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Chayote (*Sechium edule* var. *virens levis*) cultivation and environmental factors

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ABSTRACT
Objective: The objective of this study was to identify the factors that influence chayote production through a biophysical and descriptive characterization.
Design/methodology/approach: The methodology consisted of a biophysical characterization based on the analysis of land use and vegetation mapping, soil type, climate, relief, and altitudinal range. The descriptive analysis focused on cultivation practices, agricultural techniques, adaptation to different biophysical conditions, pests, diseases, and socioeconomic factors that affect production.
Results: The results show that in the municipality of Coscomatepec, chayote occupies 80% of the agricultural land. Currently, the crop is grown under suitable conditions of climate, slope, and altitude; however, it faces challenges related to water availability. Chayote is drought-sensitive and requires irrigation. In some cases, the irrigation method is inadequate, increasing the risk of disease, especially in clay soils. Additionally, the lack of phytosanitary control and technological lag hinder the crop's competitiveness.
Limitations/implications: It is necessary to deepen the economic analysis of irrigation-related costs by evaluating their impact on crop yield and profitability.
Findings/conclusions: To improve production and address current challenges, it is recommended to implement efficient irrigation systems, construct water catchment infrastructure to reduce costs, enhance drainage in clay soils, and promote preventive phytosanitary control to ensure crop sustainability.

Keywords: agricultural practices, production, irrigation, phytosanitary control

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INTRODUCTION

Chayote (*Sechium edule* var. *virens levis*) is a species of great economic importance in Mexico. Nationally, approximately 3,500 hectares are cultivated, positioning the country as the world's leading producer of this species, accounting for 53% of the global market share (Martín, 2014). The central region of the state of Veracruz stands out as the primary production area (Barrera-Guzmán *et al.*, 2022), generating significant income both from domestic sales and exports, thereby contributing to improved living standards for producers (Cadena-Íñiguez *et al.*, 2010). This crop is mainly cultivated in family orchards and small properties (Guevara *et al.*, 2014). However, chayote production faces a high risk of loss due to various factors, including limited technical management, adverse climatic conditions,

the presence of pests and diseases, high production costs, and poorly designed institutional policies (Alvarenga *et al*., 2007). All these factors directly affect the economic stability of producers. Therefore, it is essential to understand the biophysical characteristics associated with chayote cultivation to be better prepared to meet current and future challenges. One of the most effective strategies for identifying the factors that directly influence chayote production is conducting a biophysical and descriptive characterization. This approach allows for a comprehensive understanding of the production context and the optimization of crop management. Biophysical analysis involves the study of abiotic elements such as soil type, climatic conditions, water resource availability, and topography (Nkiaka *et al*., 2024). In contrast, the descriptive analysis focuses on aspects directly related to the crop, including agricultural techniques, adaptability to different biophysical conditions, presence of pests and diseases, and certain socioeconomic factors affecting production.

The information derived from these analyses is crucial for decision-making in the integrated management of the crop (Ruiz-García *et al*., 2020). Given the agricultural importance of chayote in the region, it is essential to carry out an analysis that identifies the key factors influencing its production, particularly in one of the most significant areas: the central micro-watershed of the municipality of Coscomatepec, Veracruz. This study aims to provide a detailed description of the biophysical conditions and the cultivation system, offering useful tools for decision-makers to sustain and enhance productivity, thereby ensuring the crop's viability in the medium and long term.

MATERIALS AND METHODS

Study area

The study area is located in the central zone of the municipality of Coscomatepec, in the central region of the state of Veracruz (Figure 1). It corresponds to a micro-watershed situated within the Jamapa River basin. The average annual temperature is 17.5 °C, with minimum values of 12 °C and maximums of 21 °C, and an average annual precipitation of 1,750 mm.

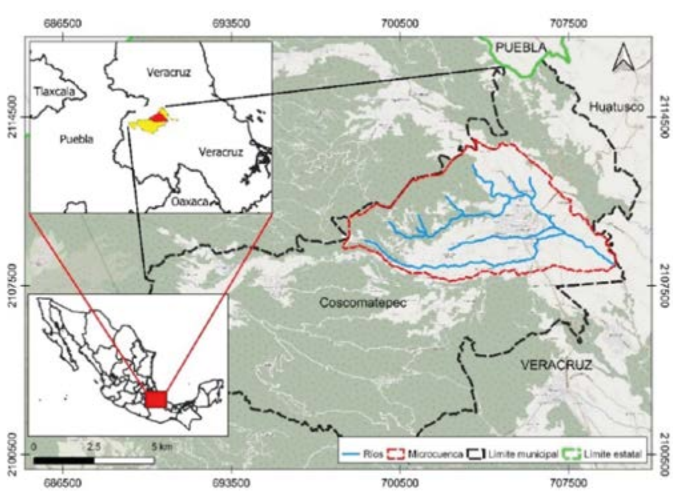

Figure 1. Geographical area of the study. Prepared by the authors using information from INEGI and CONABIO.

Biophysical characterization

For the biophysical characterization analysis, specific cartography was developed for the following aspects: land use and vegetation, soil type, relief, and altitudinal range. Additionally, official data on climate, temperature, and precipitation were incorporated.

Data and information sources

Land use and vegetation cartography was created through supervised classification based on SENTINEL satellite images (USGS, 2023). Climatic data, including precipitation and average annual temperature, were obtained from layers provided by CONABIO. Slope and elevation data were derived from processing the Digital Elevation Model (DEM) by INEGI (2023). The soil map was developed using sampling results, local producers' knowledge, and the INEGI (2014) edaphological dataset.

Land use and vegetation cartography

To accurately determine and quantify the areas where chayote cultivation is established, a supervised classification was carried out. This cartographic process involved field sampling to define control points in cultivated zones. Classification began with preprocessing SENTINEL-2 imagery using a false color band composite (bands 4, 3, and 2) via the Semi-Automatic Classification Plugin (SCP) in QGIS (Congedo, 2021). Recognition polygons identified five dominant land cover classes besides chayote: urban, pine forest, avocado, maize, and livestock production areas.

Soil type cartography

To enhance accuracy in the distribution of soils within chayote cultivation zones, a specific soil type cartography was developed, as soil conditions directly impact crop growth, yield, and health. Following the methodology of Ortiz *et al.* (1990), sampling consisted of 15 composite samples distributed across upper, middle, and lower areas of the plots. This process was supported by local knowledge to delineate soil boundaries. Subsequently, with laboratory data on physical and chemical characteristics pH, electrical conductivity (EC), field capacity (FC), permanent wilting point (PWP), texture, bulk density (BD), porosity (P), and color a new taxonomic soil classification was performed in accordance with the World Reference Base for Soil Resources (FAO, 2014).

Slope and altitudinal range cartography

The analysis of slope and altitudinal range helps identify factors directly related to cultivation, such as water distribution, soil erosion, drainage type, and climatic variability. This cartography was generated through DEM processing. Slope categories were defined within the ranges of 0-2%, 2-4%, 4-8%, and 8-15%, while altitudinal ranges were classified in 250-meter intervals.

Descriptive characterization

The descriptive characterization aimed to understand the features of the cultivated variety, agricultural practices, and water and soil requirements, as well as climatic factors affecting crop development. Information was gathered following the methodology of Ortiz and Gutiérrez (1999), through field visits with 15 key informants selected for their deep knowledge of chayote cultivation management within the community. This method integrates local and technical knowledge to refine management techniques, minimize risks from pests, diseases, or nutritional deficiencies, and optimize resource use. The information generated supports local-level planning and decision-making, enabling small producers to adapt their practices to current environmental conditions.

RESULTS AND DISCUSSION

Cultivated variety

In the study area, the most commonly cultivated variety is white chayote (*Sechium edule* var. *virens levis*). This variety is prevalent in the region due to its strong adaptation to local climatic and edaphic conditions, in addition to its high demand in both local and national markets (Nataren-Velázquez, 2021).

Land Use and vegetation

According to the supervised classification, agricultural land use predominates, covering 38.6% (1,480 ha), followed by temperate pine forest at 35% (1,342.1 ha), and areas designated for livestock production at 14.4% (Figure 4). Specifically within the agricultural area, the dominant crop is chayote, occupying 1,032.2 ha (69.7%), followed by maize at 21.7% and avocado at 8.6% (Figure 2).

Climate

According to the literature, chayote requires an average annual precipitation between 1,500 and 2,000 mm, well distributed throughout the year, and temperatures ranging from 18 to 25 °C, with tolerable minimums down to 10 °C (Cadena *et al.*, 2005; Cadena *et al.*, 2006). In the study area, 72.8% of chayote is established in a temperate-humid climate; 97.5% of the crop is located in zones with average annual temperatures

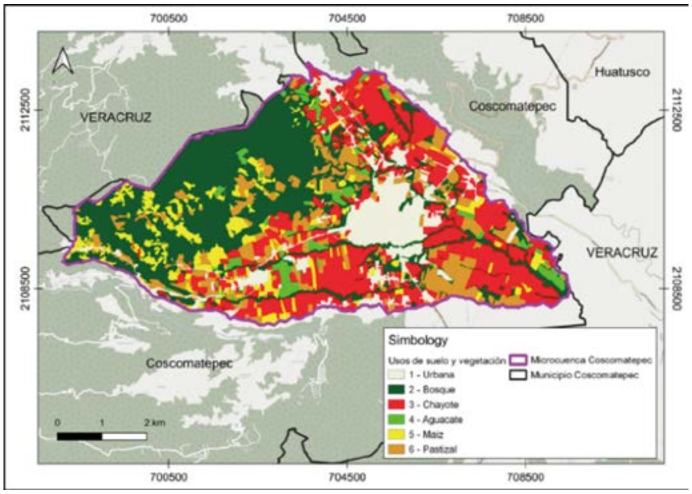

Figure 2. Geographic location of the areas cultivated with chayote. Own elaboration.

of 17 °C (minimum of 10 °C and maximum of 24 °C), and 99.9% grows in areas with an average annual precipitation of 1,750 mm. These conditions fall within the optimal range for chayote development, allowing for high-quality production without requiring significant management adjustments. However, thermal variations particularly low temperatures and periods of drought remain persistent challenges for production in this region.

Slope and altitudinal range

The general slope reclassification analysis in the micro-watershed yielded the following values: 0-2% (63.4%), 2-4% (9.1%), 4-8% (23.3%), and 8-15% (4.1%) (Figure 3a). Regarding altitudinal range, the 1,500-1,750 meters above sea level (masl) interval predominates, covering 48.5% of the area, followed by the 1,250-1,500 masl range, with 21.5% (Figure 3b). Although chayote cultivation can occur between 300 and 2,800 masl, its optimal altitude is between 500 and 1,500 masl (Montecinos *et al.*, 2019). In the study area, 94.8% of the crop is located between 1,250 and 1,750 masl. Additionally, 91.1% is established on nearly level surfaces, with slopes ranging from 0 to 2%. This topography facilitates agronomic management, reduces production costs, improves accessibility, and enables more efficient irrigation control, mitigating issues associated with excessive surface runoff and minimizing the risk of water erosion.

Soil type

According to the analysis based on taxonomic classification, three soil types were identified within the micro-watershed. The dominant soil type is Humic Andosol (AnHu), covering 56.8% of the area, followed by Orthic Acrisol (AcOr), accounting for 24.3% (Figure 4). These results provide greater precision in the delineation and distribution of soils, which is essential for optimizing agricultural management and promoting sustainable cultivation planning.

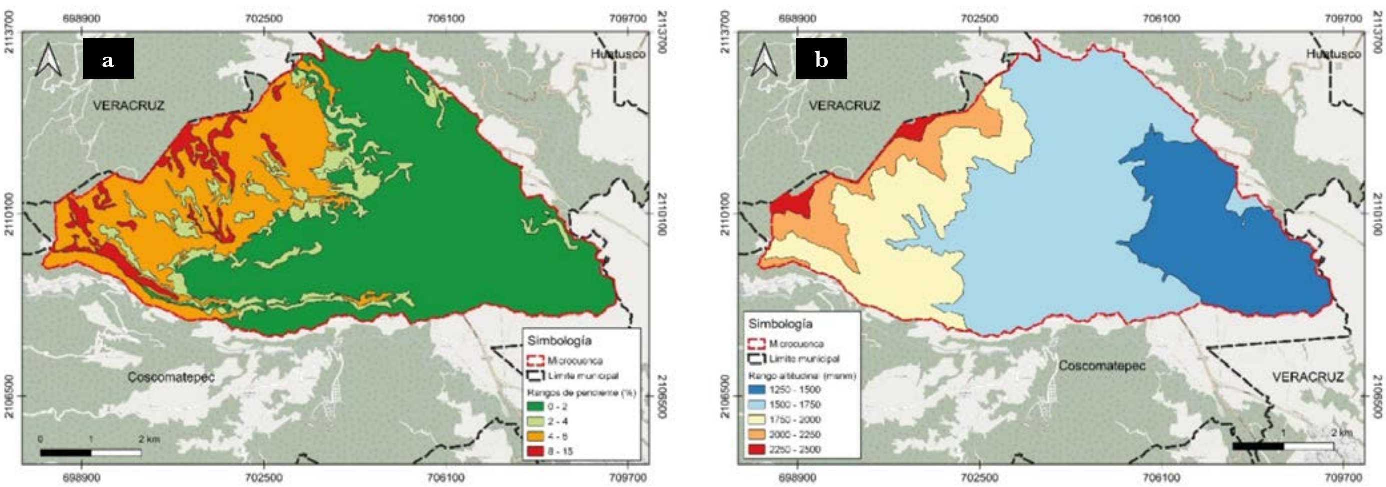

Figure 3. Slope (a) and altitudinal range (b) in the central Coscomatepec micro-basin. Prepared by the authors, based on information from INEGI (2013).

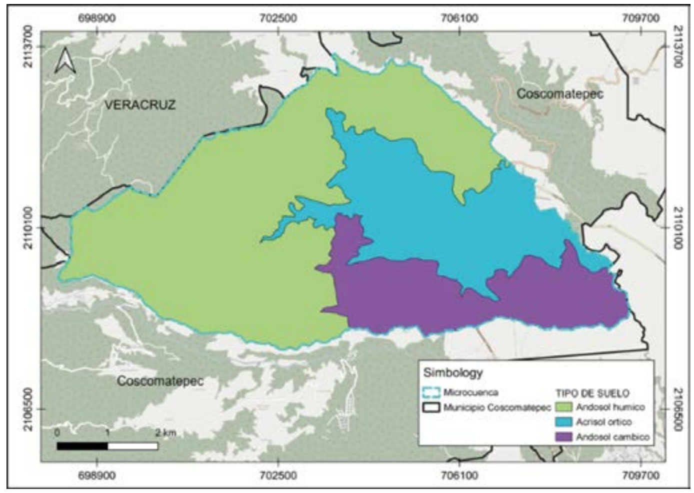

Figure 4. Soil types in the central micro-watershed of Coscomatepec. Source: Own elaboration.

Studies have shown that chayote thrives in acidic to slightly acidic soils (pH 4.5 to 6.5), well-drained, and rich in organic matter (Cadena *et al.*, 2005), preferably with a loamy-sandy texture (Cisneros-Solano, 2016). Within the micro-watershed, 44.3% of chayote is cultivated in Humic Andosol soils, followed by 33.6% in Cambic Andosol and 22.1% in Orthic Acrisol. Humic Andosol presents optimal characteristics for crop development (pH 5.2, loamy-sandy texture, depth, good drainage, and high organic matter content), although it is prone to erosion if water resources are not properly managed. On the other hand, crops established in areas with Orthic Acrisol face greater challenges due to its higher acidity (pH 4.7) and low fertility (Table 1). Additionally, its clay texture, combined with poor water management and inadequate drainage, creates conditions favorable for pathogen development.

Descriptive characterization

The chayote plant is classified as a perennial herbaceous vine with tuberous roots and a high production of stems featuring abundant branching (tendrils) (Rincón *et al.*, 2020). This variety exhibits a rapid growth rate, reaching harvest maturity between 18 and 21 days (Avendaño-Arrazate *et al.*, 2010). Each plant produces between 150 and 300 fruits during its productive cycle, with a productive lifespan in the region ranging from 3 to 5 years. In the study area, it is cultivated at an average density of 2,500 plants per hectare, with a

Table 1. Average surface area and physical and chemical properties by soil type.

Soil Type	Surface %	Physical and chemical properties						
		pH	C. E. (dS m^{-1})	D. A. (G cm^{-3})	C.C. %	P.M. %	P %	Texture
Humic Andosol	44.3	5.2	0.18	0.91	58.7	34.8	61.3	Sandy Loam
Andosol Cambico	33.6	4.9	0.18	0.99	49.3	30.4	58.0	Loam
Acrisol Orthic	22.1	4.7	0.14	1.00	47.7	33.2	58.6	Clay Loam

spacing of 2 to 3 meters between plants. During the rainy season harvest (June-October), the average yield is 30 to 50 tons per hectare, while during the dry season (November-May), yields range from 20 to 30 tons per hectare. Regarding crop establishment and maintenance, producers indicate that the main limitation to productivity is water availability, as chayote is highly susceptible to drought. This is consistent with its high water content, close to 90% (Cruz-León & Querol-Lipcovich, 1985). Depending on the duration of the dry season, the crop requires approximately 900,000 to 3 million liters of water per hectare (Dzib *et al.*, 1993). According to Cisneros-Solano (2016), the dry period (November-May) averages seven months per year, creating a deficit of about 35% of total annual precipitation in the water balance. To meet water demands during the dry season and mitigate frost damage, producers rely on water trucks sourced from the same micro-watershed. Water requirements account for 35% to 40% of total production costs, making it the main input. On average, three supplemental irrigations are applied per week, totaling approximately 840,000 liters of water during the dry months. Irrigation is typically performed using hoses through basin flooding, which represents inefficient water management. This excess moisture often causes plant death due to the development of pathogenic fungi (Cadena *et al.*, 2001; Montecinos *et al.*, 2019), especially in clay soils. These issues are more frequent in the 22% of the crop grown in Acrisol soils, due to their clay texture and poor drainage, which create anaerobic conditions favorable to the development of fungi, particularly *Phytophthora capsici*, the causal agent of chayote wilt in the region (Olguín Hernández *et al.*, 2013). Regarding pests, producers report problems with red spider mites (*Tetranychus urticae*) and other mites (Nataren-Velázquez, 2021). Additionally, 50% of producers have reported damage from severe hailstorms in the past three years, and 40% have experienced frost damage in recent production cycles. A deficiency in management practices has been identified in the study area, as 60% of producers do not implement preventive phytosanitary control (Cadena *et al.*, 2016). There is also a lack of a fertilization plan adapted to the crop's phenological stages (Rincón *et al.*, 2020). Furthermore, a technological lag persists due to the limited adoption of new agricultural techniques that could enhance productivity and competitiveness (Rincón *et al.*, 2020). There is also an absence of business culture, equipment, infrastructure, market access, and productive association schemes that would ensure crop profitability (Cadena *et al.*, 2016). To improve chayote production, it is recommended to implement drip or micro-sprinkler irrigation systems that optimize water use, reduce the incidence of fungal diseases, and minimize frost damage. The construction of water catchment infrastructure, such as ponds or small dams, would help reduce water stress and dependence on water trucks, thereby lowering costs. Additionally, installing moisture sensors would support precise irrigation decisions. In clay soils (Acrisol), it is necessary to improve drainage through ditches, channels, or soil tillage to remove excess moisture and prevent pathogen-related diseases. Preventive phytosanitary control should be encouraged, especially early detection of *Phytophthora capsici* and the application of appropriate fungicide treatments. The use of biological control agents such as phytoseiid mites (Phytoseiidae) is also recommended for the natural control of red spider mites and other pests. It is essential to establish a stage-based fertilization plan, install anti-hail netting, adopt new production technologies, and provide training to producers to optimize crop management and ensure profitability.

CONCLUSIONS

Chayote is a crop of economic importance in Mexico; therefore, conducting biophysical and descriptive studies in the central micro-watershed of Coscomatepec is essential to optimize its management, enhance productivity, and ensure long-term sustainability. The region exhibits climatic conditions that are close to ideal for crop development, favoring high-quality production. However, temperature and precipitation variations pose significant challenges. While Humic Andosol offers optimal conditions, Orthic Acrisol presents limitations due to its higher acidity, low fertility, clayey texture, and poor drainage, which increase the risk of disease. The main constraint to production is water availability, given the crop's high susceptibility to drought. The reliance on irrigation and its inefficient use particularly in clay soils elevate the risk of fungal diseases. To improve chayote production, it is recommended to implement efficient irrigation systems, develop water catchment infrastructure, enhance drainage in soils with physical limitations, and strengthen preventive phytosanitary control.

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