

Design of a Mobile Application with a Hybrid Recommendation System for Connecting Andean Farmers and Urban Consumers in Peru

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Abstract—The dependence on intermediaries within agricultural marketing chains not only reduces producers' profits but also generates consumer distrust regarding the quality and traceability of the products they obtain. This work proposes a mobile application with a hybrid recommendation system aimed at connecting farmers and consumers in Peru. The combination of collaborative filtering and content-based filtering achieves personalization of the shopping experience based on the producer's offer and the user's interests. Likewise, mobile geolocation technology is incorporated to support delivery tracking, together with an offline-first approach to support the application's operation in rural areas with limited connectivity. A preliminary evaluation of the recommendation system, using the Amazon Reviews 2023 dataset (100,000 interactions), compares the hybrid model against collaborative filtering, content-based filtering, and a popularity baseline across RMSE, F1-score@5, catalog coverage, and diversity. The results show that collaborative filtering provides the strongest performance among the models offering meaningful catalog coverage, while the fixed-weight hybrid configuration evaluated in this study did not outperform it, identifying weight optimization as a priority for future work. The offline-first architecture maintains a 100% synchronization rate even under intermittent connectivity conditions, providing preliminary technical evidence under controlled conditions.

Keywords—Andean agriculture; direct trade; hybrid recommendation system; order tracking; mobile application; offline-first

I. INTRODUCTION

Currently, in Peru, there is a structural disconnection between Andean farmers and urban consumers, which negatively impacts both farmers' profitability and end consumers' trust regarding the origin and quality of products. On one hand, farmers depend largely on intermediaries to market their products. In 2019, 46.8% of producers accessed regional, agro-industrial, or export markets; by 2024, this percentage decreased to 45.7% [1], showing a decline in the overall percentage of producers accessing the market. This limitation affects family farming, which represents 99.8% of the country's agricultural units, of which approximately two-thirds correspond to subsistence family farming [2], a segment characterized by lower access to direct markets and, consequently, greater dependence on intermediaries for selling their production. On the other hand, urban consumers are uncertain about the quality, origin, and traceability of agricultural products, which decreases their trust in traditional

purchasing channels [3]. This situation shows why traditional supply chain systems are unable to respond to consumers' growing interest in knowing the origin of what they buy, due to the centrality and vulnerability of the information they handle, reducing trust among the actors in the logistics process [4].

This study aims to design, implement, and preliminarily evaluate a mobile application that connects farmers and consumers for the sale of agricultural products through a personalized recommendation system. This will allow farmers to access a direct marketing channel, while consumers will have greater trust and transparency regarding the products.

The main problem lies in the disconnection between Andean farmers and urban consumers, which limits access to detailed product information. Simple approaches, such as product lists, fail because they ignore user preferences and the variation in supply when relying on historical interaction data processing; as a result, they struggle to capture dynamic changes in user interests and product attributes [5]. Furthermore, when there is a lack of initial data, the problem known as "cold start" arises, which affects the performance and accuracy of the recommendation system, becoming evident as the number of new users and items increases [6].

There are several technological solutions aimed at improving agricultural marketing, such as e-commerce platforms, digital agriculture systems, and mobile applications [7]. First, several platforms are not designed for low-connectivity contexts, given that internet use in rural areas in 2024 was 62.6% compared to 86.1% in urban areas, a difference of 23.5 percentage points [8], showing the difficulty of their adoption in Andean rural areas [9]. Second, existing solutions tend to focus only on the transaction itself, that is, buying and selling, without integrating traceability mechanisms [10]. Furthermore, although some systems incorporate recommendations, these are generally basic or not adapted to the agri-food context [11]. Finally, many proposals fail to adequately account for the digital literacy limitations of the agricultural population, which creates barriers to the use of advanced technologies and results in low technology adoption [12]. Likewise, insufficient technical training and the persistence of the digital divide restrict access to learning opportunities and technological resources, representing factors that limit the development and modernization of the agricultural sector [13].

The key components of this research include the use of a hybrid recommendation system that combines collaborative filtering and content-based filtering to improve the recommendations of products offered to users. Likewise, mobile geolocation technology is integrated to support order tracking of agricultural products. The system also integrates a data management module that stores and processes information related to products, users, and transactions, facilitating interaction between stakeholders through an intuitive interface. As a limitation, hybrid recommendation systems may require greater computational complexity and proper integration of multiple data sources, since these can affect their performance.

The main contributions of this work are as follows:

- A mobile application is developed that integrates a hybrid recommendation system to connect Andean farmers with urban consumers in Peru.
- A hybrid recommendation model is proposed that combines collaborative and content-based filtering to improve the personalization of agricultural products.
- An order tracking system based on mobile geolocation is designed and implemented, allowing consumers to monitor the status and route of deliveries.
- A preliminary evaluation of the recommendation system is conducted using a public dataset from the agri-food domain (Amazon Reviews 2023).
- The offline-first architecture is validated through controlled synchronization tests under three network conditions (full connection, total offline, and intermittent connection).
- As future work, the construction of a proprietary dataset from real user interactions and an evaluation with real users (farmers, consumers, and delivery drivers) are proposed.

This article is organized as follows. Section II presents the related work. Section III describes the conceptual background, system architecture, and proposed method. Section IV presents the experimental protocol, results, and discussion. Section V presents the conclusions and future work.

II. RELATED WORK

In recent years, various digital solutions have attempted to connect farmers with consumers to reduce the information gap, increase product visibility, and simplify purchasing decisions. Faced with limitations such as intermediation, the scarcity of structural data in rural environments, and distrust, approaches based on recommendation systems have emerged, with hybrid systems improving the accuracy and adaptability of recommendations in dynamic environments. This section reviews related works that employ this type of approach or similar proposals. These studies show that, although hybrid systems represent an improvement over traditional methods, they still face significant challenges, such as the integration of heterogeneous data and the complexity of managing supply fluctuations.

In [14], the authors propose APGCN-CF, a model based on graph convolutional neural networks that optimizes agricultural product recommendation in rural e-commerce by integrating spatial and temporal information. This approach improves recommendation accuracy, especially for minor products, outperforming conventional methods. However, its performance depends on large volumes of high-quality data and constant connectivity, which limits its applicability in rural environments with restricted technological infrastructure. In contrast, the proposed system adopts a hybrid recommendation approach centered on collaborative filtering combined with content-based filtering, plus a fallback mechanism for cold-start, which seeks to maintain a good level of personalization even when interaction data is limited, without requiring large volumes of high-quality information.

In [15], the author proposes P-FARM, an e-commerce recommendation system based on profit-supported fuzzy association rule mining, which incorporates economic criteria to optimize both recommendation accuracy and transaction profitability. This approach demonstrates improvements in system effectiveness by balancing user satisfaction with business benefits. However, it requires large volumes of consistent transactional data, which restricts its application in informal or low-digitalization agricultural contexts. Furthermore, its emphasis on profit maximization may conflict with equity objectives for producers. By contrast, the proposed approach integrates two distinct components: personalized, consumer-oriented recommendation algorithms and an offline-first architecture that allows farmers and delivery drivers to register and manage their products in areas with limited connectivity, synchronizing once the connection is restored.

In [16], the authors present FarmFresh, a web and mobile application developed in India that allows small farmers to sell their products directly to consumers without intermediaries. Their system incorporates features such as inventory management, order intake, and purchase tracking, which improve the organization and control of sales. The results obtained show an increase in sales and a high level of satisfaction among both farmers and consumers. However, the proposal is oriented toward an environment with better connectivity conditions and does not account for the technological limitations specific to rural areas. By contrast, the proposed system integrates personalized recommendation algorithms and an offline-first architecture oriented toward Andean areas with limited connectivity.

In [17], the authors analyze how the use of digital platforms in Peru influences the profitability of family farmers. The authors find that the use of these tools makes it possible to increase income, reduce transaction costs, and improve efficiency in the marketing of agricultural products. However, they also show low technology adoption due to digital infrastructure limitations and low levels of technological literacy in rural areas. These barriers restrict the impact of existing digital solutions. On the other hand, this work designs a mobile application adapted to these problems through simple interfaces and an offline-first architecture that allows it to function even without a constant connection, facilitating its adoption in the Andean context.

In [12], the authors present AgroTIC, a mobile application developed in Colombia that connects farmers, agronomists, and merchants through the use of technologies such as ICT, IoT, and machine learning, focusing on crop recognition and agricultural information management. This solution seeks to improve productivity and decision-making in the agricultural sector through the use of smart technology. Despite having active users, adoption in rural areas was limited due to a lack of trust in technology and internet connectivity problems. These limitations affect the system's scalability in rural contexts. By contrast, the proposed system focuses mainly on product recommendation, order tracking, and direct trade between Andean farmers and urban consumers, taking intermittent connectivity and ease of use into account from the design stage.

Table I summarizes the key characteristics of the reviewed works compared to the current proposal.

TABLE I. COMPARISON OF RELATED WORK

Work	Personalized Recommendation	Order Tracking	Offline-First	Direct Trade
[14] APGCN-CF	✓	✗	✗	✗
[15] P-FARM	✓	✗	✗	✗
[16] FarmFresh	✗	✗	✗	✓
[17] Digital platforms (Peru)	✗	✗	✗	✓
[12] AgroTIC	✗	Partial	✗	Partial
Proposal	✓	✓	✓	✓

Beyond merely integrating existing recommendation techniques into a single system, the technical novelty of this work lies in the design of a hybrid model built for the specific constraints of the deployment environment. Instead of relying on external machine learning libraries, both collaborative and content-based filtering are implemented natively in Java 21 using cosine similarity; this keeps the recommendation engine lightweight and free of heavy runtime dependencies that would be difficult to maintain in a resource-constrained, intermittently connected backend. Their outputs are combined through a fixed weighting scheme (45% collaborative, 55% content-based), together with a fallback mechanism that mitigates the cold-start problem for new users and products. As discussed in the Results and Discussion, this fixed ratio was set a priori rather than tuned through systematic search, and the evaluation reported in this study identifies weight optimization as a necessary next step; the contribution of this component lies in the dependency-free, configurable fusion mechanism itself, rather than in a claim that the current weighting is already optimal. This combination of a dependency-free implementation and an explicit cold-start fallback distinguishes the proposed approach from prior agricultural recommender systems, which typically rely on specialized ML infrastructure (e.g., graph neural networks) that assumes larger, denser datasets and more stable computational environments than those available in the target context.

III. CONTRIBUTION AND METHOD

A. Preliminary Concepts

This section presents the main theoretical concepts used in the research. These concepts allow us to understand the use of digital technologies, recommendation algorithms, and supply chain management in the agricultural context, which underpin the development of a mobile application to connect Andean farmers with urban consumers.

1) *Agricultural digitalization [18]*: Digitalization in agriculture consists of the use of technological tools to optimize agricultural practices and improve production and commercial processes.

In this context, digital platforms, such as mobile applications, make it possible to directly connect farmers with urban consumers, eliminating intermediaries and optimizing logistics.

2) *Recommendation algorithms [12]*: These are techniques used to predict which items might be of interest to a user based on their previous preferences and behavior patterns.

These algorithms make it possible to personalize user experience, improve customer satisfaction, and optimize sales on agricultural digital platforms.

3) *Logistics and supply chain [19]*: Logistics comprises the processes of transportation, storage, and distribution of products within a supply chain.

In the agricultural field, efficient supply chain management helps minimize post-harvest losses, ensure product quality, and facilitate traceability, which contributes to building consumer trust.

4) *Hybrid recommendation system [20]*: A hybrid recommendation system combines more than one recommendation technique with the aim of leveraging the strengths of both systems used and reducing the limitations of each system. It generally integrates methods such as collaborative filtering and content-based filtering to improve the accuracy and relevance of recommendations.

This approach allows the urban consumer to have a personalized shopping experience while, at the same time, increasing the visibility of products offered by Andean farmers within the platform.

5) *Collaborative filtering [20]*: Collaborative filtering is a recommendation technique that generates suggestions based on the preferences, behaviors, or interactions of users with similar interests. This approach is based on the idea that users who shared consumption patterns in the past may show similar preferences in the future.

This technique makes it possible to recommend agricultural products to a consumer based on the purchases, views, or preferences of other consumers with similar behavior within the platform.

6) *Content-based filtering* [20]: Content-based filtering is a recommendation technique that uses product characteristics to identify items similar to those the user has previously viewed, purchased, or rated.

In the agricultural context, this approach allows products to be recommended considering attributes such as category, product type, price, origin, or availability.

7) *Mobile geolocation* [21]: Mobile geolocation is the process by which the approximate geographic location of a mobile device is determined using technologies such as GPS, smartphone sensors, mobile networks, or geofencing mechanisms.

In the proposal, geolocation makes it possible to record the approximate location of delivery drivers or farmers during order transport, facilitating delivery coordination and giving the consumer greater confidence about the status and route of the products ordered.

8) *Offline-first architecture* [22]: Offline-first architecture is an application design approach that keeps critical functionality available even when there is no internet connection or connectivity is limited. To achieve this, the application prioritizes local storage and allows certain operations to be carried out without permanently depending on the server.

This approach is mainly aimed at farmers and delivery drivers, who may operate in rural areas or routes with intermittent connectivity.

9) *Data synchronization in mobile applications* [22]: Data synchronization in mobile applications is the process by which information recorded locally on the device is subsequently updated with the central server once the internet connection is restored.

In an offline-first architecture, this process is essential for maintaining data consistency, allowing products registered by farmers and delivery statuses recorded by delivery drivers to be correctly reflected on the platform.

B. System Architecture Overview

The general architecture of the proposal is presented in Fig. 1. The solution was developed as a mobile application in Flutter under an offline-first approach, with a backend implemented in Spring Boot and a central MySQL database. Communication between the mobile application and the backend is carried out through a REST API protected with JWT-based authentication and authorization. As shown in Fig. 1, the application incorporates a local database (SQLite with Drift), an automatic synchronization client, a pending-changes queue, and a geolocation module, allowing consumers, farmers, and delivery drivers to keep using the platform even in scenarios of limited or intermittent connectivity.

On the backend side, business logic is centralized through modules for product and farmer management, orders and deliveries, geolocation, hybrid recommendations, synchronization, authentication, and notifications. The

recommendation engine combines collaborative and content-based filtering to generate personalized recommendations, while the cold-start problem is addressed using products with higher ratings, popularity, or demand. Additionally, Azure Storage stores product images, and Firebase Cloud Messaging enables push notifications.

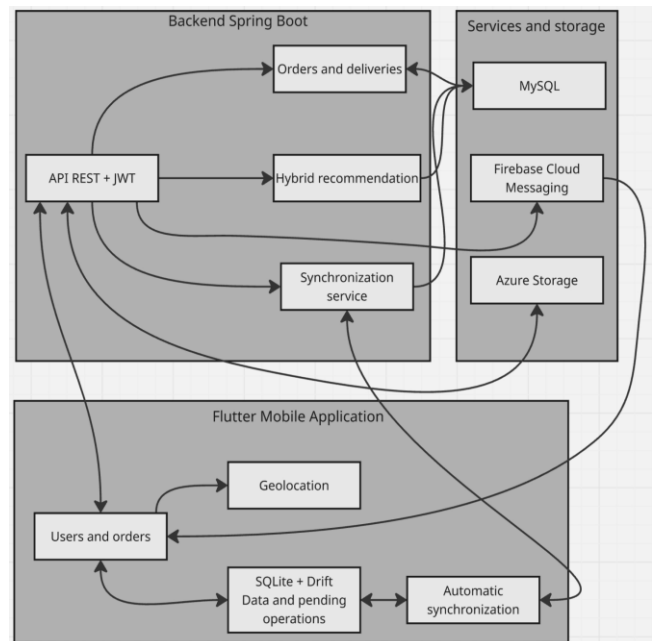


Fig. 1. General architecture of the proposed mobile application.

To protect sensitive location and identity information, the platform's security model addresses a specific threat scenario rather than offering general security guarantees. Payment processing is out of scope, as financial transactions take place outside the application. The primary focus is on safeguarding user identities, maintaining Role-Based Access Control (RBAC) boundaries among farmers, consumers, and delivery personnel, and preserving data integrity during transmission. Authentication and access permissions rely on JSON Web Tokens (JWT), chosen to align with the system's "offline-first" operational capabilities.

Since mobile devices often operate without constant backend connectivity, maintaining session states on the server would disrupt offline usage; instead, self-contained tokens allow for the local verification of authorization credentials between synchronization intervals. Geolocation data collected for delivery tracking requires explicit consent, as it is processed solely during delivery operations and transmitted via encrypted channels. Access to these tracking records is strictly restricted to the relevant consumer, producer, and driver. Furthermore, cached tokens and synchronization queues are kept in encrypted local storage, while location records are deleted once deliveries are completed and any potential disputes resolved. These measures mitigate key risks such as unauthorized access, session hijacking under fluctuating network conditions, and the misuse of location data; however, as they do not constitute a comprehensive security guarantee, the implementation of additional measures, such as formal security audits, is reserved for future stages of the project.

C. Method

The proposal is structured around three main contributions that address the identified problems: personalization of agricultural products through a hybrid recommendation system, logistical coordination through mobile geolocation, and operational continuity through an offline-first architecture for farmers and delivery drivers. These contributions help explain how the solution's main components interact and how technical problems such as cold-start, limited connectivity, and data synchronization are addressed.

The first contribution of this research consists of the implementation of a hybrid recommendation system aimed at improving the shopping experience within the TinkiyAgro platform. This system seeks to facilitate the connection between Andean farmers and urban consumers by generating personalized agricultural product recommendations.

The recommendation module implements a weighted hybrid strategy that combines collaborative filtering and content-based filtering. User-item interactions are built from three behavioral signals: favorites, product reviews, and purchases. Favorites receive a weight of 5.0, reviews use the explicit rating value, and purchases receive a weight of 3.0 plus a quantity-based increment capped at 2.0. These signals are aggregated by user and product.

The collaborative component computes user-user similarity using cosine similarity over the weighted interaction vectors. Candidate products are scored by accumulating the interaction weights of similar users, weighted by their similarity to the target user. The resulting scores are normalized by the maximum score observed in the candidate set.

The content-based component builds a user profile from the attributes of previously interacted products. The implemented features are product category, farmer identifier, sale format, and product popularity. The content score is computed as a weighted combination of category affinity, farmer affinity, sale-format affinity, and popularity, using weights of 0.55, 0.20, 0.15, and 0.10, respectively.

The final hybrid score is computed as 0.45 times the collaborative score plus 0.55 times the content-based score. Products already seen by the user receive a penalty of 0.20 in order to prioritize unseen items. For cold-start users without interaction history, the system falls back to a popularity score based on average rating and number of reviews.

Likewise, the system addresses the cold-start problem, which occurs when a new user does not yet have enough interaction history to generate personalized recommendations. For this case, the platform proposes an initial strategy based on products with higher ratings, popularity, or demand within the system. Subsequently, as the user performs searches, views products, or makes purchases, the system progressively updates its recommendations according to their actual behavior.

As illustrated in Fig. 2, the inclusion of this recommendation system makes it possible to personalize the browsing experience within the platform, facilitate the discovery of new agricultural products, and contribute to increased sales opportunities for registered farmers.

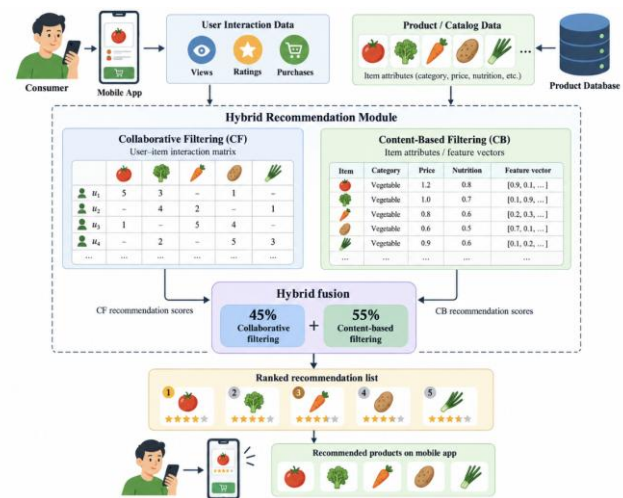


Fig. 2. Operation of the proposed hybrid recommendation system.

The second contribution of this research consists of the implementation of an offline-first architecture aimed at guaranteeing the availability of the application's main functionalities in environments with limited or intermittent connectivity.

As shown in Fig. 3, the system allows information to be temporarily stored on the mobile device, enabling farmers to register products, update them, and view relevant information without needing a permanent internet connection. Similarly, delivery drivers can view assigned orders and record delivery statuses even when there is no network coverage.

Once the device regains connectivity, the locally stored information is automatically synchronized, ensuring data consistency within the platform.

This approach responds to the connectivity conditions present in various Andean rural communities, where limited internet access can affect the continuous use of digital applications. Through this architecture, the goal is to ensure the operational continuity of critical processes such as product publishing and delivery management, reducing dependence on a permanent connection.

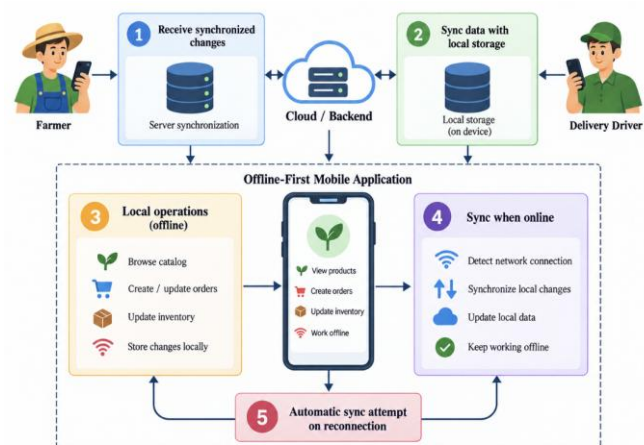


Fig. 3. Offline-first architecture for farmers and delivery drivers.

IV. EXPERIMENTS

A. Experimental Protocol

1) *Development environment*: This work was developed on a computer with a 2.6 GHz 6-core Intel Core i7 processor, an AMD Radeon Pro 560X 4 GB and Intel UHD Graphics 630 graphics, and 16 GB of 2400 MHz DDR4 memory. The mobile application was built using Flutter, and the recommendation engine was implemented in Java 21, running JDK 22.0.2 using the Spring Boot 4.0.1 framework. The application's source code is publicly available: the backend at <https://github.com/JuanMontes18/TinkiyAgro> and the mobile application (frontend) at <https://github.com/TinkiyAgro/TinkiyAgro-Frontend>

2) *Data used*: For the quantitative evaluation of the models, the public Amazon Reviews 2023 dataset (Grocery and Gourmet Food category) [23], published by McAuley Lab, was used. It was selected for its relevance to the agri-food sector and because it contains both explicit (ratings) and implicit (text reviews) interactions between users and products, allowing simulation of the purchasing and rating behavior the system seeks to model. In later stages, a proprietary dataset is planned to be built from real interactions between farmers and consumers within the application.

The evaluation used the Grocery and Gourmet Food category from Amazon Reviews 2023. According to the dataset documentation, this category contains approximately 7.0M users, 603.2K items, and 14.3M ratings. User-item interactions were built from explicit ratings using parent_asin as the item identifier. Items with ratings greater than or equal to 4.0 were treated as relevant for top-k evaluation.

To assess robustness, the experiment was repeated with five random seeds (1, 2, 3, 4, and 5) using an 80/20 user-stratified random holdout split. The same dataset, preprocessing rules, model parameters, and evaluation metrics were kept fixed across runs. Results are reported as mean $\pm$ standard deviation.

To validate the offline-first architecture, an automated and controlled test was run on the repositories responsible for local storage (SQLite via Drift) and synchronization with the backend. Network conditions (full connection, total offline, and intermittent connection) were simulated using instrumented remote services, allowing control over network behavior during each test.

B. Result

This subsection details the experiments carried out and the results obtained in each of them:

1) *Comparison of recommendation models*: Before evaluating the recommendation models, the Amazon Reviews 2023 dataset (Grocery and Gourmet Food category) was processed to prepare an appropriate evaluation subset. Table II outlines the primary attributes of the resulting dataset, detailing the counts of users and items included, total retained interactions, overall sparsity, and the train-test splitting methodology applied consistently across all experimental runs and random seeds.

TABLE II. CHARACTERISTICS OF THE EVALUATION DATASET (AMAZON REVIEWS 2023)

Field	Value
Users	10,459
Items	47,961
Interactions	100,000
Unique user-item pairs	97,884
Sparsity	0.999805
Split	User-stratified random holdout, test ratio = 0.2
Seeds	1, 2, 3, 4, 5

To evaluate the proposed hybrid system, its performance was compared against a pure collaborative filtering model and a pure content-based model, using the Amazon Reviews 2023 dataset (Grocery and Gourmet Food). The metrics used were RMSE (rating prediction error), F1-score@5 (top-5 ranking quality), Coverage (catalog coverage), and Diversity@5 (intra-list diversity). Table III shows the results obtained for each model.

TABLE III. COMPARISON OF RECOMMENDATION MODELS ACCORDING TO ACCURACY, RANKING, COVERAGE, AND DIVERSITY METRICS

Model	RMSE	F1-score@5	Coverage	Diversity@5
Popularity	2.3199 $\pm$ 0.0039	0.0245 $\pm$ 0.0005	0.02% $\pm$ 0.00%	0.7346 $\pm$ 0.0260
Collaborative	2.8651 $\pm$ 0.0063	0.0200 $\pm$ 0.0005	11.63% $\pm$ 0.15%	0.8986 $\pm$ 0.0040
Content Based	2.8881 $\pm$ 0.0043	0.0149 $\pm$ 0.0002	5.47% $\pm$ 0.07%	0.3952 $\pm$ 0.0088
Hybrid	3.0342 $\pm$ 0.0034	0.0185 $\pm$ 0.0005	10.39% $\pm$ 0.11%	0.6072 $\pm$ 0.0042

Table III shows that the popularity baseline achieves the lowest RMSE (2.3199) and the highest F1-score@5 (0.0245), reflecting a well-documented behavior of top-k ranking metrics: recommending the most frequently purchased items maximizes short-term accuracy and ranking overlap with a sparse test set, but at the cost of catalog coverage, which remains close to zero (0.02%), effectively recommending the same narrow set of products to nearly all users, which runs counter to the platform's goal of increasing visibility for a broader base of farmers and products. Among the models that provide meaningful catalog coverage, collaborative filtering achieved the best result across all four metrics (RMSE 2.8651, F1-score@5 0.0200, Coverage 11.63%, Diversity@5 0.8986), outperforming both content-based filtering and the hybrid configuration evaluated in this study. The hybrid model, combining collaborative and content-based scores with a fixed 45%/55% weighting, did not outperform collaborative filtering alone at this scale. This indicates that the specific weighting ratio used was not optimal for the sparsity and interaction patterns observed in this dataset; the 45/55 split was selected a priori rather than tuned through systematic search. Optimizing this parameter, potentially through per-context rather than fixed weighting, is identified as a priority for future work.

Rather than presenting the fixed-weight hybrid configuration as an optimized final model, the contribution of

this component lies in the native, dependency-light implementation described in Section II, together with a reproducible evaluation protocol, repeated runs with standard deviations, and a popularity baseline that makes the current limitation transparent: at the tested weighting ratio, the hybrid model does not outperform collaborative filtering alone. Reporting this result, rather than obscuring it, identifies the necessary next step for this line of work: a systematic search over the weighting parameter, rather than assuming the current fixed ratio is production-ready.

2) *Validation of offline-first functionality*: To evaluate the system, 4 key flows were analyzed: product creation, product editing, pickup point creation, and marking an order as ready. Each one was evaluated under 3 different network conditions. The study covered 240 operations, running 20 per flow in each scenario evaluated. The integration of local logging was validated through the syncOperations table in Drift/SQLite, while synchronization effectiveness was determined by checking whether operations changed to the synced state. A Stopwatch was also used to quantify latency, measuring the interval from the start of the process to its successful confirmation. Table IV presents the results obtained.

TABLE IV. RESULTS OF COMPLETENESS, SYNCHRONIZATION, AND LATENCY OF THE OFFLINE-FIRST ARCHITECTURE

Network Condition	Operation	Complete local registration	Successful synchronization after reconnection	Synchronization latency
Full connection	80	100%	100%	0.031 s
Total offline	80	100%	100%	0.049 s
Intermittent connection	80	100%	100%	0.311 s

The "total offline" scenario does not imply immediate synchronization with the server while offline. Instead, it means that all operations were saved in the local SQLite queue during the outage and successfully synced once the connection was restored. Thus, the recorded latency reflects only the time taken by the synchronization process after triggering the routine for pending tasks.

C. Discussion

1) *Comparison of recommendation models*: The hybrid model should not be interpreted as the best model across all individual metrics. Instead, the results show different trade-offs. The popularity baseline achieved the best RMSE and F1@5 in this highly sparse sample, which indicates that frequently rated and highly rated products are easier to recover under limited interaction density. Collaborative filtering achieved the highest coverage and Diversity@5, suggesting broader catalog exploration when enough overlapping user behavior exists. The hybrid model combines collaborative and content signals, but in this configuration it should be presented as a balanced alternative rather than as a universal improvement over all baselines.

2) *Validation of offline-first functionality*: As shown in Table IV, the offline-first architecture guarantees 100% effectiveness in local registration and synchronization under all three conditions analyzed, ensuring the integrity of all operations regardless of network stability. However, a notable variation in latency is evident: while in full-connection scenarios the average is 0.031 s, this value rises to 0.311 s under intermittent connections. This increase, close to ten times the initial figure, is attributable to the additional processing required to detect and transmit the queue of pending operations after reconnection.

This result is consistent with the expected behavior of an architecture that seeks to prioritize data integrity, ensuring that nothing is lost, over synchronization speed when the network is unstable, which is especially relevant for the context of Andean rural areas with limited connectivity.

It should be noted that, to support the experiment's repeatability, instrumented services were used to simulate network conditions. Consequently, the findings reflect how the offline-first architecture behaves in controlled environments, which means they are not a direct measure of the inherent volatility of mobile networks in real-world scenarios. This distinction represents an important limitation that should be addressed in future validations carried out under uncontrolled network conditions.

Upon reconnecting, the system automatically initiates synchronization to upload all pending local operations to the server. However, the present build lacks mechanisms for resolving concurrent editing conflicts and managing retry attempts for failed transmissions. Handling these edge cases, such as duplicate operations, expired authentication tokens, application restarts, and simultaneous edits, remains a key priority for future work.

V. CONCLUSION

TinkiyAgro was developed as a mobile application that connects Andean farmers, consumers, and delivery drivers through a hybrid recommendations system, a GPS/GNSS-based delivery-tracking module, and an offline-first data architecture. From the outset, the recommendation module includes a fallback strategy to mitigate the cold-start problem for users without purchase history and adapts suggestions progressively as interaction data becomes available.

The evaluation focused on two of these components under controlled conditions: the recommendation model, assessed through RMSE, F1-score@5, Coverage, and Diversity@5 on the Amazon Reviews 2023 dataset, and the offline-first architecture, assessed through local-registration completeness, synchronization success rate, and latency under simulated network conditions. The results provide preliminary technical evidence that both components operate as intended under these controlled scenarios. The geolocation-based delivery-tracking module was implemented but not subjected to a comparable empirical evaluation; its accuracy, update latency, and behavior under connectivity loss remain untested. Validation with real users (farmers, consumers, and delivery drivers), including usability, perceived trust, and field performance of the tracking

module, remains pending and is identified as a priority for future work. A geolocation-based delivery tracking module was implemented but did not undergo a comparable empirical evaluation; details such as its accuracy, update latency, and behavior during connectivity loss remain untested. Validation with real users (farmers, consumers, and delivery personnel), covering the module's usability, perceived trustworthiness, and field performance, is still pending and has been identified as a priority for future work.

In conclusion, the results obtained provide preliminary technical evidence for two core components of the proposed solution: a recommendation module comparing hybrid, collaborative, and content-based filtering under a reproducible, multi-seed evaluation protocol, which found that collaborative filtering alone provided the strongest results among the evaluated models and identified weight optimization as a necessary next step for the hybrid formulation to realize its intended benefit, and an offline-first architecture designed to support operational continuity under limited or intermittent connectivity. These findings should be interpreted as evidence of technical feasibility under controlled conditions rather than as validation within the Andean rural context itself. As future work, it is proposed to evaluate the complete application, including the geolocation module, with real users in field conditions, to assess usability, scalability, and the system's actual impact on farmer income and consumer trust.

DECLARATIONS

A. Declaration on Generative AI Use

During the preparation of this study, the authors used a generative AI tool to help refine the language and formatting consistency, as well as to generate illustrative figures (Fig. 2 and Fig. 3). All AI-assisted text and figures were critically reviewed, verified, and edited by the authors, who assume full responsibility for the accuracy and content of the final paper. The generative AI tool played no role in the development of the scientific ideas, the design of the recommendation algorithm, the experimental methodology, or the interpretation of the results.

B. Conflict of Interest

The authors declare no conflict of interest.

C. Data Availability

The Amazon Reviews 2023 dataset used for the recommendation model evaluation is publicly available at <https://amazon-reviews-2023.github.io/>.

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