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Agroclimatic Suitability of *Malanga* (*Colocasia esculenta* L. Schott) under Rainfed Conditions in Mexico

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

[1]Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias, Campo Experimental Mocochá, Yucatán, México
[2]Centro de Investigación Regional Sureste del Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP), Mérida, Yucatán, México
Email: lozano.monica@inifap.gob.mx

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Abstract

Malanga (*Colocasia esculenta* L. Schott), also known as *taro* or *quiscamote* in Latin America, is a plant species with ornamental, culinary and industrial uses, adapted to warm and humid climates. Nowadays, *Malanga* fit very well in the overseas growing trend towards a healthier lifestyle, which is reflected in the incorporation of foods and drinks that have nutraceutical characteristics. These products, which offer numerous health benefits, are driving a notable increase in their consumption and popularity. Considering that the cultivation of *Malanga* could be a great opportunity to diversify the Mexican market this work had the objective to identify suitable agroclimatic areas for the cultivation of *Malanga* under rainfed conditions in Mexico. For zoning, two sets of key factors were evaluated for optimal crop development: Edaphic factors, such as slope, depth, texture and pH of the soil; And climatic factors, such as precipitation, temperature, hours of daylight and altitude. The results revealed areas with high and medium productive potential. The methodology used included the definition of the agroecological requirements of the crop, based on databases, scientific literature and consultations with experts. The information was processed by using: 1) The QGIS 3.22.14 Biatowieza software, 2) the georeferenced databases of the Mexican-INEGI Digital Elevation Model, 3) the World climate database version 2.0 and 4) the WRB soil database with maps at a scale of 1:250,000. The results indicated the existence of more than two million hectares with high productive potential and more than three million with medium potential, located mainly in the states of Tabasco, Veracruz, Oaxaca, Chiapas and Campeche.

Subject Areas

Agricultural Engineering

Keywords

Malanga, Regionalization, GIS, Climate, Soils

1. Introduction

Nowadays, there is a growing trend towards a healthier lifestyle, which is reflected in the incorporation of foods and drinks that have nutraceutical characteristics. These products, which offer numerous health benefits, are driving a notable increase in their consumption and popularity. An example of these foods is *Malanga* (*Colocasia esculenta* L. Schott), an edible tuber belonging to the *Araceae* family, native to Asia that later spread to Africa. The plant has an edible central tuber or cormels, formed in the soil at the base of the plant. It has a spherical, ellipsoidal or conical shape with a white pulp rich in starch (21.1% - 26.2% on a wet basis), and a dark brown peel [1]-[3].

This crop is important in the food and industrial sectors. In the industry, it is used due to the high proportion of *amylose* and *amylopectin* in its *corms*. It can be used in the manufacturing industry to make paper, adhesive and biodegradable packaging, as well in the pharmaceutical industry [4].

In the food sector, the *Malanga* is considered nutritious and highly digestible food rich in minerals such as: Magnesium, iron, phosphorus, potassium, sodium, copper and manganese; and vitamins C, E and B6 [5]. It is used for snacks, soups, pastas, salads, stews, cookies, bread, tortillas, drinks and sweets.

Malanga has gained great interest worldwide, especially due to its good acceptance among consumers, the low inputs required for its establishment, easy management and adaptation to agroclimatic conditions, and resistance to adverse environmental and biological factors. Due to its partial tolerance to shade, it can be stablished under intercroped systems [6].

Two types are planted worldwide, those that grow in wetlands (flooded cultivation) and those that prefer well-drained soils (dry crops) [7]. In Mexico, this crop was introduced in the 1970s by the National Institute of Agricultural Research (INIA), which is currently known as the National Institute of Agricultural, Livestock and Forestry Research (INIFAP). With the aim of observing its adaptability and development in the country, using some improved *taro* genotypes from Cuba [8] [9].

Malanga has been grown commercially in the states of Oaxaca, Puebla, Nayarit, Tabasco and Sinaloa. However, the state of Veracruz is, currently, the only national producing state with a planted area of 495 hectares and a production value of 250,172.35 million pesos (MXN). In Veracruz, the main producing municipalities are Paso de Ovejas, La Antigua, Puente Nacional, Úrsulo Galván and Actopan [10]-[12].

Economically, it is a profitable crop for producers, since it is a marketable product nationally and internationally, particularly in the United States of America and Canada [2]. According to Martínez-Herrera *et al.*, (2022) [13], producing *Malanga* or Taro is a profitable business, since there is a growing demand in Mexico and abroad. However, to supply the increase in national and international markets, greater production is required and taro cultivation should be directed where the best conditions exist for its development. Therefore, the objective of this study was to determine the best agroclimatic zones to produce *Malanga* in Mexico.

2. Methodology

The spatial determination of optimal and sub-optimal areas of a crop can be carried out using different methodologies; however, in this case it was done based on the use of map algebra, taking as input variables such as: the agroecological requirements of *Malanga* in Mexico.

The use of Geographic Information Systems (GIS), as a tool to develop and plan agricultural programs, has been a successful method to discriminate areas of different productive potentials for different crops [14]. Through GIS, it is possible to manage the agroecological variables representing different spatial physical environment (climate and soil) where the agriculture programs are to be developed.

The main contribution of these maps is to facilitate the adequate management of resources and, in this way, support producers, technicians and those responsible for public policies in agricultural management and planning.

In this study, three fundamental aspects were addressed: agroecological requirements, the use of agroclimatic variable databases, and information processing, following the recommendations proposed by Ramírez-Jaramillo *et al.* (2023) [15].

2.1. Determination of Agroecological Requirements

The agroecological information was integrated based on different bibliographic sources in: [16]-[18]. On the other hand, the experience of some experts in the cultivation of *Colocasia esculenta* L. was also taken into consideration.

2.2. Obtaining Spatial Information

Several geospatial databases were considered. The edaphic information was taken from the World Soil Resource Reference Base, known by its acronym in English as WRB, published by FAO (2014) [19], in vector format.

Climatic data were taken from the WorldClim version 2.0 database, specifically average temperature and precipitation during the crop cycle. The Digital Elevation Model (DEM) was obtained from the National Institute of Statistics and Geography (INEGI), in raster format with a resolution of 500 m^2.

The map of slopes, bodies of water, mangroves, urban and rural areas of

Mexico, as well as protected natural areas, were recovered from the Geoportal of the national information system for biodiversity of the National Commission for the Knowledge and Use of Biodiversity (CONABIO).

2.3. Data Processing

Map algebra is understood as the set of techniques and procedures that, operating on one or several layers in raster and/or vector format, allow us to obtain derived information, generally in the form of new data layers. For this case, the procedures that were applied to the geographical information, in vector format, basically consisted of classifying the climatic and edaphic attributes in the agroecological ranges established under rainfed conditions.

Vector data are entities associated with each attribute, and have their own spatial characteristics, and the geometry that defines each attribute serves on its own to carry out numerous analyzes, such as cuts and intersections. With these geometric operations on vector data, it is possible to intercept the edaphic and climatic layers in order to subsequently eliminate the areas related to mangroves, protected areas, and urban and rural settlements.

All information was processed and reclassified using the QGIS 3.22.4 Biatowiza Public License software [20].

3. Results

3.1. Agroecological Requirements of *Colocasia Esculenta* L. Shott

The main variables considered to regionalize the agroclimatic suitability for *Malanga* under Mexican rainfed conditions were: 1) Average annual temperature, 2) average annual precipitation, 3) altitude, 4) daylight hours, 5) soil types, 6) soil texture (Sand-clay-silt), 7) soil depth, 8) soil pH and 9) drainage. For each of the variables, an optimal, suboptimal and unsuitable ranges were proposed (**Table 1**).

The cultivation of *Malanga* requires a warm and humid climate, that is, tropical monsoon or mesothermal climates, with temperatures greater than 20˚C, with adequate luminosity. It does not tolerate low temperatures [18].

In Mexico, warm-humid climates are distributed mainly in the coastal areas of the country, both those near the Caribbean and Gulf of Mexico, and in the Pacific.

3.1.1. Average Annual Temperature for Taro

The ideal temperature for *Malanga* development ranges from 25˚C to 30˚C. When temperatures are lower than 18˚C, plant growth stops and the photosynthesis process is interrupted. Therefore, to ensure healthy growth, it is essential to maintain a warm and adequate environment [16].

The optimal average annual temperatures (25˚C to 30˚C) for *Malanga* are well distributed in the south and south-southeast of Mexico, while the suboptimal ones occur mainly in the north of the state of Veracruz, Tamaulipas and part of Nuevo León, as well as Sonora, Baja California North and South (**Figure 1**).

Table 1. Agroecological requirements of *Colocasia esculenta* L. Schott

Variable	Unit	Optimal	Suboptimal	Not Suitable
Average Annual Temperature	*˚C*	25 - 30	20 - 25 30 - 35	Less than 20 Greater than 35
Altitude	*masl*	0 - 1000	1000 - 2000	Greater than 2000
Average Annual Precipitation	*mm*	2000-2500	1000 - 1500 2500 - 3500	Less than1000 Greater than 3500
Soils	*Types*	Fluvisoles Luvisoles Nitisoles Vertisoles Gleysoles Phaeozems Kastañozems	Cambisoles Andosoles	Solonchaks Leptosoles Arenosoles Calcisoles Regosoles
Texture	*Types*	Loamy	Sandy	Clay
Depth	*m*	Greater than 1	1 to 0.5	Less than 0.5
pH	*Indicator*	6.0 to 7.0	5.5 to 5.9 7.1 to 7.5	Less than 5.5 Greater than 7.5
Ligth Hours	*Light hours*	Greater than 3000	2500 to 3000	Less than 2500
Drainage	*Types*	Efficient	Efficient	Deficient

3.1.2. Average Annual Rainfall of Taro

The humidity requirements are significant for *Malanga´s* good development. A significant amount of precipitation, ranging between 1800 and 2500 mm. It is essential, but it should be distributed uniformly over time. When soil moisture is a limiting factor to the crop, the leaves will change color, turning yellowish and wither [16].

As for Mexico, the optimal average annual precipitation is considered to be 2000 to 2500 mm, which is distributed mainly in the states of Tabasco, Chiapas, Campeche, Veracruz, Puebla, San Luis Potosí, Oaxaca, Guerrero, Jalisco and Nayarit (**Figure 2**).

3.1.3. Light Hours Per Year for Taro

Light is a key factor in plant care, since it is essential for photosynthesis and growth process. Light provides the energy necessary for plants to convert carbon dioxide and water into sugars and oxygen.

Malanga requires an optimal number of light hours per year and the optimal number is considered to be more than 3000, which is distributed in most of the country (**Figure 3**). When temperatures are very high, *Malanga* prefers partial shade in full sun. On the other hand, in very warm climates, it may need protection from direct sun during the hottest hours of the day. It is a species that can be considered to intercrop or associate with other perennial species that provide the shade required.

Veracruz, Puebla, San Luis Potosí, Oaxaca, Guerrero, Jalisco y Nayarit (Figure 2).

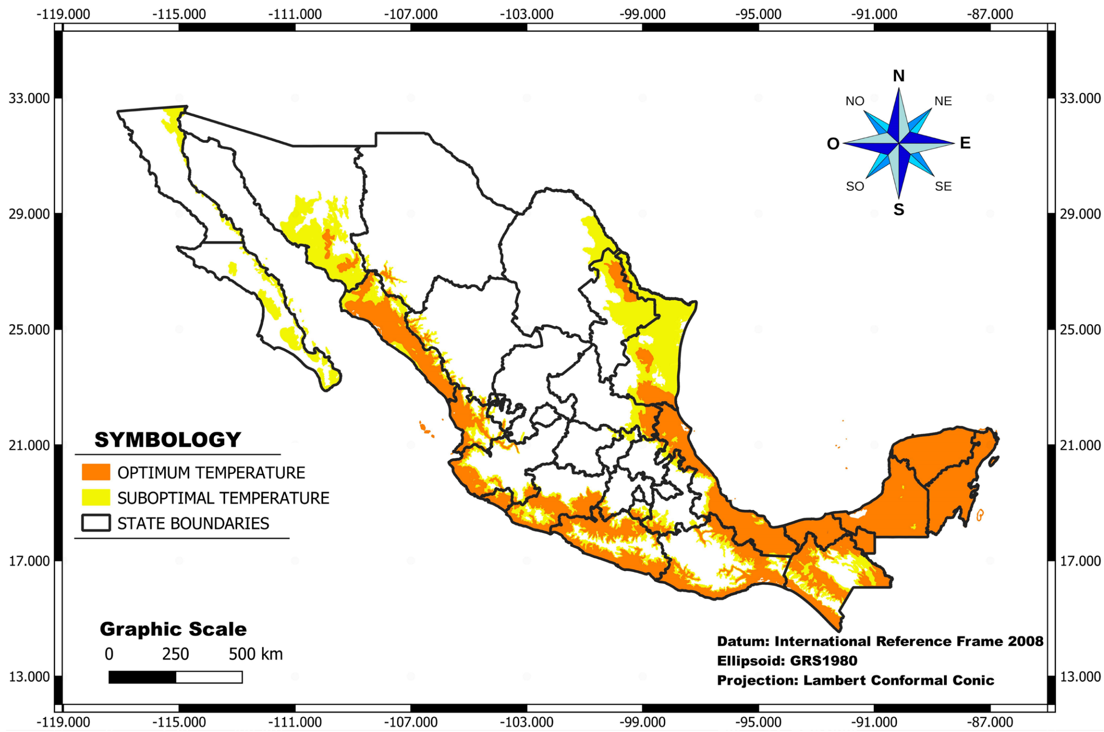

Figure 1. Suitability of mean annual temperature for *Colocasia esculenta* L.

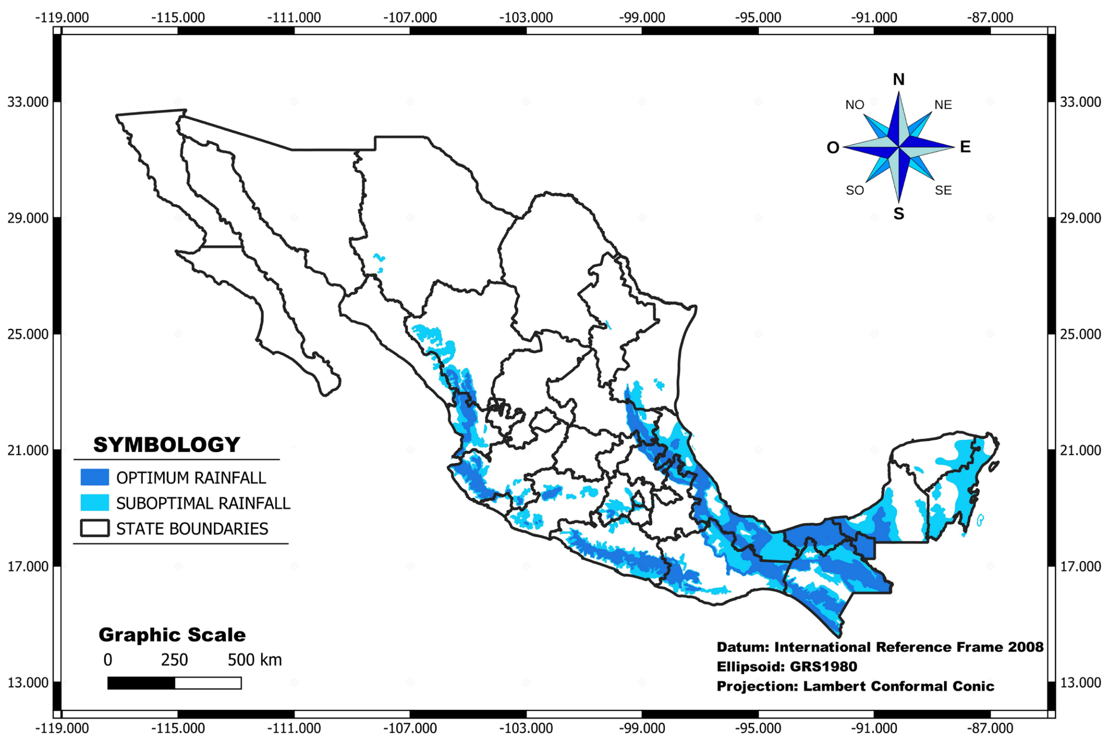

Figure 2. Suitability of mean annual precipitación for *Colocasia esculenta* L. Schott.

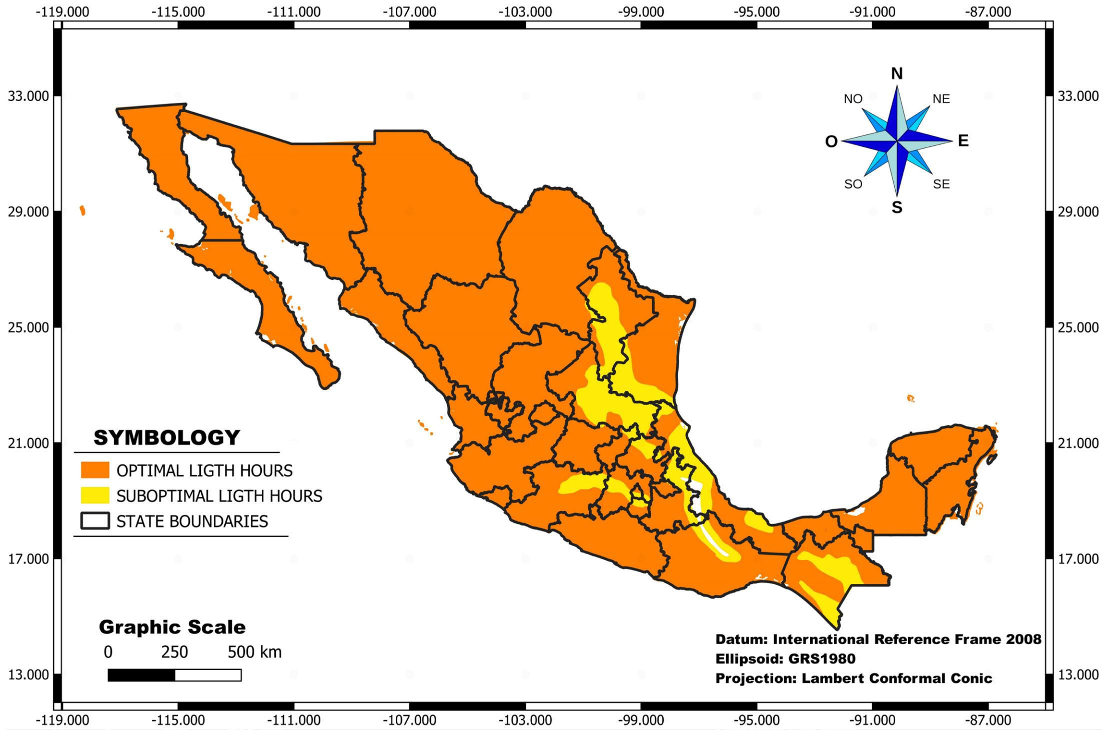

Figure 3. Suitability of light hours per year for *Malanga*.

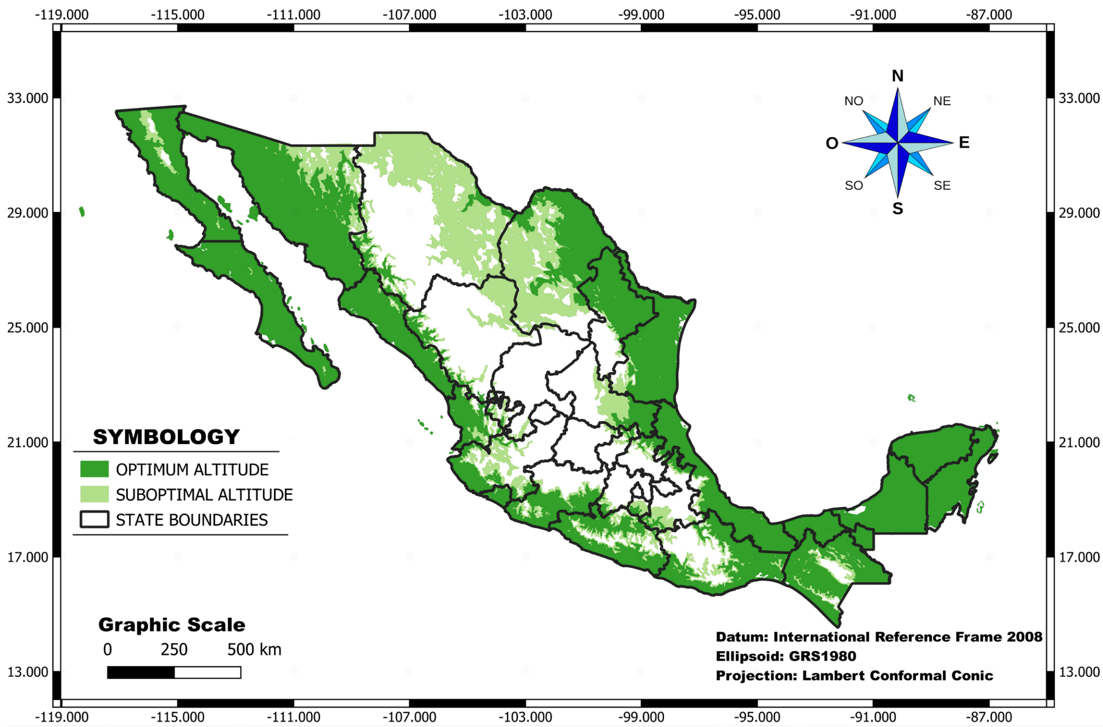

Figure 4. Distribution of altitude in Mexico to produce *Malanga.*

3.1.4. Height Above Sea Level Taro

Altitude is the vertical distance between any point on Earth in relation to sea level. To calculate the altitude, the sea level is taken as a reference, and that is why the altitude is expressed with the acronym *masl* (meters above sea level).

Malanga is a tropical plant that thrives in low and medium altitude areas no higher than 1000 meters above sea level [18]. The optimum for this crop ranges from 0 to 1000 *masl* which is distributed in all states bordering the Pacific and Atlantic Oceans of Mexico, with the exception of the states of Nuevo León and Coahuila (**Figure 4**).

3.1.5. Types of Soils for Taro

Malanga adapts perfectly in fertile and deep soils, with a sufficient amount of natural water and well drained. Soils with excessive clay or sand content should be avoided. The optimum pH should be between 5.5 - 6.5, although there are other materials adapted to 4.5 - 7.5. The crop shows problems in sandy or very heavy soils, as well as rocky and stony soils [21].

However, some materials grow best in clayey-heavy soils with high moisture-holding capacity. Well-drained clay soils with a high water table are preferred. For any type of *Malanga*, flooded and waterlogged soils are well tolerated and preferred for certain cultivars.

Apparently, *Malanga,* growing under flooded conditions and poor soils, is capable of transporting oxygen from the aerial parts to the roots; in this sense, roots are capable to breathe and grow normally. This plant can tolerate saline soils better than many other crops [22]. In all states of the country there are optimal and suboptimal soils to produce *Malanga* (**Figure 5**).

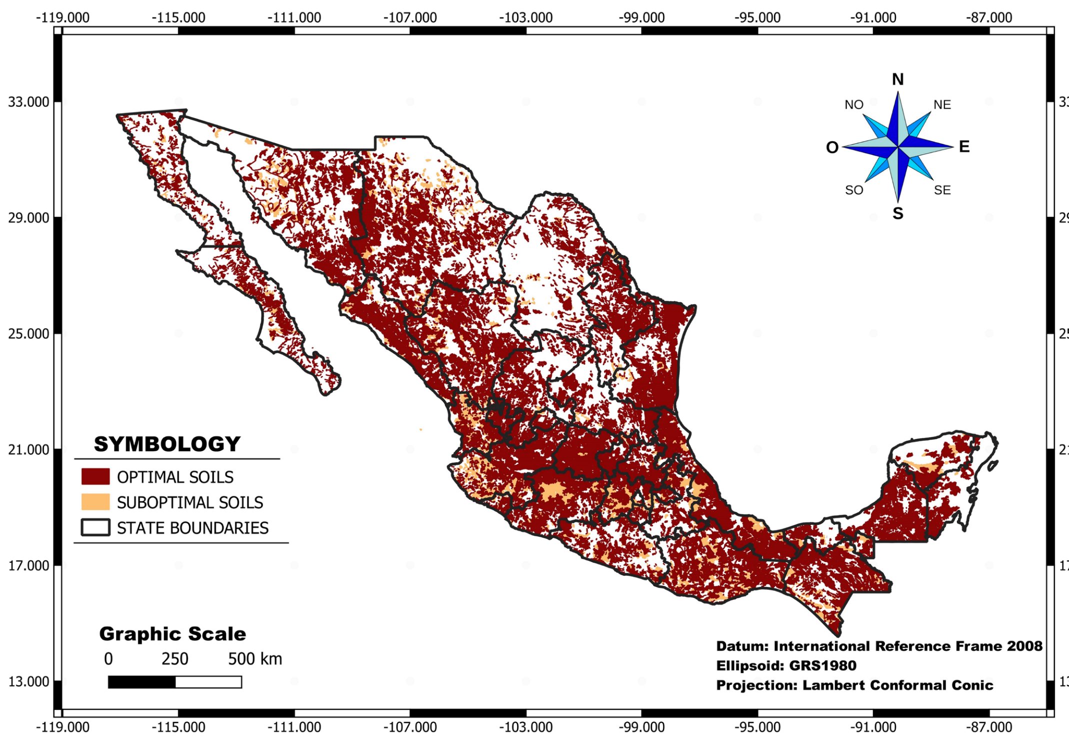

Figure 5. Distribution of optimal and sub-optimal soils in Mexico for *Malanga.*

3.1.6. Distribution of Potential Areas for Taro

The distribution of potential areas in the Mexican Republic is presented in **Figure**

6 where the green and orange colors represent the high and medium potential areas respectively. The surface in hectares is shown in Table 2.

Malanga adapts perfectly in fertile and deep soils with sufficient amount of natural water and well drained. In some Mexican states, *Malanga* can be found under natural vegetation and it is traditionally cooked by Boyling. It is eaten with honey and different beverages like the *Atole*. Its cultivation can be a profitable business, although greater production is required to satisfy the growing demand.

In Mexico, some *Malanga* producers grow it in a small scale, either in monoculture or intercropped with other crops in the household garden by using traditional technology. Under rainfed conditions, the average yield of 20 t ha^{-1} is very low as compared to more than 70 t ha^{-1} under irrigation.

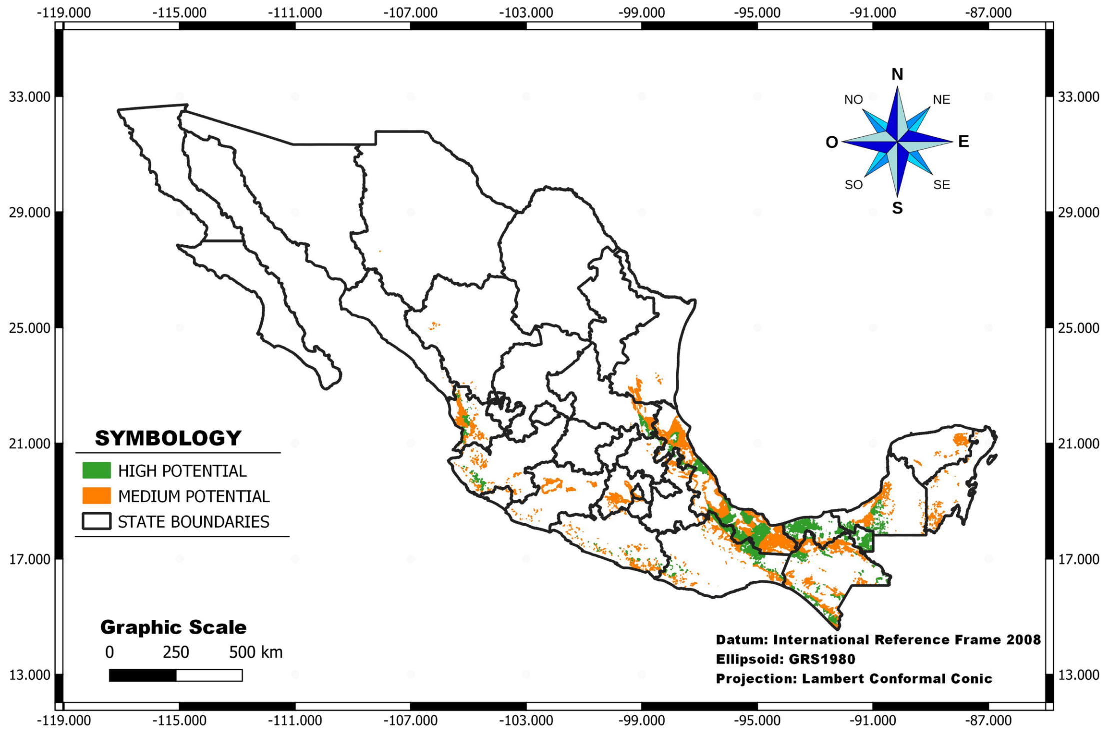

Figure 6. Distribution of Potential areas in Mexico for *Malanga* production.

Table 2. High and medium potential areas (hectares) in Mexico to cultivate *Malanga* under rainfed conditions in different states.

State	High Potential (has)	Medium Potential (has)
Campeche	103,207.00	169,541.00
Chiapas	206,721.00	585,912.00
Oaxaca	331,354.00	231,213.00
Tabasco	486,891.00	125,635.00
Veracruz	889,286.00	1,672,057.00
Oher States	151,477.00	1,062,004.00
TOTAL	**2,168,936.00**	**3,846,362.00**

4. Discussion

In Mexico, there are both optimal and suboptimal soils for growing *Malanga*, thanks to its notable adaptability to various soil conditions. This species can thrive in a wide range of environments, from well-drained and dry soils to areas with high rainfall and waterlogged soils [23]. However, it is recommended to avoid its establishment in soils with excessive clay or sand content, since these conditions can limit its development [20], as well as in rocky and stony soils, such as those of the Yucatan Peninsula in Mexico.

Furthermore, *Malanga* prefers soils with a high content of organic matter and optimal pH between 5.5 and 6.5, such as those found in the states of Oaxaca, Puebla, Veracruz and in the south of the state of Sinaloa [13].

Although in Mexico, the optimal altitude ranges between 0 and 1000 *masl,* in Ethiopia, it is cultivated from 1300 to 2300 *masl* [24] whilst in Vietnam 5 to 1800 *masl* has been reported [25]. In Bhutan (South Asia) located in the Himalayan Mountain range, it thrives at altitudes between 500 and 3000 *masl* [26].

Malanga also known as *Taro* is one of the least water-efficient crop [27], with high water demand to achieve optimal yields. It is estimated that it requires an annual precipitation of approximately 2500 mm, uniformly distributed [28] [29]. The lack of rainfall inhibits the growth of corms, since water stress generates low yields, deformations in the corms (such as the dumbbell shape) and lower-quality products [30].

In India, *taro* is grown both in flooded lowlands, taking advantage of *monsoon* rain but in the highlands where the precipitation ranges between 1500 and 2000 mm [31] supplementary irrigationan is needed. In Mexico, it is suggested an optimal average annual rainfall from 2000 and 2500 mm and these conditions are found in the states of Tabasco, Chiapas, Campeche, Veracruz, Puebla, San Luis Potosí, Oaxaca, Guerrero, Jalisco and Nayarit.

Malanga is a *heliophilous* plant that requires an average of 12 sunlight hours per day for optimal growth [32]. In Mexico, that light condition is fully satisfied. Regarding temperature, according to Raju *et al.* (2022) [33], the crop in India can tolerate maximum temperatures of at least 21˚C and a minimum of 10˚C. This qualified *Malanga* as the more cold-resistant tuber than other ones.

Mazariegos-Sánchez *et al.* (2017) [34] point out that the crop thrives in warm-humid climates, with an ideal temperature range between 15˚C and 35˚C. For Mexico, the *optimal* temperature is between 25˚C and 30˚C, mainly in the southern and southeastern regions. In contrast, *suboptimal* conditions occur in northern Veracruz, Tamaulipas, parts of Nuevo León, and the states of Sonora, Baja California Norte and Sur.

To date, in Mexico there are no official reports of *Malanga* cultivated under rainfed conditions. However, previous studies by López *et al.*, (2020) [35] and Salgado-Molina *et al.*, (2023) [36] agree in pointing out that: Tabasco, Veracruz and Campeche are the main states with the largest high potential areas.

Our analysis expands this perspective by identifying additional areas with high productive potential as in the case of: Oaxaca, Chiapas, Guerrero, Jalisco and Nayarit located in Humid Tropic of Mexico, representing only 9% of the national territory [37]. On the other hand, *Taro* is a viable economic alternative to offer new employments since it is a high demanding labor crop.

5. Conclusions

Nowadays, *Malanga* fit very well in the overseas growing trend towards a healthier lifestyle reflected in the incorporation of foods and drinks with nutraceutical characteristics. These products can offer different health benefits, and that is the reason why there has been a notable increase in their consumption and popularity.

Malanga could be a great opportunity to diversify the Mexican market and so was the reason to launch this work with the objective to identify suitable agroclimatic areas for the cultivation of *Malanga* under rainfed conditions in Mexico.

The main findings of this work were the following:

1) There are optimal agroecological conditions to produce *Malanga* under rainfed conditions in Mexico.

2) The states with the largest High Potential Areas under rainfed conditions are: Veracruz, Tabasco, Oaxaca, Chiapas and Campeche.

3) Altitude, precipitation and temperature are determining factors in the definition of High and Medium potential areas under rainfed conditions.

4) The High Potential areas detected in this work far exceed the current cultivated area of *Malanga* in the country.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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