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ARTICLE

The Role of Agricultural Cooperatives in Enhancing Credit Access, Market Information, and Smart Farming among Rural Farmers

Shaymaa Hussein Nowfal [1,2], Sireesha Nanduri [3], W. Gracy Theresa [4], B. Keerthi Samhitha [5], R. Vinoth [6], Ashokkumar Veerapandi [7], Ravi Kumar Bommisetti [8*]

[1] Department of Medical Physics, College of Science, University of Warith Al-Anbiyaa, Karbala 56001, Iraq
[2] Department of Medical Physics, College of Applied Medical Sciences, University of Kerbala, Karbala 56001, Iraq
[3] Faculty of Management Studies, CMS Business School, JAIN (Deemed-to-Be University), Bengaluru 560009, Karnataka, India
[4] Department of Artificial Intelligence and Data Science, Panimalar Engineering College, Chennai 600029, Tamil Nadu, India
[5] Department of Computer Science and Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram 522502, Andhra Pradesh, India
[6] Department of Computer Science and Engineering, RMK College of Engineering and Technology, Chennai 601206, Tamil Nadu, India
[7] Department of Information Technology, V.S.B College of Engineering Technical Campus, Coimbatore 642109, Tamil Nadu, India
[8] PG Department of Business Administration and Dean-Research and Development Cell, Maris Stella College, Vijayawada 520008, India

ABSTRACT

This study examines the role of agricultural cooperatives in enhancing Credit Access (CA), Market Information (MI), and Smart Farming (SF) among rural farmers in Kerala. Agricultural cooperatives serve as vital organizations that address key challenges smallholder farmers face, including limited CA, MI, and SF. Using a quantitative research

*CORRESPONDING AUTHOR:
Ravi Kumar Bommisetti, PG Department of Business Administration and Dean-Research and Development Cell, Maris Stella College, Vijayawada 520008, India; Email: ravi9949418650@yahoo.com

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design, structured surveys collected data from 421 cooperative and non-member farmers. The study aims to identify the effects of cooperative membership in CA services, MI and SF among rural farmers. Analysis of key findings shows that cooperative members loan from multiple financial sectors, are provided with more frequent MI, and have higher adoption of SF practices, thus featuring the importance of cooperatives in financial development, MI, and environmental organization. The analysis employs t-tests, Chi-square tests, Pearson correlations, and regression models to compare the impact of cooperative membership on CA, MI, and SF. The results reveal that cooperative members are significantly more likely to secure loans, receive more significant loan amounts, and report higher satisfaction with loan terms than non-members. Cooperative members also receive more frequent and reliable MI, which enables them to adjust their sales approaches and access better market opportunities. In addition, cooperative members exhibit higher adoption rates of SF and perceive more significant economic benefits. The study confirms that agricultural organizations are critical in promoting financial inclusion, market participation, and environmental sustainability among rural farmers. These findings underscore the importance of cooperatives as a key tool for rural development and SF growth.

Keywords: Smart Farming; Chi-Square Tests; Pearson Correlations; Rural Farmers; Machine Learning

1. Introduction

Agricultural cooperatives have long been recognized as key drivers of rural development, particularly in regions where smallholder farmers face significant challenges in accessing essential resources such as Credit Access (CA), Market Information (MI), and Smart Farming (SF)[1–3]. In many rural areas, farmers operate in isolation, lacking the financial means, knowledge, and formal support to compete effectively in increasingly volatile and globalized agricultural markets[4, 5]. These limitations frequently result in poor farm productivity, limited income, and vulnerability to economic and environmental shocks[6, 7]. Agricultural cooperatives have emerged as a powerful solution to these challenges, contributing a collective model through which farmers can pool resources, share knowledge, and leverage collective bargaining power to secure better financial terms, access market opportunities, and adopt environmental SF[8–10].

The importance of agricultural cooperatives in addressing rural poverty and promoting SF has been widely acknowledged, especially in developing regions[11]. By organizing farmers into groups, cooperatives reduce individual risks and enhance their members' ability to negotiate better deals with financial institutions, buyers, and input suppliers[12–14]. Furthermore, cooperatives serve as a conduit for disseminating critical MI and adopting SF, essential for improving SF communities' economic and environmental flexibility[15, 16]. These institutions are particularly effective in regions with limited access to formal financial services, up-to-date MI, and SF[17].

This paper explores agricultural cooperatives' role in enhancing access to CA, MI, and SF practices among rural farmers in Kerala. By examining these three critical areas, the study aims to provide visions into how cooperative membership impacts CA, MI, and SF. The research draws on quantitative data collected from cooperative and non-cooperative farmers to assess the impact of cooperative membership on key SF outcomes. The findings will contribute to the growing body of evidence supporting the positive role of agricultural cooperatives in fostering rural development and SF.

2. Background

2.1. Agricultural Cooperatives and CA

Agricultural cooperatives have long played a critical role in improving access to financial services for rural farmers, who frequently face significant barriers when attempting to secure formal CA. Traditional financial institutions, such as banks, hesitate to propose loans to smallholder farmers due to perceived risks, such as fluctuating Crop Yields (CY), market instability, and lack of collateral. This situation is particularly acute in ru-

ral areas where banking infrastructure is weak and financial literacy among farmers remains low. In response to these challenges, agricultural cooperatives have emerged as vital mediators, bridging the gap between farmers and financial institutions by collectively organizing resources, negotiating better loan terms, and providing financial management support [18–20].

One of the primary advantages of agricultural cooperatives is their ability to pool member resources, which enhances their collective bargaining power. Cooperatives can secure larger loans at more favourable interest rates from financial institutions by acting as a group rather than individual farmers applying for CA separately [21–25]. Members' collective loans are distributed based on their requirements and repayment capacities. In many cases, cooperatives also act as guarantors for their members, reducing the financial risk for lenders. This collaborative model improves CA and fosters a sense of shared responsibility, where members are motivated to repay loans on time to maintain the cooperative's reputation and financial stability. The following **Figure 1** shows the structure of cooperative credit institutions.

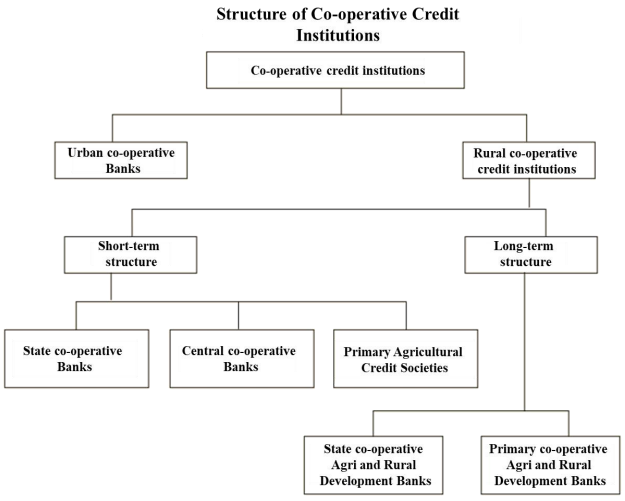

Figure 1. Structure of cooperative credit institutions.

The organizational structure, as depicted in **Figure 1**, depicts the pyramid structure of cooperative credit institutions while focusing on their operational context in extending finance. At the apex level, some institutions, such as state cooperative banks, play the roles of policy formulation, financing, and monitoring for the lower levels. District cooperative banks are intermediaries at the intermediate level; they provide funds to primary societies and pool the financial activities of the region. Primary agricultural credit societies directly address the farmers at the pyramid's base, providing CA services. It thus provides for optimum and equitable use of available resources, outreach, and financial deepening, as well as SF and broader socio-economic development of the agricultural producing regions.

Moreover, agricultural cooperatives frequently provide financial literacy and training programs to their members, which is crucial in ensuring farmers recognize how to manage their loans effectively. These training initiatives protect various features, including budgeting, investment in farm inputs, and financial planning, which help farmers make informed decisions about loan utilization. As a result, farmers who are part of cooperatives tend to have higher financial literacy levels, making them more attractive to formal lenders. This increases the probability of timely loan repayments, further improving their creditworthiness [26].

Additionally, cooperatives frequently facilitate access to microfinance institutions (MFI) and government-backed rural CA schemes. MFI works closely with cooperatives in many developing regions to extend small-scale loans tailored to smallholder farmers' requirements. Cooperatives also serve as conduits for government subsidies and low-interest loans targeted at promoting rural development. By leveraging these partnerships, agricultural cooperatives ensure that their members have continuous access to credit, even during periods of economic uncertainty.

Another key aspect of cooperative-based credit systems is the promotion of investments among members. Many agricultural cooperatives encourage farmers to save regularly by contribution saving schemes that align with the seasonal nature of agriculture. These savings serve as a safety net during difficult times and strengthen the cooperative's financial position, allowing them to propose internal loans to members during the off-season or in case of emergencies. This self-reliant approach helps farmers maintain financial stability and reduces dependence on external credit sources, which may not always be reliable or available [27].

2.2. Cooperatives and MI

Agricultural cooperatives are pivotal in bridging the information gap between rural farmers and broader market dynamics. For smallholder farmers, staying informed about real-time market trends, such as price fluctuations, demand patterns, and emerging opportunities, can be daunting. This lack of access to timely and accurate MI disadvantages farmers, frequently leading to suboptimal decisions regarding the sale of produce or investments in farm inputs. By organizing farmers into collective bodies, agricultural cooperatives are instrumental in overcoming these challenges by acting as key facilitators in disseminating crucial MI.

One of the fundamental functions of cooperatives is to aggregate MI and deliver it to their members in an accessible and actionable format. This aggregation includes real-time updates on local, national, and even international commodity prices, forecasts on market demand, and information on potential buyers and contracts. By providing this info, cooperatives help farmers make more informed decisions on when and where to sell their produce to maximize profits. Farmers in cooperatives are less likely to fall victim to price volatility or exploitative mediators, as they can directly access reliable MI to negotiate better deals for their produce.

In addition to sharing market prices, cooperatives frequently serve as mediators between farmers and buyers. Through collective marketing efforts, cooperatives can negotiate wholesale sales contracts with wholesalers, processors, or exporters, ensuring farmers secure stable prices for their produce. By acting as the central point of contact for more significant market players, cooperatives streamline the process and empower farmers who may otherwise lack the individual capacity to engage with such buyers directly. This collective marketing approach increases the bargaining power of farmers, making it easier for them to access more significant and more lucrative markets.

Moreover, digital technology has revolutionized how cooperatives disseminate MI. Many cooperatives now utilize mobile applications, Short Message Service (SMS) alerts, and online platforms to give farmers real-time updates on market trends and price changes. These digital tools are especially effective in regions where farmers may have limited access to traditional market setups but possess mobile phones. Cooperatives frequently collaborate with governments, Non-Governmental Organizations (NGOs), or private tech companies to deploy these technologies, ensuring that even farmers in remote areas are not left out of the digital information loop. This rapid flow of MI allows farmers to be more agile in responding to market shifts, which can significantly improve their income [28].

Furthermore, agricultural cooperatives frequently act as training and capacity-building centres, equipping their members with the skills to interpret and utilize MI effectively. Training programs organized by cooperatives may cover topics such as price negotiation, Supply Chain Management (SCM), and market diversification strategies. By empowering farmers with the knowledge to analyze market trends and buyer behaviour, cooperatives enhance their members' ability to make strategic decisions that optimize short-term profits and long-term market positioning.

Cooperatives also play a key role in linking farmers to supply chains, prioritizing fair trade and SF, and providing access to niche markets that propose premium prices for products grown under ethical conditions. Many cooperatives are certified under fair trade or organic labels, which enables farmers to tap into consumer segments willing to pay higher prices for sustainably produced goods. By consolidating the produce of their members and adhering to certification standards, cooperatives make it easier for smallholder farmers to participate in these high-value markets, further enhancing their income potential.

Additionally, cooperatives facilitate access to market set-ups such as storage, transportation, and distribution networks. Many rural farmers face difficulties storing their produce post-harvest, leading to degeneration or forced sales at low prices. Cooperatives help by contributing collective storage solutions and transportation services, ensuring farmers can hold their goods until favourable market conditions arise. This collective infrastructure reduces post-harvest losses and allows farmers to take advantage of higher market prices when demand spikes [29].

2.3. SF through Cooperatives

Agricultural cooperatives are at the forefront of promoting SF among rural farmers. As environmental concerns such as soil degradation, water shortage, and climate change increasingly affect SF productivity, adopting SF has become essential for long-term farm viability. Cooperatives are vital in facilitating the transition to SF by pooling resources, providing education and training, and enabling access to technologies that support SF.

One of the primary methods cooperatives boost SF is through collective education and knowledge-sharing initiatives. By organizing workshops, training sessions, and field demonstrations, cooperatives expose their members to various SF, such as crop rotation, Organic Farming (OF), Integrated Pest Management (IPM), and conservation agriculture. These practices help farmers reduce reliance on synthetic fertilizers and pesticides, improve soil health, and enhance biodiversity. Cooperatives also promote using locally available and natural inputs, reducing costs and minimizing environmental harm. Through regular meetings and peer-to-peer learning, cooperatives create an environment where farmers can exchange ideas and experiences, making adopting new methods across the community easier.

Access to eco-friendly technologies is another area where cooperatives are instrumental in advancing SF. For many smallholder farmers, the initial investment required to adopt SF, such as drip irrigation, solar-powered machinery, or OF, can be too costly. Cooperatives, by leveraging their collective buying power, enable farmers to purchase these technologies at reduced prices or through shared ownership models. For example, cooperatives may invest in a communal irrigation system or solar-powered cold storage facility that can be used by all members, ensuring that even the smallest farms can benefit from modern SF. By reducing costs and risks, cooperatives make it feasible for more farmers to engage in SF practices that would otherwise be out of reach.

Cooperatives also facilitate access to financial resources and subsidies to promote SF. Many governments and international organizations propose grants, low-interest loans, or subsidies to farmers who adopt environmentally friendly practices, but accessing these funds can be challenging for individual farmers due to bureaucratic hurdles and lack of awareness. Cooperatives act as intermediaries, navigating these processes on behalf of their members and ensuring that funds are distributed fairly and efficiently. By organizing farmers into a cooperative structure, these organizations are better positioned to meet eligibility norms for SF contributions, allowing a more significant number of farmers to benefit from government and donor support for green practices.

In addition to financial support, cooperatives play a crucial role in advocating for sustainable policies at the local and national levels. Many cooperatives actively engage in policy discussions, pushing for reforms that favor smallholder farmers and incentivising SF. By participating in farmer unions or forming alliances with NGOs, cooperatives amplify the voice of rural farmers in decision-making processes related to land use, water management, and environmental conservation. This advocacy ensures that rural farming communities receive the institutional support needed to make SF more viable and profitable.

Another key contribution of cooperatives to SF is the promotion of certification schemes, such as OF or fair trade certification. Many cooperatives assist their members in obtaining certification for SF products, which allows them to access premium markets that prioritize eco-friendly practices. These certifications frequently come with strict guidelines on chemical usage, labor practices, and environmental organization, encouraging farmers to maintain high SF standards. By collectively organizing the certification process, cooperatives lower the individual burden of compliance while opening up new market opportunities that propose higher financial returns. The cooperative model also allows small-scale farmers to meet the production volumes required for certification, making it easier to compete in international markets.

Moreover, cooperatives frequently emphasize the importance of sustainable water management, which is crucial in regions prone to droughts or water shortages. By promoting efficient irrigation techniques like drip or sprinkler systems, cooperatives help farmers reduce water usage and minimize waste. Cooperatives may also

facilitate the adoption of rainwater harvesting systems or the restoration of traditional water bodies, ensuring farmers have access to water resources throughout the growing season. These practices contribute to environmental conservation, increased farm productivity, and resilience against climate variability.

Lastly, cooperatives foster long-term SF by promoting a sense of community ownership and responsibility for the environment. In many cases, SF requires collective action, such as maintaining shared resources like grazing lands, forests, or water sources. Cooperatives provide the organizational structure for farmers to work together on these initiatives, ensuring that resources are managed SF for the entire community's benefit. This collaborative approach to resource management helps protect the local environment while securing the incomes of future generations [30–35].

3. Methodology

3.1. Conceptual Framework and Hypothesis

The conceptual framework for this study is built around the core functions of agricultural cooperatives and their influence on enhancing access to CA, MI, and SF among rural farmers. Agricultural cooperatives are collective organizations that bridge gaps in CA, MI, and SF, particularly for smallholder farmers. The framework assumes that cooperatives are key facilitators by pooling resources, providing training, and presenting access to otherwise inaccessible services to individual farmers.

The model identifies three primary areas where cooperatives exert influence:

1. **Access to CA:** Cooperatives act as intermediaries between financial institutions and farmers, improving farmers' ability to obtain CA through collective bargaining and shared financial resources. This is hypothesized to lead to higher rates of CA availability and better loan terms for cooperative members.
2. **MI:** Through organized communication channels and collective marketing efforts, cooperatives are posited to enhance farmers' access to real-time MI. This improves farmers' ability to make informed decisions about pricing, timing of sales, and input investments.
3. **SF Practices:** Cooperatives promote SF by providing access to eco-friendly technologies and practices, financial incentives for adopting these practices, and training programs to enhance environmental organization.

The study tests the following hypotheses to evaluate the impact of cooperative membership on rural farmers:

- **H1:** Membership in agricultural cooperatives positively and significantly affects farmers' CA, reflected in increased loan acquisition and favorable borrowing terms.
- **H2:** Membership in agricultural cooperatives positively influences the availability and use of MI, leading to better decision-making regarding MI and cost approaches.
- **H3:** Membership in agricultural cooperatives leads to greater adoption of SF, as evidenced by higher implementation rates of eco-friendly SF compared to non-cooperative members.

This conceptual framework and set of hypotheses guide the quantitative analysis, with data collected from rural farmers in Kerala used to assess the validity of these assumptions. Statistical tests will determine whether cooperative membership significantly impacts CA, MI, and SF results, providing insights into the cooperative model's effectiveness in rural development.

3.2. Study Design

This study employs a quantitative research design to evaluate the impact of agricultural cooperatives on rural farmers' access to CA, MI, and SF in Kerala. The research adopts a cross-sectional survey method, where data was collected at a single point in time from a sample of rural farmers. The study targets members of agricultural cooperatives and non-members to draw comparisons and assess the impact of cooperative membership on the key variables.

The primary data was collected through structured questionnaires designed to measure farmers' CA, the frequency and relevance of MI received, and the extent to which SF has been adopted. These variables were oper-

ationalized into quantifiable indicators, allowing for statistical analysis. The survey also includes demographic and socio-economic factors, such as farm size, income, and education level, to control for external impacts on the study results.

The study sample was drawn from different regions of Kerala, ensuring a representative mix of cooperative members and non-members across several agricultural sectors. A Stratified Random Sampling (SRS) was employed to capture differences in cooperative participation, farm size, and geographic diversity, ensuring the robustness of the results. The quantitative design of the study allows for objective measurement and comparison, aiming to provide empirical evidence on the role of cooperatives in enhancing CA, MI propagation, and SF in rural farming communities.

3.3. Study Region and Sampling

The study was conducted in Kerala, which has a rich history of agricultural cooperatives playing a crucial role in rural development. Kerala's diverse agricultural landscape, ranging from highlands to lowland plains, provides an ideal setting for assessing how cooperatives impact several features of SF, such as CA, MI, and SF. The region's cooperative solid movement, coupled with the presence of a collection of smallholder and medium-scale farmers, proposes valuable visions for the functioning of cooperatives in different agricultural contexts.

Of the 1500 farm households selected, 421 participants were selected based on the ability to get a representative sample to measure variability within the farming people of Kerala. This study employed the SRS to ensure that each of the following factors was considered in proportion to the population: Cooperative membership, geographical location, and farm size. This approach helped the researchers have an adequate diverse sample that captures the heterogeneity of the agriculture space in Kerala to compare the groups and generalize the findings. The selected sample size provides reasonable statistical power to assess cooperative influence on farmers' financial and operational performance.

The SRS employed for this study involved selecting 421 participants, comprising members of agricultural cooperatives and non-members. A stratified random sampling method was used to ensure a representative sample of farmers across different geographic locations and farming sectors within Kerala. Stratification was based on cooperative membership status, geographic region (highland, midland, and coastal areas), and farm size (small, medium, and large-scale farms). This approach included diverse perspectives and experiences, enabling a comparative analysis of cooperative and non-cooperative farmers.

The sample distribution was designed to collect the variation in cooperative participation, ensuring that active cooperative members and non-members were adequately represented. This allows for meaningful comparisons between the two groups regarding CA, exposure to MI, and SF. The sample size of 421 was deemed sufficient for the statistical analysis and generalizability of the findings within the broader context of Kerala's agricultural sector.

3.4. Survey Questionnaire

The survey questionnaire was meticulously structured to align with the hypotheses and gather relevant data for the quantitative analysis. Each question was carefully crafted to measure specific variables related to cooperative membership and its influence on farmers' CA, MI, and SF. For CA, the questionnaire includes questions that assess whether farmers have attained loans recently, the sources of these loans (whether from cooperatives, commercial banks, or informal sources), the size of the loans, and the interest rates applied. This set of questions is designed to evaluate Hypothesis H1, which explores how membership in agricultural cooperatives positively impacts farmers' ability to secure CA and the terms under which they receive financial support.

In the MI section, **Tables 1** and **2** questions focus on how frequently farmers receive updates on market trends, price fluctuations, and demand from various sources, including cooperatives. These questions aim to test Hypothesis H2, which proposes that cooperatives significantly improve farmers' access to timely and relevant MI, enabling them to make better decisions about when and where to sell their produce. For adopting SF, the questionnaire includes items that examine the extent to which farmers implement eco-friendly methods

such as OF, crop rotation, and water conservation. These questions are directly linked to Hypothesis H3, which posits that cooperatives play a vital role in promoting SF practices by present education, resources, and incentives.

The questionnaire was validated using several key metrics to ensure reliability and internal consistency. The Cronbach's Alpha score for the Likert scale items was 0.85, indicating good internal consistency, meaning that the questions align well with one another and reliably measure the same constructs, such as access to CA, MI, and SF. The Item-Total Correlation ranged between 0.45 and 0.70, showing that individual items contribute meaningfully to the overall scale, with no weak or irrelevant questions.

Table 1. Questionnaire.

Question No.	Question	Type	Hypothesis
1	Have you obtained a loan for SF purposes in the last two years?	Yes/No	H1
2	What was the source of the loan? (Cooperative Bank, Commercial Bank, Informal Source, Other)	Open-Ended (Value)	H1
3	How satisfied are you with the loan terms provided by your cooperative?	Likert (1-5)	H1
4	Cooperative membership has improved my ability to secure financial resources for farming.	Likert (1-5)	H1
5	Have you ever been denied a loan by your cooperative?	Yes/No	H1
6	How frequently do you receive market price updates from your cooperative?	Likert (1-5: Never-Always)	H2
7	How do you usually receive MI? (e.g., meetings, SMS, newsletters)	Open-Ended (Value)	H2
8	The MI provided by the cooperative has helped me improve my sales approach.	Likert (1-5)	H2
9	How useful do you find the MI provided by your cooperative?	Likert (1-5)	H2
10	Have you participated in cooperative-organized MI sessions in the last year?	Yes/No	H2
11	I have adopted SF due to training or guidance from my cooperative.	Likert (1-5)	H3
12	What specific SF have you adopted?	Open-Ended (Value)	H3
13	The cooperative provides adequate training on SF methods	Likert (1-5)	H3
14	How frequently do you implement SF introduced by the cooperative?	Likert (1-5: Never-Always)	H3
15	Has your cooperative presented financial support specifically for SF?	Yes/No	H3
16	I have observed economic benefits from using SF promoted by the cooperative.	Likert (1-5)	H3
17	How likely are you to continue or expand your use of SF in the future due to cooperative support?	Likert (1-5)	H3
18	Do you plan to expand your SF practices in the coming year?	Yes/No	H3
19	Has adopting SF practices impacted your farm's productivity or profitability?	Yes/No	H3
20	Cooperative membership has significantly improved my overall farm management.	Likert (1-5)	H1/H2/H3

Table 2. Validation Metrics for the Questionnaire.

Metric	Description	Score	Interpretation
Cronbach's Alpha	Measures internal consistency of Likert scale items across sections (CA, MI, SF).	0.85	Good internal consistency
Item-Total Correlation	Correlation between each question and the total score to check how well each item fits the overall scale.	0.45–0.70	Acceptable to strong correlation per item
Test-Retest Reliability	Measures the stability of responses over time by administering the same questionnaire twice.	0.80	Good reliability (stable responses)
Inter-Item Correlation	Examines the correlation between individual items to ensure they measure the same construct.	0.40–0.60	Moderate, acceptable correlation between items
Content Validity Index (CVI)	Measures the relevance of each question to the overall construct based on expert review.	0.90	High content validity
Construct Validity	Assesses how well the questions measure the theoretical construct (e.g., CA or SF).	0.88	Strong construct validity

To assess the stability of the responses over time, a Test-Retest Reliability score of 0.80 was achieved, suggesting that the questionnaire produces consistent results when administered on multiple occasions. The Inter-Item Correlation values, ranging from 0.40 to 0.60, indicate that the questions are moderately related, ensuring they measure the same constructs without being redundant. Based on an expert review, the CVI was 0.90, reflecting high content validity and agreement on the relevance of each question. Finally, a CVI of 0.88 demonstrates that the questionnaire effectively measures the intended theoretical constructs, confirming its robustness as a data collection tool.

3.5. Analysis Techniques

The data collected from the survey is analyzed using descriptive and inferential statistical techniques to assess the impact of agricultural cooperatives on access to CA, MI, and SF. The analysis compares cooperative members and non-members across the three key variables.

A. Descriptive Statistics

Initially, basic descriptive statistics such as mean, median, standard deviation, and frequency distributions will be considered for each variable. This will provide an overview of the characteristics of the sample, including loan sizes, market update frequency, and SF practices' adoption rates. Descriptive statistics will also help to summarize the general trends and patterns observed in the data.

B. T-tests and Chi-Square Tests

To compare the differences between cooperative members and non-members, independent t-tests will be employed for continuous variables such as loan size and frequency of market updates. For categorical variables like "adoption of SF" (Yes/No), Chi-square tests will be used to determine if the two groups have statistically significant differences.

For example, the t-test will follow the equation:

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}} \quad (1)$$

where $\overline{X}_1$ and $\overline{X}_2$ are the means of the two groups (cooperative members and non-members), and S_1^2 and S_2^2 are their respective variances, with n_1 and n_2 representing the sample sizes.

C. Regression Analysis

To assess the impact of cooperative membership on the three key results of CA, MI, and SF, Linear Regression (LR) models will be applied for continuous dependent variables. In contrast, logistic regression will be used for binary outcomes, such as adopting SF (Yes/No). The regression models will control for farm size, income, and education level variables. The general form of the LR will be:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \in \quad (2)$$

where Y represents the dependent variable (e.g., CA), $X_1, X_2, \ldots, X_n$ represent independent variables (*e.g.,* cooperative membership, farm size), $\beta_1, \beta_2, \ldots, \beta_n$ are the coefficients, and $\in$ is the error term.

D. Correlation Analysis:

Pearson correlation will be used to analyze the relationships between continuous variables, such as loan size and farm productivity. The correlation coefficient 'r' will show how strongly these variables are related.

For example, the equation for Pearson correlation is:

$$r = \frac{\sum \left(X_i - \overline{X}\right)\left(Y_i - \overline{Y}\right)}{\sqrt{\sum \left(X_i - \overline{X}\right)^2 \sum \left(Y_i - \overline{Y}\right)^2}} \quad (3)$$

where X_i and Y_i represent the data points for two continuous variables, and $\overline{X}$ and $\overline{Y}$ are their means.

E. Statistical Significance

The level of statistical significance will be set at $p < 0.05$. Results will be interpreted based on whether the $P-v$alue falls below this threshold, indicating significant differences or relationships between cooperative members and non-members regarding the outcomes measured.

Correlation and regression are two statistical methods which bear similar relationships but are used for different purposes. Whereas regression analyses find the nature of the relationship between two or more variables, correlation proposes a simple index of the magnitude and direction of an LR and permits an evaluation of whether two variables are positively or negatively related. Pearson's correlation coefficient is most frequently employed in exploratory analysis to find out

if there is any correlation before the construction of a regression equation. The correlation helps to check assumptions for regression, like checking for multicollinearity, which, if not dealt with, can complicate the conclusion of a regression. It is also used in the feature selection steps to show the best independent variables for the dependent variable. Also, correlation may confirm the stability of relations across data sets or time, as needed for the validity of a model before the regression analysis. The correlation analysis is still helpful for initial data examination, choosing variables of interest, and preparing data for regression most of the time.

4. Result Analysis

Thus, this study's target population is based on farmers who are not part of the agricultural cooperatives and those who are part of the cooperatives. In this method, the author guarantees a comparative perspective on the effects of cooperative membership on financial knowledge, CA, and SF. People joining cooperatives make business decisions since they are part of a collective that benefits from cooperation; they receive training, and thus, they are the best to give feedback on how effective cooperatives are. Those non-members are also selected to compare market access and financial status results. The cross-sectional nature of the respondents and the consideration of demographic and geographic factors guarantee the coverage of the cooperative impact on different types of SF. Focusing on smallholder farmers, especially those in rural areas, shows the problems and possibilities of this group. The study limits its sample to those directly engaging in the agricultural sector to guarantee that the results are helpful for policymakers and other participants interested in enhancing cooperation-based arrangements and rural development. From **Table 3** SRS aligns with the study's aim of assessing how cooperatives provide solutions to organized and market vulnerabilities towards SF.

The demographic and socio-economic profile of the 421 participants provide essential context for understanding the characteristics of farmers in the study. The participants have an average age of 43.82 years (SD = 11.27), indicating that most farmers are middle-aged. A closer look at the age distribution shows that 28.50% of participants are between the ages of 41 and 50, making this the most represented age group, followed by those aged 31–40 years (25.65%) and 51–60 years (21.62%). Only 17.34% are younger than 30 years, and 6.89% are older than 60, suggesting that a significant portion of farmers are in their prime working years, with relatively fewer younger or older individuals engaged in SF.

In terms of gender, the sample is predominantly male, with 65.08% Male and 34.92% Female. This indicates a gender imbalance, which is common in many agricultural contexts where men frequently dominate SF roles while women may play supportive or secondary roles in certain regions. The participants' education levels reveal a broad distribution of formal education, with 33.97% having completed secondary education, the largest educational group. Additionally, 30.87% have achieved higher education, indicating that a considerable portion of the population has access to more advanced learning. However, 25.18% of participants have only primary education, and 9.98% have no formal education, highlighting a substantial variation in educational background that could impact farm management practices and decision-making.

The average farm size is 2.13 hectares (SD = 1.74), but the distribution shows that most participants have relatively small farms, with 38.48% of farms falling in the 1–2 hectare range and 22.09% operating on less than 1 hectare. Larger farms, over 4 hectares, are less common, representing only 13.55% of the sample. This reflects an SF landscape where smallholder agriculture dominates, which could impact the types of SF practices and financial needs of these farmers. In terms of annual farm income, the average income is 164,732.48 local currency units (SD = 68,501.92), with incomes ranging from 45,892 to 299,526. A considerable portion of the sample (32.54%) earns between 100,001 and 150,000 units annually, while 24.47% earn less than 100,000 units, indicating economic diversity. Farmers with higher incomes, over 200,001 units, represent 21.14% of the sample. This income distribution highlights the variability in economic capacity among the farmers, with implications for their access to CA, SF, and investment in farm improvements.

Table 3. Descriptive Analysis – Demographic and Socio-Economic Profile & Cooperative Membership.

Variable	N	Mean	Standard Deviation (SD)	Min	Max	Frequency Distribution (%)
Age (years)	421	43.82	11.27	22	68	< 30 years: 17.34% 31–40 years: 25.65% 41–50 years: 28.50% 51–60 years: 21.62% > 60 years: 6.89%
Gender	421	-	-	-	-	Male: 65.08% Female: 34.92%
Education Level	421	-	-	-	-	No Formal Education: 9.98% Primary Education: 25.18% Secondary Education: 33.97% Higher Education: 30.87%
Farm Size (hectares)	421	2.13	1.74	0.30	8.56	< 1 hectare: 22.09% 1–2 hectares: 38.48% 2–4 hectares: 25.89% > 4 hectares: 13.55%
Annual Farm Income (local currency)	421	164,732.48	68,501.92	45,892	299,526	< 100,000: 24.47% 100,001–150,000: 32.54% 150,001–200,000: 21.85% > 200,001: 21.14%
Cooperative Membership	421	-	-	-	-	Cooperative Members: 61.33% Non-Members: 38.67%

Finally, the analysis of cooperative membership shows that the majority of participants (61.33%) are members of agricultural cooperatives, while 38.67% are non-members. This distribution provides a solid basis for comparing the impact of cooperative membership on various factors, such as access to CA, MI, and SF. The substantial representation of cooperative members in the study reflects the importance of cooperatives in the agricultural sector and sets the stage for an in-depth analysis of their role in enhancing SF outcomes.

4.1. Analysis of CA (H1)

As shown in **Table 4**, the analysis of loan access reveals a significant difference between cooperative members and non-members. A substantial 72.09% of cooperative members obtained loans in the past 2 years, compared to only 45.40% of non-members. This difference is statistically significant, with a p-value < 0.001, indicating that cooperative membership positively influences farmers' ability to secure loans. Regarding mean loan size, cooperative members received an average loan of 137,892.61 local currency units, whereas non-members received a significantly smaller average loan of 98,541.73. The *t*-value of 5.39 and p-value < 0.001 further confirm that cooperative members receive larger loans, highlighting the financial rewards of cooperative membership. The standard deviation for loan size is higher among cooperative members (43,915.23) compared to non-members (30,748.96), reflecting more significant variability in loan amounts received by cooperative members. This could indicate that cooperative members can access a broader range of loan sizes, potentially due to collective bargaining power or better financial support through the cooperative system.

Regarding satisfaction with loan terms, the distribution of responses reveals that cooperative members are generally more satisfied than non-members. As illustrated in **Table 5**, only 5.81% of cooperative members report being "Very Dissatisfied" with their loan terms, compared to 15.34% of non-members. The most significant proportion of cooperative members (40.70%) reported being "Satisfied" with their loan terms, compared to only 25.15% of non-members. A significant difference is also seen in the "Very Satisfied", with 15.89% of cooperative members expressing high satisfaction compared to 8.28% of non-members. The Chi-Square value of 18.34 and p-value < 0.001 confirm that the difference in satisfaction levels between cooperative members and

Table 4. Loan Access Comparison (H1).

Variable	Cooperative Members (N = 258)	Non-Members (N = 163)	t-Value	p-Value
Percentage Obtained Loans	72.09% (186/258)	45.40% (74/163)	-	< 0.001 **
Mean Loan Size (local currency)	137,892.61	98,541.73	5.39	< 0.001 **
Standard Deviation (Loan Size)	43,915.23	30,748.96	-	-
Minimum Loan Size	56,382	32,562	-	-
Maximum Loan Size	244,196	174,536	-	-

Table 5. Satisfaction with Loan Terms (H1) – Likert Scale Comparison.

Satisfaction with Loan Terms	Cooperative Members (%)	Non-Members (%)
1 (Very Dissatisfied)	5.81%	15.34%
2 (Dissatisfied)	12.79%	20.86%
3 (Neutral)	24.81%	30.67%
4 (Satisfied)	40.70%	25.15%
5 (Very Satisfied)	15.89%	8.28%
Chi-Square Value	18.34	-
p-value	<0.001	-

non-members is statistically significant, with cooperative members reporting higher satisfaction.

As summarized in **Table 6**, the multiple LR analysis shows that cooperative membership positively impacts loan size, with cooperative members receiving 41,382.14 more in loans on average than non-members ($p < 0.001$). The model also accounts for other factors, such as farm size and annual income. For every additional hectare of farm size, the loan size increases by 9,254.36 units ($p < 0.001$), and for every unit increase in annual income, the loan size increases by 0.39 units ($p < 0.001$). The model explains approximately 47.2% of the variance in loan size, indicating that cooperative membership, farm size, and income are essential determinants of loan access. This further supports the notion that cooperative membership is crucial in improving rural farmers' CA.

Table 6. Multiple LR Analysis – Impact of Cooperative Membership, Farm Size, and Income on Loan Size (H1).

Variable	Coefficient (β)	Standard Error	t-Value	p-Value
Constant	56,532.81	10,715.32	5.28	<0.001 **
Cooperative Membership	41,382.14	6,954.17	5.95	<0.001 **
Farm Size (hectares)	9,254.36	2,547.58	3.63	<0.001 **
Annual Income	0.39	0.04	9.88	<0.001 **
R-squared	0.472	-	-	-

4.2. Analysis of MI (H2)

As shown in **Table 7**, the frequency of MI updates is significantly higher among cooperative members than non-members. On a 5-point Likert scale, cooperative members reported a mean score of 4.21, indicating they frequently receive market updates, whereas non-members had a much lower mean score of 3.12. The t-value of 8.43 and p-value < 0.001 confirm this difference is statistically significant. The standard deviation was slightly lower for cooperative members (0.76) compared to non-members (0.94), indicating more consistent responses among cooperative members regarding the frequency of updates they receive.

Regarding MI sources, **Table 8** shows that 67.83% of cooperative members primarily rely on cooperative networks for MI, while only 11.96% of non-members use this source. On the other hand, non-members rely more on private buyers (34.36%) and digital plat-

forms (26.07%) for MI. Many non-members also depend on government agencies (27.61%), compared to only 9.30% of cooperative members. These results suggest that cooperative members benefit significantly from internal cooperative communication, while non-members are more reliant on external and possibly less reliable sources of MI.

Table 7. Frequency of MI Updates (H2) – Likert Scale Comparison.

Frequency of MI Updates	Cooperative Members (N = 258)	Non-Members (N = 163)	t-Value	p-Value
Mean Score (Likert Scale 1–5)	4.21	3.12	8.43	< 0.001 **
Standard Deviation	0.76	0.94	-	-

Table 8. Sources of MI – Breakdown by Source (H2).

Source of MI	Cooperative Members (%)	Non-Members (%)
Cooperative Networks	67.83%	11.96%
Private Buyers	12.79%	34.36%
Government Agencies	9.30%	27.61%
Digital Platforms (e.g., SMS, apps)	10.08%	26.07%

As shown in **Table 9**, cooperative members are more likely to change their sales approaches based on MI, with 58.14% reporting such changes compared to only 31.29% of non-members. The Chi-Square value of 24.72 and p-value < 0.001 indicate this difference is statistically significant. This proposes that the MI provided by cooperatives reaches their members more frequently and influences decision-making and strategy changes, resulting in better market outcomes for cooperative members.

Table 9. Impact of MI on Sales Strategy (H2) – Chi-Square Test.

Change in Sales Strategy Based on MI	Cooperative Members (%)	Non-Members (%)	Chi-Square Value	p-Value
Yes	58.14%	31.29%	24.72	< 0.001 **
No	41.86%	68.71%	-	-

The logistic regression analysis in **Table 10** demonstrates the significant impact of cooperative membership on the probability of using MI. Cooperative members are 4.16 times more likely to use MI than non-members ($p < 0.001$), controlling for other factors like farm size, income, and education. Additionally, larger farm sizes slightly increase the probability of using MI (Odds Ratio = 1.39, $p = 0.043$), while higher annual income (Odds Ratio = 1.01, $p < 0.001$) and education levels (Odds Ratio = 1.53, $p = 0.008$) are also significant positive predictors. The pseudo-R-squared value of 0.278 indicates that the model explains around 27.8% of the variance in the likelihood of using MI, highlighting the critical role of cooperative membership and demographic factors in shaping how farmers access and utilize MI.

4.3. Analysis of SF (H3)

As shown in **Table 11**, cooperative members are significantly more likely to adopt SF than non-members. A substantial 69.77% of cooperative members have adopted SF practices, whereas only 42.94% of non-members have. The Chi-Square value of 27.56 and p-value<0.001 indicate that this difference is statistically significant, highlighting cooperatives' role in promoting environmentally friendly SF among their members.

Regarding the types of SF adopted, **Table 12** shows that cooperative members are likelier to implement var-

Table 10. Logistic Regression – Probability of Using MI Based on Cooperative Membership and Demographic Factors (H2).

Variable	Odds Ratio (Exp β)	Standard Error	z-value	p-value
Cooperative Membership	4.16	0.82	6.21	<0.001 **
Farm Size (hectares)	1.39	0.24	2.02	0.043 *
Annual Income	1.01	0.002	3.98	<0.001 **
Education Level	1.53	0.34	2.67	0.008 **
Constant	0.48	0.11	-3.49	<0.001 **
Pseudo R-squared	0.278	-	-	-

Table 11. Adoption of SF Practices – Chi-Square Test (H3).

Adoption of SF Practices	Cooperative Members (%)	Non-Members (%)	Chi-Square Value	p-value
Yes	69.77%	42.94%	27.56	< 0.001 **
No	30.23%	57.06%	-	-

ious SFs than non-members. For example, 36.82% of cooperative members practice OF, compared to 18.40% of non-members. Similarly, cooperative members engage in crop rotation (51.55%) and water conservation (43.02%) at significantly higher rates than non-members, who adopt these SF at 28.22% and 23.93%. Practices such as renewable energy and IPM are more prevalent among cooperative members. These results suggest that cooperatives encourage adopting SF and diversify the range of practices their members can implement.

Table 12. Types of SF Practices Adopted by Cooperative Members vs. Non-Members (H3).

Type of SF	Cooperative Members (%)	Non-Members (%)
OF	36.82%	18.40%
Crop Rotation	51.55%	28.22%
Water Conservation	43.02%	23.93%
Use of Renewable Energy in Farming	21.71%	10.43%
IPM	30.62%	14.72%

Table 13 compares the perceived economic benefits of adopting SF as measured on a 5-point Likert scale. Cooperative members reported a mean score of 4.12, indicating substantial perceived economic benefits, whereas non-members reported a lower mean score of 3.45. The t-value of 6.78 and p-value < 0.001 demonstrate that this difference is statistically significant. The standard deviation for cooperative members (0.86) is lower than for non-members (1.07), indicating more consistency in cooperative members' responses regarding the economic benefits of adopting SF. This finding suggests cooperative members adopt SF more frequently and perceive greater economic returns.

The logistic regression analysis in **Table 14** further confirms the significant impact of cooperative membership on the probability of adopting SF. Cooperative members are 3.67 times more likely to adopt SF than non-members ($p < 0.001$), controlling for farm size, income, and education level. Larger farms are also more likely to adopt SF (Odds Ratio = 1.43, $p = 0.033$), and higher annual income significantly increases the probability of adopting SF (Odds Ratio = 1.02, $p < 0.001$). Additionally, education plays a key role, with more educated farmers being 1.56 times more probable to adopt SF practices ($p = 0.004$). The model explains 30.9% of the variance in adopting SF, as indicated by the pseudo-R-squared value 0.309.

4.4. Correlation Analysis

As shown in **Table 15**, the correlation between loan size and farm productivity is positive and statistically sig-

Table 13. Economic Benefits of SF Practices – Likert Scale Comparison (H3).

Perceived Economic Benefits of SF	Cooperative Members (N = 258)	Non-Members (N = 163)	t-Value	p-Value
Mean Score (Likert Scale 1–5)	4.12	3.45	6.78	< 0.001 **
Standard Deviation	0.86	1.07	-	-

Table 14. Logistic Regression – Impact of Cooperative Membership on the Adoption of SF Practices (H3).

Variable	Odds Ratio (Exp β)	Standard Error	z-Value	p-Value
Cooperative Membership	3.67	0.78	5.34	<0.001 **
Farm Size (hectares)	1.43	0.27	2.14	0.033 *
Annual Income	1.02	0.003	5.12	<0.001 **
Education Level	1.56	0.36	2.89	0.004 **
Constant	0.52	0.13	−3.14	0.002 **
Pseudo R-squared	0.309	-	-	-

nificant. The correlation coefficient (r = 0.43) indicates a moderate positive relationship between the size of loans farmers receive and SF productivity, measured as kilograms of yield per hectare. This suggests that farmers can increase their productivity by securing larger loans. The p-value < 0.001 confirms that this relationship is statistically significant, implying that access to larger loans may facilitate investment in inputs like fertilizers, better seeds, or technology, leading to higher productivity. The mean loan size is 123,654.78 local currency units, with a standard deviation of 39,876.12, reflecting some variability in loan amounts across the sample. Farm productivity has a mean of 2,487.62 kg/hectare, indicating diverse productivity levels, possibly influenced by factors such as farm size, crop type, and the effectiveness of loan utilization.

Table 15. Correlation between Loan Size and Farm Productivity.

Variable	Mean	Standard Deviation	Correlation Coefficient (r)	p-Value
Loan Size (local currency)	123,654.78	39,876.12	0.43	< 0.001 **
Farm Productivity (kg/hectare)	2,487.62	597.89	-	-

Similarly, **Table 16** shows the correlation between the adoption of SF and farm income, revealing a moderate-to-strong positive relationship. The correlation coefficient (r = 0.49) proposes that farmers who adopt SF practices tend to have higher farm incomes. The p-value < 0.001 confirms that this relationship is statistically significant, meaning that adopting practices such as OF, water conservation, and crop rotation is linked to improved economic performance for farmers. This may be due to increased crop yields, cost savings from resource efficiency, and access to premium markets that reward environmental SF. The mean farm income for the sample is 164,732.48 local currency units, with a standard deviation of 68,501.92, showing a wide range of income levels, which could be influenced by the degree of SF adoption and market conditions.

4.5. Hypothesis Testing

As shown in **Table 17**, statistical significance was tested across various analyses using t-tests, Chi-square tests, and regression models, with the threshold for significance set at p<0.05. In every analysis, the p-values were well below this threshold, confirming the statistical significance of the results. For example, comparing loan access between cooperative members and non-members yielded a p-value < 0.001, indicating a significant difference in the probability of obtaining loans. Similarly, the mean loan size for cooperative members was significantly higher than non-members (p < 0.001), reinforcing the idea that cooperative membership positively

Table 16. Correlation between Adoption of SF and Farm Income.

Variable	Mean	Standard Deviation	Correlation Coefficient (r)	p-Value
Adoption of SF Practices **(0 = No, 1 = Yes)**	0.57	-	0.49	<0.001 **
Farm Income (local currency)	164,732.48	68,501.92	-	-

Table 17. Summary of P-values from Different Analyses.

Analysis	Test Type	p-Value	Significance (p < 0.05)
Loan Access Comparison	t-test	< 0.001 **	Significant
Mean Loan Size (Cooperative Members vs. Non-Members)	t-test	< 0.001 **	Significant
Satisfaction with Loan Terms	Chi-square test	< 0.001 **	Significant
Frequency of MI Updates	t-test	< 0.001 **	Significant
Impact of MI on Sales Approach	Chi-square test	< 0.001 **	Significant
Adoption of SF	Chi-square test	< 0.001 **	Significant
Economic Benefits of SF	t-test	< 0.001 **	Significant
Correlation: Loan Size and Farm Productivity	Pearson correlation	< 0.001 **	Significant
Correlation: SF and Farm Income	Pearson correlation	< 0.001 **	Significant
Regression: Impact of Cooperative Membership on Loan Size	Multiple regression	< 0.001 **	Significant
Regression: Likelihood of Using MI	Logistic regression	< 0.001 **	Significant
Regression: Adoption of SF	Logistic regression	< 0.001 **	Significant

**mean value

impacts financial access.

In analyzing MI access, the frequency of updates and their impact on sales strategy significantly differed between cooperative members and non-members, with p-values<0.001. Likewise, adopting SF was significantly more prevalent among cooperative members, with a Chi-square value and p-value that further emphasized the strong relationship between cooperative membership and environmental SF.

As summarized in **Table 18**, the results from the numerous statistical tests were used to validate or refute the study's three main hypotheses:

- **H1: Impact of Cooperatives on CA:** Cooperative members were significantly more likely to obtain loans, receive larger loans, and express greater satisfaction with loan terms than non-members. The results from the t-tests, Chi-square tests, and regression models all yielded p-values<0.001, leading to the conclusion that H1 is validated.
- **H2: Impact of Cooperatives on MI Access:** Cooperative members received MI more frequently and were likelier to use this information to adjust their sales strategies. The analyses showed statistically significant differences in the frequency and impact of MI, with p-values<0.001, supporting the conclusion that H2 is validated.
- **H3: Impact of cooperatives on adopting SF:** **Cooperative members were likelier** to adopt SF and reported more significant perceived economic benefits from these practices. The Chi-square and regression analyses confirmed the significant relationship between cooperative membership and adopting SF practices, with p-values < 0.001, validating H3.

5. Conclusion and Future Work

This study highlights the significant role that agricultural cooperatives play in enhancing rural farmers' access to CA, MI, and SF. The findings demonstrate that cooperative membership gives farmers a distinct advantage, enabling them to secure larger loans with more favorable terms, access critical MI, and adopt environmentally friendly SF. By pooling resources and collective bargaining power, cooperatives bridge the gap between smallholder farmers and formal financial institutions, improving CA and fostering financial resilience. The study highlights cooperatives' pivotal role in market participation, as members receive more frequent and reliable MI, allowing them to make informed decisions about pricing and sales approaches. This access to real-time MI empowers cooperative members to navigate market volatility more effectively than non-members. Furthermore, cooperatives actively promote

Table 18. Hypothesis Testing Summary.

Hypothesis	Test Type	Key Findings	Statistical Test Results	Conclusion
H1: Impact of Cooperatives on CA	T-test, Chi-square, Regression	Cooperative members are more likely to obtain loans, receive larger loans, and show higher satisfaction with loan terms.	Loan Access (t-test): $p < 0.001$ Mean Loan Size (t-test): $p < 0.001$ Satisfaction (Chi-Square): $p < 0.001$ Loan Size (Regression): $p < 0.001$	H1 Validated
H2: Impact of cooperatives on MI access	T-test, Chi-square, Regression	Cooperative members receive MI more frequently and are likelier to use it to change their sales strategy.	Frequency of Info (t-test): $p < 0.001$ Sales Strategy (Chi-square): $p < 0.001$ MI Use (Regression): $p < 0.001$	H2 Validated
H3: Impact of cooperatives on the adoption of SF	Chi-square, Regression	Cooperative members are likelier to adopt SF and perceive more significant economic benefits.	SF (Chi-square): $p < 0.001$ SF (Regression): $p < 0.001$	H3 Validated

the adoption of SF through training, collective resources, and financial support, leading to better environmental stewardship and higher economic returns for farmers engaged in eco-friendly practices.

The study finds that agricultural cooperatives are essential in improving smallholder farmers' financial literacy and CA levels. Members are provided with appropriate training in Budgeting, Investment & financial planning, thus enhancing creditworthiness & reliability regarding repayments. Cooperatives also act as gateways through which members attain CA from microfinance institutions and government-sponsored rural credit facilities where credit is always available. Through MI and making pooled purchases, cooperatives assist farmers with better market amenities and achievable costs. The cooperatives support SF by providing inputs, training, and distribution of SF and supporting smallholder farmers in accessing subsidies and certifications for high-value markets. These initiatives taken together enhance the financial position and market standing of farmers.

These findings suggest that policymakers and development agencies should continue to support and strengthen agricultural cooperatives as part of broader strategies to enhance rural agricultural productivity, sustainability, and resilience in the face of economic and environmental challenges.

Author Contributions

Conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing—original draft preparation, writing—review and editing, visualization, supervision.; project administration, funding acquisition, S.H.N., S.N., W.G.T., B.K.S., R.V., A.V., R.K.B. All authors have read and agreed to the published version of the manuscript.

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