Digital technologies applied to the sustainable technical and financial design of sago cultivation (Manta, Cundinamarca)

Tecnologías digitales aplicadas al diseño técnico y financiero sostenible del cultivo de sagú (Manta, Cundinamarca)

Tecnologias digitais aplicadas ao projeto técnico e financeiro sustentável do cultivo de sagu (Manta, Cundinamarca)

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Abstract

Introduction: This article presents the results of research conducted during 2024 and 2025 at San Rafael Farm, located in the municipality of Manta, in the department of Cundinamarca.

Problem: The development of agro-productive systems under sustainability criteria requires the integration of technical planning, appropriate technologies, and financial evaluation to address local conditions and strengthen rural economies.

Objective: This research aims to formulate a proposal for the sustainable production of sago starch (*Canna indica* L.) in order to diversify the rural economy through an agroecological approach supported by accessible technological tools.

Methodology: For the planning of the productive system, a three-dimensional model of the property was developed using QGIS software, integrating edaphoclimatic, topographic, and land-use variables. The financial analysis was conducted using RIV20 software, considering investment requirements and associated costs.

Results: The project is economically viable, with an internal rate of return of 55.85%, demonstrating its potential to generate income and preserve traditional practices associated with this product in the municipality.

Conclusion: The integration of digital tools and agroecological principles makes the sustainable production of sago at San Rafael Farm technically and financially viable.

Originality: This research can be replicated on other farms in the region, serving as a practical tool for local initiatives through the integration of technology and traditional knowledge.

Limitations: Limited information on local supply and demand for sago starch and the loss of knowledge transmission associated with this product.

Keywords: sustainability; agro-productive models; sago; geospatial technologies; financial evaluation.

Resumen

Introducción: Este artículo presenta los resultados de una investigación realizada durante los años 2024 y 2025 en la Finca San Rafael, ubicada en el municipio de Manta, en el departamento de Cundinamarca.

Problema: El desarrollo de sistemas agroproductivos bajo criterios de sostenibilidad requiere la articulación de la planificación técnica, tecnologías apropiadas y la evaluación financiera para responder a las condiciones locales y fortalecer la economía rural.

Objetivo: Esta investigación tiene como objetivo formular una propuesta para la producción sostenible de almidón de sagú (*Canna indica* L.), con el fin de diversificar la economía rural mediante un enfoque agroecológico respaldado por herramientas tecnológicas accesibles.

Metodología: Para la planificación del sistema productivo, se desarrolló un modelo tridimensional de la propiedad utilizando el software QGIS, integrando variables edafoclimáticas, topográficas y de uso del suelo. El análisis financiero se realizó mediante el software RIV20, considerando los requerimientos de inversión y los costos asociados.

Resultados: El proyecto es económicamente viable, con una tasa interna de retorno del 55.85%, lo que demuestra su potencial para generar ingresos y preservar las prácticas tradicionales asociadas a este producto en el municipio.

Conclusión: La integración de herramientas digitales y la agroecología hace que la producción sostenible de sagú en la Finca San Rafael sea técnica y financieramente viable.

Originalidad: Esta investigación puede implementarse en otras fincas de la región, sirviendo como una herramienta útil para iniciativas locales al integrar tecnología y conocimientos tradicionales.

Limitaciones: Existe limitada información sobre la oferta y demanda local de almidón de sagú, así como pérdida en la transmisión de conocimientos asociados a este producto.

Palabras clave: sostenibilidad; modelos agroproductivos; sagú; tecnologías geoespaciales; evaluación financiera.

Resumo

Introdução: Este artigo apresenta os resultados de uma pesquisa realizada durante os anos de 2024 e 2025 na Finca San Rafael, localizada no município de Manta, no departamento de Cundinamarca.

Problema: O desenvolvimento de sistemas agroprodutivos sob critérios de sustentabilidade requer a articulação de planejamento técnico, tecnologias apropriadas e avaliação financeira para responder às condições locais e fortalecer a economia rural.

Objetivo: Esta pesquisa visa formular uma proposta de produção sustentável de fécula de sagu (Canna indica L.), a fim de diversificar a economia rural através de uma abordagem agroecológica apoiada em ferramentas tecnológicas acessíveis.

Metodologia: Para o planejamento do sistema produtivo foi desenvolvido um modelo tridimensional da propriedade utilizando o software QGIS, integrando variáveis edafoclimáticas, topográficas e de uso do solo. A análise financeira foi realizada através do software RIV20, considerando as necessidades de investimento e custos associados.

Resultados: O projeto é economicamente viável, com taxa interna de retorno de 55,85%, o que demonstra seu potencial de geração de renda e preservação de práticas tradicionais associadas a este produto no município.

Conclusão: A integração de ferramentas digitais e agroecologia torna a produção sustentável de sagu na Finca San Rafael viável técnica e financeiramente.

Originalidade: Esta pesquisa pode ser implementada em outras fazendas da região, servindo como uma ferramenta útil para iniciativas locais, integrando tecnologia e conhecimento tradicional.

Limitações: Há informações limitadas sobre a oferta e demanda local de amido de sagu, bem como perda na transmissão de conhecimento associado a este produto.

Palavras-chave: sustentabilidade; modelos agroprodutivos; sagu; tecnologias geoespaciais; avaliação financeira.

1. INTRODUCTION

In the context of climate change, soil degradation, and increasing socioeconomic vulnerability in rural areas, conventional agriculture—characterized by intensive monoculture, excessive use of agrochemicals, and strong dependence on external markets—has shown significant limitations in achieving environmental sustainability, food security, and economic stability for small-scale producers. In Colombia, the expansion of traditional agricultural models, often poorly aligned with local biophysical and socio-productive conditions, has led to widespread land degradation and increased reliance on external inputs. By 2015, 40% of Colombian soils showed some degree of erosion. This pressure is further exacerbated by the reduction in arable land, which decreased from 5.3 million hectares in 1987 to 3.6 million hectares in 2014 [1].

Under this scenario, there is a growing need to promote agricultural production models that integrate sustainability criteria, enhance biocultural diversity, and improve efficiency in the use of natural resources. One strategy to advance this objective is to strengthen agricultural systems based on native or underutilized crops with high agroecological adaptability and potential for application at different production scales.

One such crop is sago (*Canna indica* L.), which, despite its agronomic and nutritional qualities, has been progressively displaced by production systems with higher short-term profitability. Factors such as limited technological development in cultivation and processing, insufficient technical and economic characterization of its value chain, and the limited use of planning and decision-support tools have constrained the sustainable scaling of sago production in regions with favorable biophysical conditions.

The objective of this study is to design a technical and financial model for the sustainable production of sago starch at San Rafael Farm, located in the sector of Palmar Abajo, municipality of Manta, Cundinamarca. The study evaluates the potential of integrating accessible technologies adapted to rural contexts to support informed land-use planning, optimize resource use, and contribute to the development of sustainable and economically viable small-scale agricultural systems.

1.1. Literature Review or Research Background

Sago (*Canna indica* L.), also known as achira in other regions of the country, is a monocotyledonous plant native to the Andes, with archaeological evidence of use dating back to 2500 BC [2]. In Colombia, sago production is mainly concentrated in the departments of Huila, Cundinamarca, Nariño, and Cauca, with an estimated cultivated area of 1,500 hectares distributed across more than 40 municipalities [3]. This species exhibits notable adaptability, as it can be grown under climatic conditions ranging from 16 °C to 32 °C, with annual precipitation between 250 and 4,000 mm, and at altitudes from sea level up to 2,800 meters above sea level [4].

From a production perspective, the sago rhizome is characterized by its high-purity starch content, which is gluten-free and low in fat. These characteristics make it suitable for the preparation of traditional foods such as biscuits, porridges, and custards, as well as for potential applications in the food, pharmaceutical, and textile industries [5]. In addition, its amylose content—one of the main determinants of starch quality—is higher than that of other starch sources, such as cassava. This confers greater solubility, viscosity, and paste clarity, among other functional properties, making sago starch a suitable alternative for the production of pastas, thickeners, and adhesives [6]. Furthermore, the reviewed literature reports successful experiences, such as the one developed in the city of Villavicencio, which demonstrated high economic viability for a company producing sago-derived products [7]. Similarly, in the department of Huila, a proposal for integrating sago cultivation with avocado production resulted in a favorable profitability of 70% [8].

However, a decline in the availability of this product and a loss of cultural traditions associated with it have also been reported. According to a study conducted by the Bogotá District Institute of Cultural Heritage, traditional practices related to the cultivation, processing, and preparation of sago-based foods are facing reduced intergenerational transmission of knowledge. In addition, events such as the period of violence during the 1980s, inadequate road infrastructure, landslides affecting transportation routes, and the COVID-19 pandemic have negatively impacted sago commercialization. Therefore, it is necessary to strengthen marketing networks that connect rural production areas with urban markets through structured value chains [9].

This research is conducted within a context of growing interest in the functional foods market, where sago starch emerges as a product with significant potential for market positioning. According to a report by Business Research Insights, the global sago starch market reached a value of USD 0.40 billion in 2024 and is projected to reach approximately USD 0.61 billion by 2033. Consumption of this starch is driven by increasing consumer preference for natural ingredients, as well as by the expansion of gluten-free diets, in which sago starch represents a competitive alternative to other starches. In terms of geographical distribution, Asia constitutes the most relevant region, with countries such as Indonesia and Malaysia standing out due to their long-standing production traditions and agroecological conditions favorable to sago cultivation [10].

Sago starch has several characteristics that make it attractive for the functional foods market, as it is gluten-free and contributes to the intake of key nutrients such as iron, zinc, and niacin [11]. In addition, it improves intestinal barrier function, increases the production of goblet cells, reduces allergen absorption, and suppresses anaphylactic symptoms [12]. Other functional properties of sago are associated with strengthening the intestinal microbiota and enhancing immune function [13]. Consequently, the global functional foods market provides a relevant framework for understanding the commercialization potential of this product. According to a report by Grand View Research published in 2022, this market was valued at USD 280.7 billion in 2021 and is expected to reach USD 586.1 billion by 2030, with a compound annual growth rate (CAGR) of 8.5% during the period 2022–2030 [14].

This growth is explained by increasing consumer interest in products that provide additional health benefits, such as dietary fiber, prebiotics, probiotics, vitamins, and minerals. Among the most dynamic segments are dairy products, cereals, bakery products, snacks, and clinical nutrition, while the Asia–Pacific region leads market growth due to urbanization, rising disposable income, and greater awareness of healthy lifestyles [14]. These findings suggest that ingredients such as sago starch, which provide energy while also offering functional properties, could be successfully integrated into this expanding market.

Another relevant factor for this market is electronic commerce, which has enabled greater geographic reach and product diversity and, according to several studies, has contributed significantly to improving dietary health through increased availability of nutritional information, reduced transaction costs, and diversification of food consumption, particularly in middle- and low-income countries [15]. However, access remains strongly influenced by price and socioeconomic status; in 2022, the average price of organic and healthy food products was approximately 45% higher than that of conventional foods [10].

The municipality of Manta is located in the department of Cundinamarca, 114 km from Colombia's capital city, Bogotá. With an approximate area of 10,700 hectares, 99.7% of its territory corresponds to rural zones [16], resulting in an economy primarily based on primary activities such as agriculture and livestock production. According to Gacha and Ocampo [17], the main productive systems include potato, pea, maize, coffee, sweet pepper, tomato, common bean, sugarcane, and various fruit species.

Regarding the socioeconomic conditions of Manta's population, the National Administrative Department of Statistics (DANE) reports that the municipality has a multidimensional poverty index (urban centers and dispersed rural areas) of 41.8%, along with an informality rate of 88.8% among workers. This situation highlights the need to diversify and strengthen the local productive base. Consequently, sustainable production initiatives such as sago cultivation may represent a strategic alternative to stimulate the local economy, generate added value through derivative products such as starch, and promote greater socioeconomic stability in Manta's rural communities [18].

Under these conditions, agroecology is consolidated as a comprehensive approach to the design and management of productive systems. It is defined as a scientific discipline that integrates management practices and a social movement aimed at transforming conventional agriculture, incorporating principles such as resilience, stability, adaptability, and efficiency in resource use, with the objective of improving the well-being and equity of local producers [19]. Agroecology emerged as an interdisciplinary science in response to the environmental and social impacts associated with agriculture promoted during the Green Revolution beginning in the 1950s [20]. From this perspective, Sevilla [21] defines agroecology as a strategy for the ecological management of natural resources, grounded in social organization and oriented toward the development of alternatives to the current socio-environmental crisis.

In the case of sago cultivation, the adoption of an agroecological approach is feasible due to its low water requirements (it does not require artificial irrigation), its perennial nature, its high adaptability to diverse climatic conditions, its strong resistance to pests and diseases, and its compatibility with other native plant species. Principles such as crop diversification, nutrient recycling, and the strengthening of resilience to external disturbances allow sago to be integrated with other agricultural species, promoting sustainable soil management and reducing dependence on external inputs [22].

The planning of agroecological systems requires a comprehensive approach that considers the interactions among natural, economic, and social systems. In this context, decision-making based solely on experimental data is insufficient, given the spatial and temporal complexity inherent in agro-systems. For this reason, the incorporation of information technologies and analytical tools has become a key component in strengthening the sustainable management of natural resources and reducing environmental impacts.

In this context, Geographic Information Systems (GIS) have become established as key instruments for the planning and management of agro-productive systems, as they facilitate the integration, analysis, and visualization of large volumes of spatial information, thereby supporting decision-making on a stronger technical basis [23]. In this regard, their application in the management of productive resources has contributed to optimizing crop performance and increasing agricultural yields through more efficient management of soil, water, and agrochemical inputs [24].

According to the systematic review conducted by Mathenge et al. [25], GIS have been applied across multiple areas of the agricultural sector, including yield estimation, assessment of chemical soil fertility, monitoring of land-use and land-cover dynamics, risk management, early detection of pests and diseases, as well as support for precision agriculture and the management of fertilization and weed control. The authors emphasize that the main contribution of these tools lies in the incorporation of the spatial component into the formulation of agricultural policies and interventions, thereby promoting approaches that are better adapted to local conditions and oriented toward sustainability. Nevertheless, they also highlight the limited adoption of GIS in low- and middle-income countries, mainly due to the scarcity of up-to-date geospatial information, which constrains their capacity to modernize traditional production systems.

2. MATERIALS AND METHODS

Due to the complexity of the subject matter and the need to address it from multiple dimensions, a mixed methodology was adopted. This approach involves the collection, analysis, and integration of quantitative and qualitative data within the same study to provide a more comprehensive understanding of the problem under investigation [26]. The combination of both approaches allows overcoming the limitations inherent in each paradigm, providing both the analytical precision of quantitative methods and the interpretive depth of qualitative methods.

In this study, quantitative methods allowed the modeling of the financial behavior of the project based on detailed numerical projections, while qualitative methods facilitated the interpretation of the rural context and the identification of social and cultural factors relevant to the implementation of the agro-productive system. This type of design offers a richer and more contextualized understanding, which is especially useful in research applied to territorial development [27].

The methodological structure was organized into three interrelated phases: (i) spatial analysis using GIS tools for the selection and characterization of the intervention area; (ii) agroecological design of the production system based on technical and environmental criteria; and (iii) economic evaluation using RuralInvest software, adapted to the productive and financial conditions of the rural context of Manta, Cundinamarca. This interdisciplinary approach integrates technical, social, and economic components aimed at generating viable, sustainable, and replicable proposals.

Territorial Diagnosis and Spatial Planning

In the first phase, QGIS software (version 3.42 Münster) was used to perform a detailed geospatial analysis of the selected property: San Rafael Farm, located in the Palmar Abajo sector of the municipality of Manta, Cundinamarca. This analysis made it possible to characterize the soil, climate, and topographic conditions of the land, as well as to establish the relationships among vegetation cover, potential land use, and water resources.

To this end, various layers of georeferenced information were integrated, such as contour lines generated from digital elevation models (DEM), current land use, potential agricultural capacity, water networks, vegetation cover, and property boundaries. In addition, specialized add-ons such as Qgis2threejs were used to build a three-dimensional model of the property, facilitating terrain visualization and the planning of the planting system. This set of tools enabled the delimitation of homogeneous zones within the property, differentiating areas suitable for production, conservation zones, and a rhizome transformation area, following agroecological management and ecological restoration criteria.

Technical Design of the Production System

Based on the territorial characterization, an agro-productive system focused on the cultivation of sago (*Canna indica* L.) was designed under principles of sustainable soil and water management. The design included strip planting aligned with contour lines, incorporating agroecological practices such as natural fertilization and biological pest control to maintain ecological functionality and reduce dependence on external inputs. The entire design was spatially represented in QGIS for subsequent validation and socialization with farm workers and owners.

Financial Analysis of the Project

In the third phase, a financial analysis was conducted using RuralInvest (RIV20) software, a tool developed by the Food and Agriculture Organization of the United Nations (FAO) to assess the viability of productive projects in rural contexts. A cost–benefit structure was developed based on the activities required to establish the crop, maintain the agricultural production system, and process sago starch using traditional methods. The formulation included the design of an investment plan that considered minimum infrastructure, basic equipment for product processing (mill, sieve, solar dryer, among others), labor requirements, and marketing logistics. The information was organized into modules and sub-activities within the RuralInvest environment, generating a projected cash flow of income and expenses that enabled subsequent analysis of the economic sustainability of the model. This was complemented by an analysis of annual financial profitability, which provides general information on project income and costs, also considering products and services associated with self-consumption, as well as costs covered by internal resources.

3. RESULTS

Technical and Spatial Design of the Production System

The spatial planning process using QGIS enabled the development of a highly detailed three-dimensional model of San Rafael Farm. This model integrated key variables such as slope, current land use, vegetation cover, and the hydrological network. The specific results of the technical design are presented below.

Zoning Delimitation

A zoning map of the farm was developed using ArcGIS, in which four main land-use categories were identified: highly suitable areas, suitable areas, unsuitable areas, and residential areas. This classification considered terrain slope and Homogeneous Land Units, defined as the baseline input for assessing the productive capacity of rural land. According to this analysis, the study area corresponds to well-drained, loose, and deep soils, with slopes between 12% and 25% and moderately high chemical fertility [28]. Additionally, it was determined that 88.7% of San Rafael Farm is suitable for cultivation, corresponding to 23,530.94 m², of which 8,002.56 m² are classified as high-yield areas. Zoning enabled the spatial delimitation of areas with the greatest production potential, while conserving those designated for protection due to their characteristics. The areas suitable for production (2.3 net hectares) are located in zones with moderate slopes and lower erosion risk.

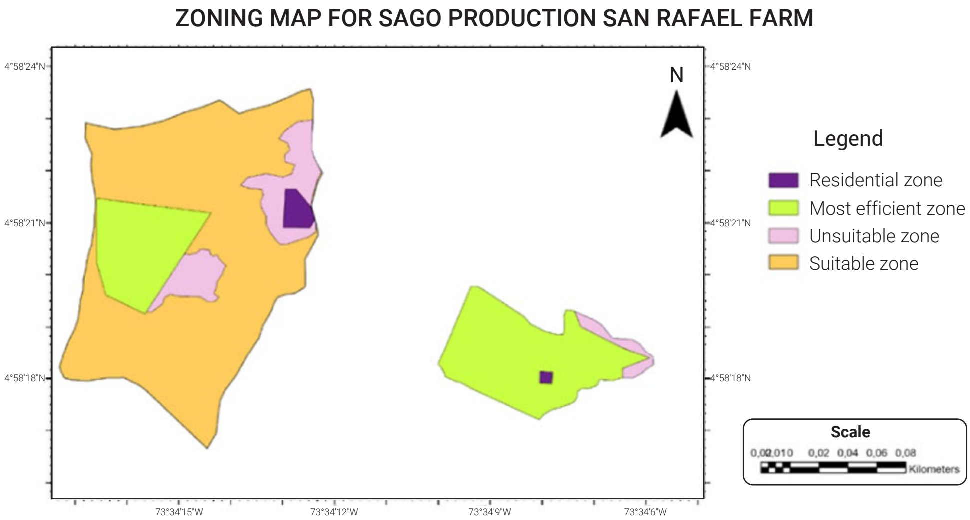

Figure 1. Zoning map of the study area.
Source: own work

Terrain Relief

The results of the geospatial processing carried out in QGIS made it possible to generate three-dimensional representations of the terrain that facilitate the interpretation of the relief of the study area. Figure 2 shows the contour lines derived from the digital elevation model (DEM), which highlights the altitude variability and allows for the planning of planting strips, drainage, internal road design, and the establishment of the tuber processing plant.

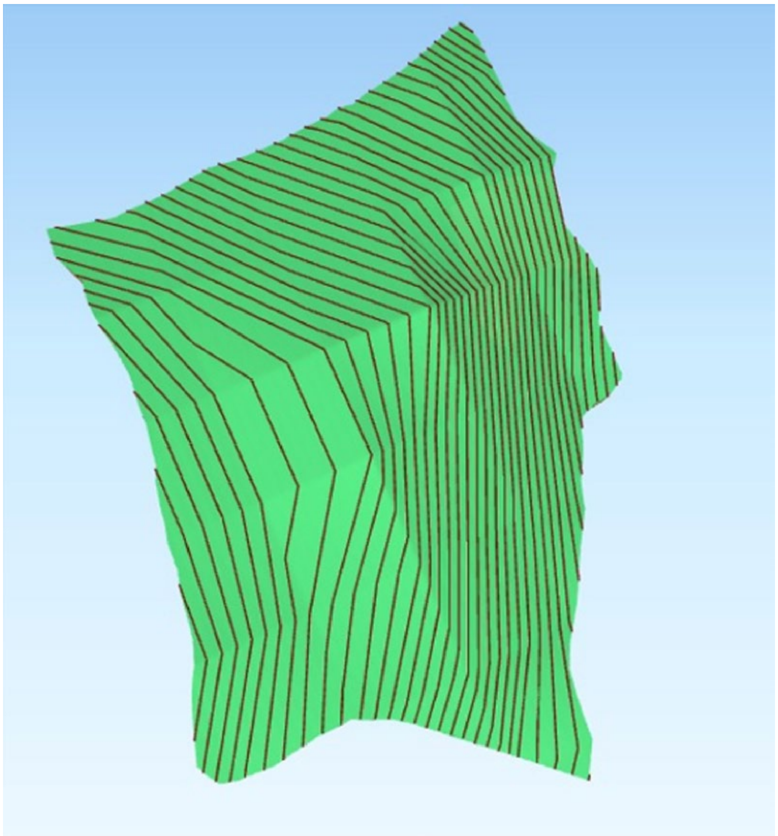

Figure 2. Contour lines of the property.
Source: own work

Subsequently, Figure 3 presents the cartographic output of the morphological terrain classification according to the established slope categories (ranging from flat to steep), which highlights the heterogeneity of the site, specifically the predominance of slightly undulating and moderately undulating terrains, followed to a lesser extent by undulating sectors in the upper part of the farm. No areas classified as flat or steep were observed, indicating that the prevailing relief is moderately irregular. This input is key for the proposed agroecological planning, as it makes it possible to contrast areas suitable for production to implement management practices such as contour planting or erosion control zones.

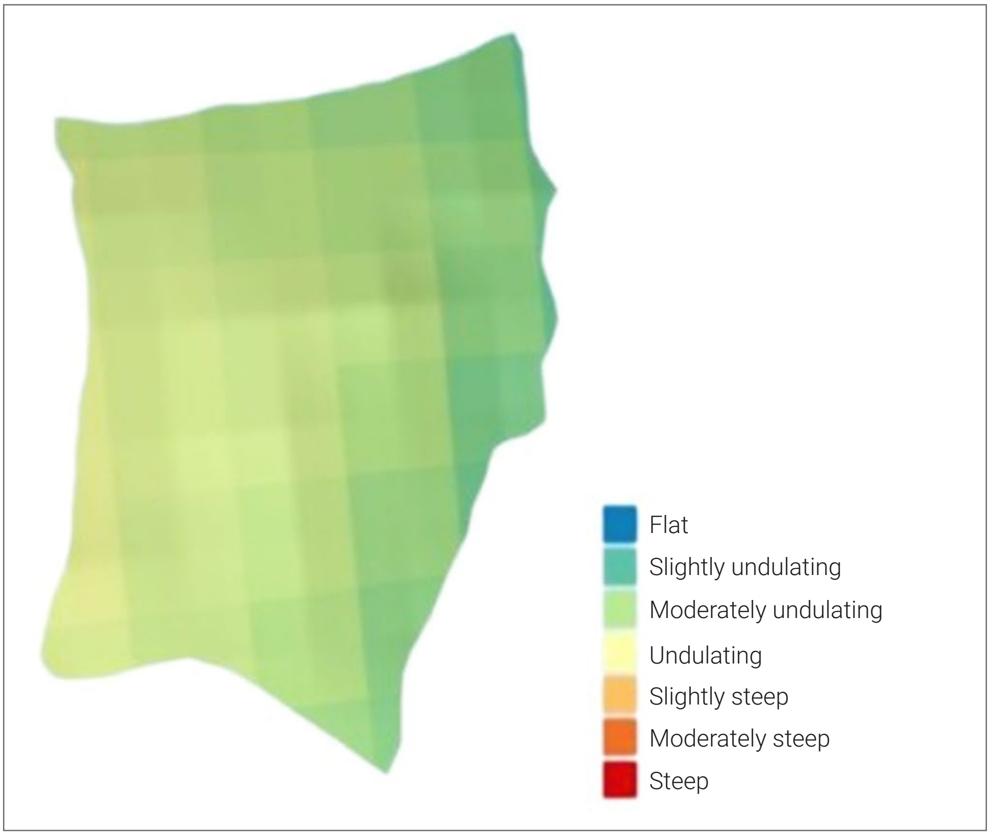

Figure 3. Morphological classification of the terrain according to slope categories on the San Rafael estate.
Source: own work

Crop Configuration

The design included planting in strips adapted to the contour lines, with a density of 1 plant/m², corresponding to a total of approximately 23,000 sago seedlings. This configuration aims to optimize manual maintenance and harvesting operations. In addition, crop association with peas is proposed, taking advantage of the space between seedlings. This represents an economic alternative for farmers by generating short-cycle income and, from an environmental perspective, contributes to production diversification, reduces monoculture risks, and improves soil fertility through biological nitrogen fixation.

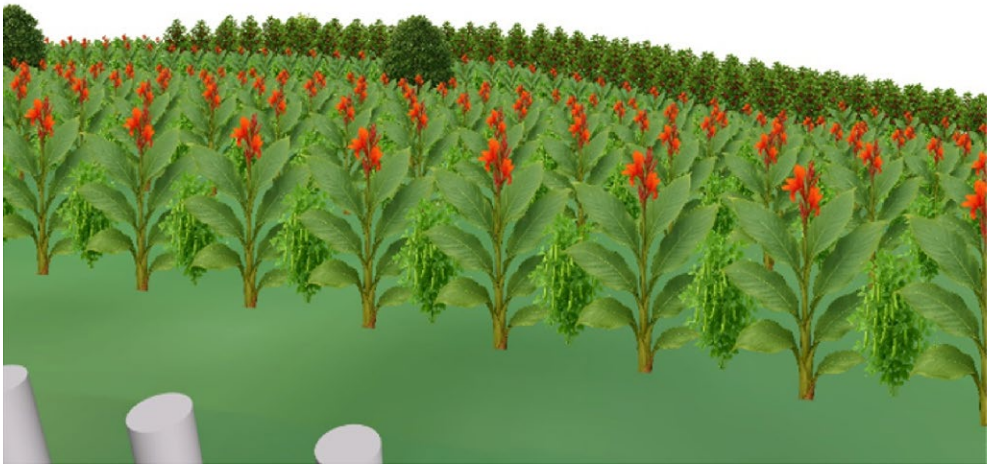

Figure 4. Contour planting adapted to the topography of the land.
Source: own work

Yield Projection

Based on technical literature for similar agroecological conditions [29], an average yield of 5.7 tons of starch per hectare per year was projected, with an annual harvest beginning in the second year, taking advantage of the semi-perennial nature of the crop.

Ecological Diversification

The model strategically incorporated the conservation of native fruit and tree species along boundaries and in specific areas, not only to diversify production for self-consumption but also to promote functional biodiversity (pollinators and biological control agents).

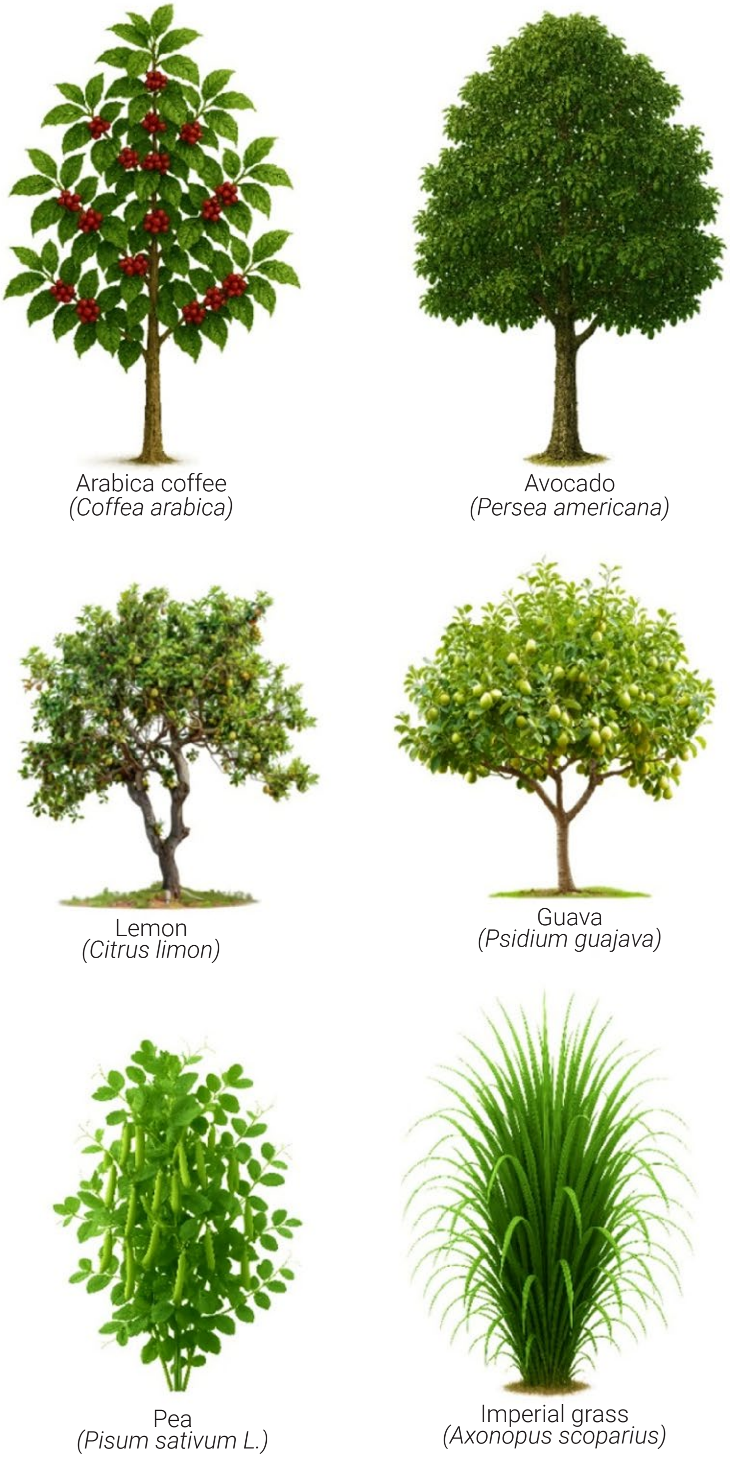

Figure 5. Species used for the diversification of the agro-productive system
Source: own work

Processing Infrastructure

The 3D model made it possible to optimally locate the infrastructure for artisanal starch processing, considering an efficient workflow that includes washing, grinding, decantation, and solar drying, thereby minimizing internal transportation costs and energy consumption.

Figure 6. Infrastructure for the artisanal processing of sago starch.
Source: own work. Part of the structural framework was generated using artificial intelligence, while the remaining elements were created by the authors.

Results of the Financial Analysis

The economic assessment conducted using RuralInvest software yielded the following viability indicators:

Initial Investment and Cash Flow

In the first year, the project showed a negative cash flow (–$47,258,000 COP), consistent with initial investments in infrastructure, equipment (mill, sieve, solar dryer), and crop establishment. From the second year onward, cash flow became positive and exhibited a stable upward trend through the fifth year of projection, without requiring additional capital injections.

Profitability Indicators:

- Internal Rate of Return (IRR): The calculated IRR was 55.85%, corresponding to the rate at which the project's Net Present Value (NPV) equals zero. This indicator reflects the capacity of the projected cash flow to generate returns on the initial investment under the productive and financial conditions established in the model. The obtained IRR significantly exceeds the reference discount rate of 12%, suggested for rural projects in Colombia by the National Planning Department [30], which was used as the benchmark for financial evaluation.

- Net Present Value (NPV): $159,845,455.22 COP. This indicator was obtained by discounting future cash flows to their present value using the defined discount rate. This positive and substantial value confirms the generation of economic value and represents the difference between discounted economic benefits and the total investment and operating costs considered over the evaluation period. The NPV calculation was based on projected revenues from starch production and expenses associated with productive activities, infrastructure, inputs, and system operation.
- Payback Period: 2.51 years. This indicates a relatively rapid recovery of the invested capital; specifically, it takes approximately two and a half years for the accumulated net cash flows to equal the initial investment. This indicator was obtained through a chronological analysis of annual cash flows, identifying the point at which accumulated revenues fully offset investment costs.

Year	1	2	3	4	5
Income [A]	0,00	203.205.000,00	203.205.000,00	203.205.000,00	216.097.083,3
Loan [B]	83.109.188,00	0,00	0,00	0,00	0,0
Own resources [C]	26.020.898,00	0,00	0,00	0,00	0,0
Investment costs [D]	50.020.898,00	0,00	0,00	0,00	0,0
Operating costs [E]	99.466.688,00	104.522.188,00	103.866.688,00	103.866.688,00	103.866.688,0
Financial costs [F]	51.922.118,74	34.687.069,26	0,00	0,00	0,0
Net income					
Net income before financing [A-D-E]	149.487.586,00	98.682.812,00	99.338.312,00	99.338.312,00	112.230.395,3
Net income after loans and before donation [A+B-D-E-F]	118.300.516,74	63.995.742,74	99.338.312,00	99.338.312,00	112.230.395,3
Net income after financing [A+B+C-D-E-F]	-92.279.618,74	63.995.742,74	99.338.312,00	99.338.312,00	112.230.395,3

Figure 7. Annual financial profitability chart.
Source: own work.

Sensitivity Analysis

Sensitivity tests demonstrated the project's robustness to potential variations. Even under a pessimistic scenario with a 9,7% reduction in the selling price (from $15.500 COP to $14.000 COP per kilogram of starch), the net present value remained positive at $100,115,980 COP and the internal rate of return at an attractive 40,32%.

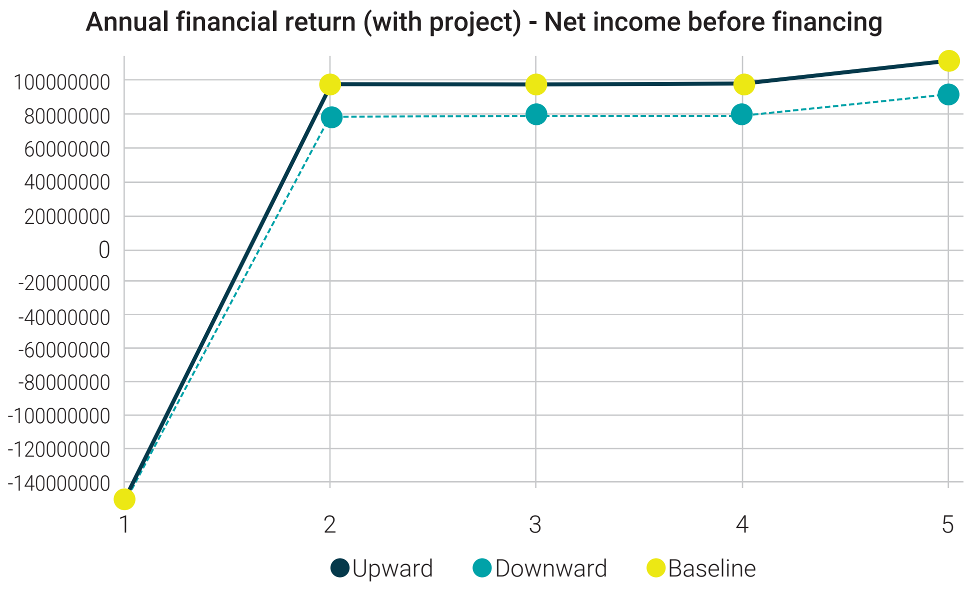

Figure 8. Annual financial profitability (with project) – Net income before financing
Source: own work.

4. DISCUSSION AND CONCLUSIONS

The results obtained from the 3D technical design and economic evaluation confirm the consistency and viability of the sago agro-productive system planned for San Rafael Farm. The territorial diagnosis and spatial planning carried out in this study were based on the processing and analysis of Digital Elevation Models (DEM), using QGIS as the central platform. The generation of derived layers—such as contour lines, slope maps, and aspect maps—from the initial DEM was essential for a comprehensive understanding of the topography and agricultural planning of the farm. Another key technological tool was the Qgis2threejs plugin, used to build an interactive three-dimensional (3D) model from the DEM. This tool provides reliable, accurate, and high-quality spatial analysis of the terrain. The transition from conventional 2D analysis to immersive 3D visualization represented a turning point in the design process, improving topographic representation and facilitating more realistic land-use planning decisions [31].

In this case, the 3D model enabled the optimization of the spatial distribution of productive components with greater precision, as the organization of cultivation areas, internal roads, and the processing zone was based on a comprehensive assessment of accessibility, slope, and functionality within a volumetric environment close to real terrain conditions. In hillside agroecological practices, this also favors uniform crop distribution, improves soil moisture retention, and reduces the need for costly water management infrastructure [32].

Similarly, the use of this technology enabled the planning of planting strips aligned with contour lines, which was enhanced by the ability to visualize and accurately quantify slopes in the 3D model. This contributes to the effective mitigation of water erosion, a central principle of agroecology [22].

In this regard, it is essential to highlight the role of agroecology as an integrating axis of the production system. Sago cultivation can be managed using sustainable practices that optimize productivity and reduce environmental impact. One of the key strategies is pest management through biological control using parasitoid wasps and entomopathogenic fungi (*Beauveria bassiana*), which allows harmful insects to be controlled without resorting to chemical pesticides [33]. In addition, crop rotation and association with legumes or other tree species improve soil fertility and reduce the incidence of pests and diseases. In terms of water requirements, sago does not require artificial irrigation, as it thrives in areas with sufficient rainfall, representing an advantage for sustainable management. This crop also responds favorably to the application of organic fertilizers such as humus and processed poultry manure, eliminating the need for chemical fertilizers. These inputs improve soil structure, increase organic matter content, and stabilize pH, promoting optimal conditions for the sustainable development of sago [2].

The technical structure was integrated with an economic evaluation conducted using RuralInvest software, which projected positive financial performance. Although the first year involves a significant investment, the perennial nature of the crop allows costs to be reduced in subsequent cycles and sustained income to be generated from the second year onward [34]. Cash flow analysis shows a progressive and sustained recovery, without the need for additional external capital, demonstrating the financial viability of the system. This experience, supported by accessible tools adapted to rural contexts, is highly replicable on other farms in Manta, Cundinamarca, with similar soil and climatic conditions, offering a profitable and sustainable agricultural alternative for small-scale producers in the region [35].

This study demonstrates that the use of digital technologies in traditional production systems such as sago cultivation represents a viable strategy for promoting sustainable rural development models. The integration of digital tools, such as geographic information systems for three-dimensional project design and RuralInvest software for financial evaluation, enabled the development of a technically robust, environmentally compatible, and economically viable agro-productive system. This technological integration not only optimizes land-use and natural resource planning but also reduces financial uncertainty through realistic and rigorous projections [36].

The financial results presented in Figure 4, together with the sensitivity analysis, confirm the robustness of the proposed agro-productive model. The positive and stable trend in cash flows from the second year onward demonstrates that the initial investment, although substantial, is recovered within a relatively short period, achieving an internal rate of return of 55.85% and a net present value of $159,845,455.22. These indicators, along with the short payback period (2.51 years), are consistent with the results of the sensitivity analysis, which show statistically significant differences among the evaluated scenarios (optimistic, pessimistic, and baseline). This demonstrates that, even under adverse conditions, the system remains profitable and capable of generating economic value. This experience, supported by accessible tools adapted to the rural context, is highly replicable on other farms in Manta.

The use of sensitivity analysis reinforces the importance of integrating simulation tools to assess risks and support informed decision-making. This capacity for anticipation is essential for small-scale producers, as it enables them to adapt their production systems to variations in prices, inputs, or climatic conditions, thereby mitigating potential negative impacts. This study also provides empirical evidence on the importance of expanding access to information and communication technologies in rural contexts [35].

Finally, the experience developed at San Rafael Farm demonstrates that this type of initiative can be scaled at the regional level, promoting short value chains, value addition at the source, and the use of underutilized crops such as sago. This model, replicable in other areas with similar edaphoclimatic conditions, offers a practical opportunity to advance the transition toward more efficient, sustainable, and community-centered agriculture. However, it is important to recognize that access to technologies such as RuralInvest and QGIS remains limited in many rural areas, which may restrict large-scale implementation without prior strategies for training and digital inclusion. These aspects should be considered in future stages of the project to ensure its sustainability and territorial impact [27].

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