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Agroclimatic Aptitude of *Anonna muricata* L. in the Yucatan Peninsula

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Abstract

In general, tropical fruits, especially those considered non-traditional, are currently in high demand in both domestic and international markets, whether fresh or processed. The soursop fruit and its cultivation in particular have the potential to become an activity that generates employment and income for producers in the Yucatan Peninsula, provided that a shift from backyard production to technified commercial production is considered. Therefore, the objective of this research was to identify areas, in the Yucatan Peninsula, with high productive potential under rainfed conditions. The altitude, temperature, precipitation, light intensity, and soil requirements for soursop were considered by consulting databases, bibliographies, and crop experts. QGIS 3.22.14 Batioweiza software was used to determine potential areas. Based on the methodology used, it was determined that in the Yucatan Peninsula there are more than 62,872 hectares with high potential, distributed as follows: 16% in Campeche, 9% in Quintana Roo, and 76% in Yucatán, and more than 1,057,524 hectares with medium potential, with 23% located in Campeche, 10% in Quintana Roo, and 67% in Yucatán.

Subject Areas

Agricultural Engineering

Keywords

Soursop, Regionalization, Geographic Information System

1. Introduction

Annona muricata L., commonly known as soursop or takob in the Mayan language, is a tropical fruit species of great economic and cultural importance belonging to the Annonaceae family [1]. Within the *Annona* genus, at least ten species have been reported in the Yucatan Peninsula (PY), many of which are found in natural areas and some are cultivated in commercial and backyard orchards [1] [2]. Among these, *A. muricata* stands out as one of the most cultivated and valued by local communities, both for its fruit and its many traditional uses [1].

Soursop is one of the most popular tropical fruits on the world market, thanks to its nutritional properties, easy digestion, and excellent flavor, which is the result of a balanced ratio of sugars and acidity [3]. It is mainly consumed as fresh fruit, although it is also widely used in the production of products such as fresh juices, ice cream, jams, sweets, liqueurs, and powders, demonstrating its versatility in the agro-industry [4]. In addition to the fruit, other parts of the plant such as the leaves, bark, and seeds are also traditionally used for medicinal purposes and as bioactive agents for the control of insects of agricultural and public health importance, including disease-carrying mosquitoes [5]. For this reason, the soursop fruit has remarkable potential for comprehensive use and expansion into new markets [6]. Its exotic flavor, nutritional value, and versatility in the food industry make it an attractive product for both domestic and international consumption.

Currently, only 3269.84 hectares are reported to be planted with this crop in Mexico, distributed across just 11 states of the Republic. The state of Nayarit has the largest cultivated area, with 2456.94 hectares, while the Yucatan Peninsula has only 88.50 hectares [7]. Mexico leads the world in soursop production, followed by other Latin American countries such as Colombia, Venezuela, Brazil, and Peru, which are also considered significant producers [8] [9]. Although soursop is the most important crop within the Annonaceae family in the country, the area devoted to its production remains considerably limited. For this reason, efforts are being made to increase its cultivation nationwide, with the Yucatan Peninsula being a viable option due to its favorable agroecological conditions and the growing interest in diversifying fruit production in the region. In this context, the objective of this study was to identify the areas with the best agroecological conditions for the development of soursop cultivation under seasonal conditions and to identify areas of high and medium potential in the Yucatan Peninsula.

2. Materials and Methods

2.1 Geographic Information and Map Algebra

A geographic information system and map algebra were used. Map algebra was a tool combining different territorial layers or variables in order to obtain alternative maps linked to specific characteristics of the territory [10]. In this case, map algebra was applied to locate the most suitable areas for soursop production under rainfed conditions, with an ecological criterion combining climatic, soil, slope and altitude mapping. It was considered an ecological criterion combining, as a whole, the climatic, soil, slope and altitude cartography.

With the help of symbols, the most suitable areas were distinguished as high potential ones, and the least suitable ones as unsuitable ones. In this study, three fundamental stages (Figure 1) were considered to define the grade of potentiality: 1) To identify altitude, temperature, precipitation and soil requirements for soursop cultivation; 2) Locate databases of agro-climatic conditions for the Yucatan Peninsula; 3) Data processing.

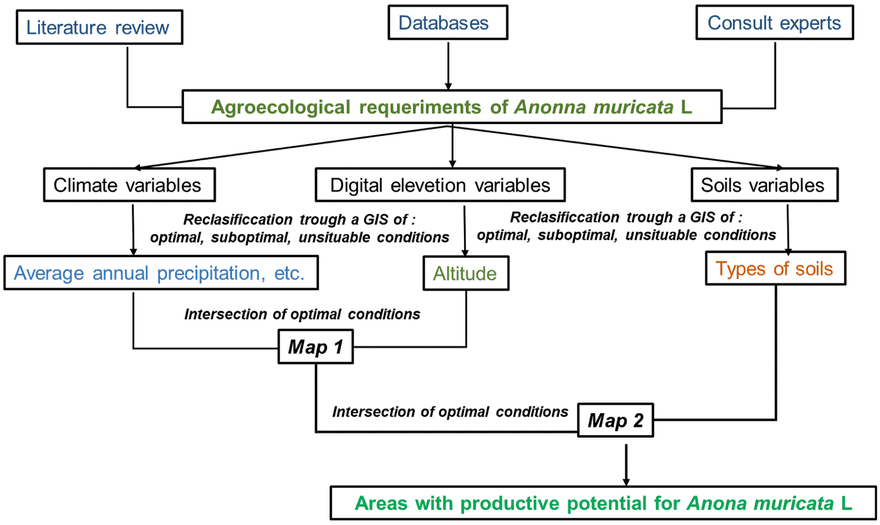

Figure 1. Methodological model used to determine the production potential areas of *Anonna muricata* L.

2.2. Determining Agroecological Needs for Soursop

The variables used were the agro-climatic requirements of soursop in Yucatan Peninsula, specifically average temperature, altitude, precipitation, light and soil (Table 1). Agro-climatic information was taken from bibliographic sources [11]-[13] and databases from **Ecocrop**, which identified more than two thousand plant species. The opinions of some soursop experts were also considered. Database of agroclimatic and Geographic conditions of Mexico were also consulted. For soil conditions, the World Reference Base for Soil Resources [14] was considered in vector format [15] at a scale of 1:250,000. The tool used for the climatological data was **WorldClim** version 2.0 [16], specifically for average temperature and precipitation. From the National Institute of Statistics and Geography, the Digital Elevation Model with three-second data of altitude values was acquired [17], in raster format with a resolution of 225 m^2 per pixel.

2.3. Database Processing

The procedure consisted on classifying the climatic and soil attributes required under rainfed conditions for soursop. The vector format was used to perform analysis, interpolations, cuts and intersections. In this format data were obtained (entities associated with each attribute) with their own spatial characteristics and the geometry of the attribute. Map algebra refers to the set of techniques and procedures used in Geographic Information Systems (GIS) to obtain information derived from mathematical, logical or statistical operations applied on one or more layers of geospatial data, whether in raster and/or vector format. These operations, by combining attributes and spatial relationships, generate new thematic layers representing synthetic variables or modeled phenomena [18]. This vector data geometry was implemented through the intersection of the edaphic and climatic layers; and the mangrove, protected areas and urban and rural settlements were eliminated. All the information was processed and reclassified using the QGIS 3.22.14 Batioweiza software [19].

Map algebra was performed using vector data, and the most commonly used geoprocessing tool was the union to integrate all the parameters, which were classified based on literature and expert opinion as optimal, suboptimal, and unsuitable. Each variable had its own optimal, suboptimal, and unsuitable conditions. All variables were then intersected at their optimal conditions to define high-potential areas, and suboptimal conditions to define areas of medium potential (See Table 1).

Table 1. Agroecological requirements of *Anonna muricata* L.

Variable	Unit	Optimal	Suboptimal	Not suitable
Average Annual Temperature	˚C	20 - 30	15 - 20 30 - 35	Less than 15 Over 35
Altitude	*masl*	0 - 500	500 - 1150	Over 1150
Average Annual Precipitation	*mm*	1300 - 1700	1000 - 1300 1700 - 2000	Less than1000 Over 2000
Soil	*Type*	Fluvisols Luvisols Nitisols	Cambisols Regosols Phaeozem Leptosols	Solonchak’s Vertisols Gleysols Arenosols Calcisols
Texture	*Type*	Loam Clayey loam	Loam Clayey loam	Clayey
Depth	*m*	Over 1	1 to 0.4	Less than 0.4
pH	*Indicator*	6.0 to 6.5	5.5 to 5.9 6.6 to 7.0	<de 5.5 >de 7.0
Light hours per year	*Hours*	Over 2500	2000 - 2500	Less than 2000
Drainage	*Type*	Moderately Efficient	Efficient	Poor efficient

3. Results

The potential areas for soursop (*Annona muricata* L.) cultivation in the Yucatán Peninsula were determined by applying a suitability analysis that integrated climatic, edaphic, and topographic variables. Only land with potential for agricultural, livestock, or forestry activities was considered; areas within urban and rural settlements, as well as protected natural areas, were excluded to ensure realistic estimates of land availability for productive purposes.

High Potential Areas

The spatial distribution of high and medium productive potential zones for *A. muricata* under rainfed conditions is presented in Figure 2. High potential areas (green) correspond to locations where the combination of environmental factors such as optimal mean annual temperature (~26˚C), adequate rainfall distribution, and favorable soil depth and texture creates conditions conducive to achieving yields at or above regional averages. Medium potential areas (orange) present conditions that are generally suitable, although one or more variables may be slightly suboptimal, potentially affecting yield stability. In contrast, nonsuitable areas (white) reflect environmental constraints, including low annual precipitation (< 800 mm), shallow or rocky soils, and zones prone to seasonal flooding, which limit the viability of commercial soursop production.

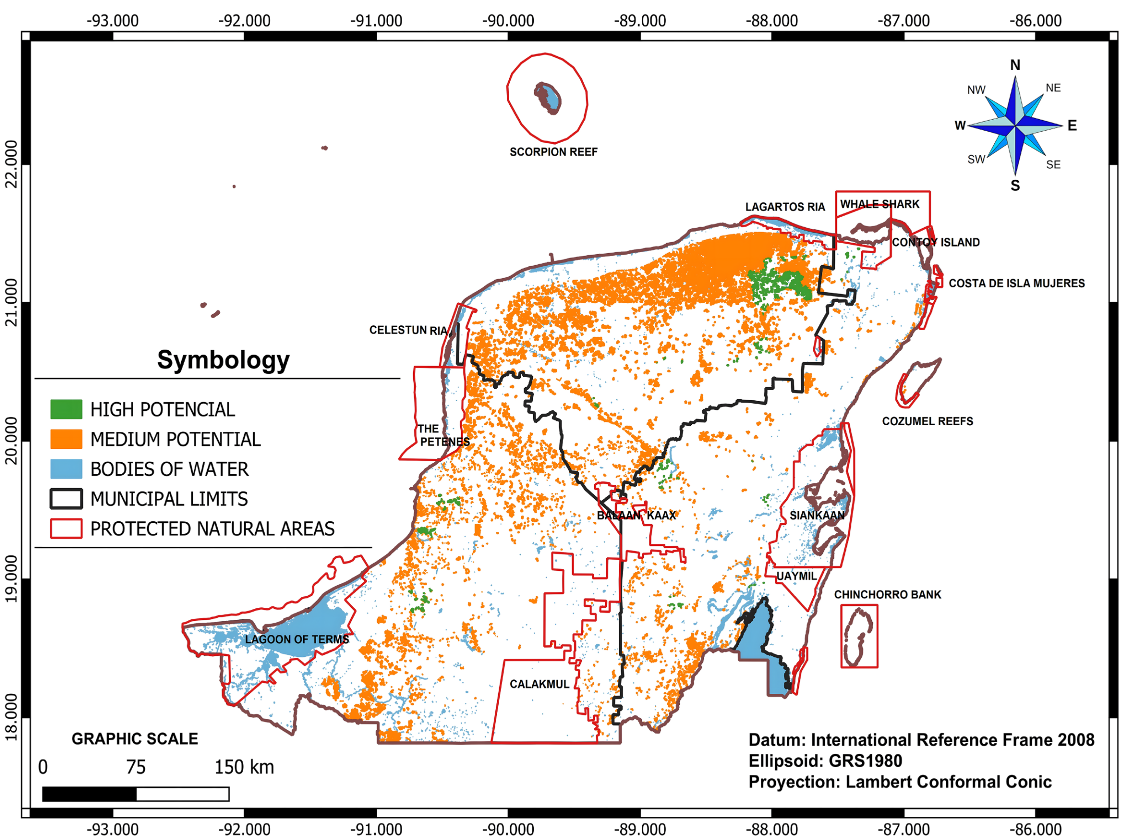

Figure 2. Distribution of areas with productive potential for *Anonna muricata* L.

Quantitatively, the analysis identified 62,872 ha of land classified as high productive potential, distributed as follows: 16% in Campeche, 9% in Quintana Roo, and 76% in Yucatán. The extent of medium potential land is considerably larger, covering 1,057,524 ha, with 23% located in Campeche, 10% in Quintana Roo, and 67% in Yucatán (**Figure 3**). These proportions indicate that while optimal conditions are relatively limited, there exists a substantial land base with moderately favorable conditions that could be improved through agronomic management practices, such as supplemental irrigation, soil fertility enhancement, or integrated pest management.

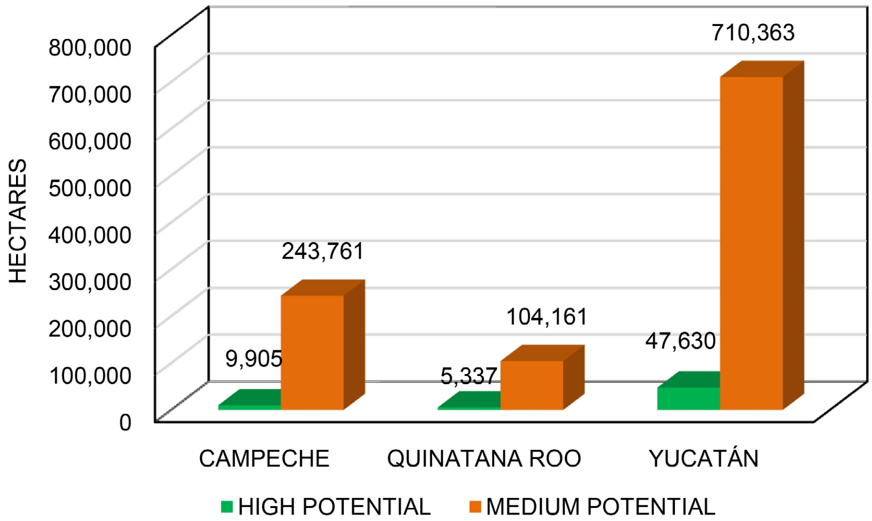

Figure 3. High and medium potential areas for soursop in the Yucatan Peninsula.

Overall, these findings underscore the presence of extensive territories suitable for the expansion of soursop cultivation in the Yucatán Peninsula. The predominance of medium potential zones suggests that targeted interventions could significantly increase the productive capacity of the crop in the region. This spatial information provides a valuable tool for regional agricultural planning, guiding investment decisions, promoting crop diversification, and supporting the design of sustainable rainfed production systems adapted to local agroecological conditions.

4. Discussion

Soursop (*Annona muricata* L.), belonging to the Annonaceae family, is a crop that grows in tropical and subtropical regions [20]. In Mexico, the geographical and climatic conditions offer high potential for its production [21]. It should be noted that the natural distribution area of this fruit covers the tropical region of southern Mexico, Central America, northern South America, and the Caribbean islands [22]. The Yucatan Peninsula is part of southern Mexico, so it is located in the natural area where soursop grows. In terms of average annual temperature, hours of sunlight per year, and altitude, most of the Yucatan Peninsula has optimal conditions for its development with regard to these three variables. In Mexico, soursop is distributed in the tropical regions of Veracruz, Tabasco, Yucatán, Oaxaca, Chiapas, Guerrero, Sinaloa, Puebla, Quintana Roo, and Michoacán, at altitudes ranging from 50 to 1150 m.a.s.l. (meters above sea level) [23].

This crop thrives in tropical and subtropical climates, and its altitudinal range varies between 0 and 1500 m.a.s.l. in different regions of Central and South America. For example, in Guatemala and Ecuador it is found below 1220 and 1500 m.a.s.l., respectively, while in the Philippines and Sri Lanka it is found below 800 and 915 m.a.s.l., respectively [24]. In the Yucatan Peninsula, where mostly flat terrain with low elevations predominates, the average altitude is close to 30 m above sea level, with maximum points reaching approximately 210 m, such as Cerro Benito Juárez in the state of Yucatan. Due to these conditions, an optimal altitude range of 0 to 500 m was considered for crop establishment in the study region. This is consistent with the findings of Kome *et al.* (2024) [25], who, based on an extensive literature review of the soil requirements of *A. muricata*, indicate that the optimal altitude range for its development is between 200 and 300 m.a.s.l.

It is important to note that soursop, is highly sensitive to temperature and therefore not tolerant to cold [26]. Soil temperatures below 10˚C have been shown to be detrimental to its development [27]. Due to this susceptibility, various authors have proposed optimal average annual temperature ranges for its cultivation, which vary between 22˚C - 25˚C [25] and 25˚C - 30°C [28], the latter considered optimal for maximizing photosynthesis. In the Yucatan Peninsula, the average annual temperature recorded is 26.0˚C, a value that falls within the optimal range reported for soursop cultivation, suggesting that, at least in terms of this climatic factor, the region has favorable conditions for its development.

In the case of the Yucatan Peninsula, one limitation is its soils, as most (53%) are shallow, stony, and shallow [17]; However, it is mentioned that it is not a demanding crop in terms of soil and that care should only be taken with flood-prone soils, so Leptosols and Cambisols were considered suboptimal and soils with good drainage and depth, such as Luvisiols, Nitisols, and Fluvisols, which unfortunately represent 6.10%, 1.17%, and 0.01% respectively, for a total of 7.28% (1,314,060 hectares) of soils with optimal conditions.

The most suitable physical characteristics of the soil are well-drained, deep soils (>180 cm) with a light texture (loam, sandy loam, silty sand, sandy clay loam). In terms of chemical characteristics, the soil pH should be between 5.5 and 6.5, with a high organic matter content, base saturation > 60%, and Al saturation < 20% [25]. In the study region, the rainy season lasts from May to November, reaching its peak in September, when an average of up to 200.5 mm is recorded. The dry season runs from December to April, with the last three months being the driest, with rainfall of less than 50 mm per month. During the rainy season, there is a phenomenon known as a heat wave, characterized by a temporary decrease in precipitation in July and August. The average annual rainfall values recorded in the study area range from 400 to 2200 mm. The distribution of rainfall volumes follows a general trend of increasing from the Yucatan coast towards the rest of the area, reaching its maximum ranges in the south of the peninsula.

For soursop cultivation, uniform rainfall throughout the year is an important factor for optimal development [29]. This aspect is particularly relevant considering that the phenological cycle of the soursop ranges from bud development (June-April), leaf emergence (April-December), and senescence (December-April), to the appearance and development of flowers (November-December), flowering (December), fruit growth (December-February), and fruiting (March-May) [30]. In Nayarit, the main producer of this fruit in Mexico, annual rainfall is reported to be between 1377.3 mm and 1403.2 mm (according to records from the state's two main producing regions: Tepic and Compostela), with light rains from October to December and heavy rains from June to September [31]. Therefore, it could be inferred that the rainfall distribution pattern in the state of Nayarit is suitable for the phenological development of soursop, since authors such as Yamarte *et al.* (2006) [32] indicate that moderate fluctuations in water availability favor its growth. For their part, Kome *et al.* (2024) [25] point out that the species develops optimally in regions with an average annual rainfall of 2000 to 2500 mm.

The driest area is located in the extreme northwest of the study area and includes the city of Mérida. Sisal, in the state of Yucatán, has the lowest rainfall, with 551.9 mm per year. From there, rainfall increases towards the east, reaching 1715.6 mm in Yokdzonot, Yucatán, the highest value within the aquifer zone, and then decreases towards the coast of Quintana Roo. The increase in precipitation is also noticeable in the southeast, around Limones and the banks of the Río Hondo in Quintana Roo, where rainfall is close to 1450 mm. in the southwest, in Carrillo Puerto, Campeche, precipitation is 1360 mm per year, and towards the border with the state of Tabasco, precipitation reaches 2200 mm [17] (INEGI, 2016). As for the optimal average annual rainfall, this is found in the Yucatan Peninsula, mainly in the eastern part of the state of Yucatan towards the Tizimín region and the south-central part of the states of Campeche and Quintana Roo.

The only state on the Peninsula that reported land planted under seasonal conditions was Quintana Roo, with 62 hectares, but no production was reported [7]. In the case of Campeche and Yucatán, only irrigated areas of 1.0 and 23.5 hectares are reported, but like Quintana Roo, they do not report any production [7]. The Yucatan Peninsula has sufficient areas of high potential to compete nationally with the state of Nayarit, the main producer of this fruit under seasonal conditions in Mexico with 2466.00 hectares [7]. Much of the area reported in the Yucatan Peninsula by the official source is located in the backyards of farmers [4], which is why it is not possible to capture production, yields, and the value of production. This study is a first step toward agroecological planning, identifying areas with high and medium potential for cultivation. In general, there are three main priorities to be followed for the development strategy of its cultivation in the Yucatan Peninsula, in addition to orienting its cultivation towards areas of high potential: first, the genetic characteristics of the propagation material; second, the health conditions of the plants, the main factor that could limit the development of soursop; and third, production technology.

5. Limitations of the Study and Future Work

The current study is aimed at identifying the regions with the best conditions for soursop production in the Yucatan Peninsula. One of its limitations is the scale of the mapping used, as it cannot identify areas as small as 1 hectare, meaning it only identifies large areas.

For subsequent, specific studies for the development of the crop in the region, work can be conducted at the plot level, complemented by specific climate data and soil analysis.

6. Conclusion

The results indicate that both optimal and suboptimal agroecological conditions exist for the production of *Annona muricata* L. under rainfed conditions in the Yucatán Peninsula. The analysis shows that high and medium productive potential is feasible across the three states of the region. Among the evaluated variables, soil type and mean annual precipitation were identified as key factors in determining areas with high and medium potential for soursop cultivation under rainfed conditions.

Conflicts of Interest

The authors declare no conflicts of interest.

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