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Determinants of Smallholder Farmers' Adoption of Integrated Poultry and Fish Farming Systems: Evidence from Sidama Region, Ethiopia

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Abstract

Integrated poultry–fish farming (IPFF) offers considerable potential to enhance resource-use efficiency, diversify agricultural production, and strengthen the livelihoods and climate resilience of smallholder farmers. However, empirical evidence regarding the micro-level correlates of IPFF adoption remains scarce in Ethiopia. This study evaluates the adoption status of IPFF and identifies the socioeconomic, farm-level, and institutional factors associated with household adoption decisions. A cross-sectional survey was conducted among 253 randomly selected smallholder farming households in southern Ethiopia. Primary data were gathered using a structured questionnaire and analyzed through descriptive statistics, independent-samples t-tests, Pearson's chi-square tests, and a multivariable binary logistic regression model. Overall, 49.8% of the sampled households had adopted IPFF. The econometric results reveal that household size ($p = 0.050$), perceived profitability ($p = 0.025$), and technical awareness of IPFF ($p = 0.028$) were positively and significantly associated with adoption, while sex of the household head ($p = 0.100$) and farming experience ($p = 0.089$) exhibited weak positive associations. Perceived relative advantage and technical familiarity emerge as primary correlates of technology uptake. These findings indicate that IPFF adoption co-occurs more strongly with family labor capacity, experiential knowledge, technical awareness, and expected economic gains than with physical asset endowments or conventional institutional support in isolation. Interventions aimed at promoting IPFF should prioritize practical technical training, demonstration ponds, peer-to-peer learning networks, localized enterprise budgeting, and gender-responsive extension frameworks.

Keywords: Integrated poultry-fish farming; Technology adoption; Smallholder agriculture; Livelihood diversification; Ethiopia

1. Introduction

Agriculture remains the primary engine of rural livelihoods, employment, and food security across developing nations, particularly in Sub-Saharan Africa where smallholder farming systems dominate agricultural landscapes (Lowder et al., 2021; Cohn et al., 2017; Struik & Kuyper, 2017). However, these farming systems face intensifying pressures from declining natural resources, acute climate variability, escalating input costs, market instability, and persistent barriers to accessing improved agricultural technologies (Cohn et al., 2017; Pretty et al., 2018). These challenges underscore the urgent necessity for sustainable agricultural strategies that enhance productivity, optimize resource-use efficiency, diversify household income streams, and build climate resilience (Struik & Kuyper, 2017; Bhagat et al., 2024). Integrated farming systems (IFS), which combine mutually supportive agricultural enterprises within a single production unit, have emerged as a viable path toward sustainable intensification, efficient nutrient cycling, and improved food security (Pretty et al., 2018; Bhagat et al., 2024).

Integrated poultry–fish farming (IPFF) represents a critical pathway within sustainable intensification strategies by establishing direct biological and economic linkages between livestock and aquaculture operations (Sun & Chen, 2014; Prein, 2002). Grounded in nutrient recycling, IPFF utilizes poultry manure as an organic fertilizer for fish ponds, reducing reliance on expensive external inputs while boosting overall

farm productivity (Sun & Chen, 2014; Sharma & Leung, 2000). Beyond resource efficiency, IPFF yields substantial socioeconomic benefits, including elevated household consumption of animal-source proteins, diversified revenue streams, rural employment generation, and increased buffer capacity against production and market shocks (Bhagat et al., 2024; Prein, 2002). Empirical evidence across several Asian countries such as China, Vietnam, Bangladesh, India, and Thailand, demonstrates that integrating aquaculture into livestock and crop systems significantly enhances smallholder income, nutrient recycling, and food security (Prein, 2002; Sharma & Leung, 2000). These successes offer vital benchmarks for regions like Sub-Saharan Africa, where resource scarcity and climate vulnerabilities severely impact rural communities (Lowder et al., 2021; Bhagat et al., 2024).

In Ethiopia, livestock and poultry production are integral to rural livelihoods, serving essential functions in household food security, capital accumulation, and income generation (Shapiro et al., 2017; FAO, 2019). Poultry production offers significant opportunities for income generation due to its low capital requirements, brief production cycles, high economic turnover, and accessibility for women and youth (FAO, 2019). Concurrently, Ethiopia possesses vast inland water resources with high aquaculture potential (Tesfaye & Wolff, 2014; FAO, 2022). Despite these favorable conditions, domestic fish production remains markedly lower than national demand, constrained by structural bottlenecks such as limited technical knowledge, inadequate extension coverage, poor market infrastructure, and low adoption rates of modern practices (FAO, 2022; Meijer et al., 2015).

The successful adoption of integrated technologies like IPFF depends on farmers' perceptions and their socioeconomic, institutional, and resource capacities (Kassie et al., 2013; Meijer et al., 2015). Rogers' Diffusion of Innovations (DOI) theory provides a robust theoretical foundation for understanding adoption mechanisms through perceived technological attributes: relative advantage, compatibility, complexity, trialability, and observability (Kassie et al., 2013). In this study, Rogers' conceptualization is directly integrated into the empirical design: (i) Perceived relative advantage is operationalized via perceived profitability, (ii) Complexity and observability are captured through technical awareness and accumulated farming experience, and (iii) Compatibility is aligned with family labor availability (household size) and resource endowments.

These attributes interact dynamically with farm-level constraints and institutional factors including formal education, family labor availability, access to credit, extension contacts, and market proximity (Meijer et al., 2015; Shitaye et al., 2024). While empirical research in Ethiopia has largely focused on single-technology adoption decisions such as improved crop varieties, soil conservation, or isolated poultry/aquaculture production (Kassie et al., 2013; Tadesse & Assefa, 2025; Neway & Zegeye, 2022; Teklewold et al., 2013), there is a critical empirical gap regarding the joint adoption determinants of combined poultry–fish systems (Prein, 2002; Kassie et al., 2013).

To address this knowledge gap, this study examines the factors associated with smallholder farmers' adoption of IPFF in the Sidama Region of Ethiopia. Specifically, it assesses the extent of IPFF adoption and identifies the primary socioeconomic, institutional, and farm-level factors correlated with smallholder decision-making. By integrating Rogers' conceptual framework alongside quantitative logit modeling, this research provides empirical insights to guide policymakers, extension services, and agricultural organizations in designing targeted strategies to scale sustainable integrated farming systems in Ethiopia.

2. Methodology

2.1. Study Area

The study was conducted in the Hawassa Zuria (Lida 01 and Nuure Dulecha Kebeles) and Dara Otilicho (Shoicho and Buna Tawaba Kebeles) districts of the Sidama Region in southern Ethiopia (Figure 1). These districts were purposively selected due to their high suitability for integrated fish–poultry farming. The region is characterized by favorable agro-ecological conditions, including moderate rainfall, fertile soils,

and consistent access to surface and groundwater resources that support aquaculture and irrigated production. The study sites are predominantly inhabited by smallholder farmers engaged in diversified agricultural activities, combining crop and livestock production to improve household livelihoods, food security, and income generation. Furthermore, the active presence of government and development partner agricultural interventions promoting sustainable intensification, climate-smart agriculture, and integrated farming practices makes these districts optimal research sites for evaluating the adoption, benefits, and challenges of integrated fish and poultry farming systems.

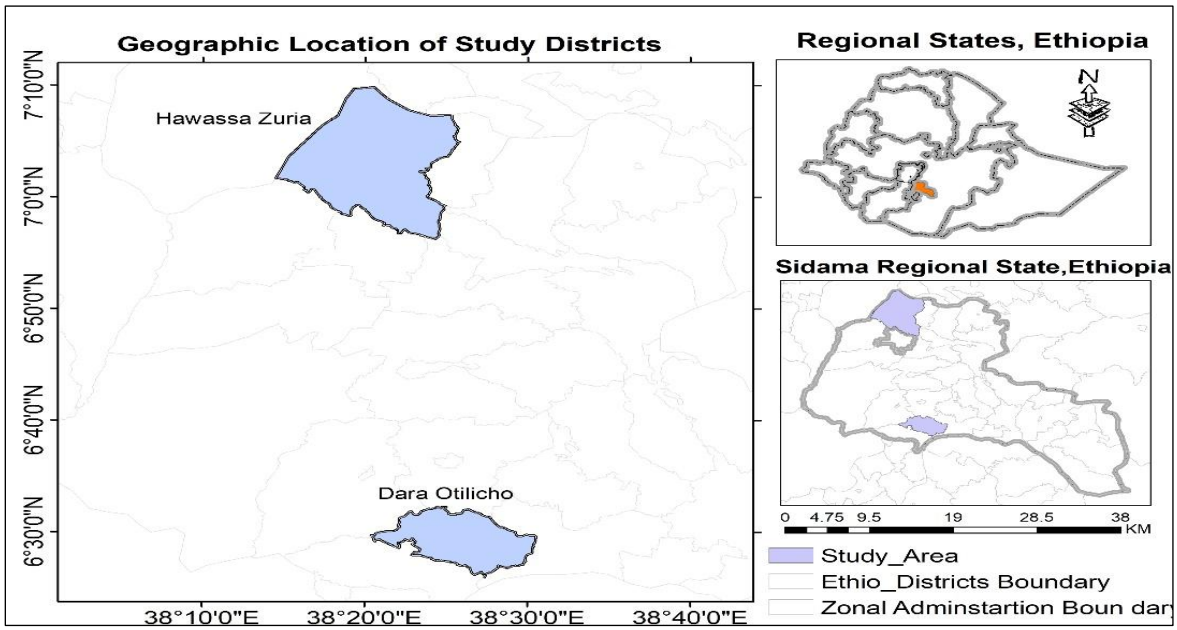


Figure 1: Map of the study areas in the Sidama Region, Ethiopia

2.2. Sampling Procedure and Data Collection

This study employed a cross-sectional household survey design to identify the correlates of smallholder farmers' adoption of IPFF. A multi-stage sampling procedure was used to select representative respondents: (i) Stage 1: Two districts and four kebeles (Shoicho, Buna Tawaba, Lida 01, and Nuure Dulecha) were purposively selected based on their high poultry production potential and suitability for integrated poultry–fish farming, (ii) Stage 2: A comprehensive sampling frame comprising 800 farm households was obtained from the respective kebele agricultural administration offices, and (iii) Stage 3: A total sample of 253 smallholder farm households was selected using simple random sampling. The sample size was proportionally allocated across the four kebeles according to their respective household population sizes. Primary data were gathered through a structured questionnaire administered by trained enumerators via face-to-face interviews. The instrument captured information regarding household socioeconomic characteristics, farm assets and resources, access to institutional support, farmers' knowledge and perceptions of IPFF, and actual IPFF adoption status (distinguishing adopters from non-adopters). To ensure conceptual clarity, validity, and measurement consistency, the questionnaire was pre-tested on a non-sample group of farmers and refined prior to the main survey execution. Secondary data were retrieved from relevant peer-reviewed literature and local institutional records.

2.3. Data Analysis

The primary survey data were organized, coded, and analyzed using Stata version 18. Descriptive statistics including frequencies, percentages, means, and standard deviations were used to summarize the socioeconomic, institutional, and farm-level profiles of sampled households. Differences in continuous explanatory variables between adopter and non-adopter households were evaluated using independent sample t-tests, whereas categorical associations were examined using Pearson's chi-square (χ^2) tests.

Because the decision to adopt IPFF is binary ($Y_i = 1$ if adopted; $Y_i = 0$ otherwise), a binary logistic regression model was formulated to identify the factors associated with adoption. Because the survey relies on single-point cross-sectional data, model estimates quantify statistical associations and conditional probabilities rather than direct causal effects or directional temporal sequences. The model estimates the probability P_i that household i adopts IPFF as a function of explanatory variables (X_i), expressed as:

$$P(Y_i = 1 \mid X_i) = \frac{\exp\left(\beta_0 + \sum_{k=1}^{K} \beta_k X_{ik}\right)}{1 + \exp(\beta_0 + \sum_{k=1}^{K} \beta_k X_{ik})}$$

where $P(Y_i = 1 \mid X_i)$ represents the probability that the i-th household adopts IPFF, X_i is a vector of socioeconomic, institutional, farm, and perception variables (Table 1), β_0 is the intercept parameter, and β_k denotes the vector of parameters to be estimated.

The corresponding logit transformation (the log-odds ratio) is expressed as:

$$\ln\left(\frac{P_i}{1 - P_i}\right) = \beta_0 + \sum_{k=1}^{K} \beta_k X_{ik} + \varepsilon_i$$

To enhance empirical interpretation, post-estimation marginal effects (ME) were calculated. The marginal effect quantifies the instantaneous change in the probability of adoption associated with a one-unit change in a given continuous explanatory variable, or a discrete shift for categorical variables, keeping all other variables constant at their mean values:

$$\frac{\partial P(Y_i = 1 \mid X_i)}{\partial X_{ik}} = P(Y_i = 1 \mid X_i) \cdot [1 - P(Y_i = 1 \mid X_i)] \cdot \beta_k$$

Model adequacy and goodness-of-fit were evaluated using the likelihood-ratio (LR) χ^2 test, Pseudo-R^2, the Hosmer–Lemeshow test, percentage classification accuracy, and the link test for specification errors. Multicollinearity among continuous explanatory variables was inspected using the Variance Inflation Factor (VIF), where VIF values strictly below 10 confirmed the absence of severe multicollinearity. Statistical significance was tested at 1%, 5%, and 10% threshold levels.

Table 1. Description, measurement, theoretical alignment, and expected signs of variables used in the logit model.

Variable	Code / Measurement	Description	Theoretical Alignment (Rogers' DOI)	Expected Sign
Dependent Variable				
IPFF adoption	1 = adopter; 0 = non-adopter	Participation in integrated poultry-fish farming	Innovation decision stage	N/A
Independent Variables				
Age of household head	Continuous (years)	Age of the household head	Human capital / Planning horizon	±

Sex of household head	1 = male; 0 = female	Biological sex of the household head	Resource access / Decision autonomy	±
Education level	Continuous (years)	Years of formal schooling completed	Cognitive capacity / Information processing	+
Household size	Continuous (number)	Total number of family members in household	Operational compatibility (Labor supply)	+
Farming experience	Continuous (years)	Years of experience in poultry or fish production	Complexity reduction / Trialability	+
Total landholding	Continuous (hectares)	Total agricultural land area owned or managed	Asset compatibility	+
Poultry ownership	Continuous (number of birds)	Baseline number of poultry birds owned	Baseline asset compatibility	+
Access to water	1 = yes; 0 = no	Availability of reliable water sources	Baseline technical feasibility	+
Extension access	1 = yes; 0 = no	Access to agricultural extension services	Information channel / Observability	+
Access to credit	1 = yes; 0 = no	Access to formal or informal credit facilities	Financial constraint relaxation	+
Cooperative membership	1 = member; 0 = otherwise	Active membership in local agricultural cooperative	Social network / Peer observability	+
Distance to market	Continuous (km)	Distance from homestead to nearest local market	Economic infrastructure / Transaction costs	−
Awareness of IPFF	1 = aware; 0 = not aware	Prior knowledge or awareness of IPFF practices	Knowledge stage / Observability	+
Perceived profitability	1 = profitable; 0 = not profitable	Perceived relative economic benefit of IPFF	Relative advantage	+

While this study offers valuable empirical insights, several methodological limitations must be acknowledged. First, the reliance on single-point cross-sectional survey data precludes establishing causal relationships or temporal dynamics, meaning estimates reflect statistical associations rather than causal effects. Second, the geographic scope is restricted to two districts in the Sidama Region, limiting generalizability to semi-arid or differing socioeconomic contexts. Third, operationalizing adoption as a binary indicator fails to capture variations in adoption intensity, management scale, or continuous enterprise efficiency. Finally, measures of awareness and perceived profitability rely on self-reported farmer assessments, making them potentially susceptible to recall bias or subjective expectations.

3. Results

3.1. Adoption Status Across Kebeles

Of the 253 sampled households, 126 (49.8%) had adopted IPFF, while 127 (50.2%) were non-adopters. The nearly equal distribution indicates that IPFF adoption is in an emerging diffusion stage among smallholder farmers in the study area. The proportion of adopters remained consistent across the four study kebeles (Table 2).

Table 2. Distribution of IPFF Adopters and Non-Adopters by Study Kebeles (N = 253).

District	Kebele	Total Sampled	Adopters, n (%)	Non-Adopters, n (%)
Hawassa Zuria	Lida 01	50	25 (50.0)	25 (50.0)
Hawassa Zuria	Nuure Dulecha	60	30 (50.0)	30 (50.0)
Dara Otilicho	Shoicho	88	44 (50.0)	44 (50.0)
Dara Otilicho	Buna Tawaba	55	27 (49.1)	28 (50.9)

District	Kebele	Total Sampled	Adopters, n (%)	Non-Adopters, n (%)
Total		**253**	**126 (49.8)**	**127 (50.2)**

3.2. Bivariate Analysis of Continuous and Categorical Variables

The mean comparison results indicate that IPFF adopters and non-adopters were generally similar across most continuous socioeconomic and farm characteristics (Table 3). Age of the household head ($p = 0.574$), education level ($p = 0.668$), household size ($p = 0.303$), landholding size ($p = 0.300$), poultry ownership ($p = 0.313$), and distance to market ($p = 0.437$) showed no statistically significant differences in bivariate t-tests. However, farming experience differed significantly at the 10% level ($t = 1.657, p = 0.099$), with adopters having greater average experience (24.10 years) than non-adopters (21.20 years).

Table 3. Mean comparison of continuous characteristics between IPFF adopters and non-adopters

Variables	Non-Adopters ($n = 127$) Mean	Adopters ($n = 126$) Mean	Mean Difference	t-value	p-value
Age of household head (years)	49.89	48.81	1.08	0.563	0.574
Education level (years)	6.51	6.31	0.20	0.429	0.668
Household size (members)	6.18	5.83	0.35	1.032	0.303
Farming experience (years)	21.20	24.10	2.90	1.657	0.099*
Landholding size (ha)	2.02	1.90	0.12	1.038	0.300
Poultry ownership (birds)	15.20	14.08	1.12	1.012	0.313
Distance to market (km)	7.54	7.95	-0.41	-0.779	0.437

Note: $^{*}p < 0.10$.

The chi-square test of association (Table 4) revealed that sex of the household head showed a weak association with adoption ($\chi^2 = 2.878, p = 0.090$), with a higher proportion of adopters among male-headed households (55.37%) than female-headed households (44.70%). In contrast, awareness of IPFF ($\chi^2 = 28.788, p < 0.001$) and perceived profitability ($\chi^2 = 18.121, p < 0.001$) exhibited strong statistical associations with adoption. Among farmers aware of IPFF, 61.3% were adopters, compared to 25.0% among those not aware. Similarly, 61.5% of farmers who perceived IPFF as profitable adopted the system, compared to 34.5% who did not. Institutional variables including extension access ($p = 0.230$), credit access ($p = 0.569$), and cooperative membership ($p = 0.490$) were not significantly associated with adoption in bivariate tests.

Table 4. Chi-square test of association for categorical variables ($N = 253$).

Variable	Category	Non-Adopters (%)	Adopters (%)	χ^2-value	p-value
Sex of household head	female	55.30	44.70	2.878	0.090*
	male	44.63	55.37		
Access to extension	no	46.62	53.38	1.438	0.230
	yes	54.17	45.83		
Access to credit	no	52.07	47.93	0.324	0.569
	yes	48.48	51.52		

Cooperative membership	no	48.00	52.00	0.477	0.490
	yes	52.34	47.66		
Awareness of IPFF	not aware	60 (75.0)	20 (25.0)	28.788	<0.001***
	aware	67 (38.7)	106 (61.3)		
Perceived profitability	not profitable	72 (65.5)	38 (34.5)	18.121	<0.001***
	profitable	55 (38.5)	88 (61.5)		

Note: $^{*}p < 0.10, ^{***}p < 0.01$.

3.3. Multivariable Logistic Regression Analysis

A binary logistic regression model was estimated to examine the independent factors associated with IPFF adoption while controlling for potential confounding (Table 5). The model was statistically significant (LR $\chi^2 = 30.65, p = 0.006$), with a Pseudo-$R^2$ of 0.088 and a mean VIF of 1.10, indicating good model specification and no severe multicollinearity. The multivariable logit model revealed that perceived profitability ($p = 0.025$) was positively and significantly associated with IPFF adoption at the 5% level, where a one-unit increase was associated with an 8.1 percentage-point increase in adoption probability. Similarly, awareness of IPFF ($p = 0.028$) and household size ($p = 0.050$) were positively and significantly associated with adoption at the 5% level, corresponding to 1.2 and 2.7 percentage-point increases in adoption probability per unit or additional member, respectively. Furthermore, sex of the household head ($p = 0.100$) and farming experience ($p = 0.089$) exhibited weak positive associations at the 10% significance level, with male-headed households showing an 11.6 percentage-point higher probability of adoption and each additional year of experience increasing adoption probability by 0.4 percentage points. Conversely, credit access, extension contact, age, education level, landholding size, poultry ownership, water access, market distance, and cooperative membership were not statistically significant in the multivariable model, indicating that these conventional asset and institutional indicators did not independently correlate with adoption after controlling for labor capacity, experience, awareness, and perceived economic gains.

Table 5. Logistic regression results for factors associated with IPFF adoption (N = 253).

Explanatory Variable	Coefficient (SE)	Marginal Effect (dy/dx)	p-value
Access to credit	0.186 (0.276)	0.047 (0.069)	0.500
Access to extension services	0.371 (0.288)	0.092 (0.071)	0.198
Household head age (years)	-0.006 (0.009)	-0.001 (0.002)	0.505
Sex of household head (1 = male)	0.466 (0.283)	0.116 (0.070)	0.100*
Education level (years)	0.018 (0.037)	0.005 (0.009)	0.626
Household size (members)	0.108 (0.055)	0.027 (0.014)	0.050**
Farming experience (years)	0.017 (0.010)	0.004 (0.003)	0.089*
Landholding size (ha)	0.183 (0.152)	0.046 (0.038)	0.229
Number of poultry owned	0.009 (0.016)	0.002 (0.004)	0.574

Explanatory Variable	Coefficient (SE)	Marginal Effect (dy/dx)	p-value
Access to water resources	0.072 (0.282)	0.018 (0.071)	0.799
Distance to market (km)	0.039 (0.033)	0.010 (0.008)	0.238
Cooperative membership	0.129 (0.285)	0.032 (0.071)	0.650
Perceived profitability	0.325 (0.145)	0.081 (0.035)	0.025**
Awareness of IPFF	0.047 (0.021)	0.012 (0.005)	0.028**
Constant	0.970 (1.071)	--	0.365

Diagnostics: LR $\chi^2 = 30.65, p = 0.006$; Pseudo-$R^2 = 0.088$; *Hosmer–Lemeshow* $\chi^2 = 3.63, p = 0.889$; *Correctly classified* $= 60.87\%$; *Linktest* _hatsq $= 0.038, p = 0.844$; *Mean* VIF $= 1.10$. *Note:* $^{*}p < 0.10, ^{**}p < 0.05$.

4. Discussion

The finding that approximately half of the sampled smallholder households adopted IPFF illustrates an emerging transition toward multi-enterprise diversification in the study area. This adoption pattern reflects an initial diffusion phase where smallholders weigh the bio-economic efficiencies of technology integration against structural barriers.

The weak positive association ($p = 0.100$) between male-headed households and IPFF adoption suggests potential, though statistically marginal, gender disparities in rural production systems. In smallholder contexts, gender disparities in technology uptake rarely stem from intrinsic preferences; rather, they reflect systemic inequities in resource control, land tenure security, labor availability, and access to extension network support (Fadeyi et al., 2022; Zegeye et al., 2022). Establishing an IPFF system requires control over land for pond construction and capital for poultry housing. Because female-headed households in Sub-Saharan Africa frequently face tighter credit constraints and reduced access to agricultural information, their capacity to initiate multi-component production systems may be more constrained (Prabhadevi, 2019; Zegeye et al., 2022). However, given the marginal statistical significance of this variable, this gender-differentiated pattern should be interpreted with caution and validated through further research.

The positive link between household size and IPFF adoption aligns with the labor-intensive nature of integrated farming systems and confirms the compatibility dimension of Rogers' DOI framework. Unlike single-enterprise farming, IPFF requires synchronized daily operational tasks, including poultry management, feed formulation, manure collection, pond fertilization, water quality monitoring, and fish harvesting. Larger households possess the intra-household labor supply necessary to manage these complementary labor demands without incurring high costs for hired labor (Fadeyi et al., 2022). This supports the wider consensus in smallholder agriculture literature that labor-dense innovations depend heavily on family labor availability, particularly during peak agricultural seasons (Fadeyi et al., 2022; Feyisa, 2020).

The weak statistical association ($p = 0.089$) between accumulated farming experience and adoption indicates that experienced farmers may possess slightly greater internal capacity to navigate management complexities. Experienced farmers typically possess a deeper understanding of local microclimates, resource allocation strategies, and agricultural risk mitigation (Feyisa, 2020). In terms of Rogers' complexity attribute, experience helps demystify biological complementarities, such as utilizing nutrient-rich poultry litter for pond fertilization while avoiding water quality degradation (Hailu et al., 2022).

The robust statistical significance of perceived profitability ($p = 0.025$) and technical awareness ($p = 0.028$) strongly validates Rogers' Diffusion of Innovations theory, particularly the constructs of relative advantage, observability, and complexity reduction. Smallholders operate under resource constraints and are hesitant to adopt complex innovations unless the economic returns are clear and demonstrated (Feyisa, 2020). When farmers perceive that IPFF can lower input costs through waste recycling and generate secondary income streams from fish and poultry sales, their likelihood of adoption increases markedly (Hailu et al., 2022). Similarly, technical awareness acts as an essential prerequisite by demystifying the management requirements of joint poultry and fish enterprises. Information gaps regarding fingerling stocking, feed management, and disease control often discourage interested non-adopters. Exposure to IPFF concepts through farmer field schools, field days, and peer-to-peer learning reduces uncertainty, raising farmers' confidence to adopt (Hailu et al., 2022).

The lack of statistically significant independent effects for credit access, extension contact, cooperative membership, landholding size, and market distance provides critical policy insights. Standard extension services in many developing regions remain focused on conventional monocropping or traditional livestock production, offering limited specialized guidance on aquaculture or integrated systems (Hailu et al., 2022; Prabhadevi, 2019). Consequently, general extension contact alone does not automatically co-occur with IPFF adoption unless the advisory content is tailored to integrated enterprise management (Fadeyi et al., 2022). Likewise, formal credit arrangements often lack tailored loan products for small-scale integrated aquaculture, rendering generic financial access insufficient when technical knowledge is lacking. Regarding physical assets, the results imply that land size and water access are baseline prerequisite conditions rather than active decision drivers; once these physical assets are present, adoption decisions are correlated primarily with labor availability, technical knowledge, experiential knowledge, and expected economic gains (Fadeyi et al., 2022; Feyisa, 2020). Finally, because all empirical findings stem from cross-sectional survey data, these relationships must be interpreted as statistical associations rather than direct causal pathways.

5. Conclusion and Policy Implications

This study evaluated the socioeconomic, institutional, and perceptual factors associated with Integrated Poultry-Fish Farming (IPFF) adoption among smallholder households in Ethiopia. With an overall adoption rate of 49.8%, the empirical results indicate that IPFF is establishing itself as a viable multi-enterprise diversification path, yet its broader scaling co-occurs closely with intra-household labor capacities and cognitive factors. The binary logistic regression analysis demonstrates that household labor capacity (household size), system familiarity (awareness), and perceived economic relative advantage (profitability) are key correlates of IPFF adoption ($p < 0.05$), while farming experience and gender of the household head exhibit weak statistical associations ($p < 0.10$). Conversely, conventional physical and institutional variables such as landholding size, water access, generic extension contact, and general formal credit availability did not independently associate with adoption. This indicates that IPFF uptake is associated primarily with farmers' technical confidence, perceived economic viability, and family labor capacity rather than physical resource access alone. Because these insights are based on cross-sectional survey evidence, recommendations focus strictly on addressing observed empirical bottlenecks rather than assuming causal mechanics:

- Tailored Technical Extension and Institutional Alignment: To leverage the strong empirical associations observed for technical awareness ($p = 0.028$) and perceived profitability ($p = 0.025$), generic extension services should incorporate specialized IPFF advisory packages. Extension agencies should establish active demonstration ponds and Farmer Field Schools (FFS) providing hands-on guidance on pond management, manure application rates, fingerling handling, and poultry disease control.

- Addressing Potential Gender Gaps in Training: Reflecting the marginal positive association observed for male-headed households ($p = 0.100$), rural advisory programs should ensure gender-inclusive targeting to prevent female-headed households from being excluded from technical training, demonstration visits, and practical enterprise learning.

- Practical Enterprise Budgeting to Clarify Economic Relative Advantage: Given that perceived profitability was a primary predictor of adoption ($p = 0.025$), extension officers and research institutions should prepare and share localized enterprise budgets. Transparent empirical evidence on cost savings and returns from joint poultry-fish harvesting will directly address cognitive uncertainties regarding economic relative advantage.

- Aligning Support with Family Labor Constraints: Because household size ($p = 0.050$) significantly correlates with adoption due to labor demands, extension packages should highlight labor-saving management designs (such as gravity-fed water channels or efficient manure transfer systems) to make IPFF feasible for smaller or labor-constrained households.

Declarations

Author Contributions

T.K. and S.Y. conceived and designed the study. T.K. coordinated data collection, methodological development conducted data analysis, and drafted the manuscript. A.A. contributed to data collection, and interpretation of results. Z.W. contributed to interpretation of findings, and revision. S.Y. provided overall supervision and contributed to final revisions. All authors reviewed and approved the final manuscript.

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Conflicts of Interest

The authors declare that they have no conflicts of interest.

Data Availability Statement

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

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