# Agricultura Digital: A New Approach to Agricultural Production in Zamora Chinchipe, Ecuador

Flavio Ordoñez[1] , Cinthya Guzman[2], and Cristian Molina[3]

[1] Ingeniería en Tecnologías de la Información, Departamento de Computación, Universidad de Las Fuerzas Armadas ESPE, Sangolquí, Ecuador
{fmordonez2, cdguzman3, cmmolina}@espe.edu.ec

**Abstract.** Digital agriculture emerges as an innovative solution to address the current challenges of agricultural production. Using the PRISMA methodology, a systematic review of scientific literature was conducted, identifying emerging technologies such as Internet of Things sensors, farm management software, artificial intelligence, and computer vision. Seventeen articles from the Scientific Electronic Library Online, Scopus, ScienceDirect, Dialnet, and Directory of Open Access Journals databases were selected and analyzed to explore the integration of these technologies to optimize agricultural processes, promote sustainability, and meet the growing demand for affordable food. The objective of this project is to demonstrate the feasibility of implementing digital agriculture in local agricultural production through the development of a web application. This platform integrates key services, including geospatial mapping to facilitate efficient crop monitoring and management; an artificial intelligence-based system for the detection and analysis of pests and diseases; a weather forecasting module that allows anticipating climate changes for better decision-making; and a system for managing and analyzing data generated by Internet of Things sensors, with secure storage on a server for subsequent analysis. The main purpose is to provide agricultural producers with technological tools that optimize their production processes, improve the profitability of their businesses, and contribute to the sustainable development of the province of Zamora Chinchipe.

**Keywords:** Digital Agriculture, Sustainable Agriculture, Agricultural Technology, Zamora Chinchipe, Agricultural Innovation.

# 1 Introduction

Agriculture is one of the most strategic sectors for sustainable development and global food security. Throughout history, it has evolved significantly from traditional practices to highly technological systems. Currently, digital transformation is marking a new era in agricultural production, with countries such as the Netherlands and the United States leading the implementation of advanced technologies in this sector [2]. In Latin America, Argentina and Brazil stand out for their early adoption of digital technologies applied to agriculture, particularly in areas such as precision agriculture and the use of remote sensing [2].
Digital agriculture integrates technologies such as the Internet of Things (IoT), artificial intelligence (AI), data analytics, geographic information systems (GIS), and computer vision to optimize production processes, improve decision-making, and promote sustainable practices. This approach seeks to transform data into useful information for efficient field management, enabling the monitoring of key variables such as crop health, soil moisture, weather conditions, and the presence of pests or diseases [4], [9].

For digital agriculture to be effective, three technological pillars are essential: electrification, digital connectivity, and machine learning capabilities. However, many rural regions still face limitations in one or more of these aspects, which represents a significant obstacle to large-scale adoption [9]. Furthermore, resistance to change on the part of some producers, especially those with traditional practices, can hinder the transition to these new technological models [9].

Zamora Chinchipe, located in the southern region of the Ecuadorian Amazon, is a province rich in biodiversity and agricultural production. Its main crops include sugarcane, bananas, cassava, papaya, pineapple, lettuce, mandarins, and citrus fruits such as lemons and oranges [5]. Despite the region's agricultural potential, challenges remain related to access to technology, connectivity, and technical training.

The objective of this project is to develop a web application for agricultural producers in Zamora Chinchipe that integrates key technological services, such as geospatial monitoring, weather forecasting, early pest detection using artificial intelligence, and data analysis from IoT sensors. This tool seeks to provide an innovative and accessible solution that allows farmers to optimize their production processes, increase profitability, and promote agricultural sustainability in the province.

## 2 Related Works

Technological advancement has transformed various productive sectors, including agriculture. In this context, digital agriculture has established itself as an innovative strategy that allows for the optimization of agricultural processes through the use of tools such as IoT sensors, artificial intelligence, data analysis, and digital platforms. Numerous studies have addressed the implementation of these technologies in different geographical contexts, highlighting their positive impact on agricultural efficiency, sustainability, and productivity.

Various studies show that countries such as the United States, the Netherlands, Brazil, and Argentina are leading the incorporation of digital technologies in the agricultural sector [2]. According to De León and Victorino [3], digital agriculture facilitates food traceability and improves decision-making, although it also faces challenges such as resistance to change on the part of traditional farmers. Zúñiga and Díaz [9] argue that technological integration in rural areas requires not only infrastructure but also training strategies and cultural adaptation. These international experiences serve as a reference for exploring application possibilities in regions like Zamora Chinchipe, where agriculture is a key activity for local development.

## 3 Methodology

For this research, a systematic literature review was conducted using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology, widely recognized for the development of rigorous academic reviews [6]. This methodology allowed us to identify, select, and analyze relevant studies on digital agriculture published between 2019 and 2024.

The questions that guided this review were:

- **Q1:** What is the impact of digital agriculture on agricultural production in the province of Zamora Chinchipe?
- **Q2:** What technologies could be implemented in this region to improve production efficiency?

To answer these questions, five scientific databases were consulted: Dialnet, DOAJ, SciELO, ScienceDirect, and Scopus, using key terms such as *digital agriculture, agriculture 4.0*, and *precision agriculture*, combined using Boolean operators.

The review process followed the four phases defined by PRISMA: identification, screening, eligibility, and inclusion.

The inclusion criteria considered peer-reviewed articles focusing on technologies applied to agriculture, while the exclusion criteria ruled out duplicate studies or those outside the established temporal or geographic scope. The final result was the selection of 17 scientific articles, whose findings were used to inform the design of a technological solution applied to the context of Zamora Chinchipe (see Fig. 1).

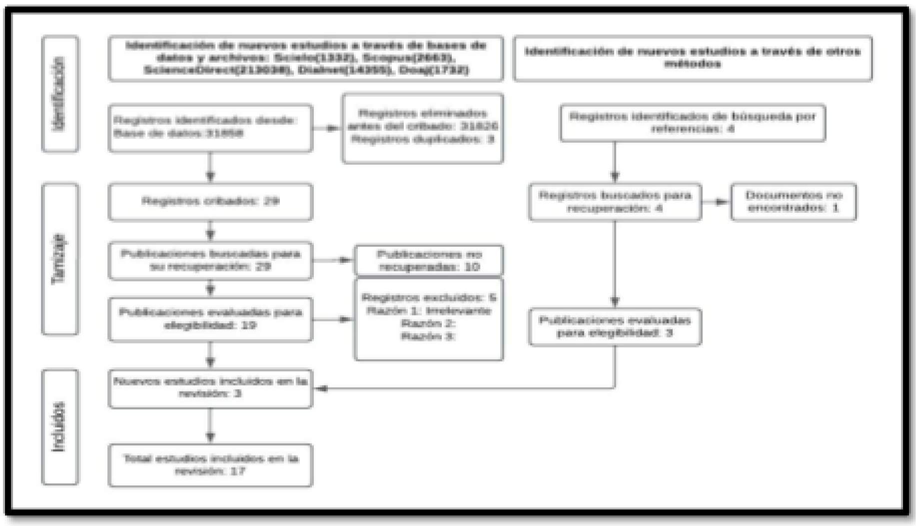


**Fig. 1.** Flowchart of the PRISMA process applied in the systematic review.

As a result of the initial search in the five selected databases, 31,858 articles related to the topic of digital agriculture were identified. To ensure the quality and relevance of the studies included in the systematic review, rigorous inclusion and exclusion criteria were applied, as detailed in **Table 1**. This process allowed us to refine the sample until only the most relevant studies were selected for the objectives of this research.

**Table 1.** Inclusion and exclusion criteria used in the systematic review.

| | Inclusion criteria | Exclusion criteria |
|---|---|---|
| 1 | Articles focused on digital agriculture. | Articles focused on topics other than the digital agricultural approach. |
| 2 | Articles published between 2019 and 2024. | Articles published outside the established time range. |
| 3 | Articles published in English and Spanish with full text available. | Articles published in other languages or without full access to the content. |
| 4 | Articles published in reliable databases: SciELO, Scopus, ScienceDirect, Dialnet, and DOAJ. | Articles from non-academic or unverifiable sources. |
| 5 | Empirical research articles (qualitative or quantitative). | Reviews, opinion pieces, book chapters, theses, and other non-refereed documents. |
| 6 | Articles available with open access. | Studies without free access to the full text. |

In Zamora Chinchipe, the incorporation of digital technologies has progressively adapted to local conditions and the traditional agricultural model. The implementation of IoT sensors allows for constant monitoring of parameters such as soil moisture, while the use of agricultural drones facilitates visual and aerial assessment of crop status [1]. However, due to structural challenges such as limited connectivity and limited technological infrastructure in certain rural areas, a gradual adoption strategy has been adopted, aimed at transforming the agricultural system toward a more sustainable, efficient, and competitive model at the national and international levels [2], [3].

Currently, there are various digital applications aimed at the agricultural sector that integrate functions designed to optimize farmers' work. These tools range from real-time crop monitoring, predictive analysis of climate variables, smart resource management (such as water and fertilizers), to optimization of marketing processes [4], [5]. Thanks to these technological solutions, farmers can make data-driven decisions, improve the efficiency of their production processes, and increase the profitability of their businesses [6], [7].

A study by Zambrano [8] on the application of digital agriculture in pitahaya production showed that the use of mobile applications integrated into smart agriculture platforms provided valuable information for decision-making in the field, even without the need for constant physical presence on the plantations. This case demonstrates the transformative potential of digital tools in non-traditional crops, and highlights the importance of agricultural digitalization as a driver of rural innovation [3], [9], [7].

## 4 Proposed Solution

In order to offer a viable alternative to boost digital agriculture in Zamora Chinchipe, various existing tools on the market that integrate emerging technologies such as artificial intelligence, geographic information systems (GIS), IoT sensors, and big data were analyzed. Among the applications evaluated, AgriMap stands out, focusing on agricultural management through geospatial mapping, allowing producers to identify critical areas and make decisions based on the spatial variability of the terrain [1], [2]. Also considered was Taranis, an advanced solution that applies artificial intelligence and computer vision for the early detection of pests and diseases, providing preventive alerts for crops such as cocoa, coffee, and bananas, contributing to improved productivity and sustainability [3], [4].

Despite technological advances, agriculture in rural contexts still faces significant challenges regarding efficiency, sustainability, and optimization of resource use. Conventional methods often lack precision due to the absence of digital tools to support decision-making [5], [6]. Therefore, this study proposes the development of a digital agriculture web platform, aimed at small and medium-sized producers in the region, that allows for the integration of various key functions for the agronomic management of their crops. This solution is based on the principles of accessibility, low cost, scalability, and technological appropriability, aligning with the Sustainable Development Goals (SDGs) proposed by the UN [10].

# 5 Application aim

To design and implement a digital agriculture web platform for small and medium-sized producers in Zamora Chinchipe. This platform integrates technological tools for real-time climate monitoring, agricultural data analysis, efficient crop management, remote technical support, and early detection of pests and diseases. This will improve decision-making, optimize resource use, and promote more sustainable, profitable, and climate-resilient agricultural production.

# 6 Application Requirements

## 6.1 Functional Requirements

The proposed application incorporates a set of essential functionalities aimed at facilitating digital agricultural management for small and medium-sized producers:

**Table 2.** Functional Requirements of the Proposed Web Application

| Category | | Description |
|---|---|---|
| 1 | User management | Registration, authentication, and password recovery for agricultural users. |
| 2 | Profile management | Creation and management of personalized farmer profiles. |
| 3 | Geoespacial visualization | Visualization of fields and crops using interactive maps. |
| 4 | Diagnostic imaging | Uploading crop images for analysis and identification of pests and diseases using computer vision. |
| 5 | Sensors Integration IoT | Real-time data collection (soil moisture, temperature) through IoT sensors. |
| 6 | Weather forecast | Connection to external platforms (such as OpenWeather) to display updated weather information. |
| 7 | Report Generation | Automatic creation of reports on crop status. |
| 8 | Real time notifications | Immediate alerts about critical events, such as adverse weather conditions or the presence of disease. |
| 6 | Access control | Assigning differentiated permissions to administrators and users based on their roles. |

### 6.2 Non-Functional Requirements

The following are the non-functional requirements, which establish the quality characteristics that the application must meet to ensure its effectiveness and acceptance by users:

**Table 3.** Non-Functional Requirements of the Proposed Web Application

| | Categoría | Descripción |
|---|---|---|
| 1 | Scalability | Complying with national and international regulations (LOPDP - Ecuador, RGPD - UE). |
| 2 | Security | Periodic security audits must be carried out, complying with national and international regulations (LOPDP - Ecuador, RGPD - EU). |
| 3 | System availability | Ensure a minimum availability of 98% of annual operating time. |
| 4 | Diagnostic imaging | Uploading crop images for analysis and identification of pests and diseases using computer vision. |
| 6 | Usability | Intuitive, accessible, and easy-to-use graphical interface for people with different levels of technological literacy. |

## 7 Arquitectura

The application was developed using the Visual Studio Code environment, structured under a three-layer architecture, described below and represented in **Figure 2**:

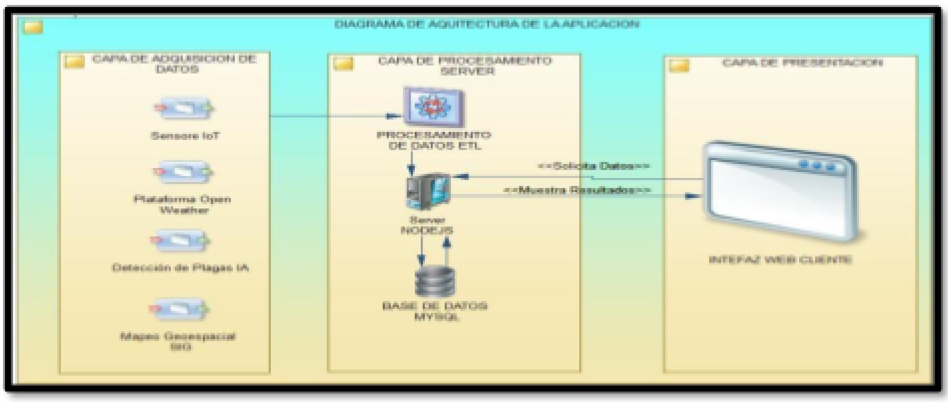


**Fig. 2.** Architecture of the web application developed in Power Designer, composed of data acquisition, processing, and presentation layers for digital agricultural management.

The figure presented shows the layers that make up the system architecture:

- *Data Acquisition Layer:* Responsible for collecting information using IoT sensors deployed in the field. It also connects to external services such as OpenWeather to acquire real-time meteorological data.
- *Processing Layer:* Composed of a backend server developed in Node.js, responsible for data processing, business logic, and request management. Data persistence is achieved through a MySQL relational database.
- *Presentation Layer:* Web interface accessible from modern browsers, which includes an interactive control panel (dashboard) to display processed information and allow interaction with system functions.

# 8 Tools

For the implementation of the digital agriculture application in Zamora Chinchipe, technological tools were selected to meet the objectives established in each phase of development.

## 8.1 Development tools

- *Visual Studio Code:* Integrated development environment (IDE) used for writing, debugging, and efficiently managing application source code.
- *Node.js:* Backend platform responsible for processing data from IoT sensors, integrating with weather APIs, and securely managing the database.
- *MySQL:* Relational database management system for the structured and efficient storage of crop information, weather forecasts, and trade data.

### 8.2 Design tools

- *Figma:* Used to create interactive prototypes and wireframes that ensure an intuitive and consistent user experience.
- *Adobe XD:* Complementary tool for detailed screen layout, defining elements such as buttons, color palettes, and visual hierarchies.

### 8.3 Monitoring Tools

- *Sensores IoT:* Devices installed to capture key data such as soil moisture, temperature, and light levels in crops.
- *OpenWeather:* Platform that provides real-time climate data and future weather predictions.
- *Google Maps:* Tool for the geospatial location of agricultural plots and distribution route planning.

### 8.4 Data Visualization Tools

- *Chart.js*: Library for creating interactive charts on the dashboard, displaying metrics such as soil moisture evolution or market prices.
- *Power BI*: Advanced analytics platform that facilitates the interpretation of complex data and supports informed decision-making by farmers.

## 9 Layout

Upon entering the application, users are greeted with a main interface offering various navigation options. Registered users can access services through the login option; otherwise, they must select the registration option to complete the form and create an account.

Once authenticated, users access a main menu that facilitates navigation between the different available features, such as Spatial Land Monitoring, OpenWeather, Pest Monitoring, Settings, and the Dashboard. Additionally, there is a shortcut to the About section, which provides information about the application, along with contact and language selection options, allowing users to adapt the interface to their language preferences (see Figure 3).

The interface design was developed based on the specific functional requirements of the project, ensuring accessibility and usability for farmers in Zamora Chinchipe.

Main sections include:

- *Begging:* Summary of key functions related to climate monitoring, crop management, and marketing.
- *Crop Management*: Area intended for the entry and display of crop-specific data.

- *Weather:* Page dedicated to displaying weather forecasts and agricultural recommendations based on climate data.
- *Technical Support:* Section with quick guides and space for technical questions.

### 9.1 Responsive Design

The interface is optimized to work correctly on mobile devices, tablets, and desktop computers. Interactive elements, such as buttons and drop-down menus, have been adapted for ease of use on touchscreens through appropriate sizes and an intuitive layout.

### 9.2 Visual Style

The color palette is inspired by natural tones that reinforce the connection with the agricultural environment. Clear and legible typography is used to facilitate navigation, even for users with limited technological knowledge (see Fig. 3).

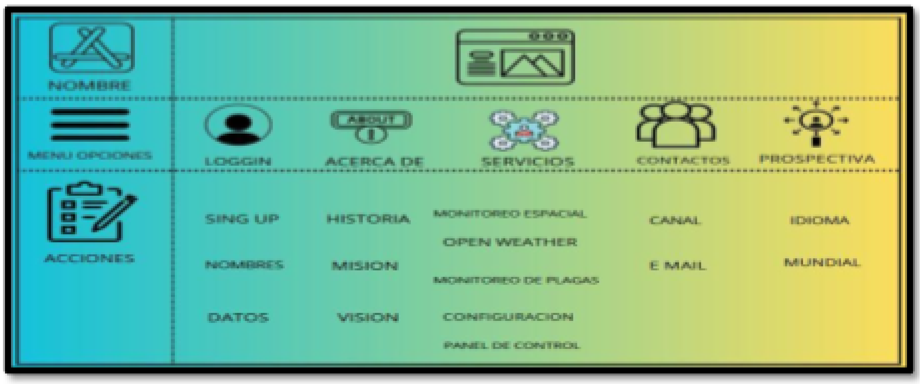


**Fig. 3.** Navigation diagram of the digital agriculture application

## 10 Results

Below are the results of the application's operation, performance, and user experience, along with the implemented fixes.

### 10.1 General Operation (see Fig. 4)

The web application loaded successfully in major browsers—Google Chrome, Mozilla Firefox, and Microsoft Edge—achieving a 96% effectiveness rate.

A 4% error rate related to page loading was identified, attributed to an incorrect API key configuration, which was corrected to improve stability.

### 10.2 API Integration

The integrated weather API demonstrated 99% effectiveness, providing accurate and timely data on temperature, humidity, and precipitation.

The average response time was 350 ms, ensuring a smooth user experience with no perceptible delays.

### 10.3 Performance

The application's average load time was 1.5 seconds, meeting the speed standards for modern web applications.

RAM usage during execution remained within an acceptable range, approximately 120 MB, reflecting efficient resource management.

Furthermore, the image optimization implemented resulted in an 18% reduction in load times, contributing to improving the platform's overall performance.

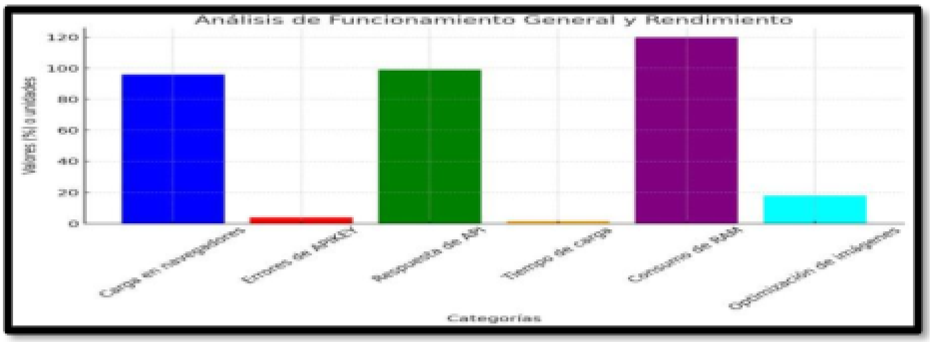


**Fig. 4.** Detailed analysis of the overall functioning and performance of the web application

### 10.4 User Experience in Application

89% of users rated the app as easy to use and highly intuitive, highlighting its accessibility even for people with limited technological experience. Ten percent recommended specific improvements to the visualization of agricultural data on mobile devices, identifying areas for improvement in the experience on small screens. Finally, 1% expressed a preference for continuing to use traditional manual techniques, reflecting a certain resistance to technological change.

### 10.5 Errors and Corrections

To improve stability, an encoding system was implemented that detects and notifies of connection failures with the weather API, enabling a rapid response to potential outages. Additionally, caching techniques were implemented, reducing unnecessary API requests by 35%, optimizing performance and minimizing server load (see Fig. 5).

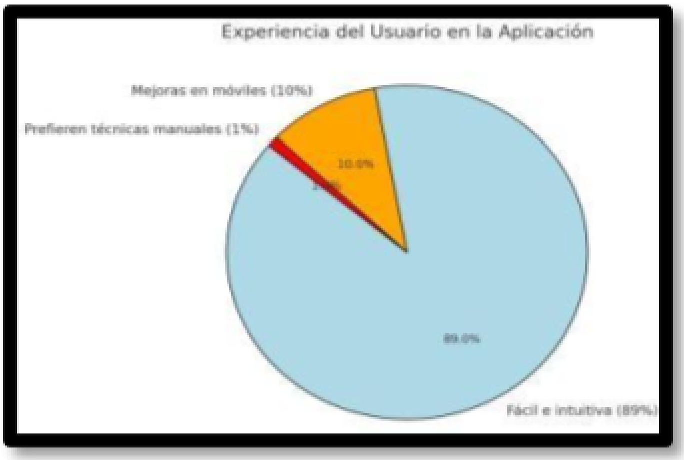


**Fig. 5.** Results obtained with respect to user experience.

# 11 Discussion

Below is a detailed analysis of the main findings obtained during the implementation and evaluation of the digital agriculture application, considering its potential technological, productive, social, and economic impact in the Zamora-Chinchipe region.

## 11.1 Potential Impact of Digital Agriculture

Digital agriculture represents a significant opportunity to optimize resources and promote sustainability in the Zamora-Chinchipe region. Its implementation could:

- Increase agricultural productivity by making decisions based on accurate and up-to-date data.
- Reduce crop losses through early detection of pests and adverse environmental conditions.
- Promote environmental sustainability through more efficient and responsible use of available natural resources.

## 11.2 Social and Economic Benefits

The proposed platform not only facilitates agricultural management for local producers but also contributes to regional economic development by improving access to national and international markets. This could help bridge the technological gap between small farmers and large agricultural companies, promoting more inclusive and competitive agriculture.

## 11.3 Challenges for Implementation

Despite the clear potential, the adoption of digital agriculture in Zamora Chinchipe faces significant obstacles:

- The need to expand and improve connectivity infrastructure in rural areas to ensure access to technologies.
- The importance of promoting technical training through workshops and training programs tailored to local producers.
- Raising awareness among farmers about the tangible benefits offered by digital tools to overcome resistance to change.

## 11.4 Comparison with Global Cases

Countries such as the Netherlands and the United States have demonstrated success in integrating digital technologies into agriculture, achieving high levels of productive efficiency. However, in Latin America, progress has been uneven due to technological, economic, and cultural limitations. Therefore, the adaptation of these solutions to local contexts, such as that of Zamora Chinchipe, must be inclusive and gradual, respecting the region's socioeconomic and environmental specificities.

## 12 Recommendations for Future Work

- Conduct pilot studies to evaluate the effectiveness and adaptability of digital technologies for specific crops in the region.
- Actively involve local farming communities in the development and continuous improvement of the platform, ensuring it meets their real needs.
- Foster strategic partnerships between the public and private sectors to finance and facilitate the sustainable adoption of these technologies.

## 13 Conclusions

The developed web application demonstrated high efficiency in obtaining and processing meteorological data, achieving 99% availability and an average response time of 350 ms. This guarantees farmers access to accurate, up-to-date, real-time information, which is essential for making sound decisions in agricultural management (see Fig. 6).

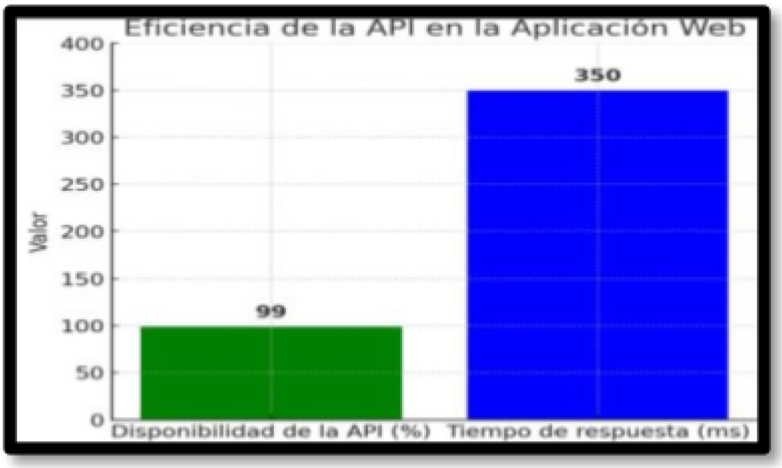


**Fig. 6.** Application Efficiency

The application's overall performance was satisfactory, with an average load time of 1.5 seconds and a RAM consumption of approximately 120 MB. Image optimization reduced load times by 18%, improving the user experience. For future versions, we recommend implementing advanced data compression and optimization techniques to maximize efficiency.

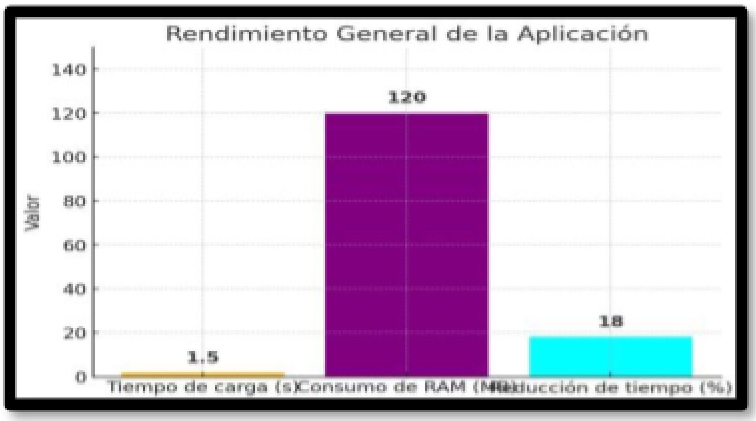


**Fig. 7.** Overall Application Performance

Regarding the user experience, 89% of participants rated the app as very intuitive and easy to use. However, 10% reported difficulty displaying graphics on mobile devices, highlighting the need to improve the interface's responsiveness.


**Fig. 8.** Experiencia del Usuario con la Aplicación

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