) to take the variables intersection process into consideration in order to generate optimal, suboptimal and unsuitable potential areas. The maps were generated through cartographic intersections between polygons, and potential classes were described and maintained in each process of intersection in vector processing; as a result, the final map provided information on all of the variables that were intercepted. These maps were more representative raster models as they were more accurate to generate estimates of a given area, due to the fact that the maps involved in the processes were polygonal. Crop requirements were identified, and those suitable for the cultivation with regards to each variable that were analyzed in the study hereby; then, the performance of the mapping features were selected intersections.

3. Results and Discussion

A lack, of history of other studies on the determination of the productive potential of S. *hispanica* in Mexico and in other regions around the world, currently prevails; however, even though INIFAP does have studies on plant

Table 1. *S. hispanic* agroecological requirements for rainfed conditions.

Criteria	Unit	Optimal	Suboptimal	Inadequate
Climate	Types*	C and Aw	Am, Af and B	D, E and H
Average annual Temperature	˚C	18 - 26	16 - 18 26 - 28	<than 16 >than 28
Altitude	msnm	1000 - 2000	0 - 1000	Higher than 2000
Annual Rainfall	mm	800 to 1800	600 to 800 1800 to 2000	<than 600 >than 2000
Soil	Type	Fluvisols Acrisols Luvisols Nitisols Histosols Xerosols Regosols Planosols Andosols Kastanozems	Cambisols	Gleysols Vertisols Rendzines Leptosols Solonchaks
Drainage	Type	Good	Average	Deficient

*Types of Climate: C = Mild; AW = Tropical with dry winter; AM = Tropical monsoon; Af = Tropical with no dry season; B = Dry; D = Mild cold; E = Cold; H = Mountain.

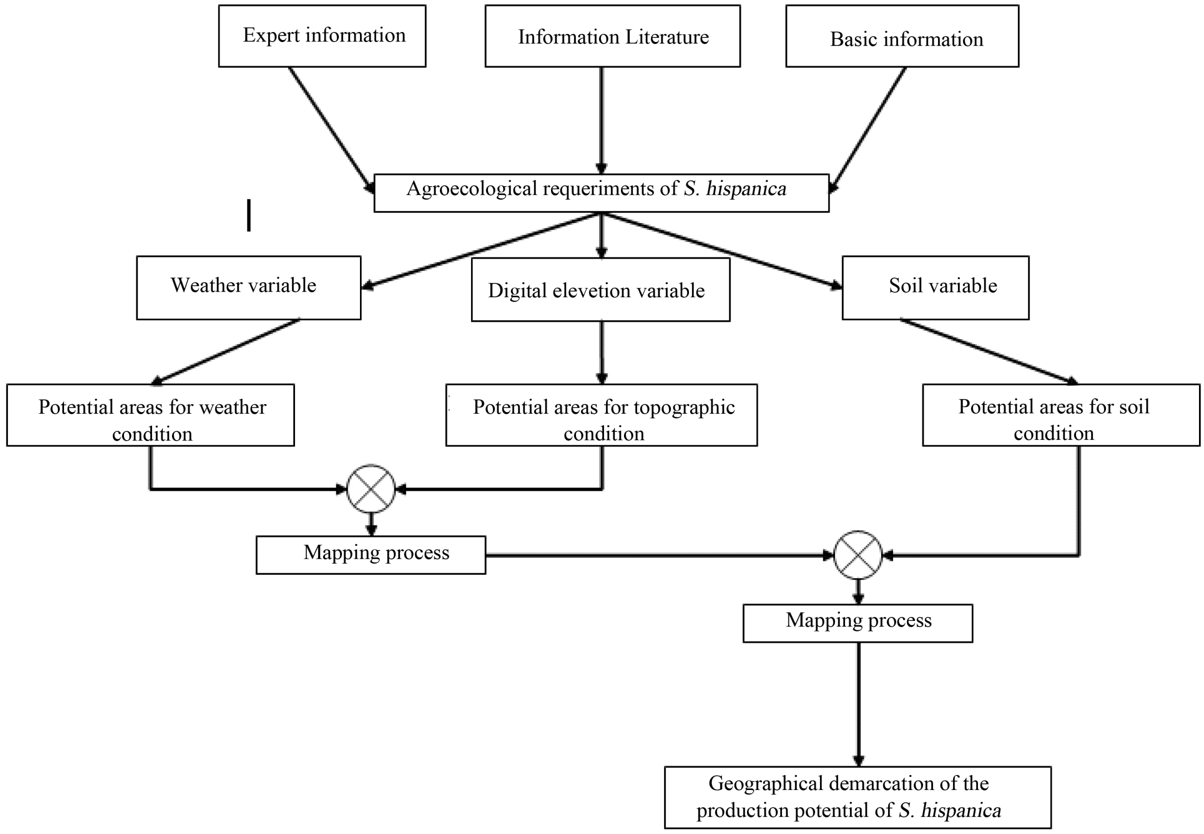

Figure 1. Process methodology used in the delimitation of production potential.

species, those related with the chia species have not currently been taken into account [18]-[23]. Their study becomes important because it is an endemic species of Mexican origin that requires the rescue and promotion nationwide, due to its nutritional properties and a favorable market along both nation and worldwide.

It was determined, according to the results of the study hereby, that a total of 2,512,359.00 hectares are present in the areas opened to be cultivated under rainfed conditions with either a high or optimal potential, whereas the areas with a medium or suboptimal potential are about 3,659,089.00 hectares (**Figure 2**).

Even though the surface with either a high or medium cultivation potential is relatively low—only 18,155 hectares in 2013, it represented less than 1% of the surface with a high potential. Out of 36 municipalities nationwide, the only states reporting official figures for that year were Jalisco (33), Puebla (2) and Sinaloa (1) (**Figure 3**). The trend of this product in the market in 2013 had a tendency towards improvement, having some of the aforementioned municipalities obtaining prices ranging from $2796.00 to $6116.00 USD (**Figure 4**).

Consequently, if Mexico wants to be internationally competitive, chia cultivation production has to be aimed towards the cultivation areas with either a high or optimal potential, strengthening both research and technological development of chia looking forward to reach farming mechanization.

It is possible to achieve a higher production potential than that obtained in 2013, with a yield of 0.44 t/ha under rainfed conditions, which was lower than the average yields reached in other countries, such as Argentina and Bolivia, who reported 0.80 t/ha [25]. Municipalities such as De la Barca, Jalisco, reported yields of 1.42 t/ha, plus a minimum yield of 0.30 t/ha in the case of the municipalities of Tequila, Tonaya and Tuxcacuexco, indicating that a high production potential is always feasible to achieve accordingly, as long as the potential optimal cultivation areas, plus an adequate crop technological management, are taken into account.

Several factors may be related to the active compounds concentration changes in the chia seed. One of those is the plant cultivation area, which is related to the environmental discrepancies, climate changes and nutrients availability [26] [27]. Furthermore, an inverse relationship between height and saturated fatty acids was observed. There was an increase in fatty acid saturation at low altitudes, especially in high temperature areas [28]

[29]. A great contribution to the fatty acids contained in the oil is provided by the temperature.

A reduction in polyunsaturated fatty acids is caused by an increase in the environmental temperature during

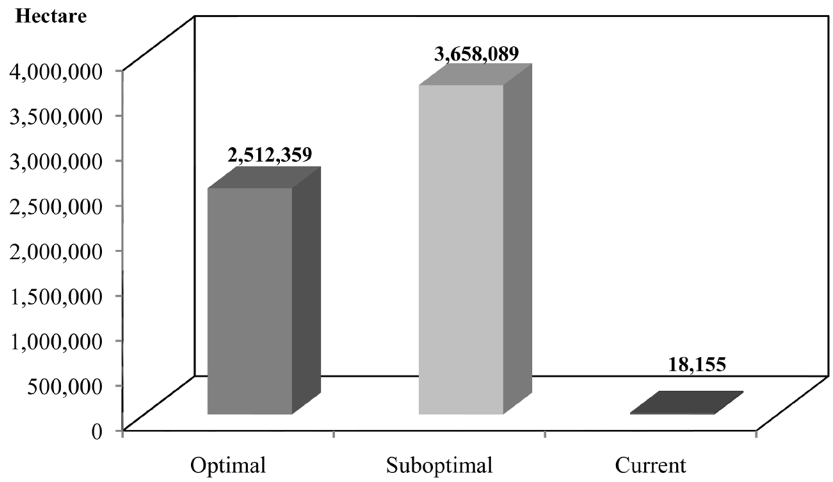

Figure 2. Area planted in 2013 and potential *S. hispanica* in Mexico.

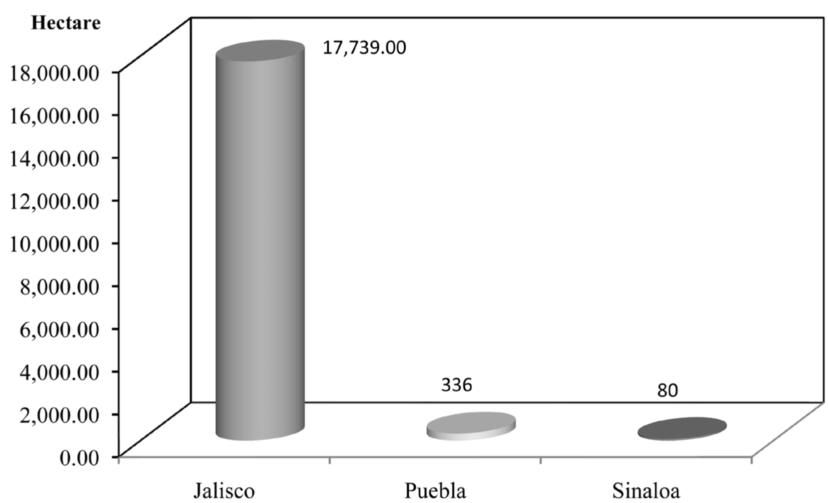

Figure 3. Plantings in hectares of *S. hispanica* in Mexico by states in 2013.

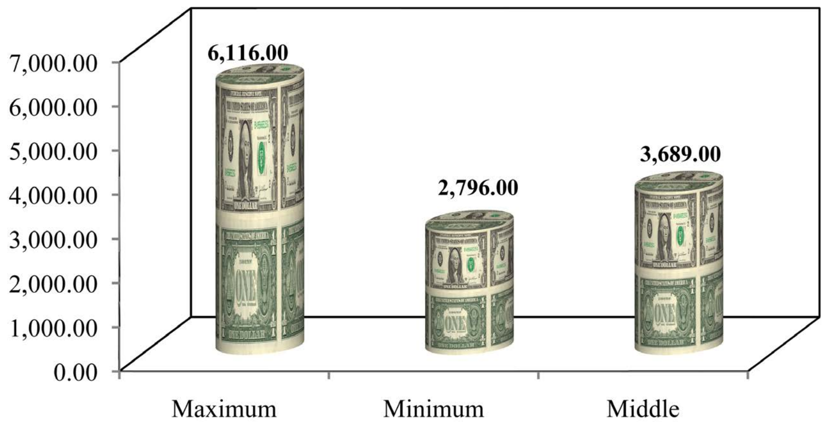

Figure 4. Price level in USD per ton of *S. hispanica* in Mexico 2013.

seed development from April to May, as reported by some studies [30]; meanwhile, a tendency to decrease the protein content with an increasing temperature was revealed [31].

3.1. Potential Areas for *S. hispanica* of Rainfed in Mexico

The optimal potential chia cultivation areas are mainly distributed in the states along the Pacific coast line, such as Nayarit, Jalisco, Colima, Michoacán, Guerrero, Oaxaca and Chiapas. Nevertheless, there are some important areas suitable for cultivation in the central region, being the most significant along the states of Morelos, Puebla and Hidalgo, as well as Veracruz and Tamaulipas in the Gulf of Mexico (**Figure 5**). Both the optimal and sub-optimal areas for chia cultivation, under rainfed conditions by state, are revealed in **Table 2**.

A second phase of the study is to conduct exploratory studies to validate the identified areas and the most suitable for production technologies, after having identified both the optimal and suboptimal potential areas; hence, it is necessary to know its technical and economic advantages. One of the limitations of the study hereby may be those revealed by the scales used in the available cartography, which sometimes did not match the conditions at the farm level; still, a solution is considered especially for decision-making and the implementation of agro-ecological crop requirements.

3.2. Soil and Climate

Chia adapts itself to different types of soil in both the mild and tropical regions; it does not withstand flooding and it requires aerated and well drainage soils, which is why it develops itself properly in sandy loam and clay loam soils with good drainage conditions. It thrives in a wide pH range, from slightly less than 7.5 to less than 5 in acid soils. Regarding soil texture, it certainly seemed that those with a soft silt loam were the best if the plant was likely to get enough moisture with a renewable groundwater. If rich in organic matter, it is possible to use

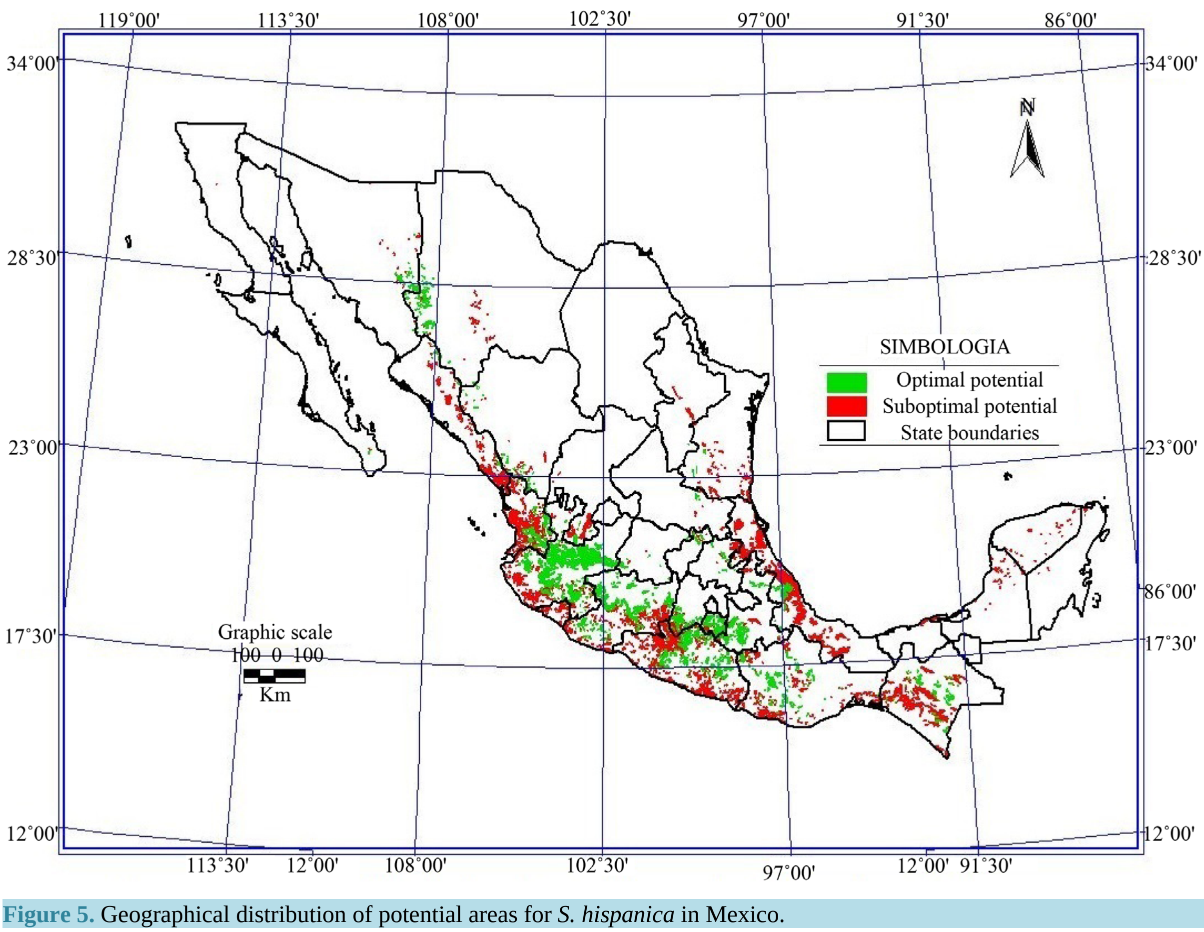

Figure 5. Geographical distribution of potential areas for *S. hispanica* in Mexico.

both clay and clay crumbs in this crop. The distribution of both optimal and suboptimal chia cultivation soils are revealed in **Figure 6**. Concerning climate, this sort of culture adapts itself to mild climates (C) and tropical climates; such climates in Mexico can take place on the coastal plains and in the states of Jalisco, Colima, Michoacán, Guerrero, Oaxaca, Chiapas, Morelos, Puebla, Veracruz, Tabasco and along most of the Peninsula of Yucatan (**Figure 7**).

Table 2. Potential areas for *S. hispanica* L. of rainfed conditions in Mexico.

State	Potential		Total
	Optimal	Suboptimal	
Veracruz	125,000	731,627	856,627
Jalisco	502,471	256,066	758,537
Michoacan	251,236	329,228	580,464
Nayarit	125,617	365,809	491,426
Guerrero	150,741	292,647	443,388
Sinaloa	25,123	365,809	390,932
Chiapas	100,494	256,066	356,560
Morelos	200,988	109,742	310,730
Oaxaca	110,000	182,904	292,904
Estado de Mexico	125,600	109,742	235,342
Puebla	125,002	73,161	198,163
Others	670,087	585,288	1,255,375
Total	**2,512,359**	**3,658,089**	**6,170,448**

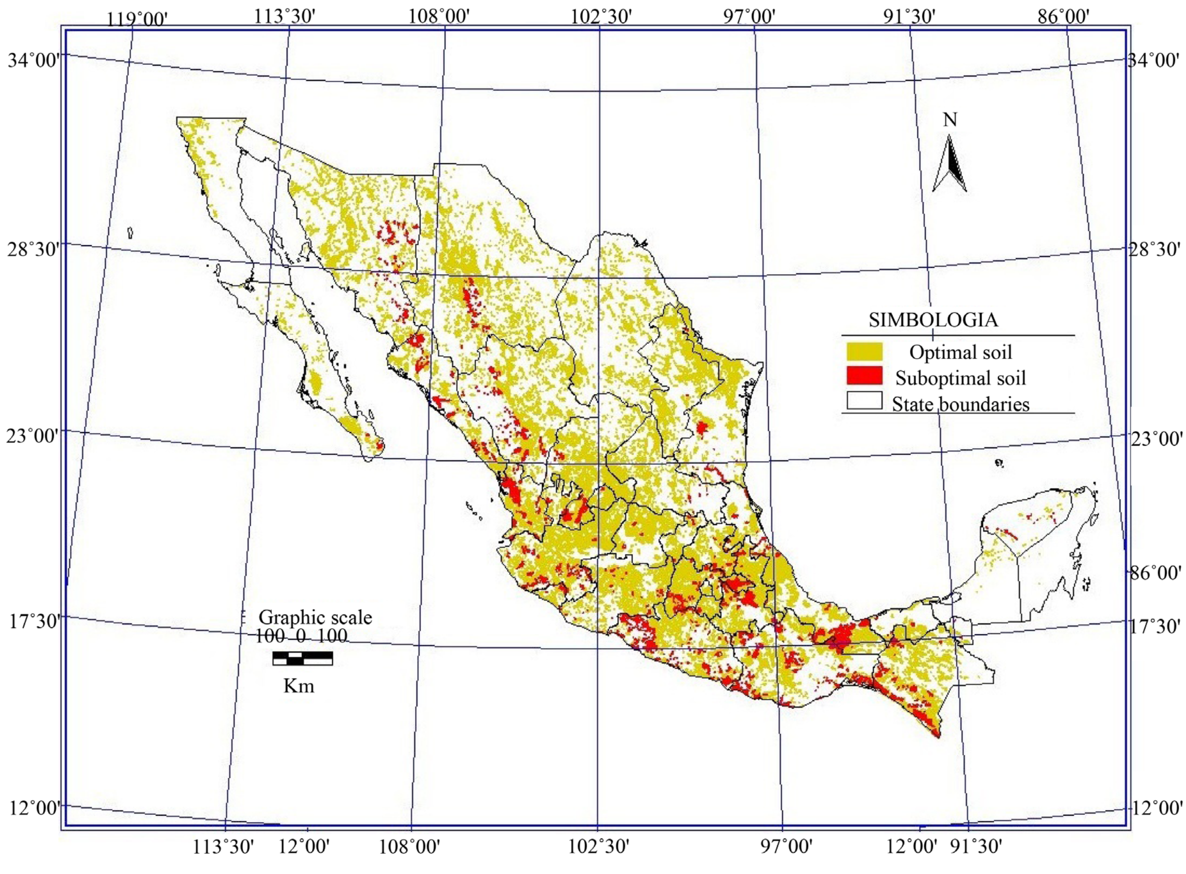

Figure 6. Aptitude of soil types for *S. hispanica* in Mexico.

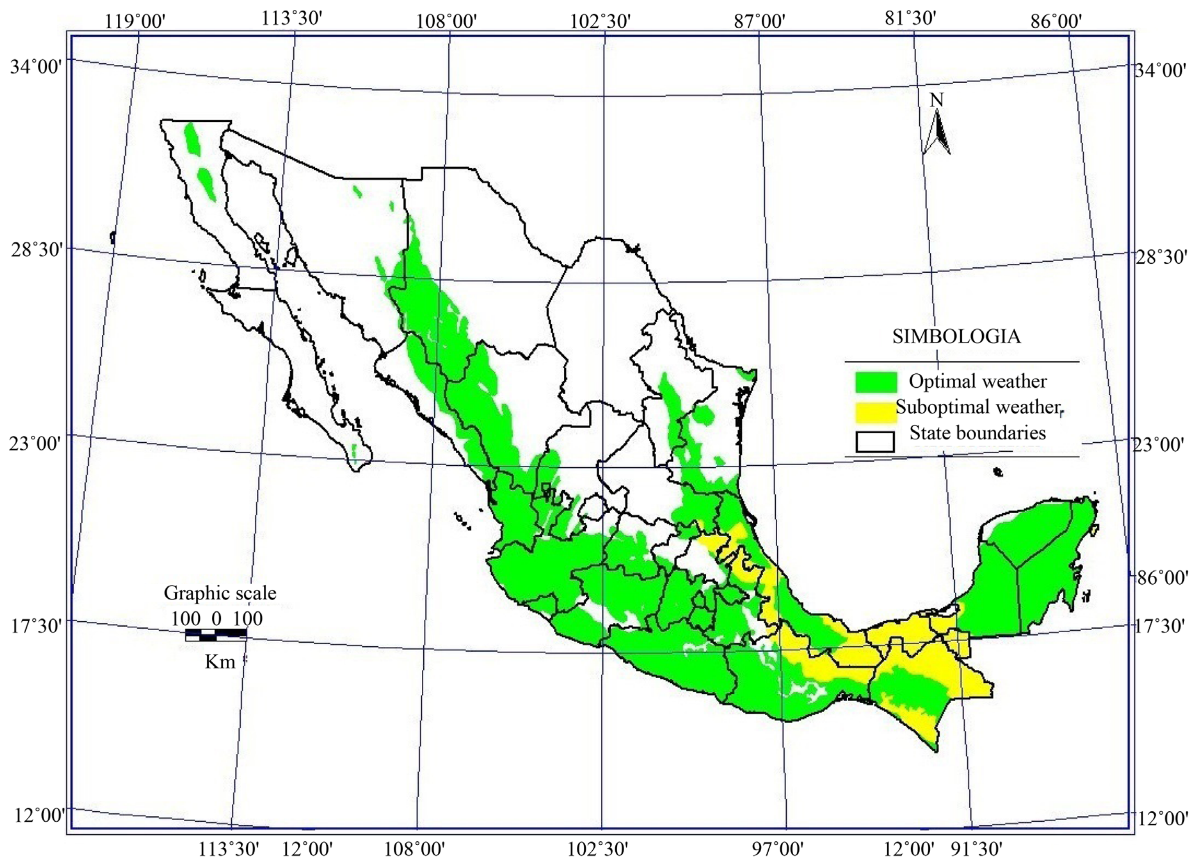

Figure 7. Aptitude for *S. hispanica* weather in Mexico.

4. Conclusion

Mexico holds the optimal ecological conditions to produce chia under rainfed conditions, with an improved productivity. The most suitable areas to produce chia under rainfed conditions are located in the central and western states of Mexico, as well as in some other states located down south, mainly in the higher regions of the states of Jalisco, Nayarit, Michoacan, Morelos, Puebla, Mexico, Guerrero, Oaxaca and Chiapas. The soil type, rainfall and altitude are determining factors to define the optimal and suboptimal potential areas for chia cultivation. The high potential areas outweighed by far the areas currently sown nationwide.

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