

Article

Agricultural Knowledge Systems and Behavioural Determinants of Smallholder Farmers' Adoption of Underutilised Crops in South Africa

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Abstract

Underutilised indigenous crops (UICs) are increasingly recognised for their potential to contribute to climate-resilient agriculture, dietary diversification, and household food security among smallholder farmers in South Africa. However, evidence regarding farmers' knowledge, attitudes, and practices (KAP) toward these crops remains limited. This study examined the KAP of smallholder farmers toward UICs and assessed factors associated with their adoption in selected municipalities of South Africa. A quantitative cross-sectional survey was conducted among 205 smallholder farming households using a structured questionnaire. Respondents were selected through a multi-stage sampling procedure involving purposive, snowball, and stratified sampling. Data were analysed using descriptive statistics, Ordinary Least Squares (OLS) regression, binary logistic regression, and bootstrap mediation analysis. Results showed that smallholder farmers generally possessed positive knowledge and attitudes toward UICs, particularly regarding their nutritional value, adaptability to local climatic conditions, and contribution to household food security. However, utilisation practices remained uneven across households. Age, farming experience, water availability, extension support, and market access were significantly associated with adoption. Formal bootstrap mediation analysis (1000 simulations) did not support attitudinal mediation of the knowledge-adoption relationship (ACME = -0.007 , 95% CI: -0.079 to 0.059 , $p = 0.802$), suggesting that knowledge operates through mechanisms other than attitudinal change. The study concludes that UICs possess significant potential to contribute to food security and climate adaptation in the study areas, but stronger institutional support, extension services, and market development are required for wider adoption.

Keywords: underutilised indigenous crops; smallholder farmers; food security; climate resilience; agricultural extension; KAP; mediation analysis



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1. Introduction

Smallholder agriculture in South Africa operates within a complex environment characterised by climatic variability, structural inequality, limited market access, and persistent resource constraints. Among these challenges, water scarcity remains a critical limiting factor, constraining crop choices, reducing agricultural productivity, and increasing household food insecurity [1]. Persistent food insecurity is especially acute in predominantly rural

provinces such as KwaZulu-Natal and the Eastern Cape, where households remain highly vulnerable to climatic and socio-economic shocks [2]. At the same time, the growing global food demand, projected to increase significantly by 2050, places additional pressure on already fragile agricultural systems [3,4]. Addressing these challenges requires the promotion of climate-resilient, resource-efficient, and nutrition-sensitive agricultural strategies.

Underutilised indigenous crops (UICs) have been recognised as a viable pathway toward these objectives. These crops, including indigenous grains, legumes, and leafy vegetables, are typically adapted to local agroecological conditions, require fewer external inputs, and offer significant nutritional benefits [5,6]. Empirical evidence shows that UICs contribute to improved dietary diversity, enhanced household food security, and strengthened rural livelihoods [7–10]. However, their adoption and utilisation remain limited and uneven across smallholder farming systems in the study municipalities of KwaZulu-Natal and Eastern Cape provinces.

Existing literature attributes this adoption gap to a range of socio-economic and institutional factors. Studies have shown that education, income, farming experience, and asset ownership are associated with farmers' willingness to cultivate underutilised crops [11,12]. Institutional factors, particularly access to agricultural extension services, also play a role in shaping farmers' engagement with these crops [13]. While these studies provide valuable insights into adoption outcomes, they largely focus on observable results, offering limited understanding of the behavioural processes that underpin farmers' decision-making. Furthermore, existing studies have not adequately integrated ecological constraints, particularly water management capacity, into behavioural models of agricultural decision-making [14].

Insufficient attention has been given to the role of knowledge and attitudes in shaping adoption. The Knowledge-Attitude-Practice (KAP) framework provides a useful analytical lens by distinguishing between cognitive awareness, perceptual orientation, and actual farming practices [15]. However, empirical applications of the KAP framework in the context of underutilised crops in South Africa remain limited [16].

This study addresses these gaps by analysing the socio-economic, institutional, and ecological factors associated with smallholder farmers' knowledge, attitudes, and practices regarding UICs in selected provinces of South Africa. Specifically, the study examines (i) the factors associated with farmers' knowledge of UICs, (ii) the determinants shaping their attitudes toward these crops, and (iii) the drivers of their cultivation and utilisation practices. The novelty of the study lies in three dimensions: (1) it is the first study to formally apply the KAP framework to UICs across two South African provinces in the context of the 2025 legislative recognition of indigenous crops under the Marketing of Agricultural Products Act; (2) it integrates water management as an ecological constraint within the KAP model, a dimension largely absent from prior KAP agricultural studies; and (3) it conducts formal bootstrap mediation analysis to test the K-A-P pathway empirically. The findings contribute to the literature on agricultural diversification and climate-resilient food systems by integrating behavioural, institutional, and ecological dimensions within a unified analytical framework.

2. Theoretical Framework: The Knowledge, Attitude, and Practice (Kap) Model

2.1. Theoretical Foundations of Agricultural Knowledge and Smallholder Farmer Behaviour

This study adopted the KAP framework to examine farmers' behavioural engagement with UICs. The KAP framework conceptualises behaviour as a sequential yet interactive process in which knowledge influences attitudes, while attitudes subsequently shape practices and behavioural outcomes [15]. The framework is theoretically grounded in

three complementary perspectives. First, Diffusion of Innovations Theory [17] emphasises the importance of communication channels, institutional support, and extension systems in shaping knowledge acquisition and innovation adoption among farming communities. Second, Social Learning Theory [18] suggests that farming behaviour is influenced by observation, interaction, and social environments. Third, the Theory of Planned Behaviour [19] proposes that behavioural intentions are jointly determined by attitudes, subjective norms, and perceived behavioural control—providing a theoretical basis for explaining why positive attitudes may not automatically translate into adoption.

Within the framework, knowledge refers to farmers' awareness and understanding of agricultural innovations, including production techniques, nutritional benefits, and climate adaptation potential associated with underutilised crops [20]. Attitude refers to farmers' perceptions, beliefs, and evaluations regarding the desirability or usefulness of cultivating UICs [19], while practice relates to the actual cultivation, utilisation, and management of these crops within farming systems. KAP-based data can help identify knowledge gaps, attitudinal barriers, and behavioural patterns that influence decision-making [21]. The framework is commonly operationalised through structured standardised survey instruments [22]. Importantly, the framework acknowledges that the transition from positive attitudes to actual practices is not automatic and may be constrained by structural, institutional, and resource-related factors [23,24].

2.2. Empirical Evidence on KAP and Underutilised Crop Adoption

Previous studies have demonstrated associations between knowledge, attitudes, and agricultural practices. Ntawuruhunga et al. [25,26], examining African Indigenous Vegetables in Kenya, found that higher knowledge levels were associated with improved adoption practices, although institutional support moderated this relationship. Torimiro et al. [27] reported that knowledge of indigenous vegetable technologies was positively associated with utilisation among young farmers in Nigeria. In Sri Lanka, Chamara et al. [16] found that although awareness was relatively high, adoption practices remained constrained by institutional and market barriers. Massawe et al. [28], analysing safflower production in Tanzania, found that farmers' attitudes were shaped by labour availability, climate perceptions, and household resource dynamics. In South Africa, Light et al. [29] demonstrated that socio-economic and institutional factors were associated with KAP regarding cassava. More recently, Mulugeta et al. [30] and Mweke et al. [31] applied the KAP framework to agricultural biologicals in Ethiopia and Kenya, documenting that attitudinal barriers often persist even when knowledge levels are adequate, a consistent pattern across the agricultural KAP literature. Across these studies, knowledge-attitude relationships are generally supported, while the attitude-to-practice pathway is more fragile and dependent on structural conditions [23,24].

2.3. KAP, Climate Change, Food Diversification, and Food Security: Conceptual Hypotheses

The relevance of the KAP framework to UICs is particularly salient in the context of climate change, food diversification, and food security. UICs are recognised for their nutritional density, drought tolerance, and agroecological adaptability, making them strategic assets for climate-resilient food systems [5,8,32]. Within the study context, water management capacity represents a critical ecological moderator of the KAP-adoption relationship. South Africa is classified as a water-scarce country, and household-level water access is a key determinant of crop choice and agricultural productivity [7,14]. While UICs are commonly promoted as drought-tolerant [5], successful cultivation may still depend on minimum water availability during establishment and prolonged dry conditions [10].

Building on these theoretical and empirical foundations, this study proposes three testable hypotheses (Figure 1):



Figure 1. Illustrates these hypothesised relationships within the broader socio-economic, institutional, and ecological context of the study.

H1. *Farmers with higher knowledge levels regarding UICs will be associated with more positive attitudes toward their cultivation.*

H2. *More positive attitudes toward UICs will be associated with a higher likelihood of adoption and utilisation.*

H3. *The association between farmers' knowledge of UICs and adoption operates both directly and indirectly through attitudinal change.*

3. Materials and Methods

3.1. Study Area

The study was conducted in KwaZulu-Natal and Eastern Cape provinces of South Africa. These provinces were purposively selected due to their predominantly rural character, high reliance on smallholder agriculture, and persistent food insecurity. Both regions are characterised by rain-fed farming systems and socio-economically vulnerable households, making them suitable for examining adoption of underutilised crops [33]. For the purpose of this study, smallholder farmers are defined consistent with South African DAL-RRD criteria: farmers cultivating less than 5 hectares, relying primarily on family labour, producing predominantly for household consumption, with limited access to formal credit and inputs.

KwaZulu-Natal has a subtropical climate with mean annual rainfall ranging from approximately 700 to 1200 mm. Agricultural systems are diverse, with maize, legumes, and vegetables dominating smallholder production [34]. The study focused on Alfred Duma Local Municipality, where farming is largely subsistence-oriented and climate variability constrains productivity. The Eastern Cape exhibits more variable agroecological conditions, with annual rainfall ranging from approximately 400 to 900 mm and frequent drought occurrences in inland areas. The study sites, Senqu Local Municipality, Mnquma Local Municipality, and Alfred Nzo District Municipality, are characterised by low-input, rain-fed agriculture and high vulnerability to climatic and economic shocks [33,35]. Market participation among smallholder vegetable farmers in the Eastern Cape remains constrained by limited irrigation access, poor road infrastructure, and weak value chain linkages [36] (Figure 2).

3.2. Research Design, Sampling, and Data Collection

The study adopted a quantitative cross-sectional research design to examine associations between socio-economic, institutional, and behavioural variables at a single point in time. A multi-stage sampling procedure was employed because no formal database of UIC farmers existed. The sample size was guided by the Cochran (1977) formula for unknown population proportions [37]:

$$n = \frac{Z^2 \times p(1 - p)}{e^2}$$

where

n = required sample size

Z = Z-value corresponding to the desired confidence level (1.96 for 95% confidence)

p = estimated population proportion (0.50)

$(1 - p)$ = complement of the estimated proportion (0.50)

e = desired margin of error (0.07)

$$n = \frac{(1.96)^2 \times 0.50(1-0.50)}{(0.07)^2}$$

$$n = \frac{(1.96)^2 \times 0.50 \times 0.50}{(0.07)^2}$$

$$n = \frac{3.8416 \times 0.25}{0.0049}$$

$$n = \frac{0.9604}{0.0049}$$

$$n = 196$$

Therefore, the minimum required sample size was: 196. The final sample of 205 slightly exceeds this threshold.

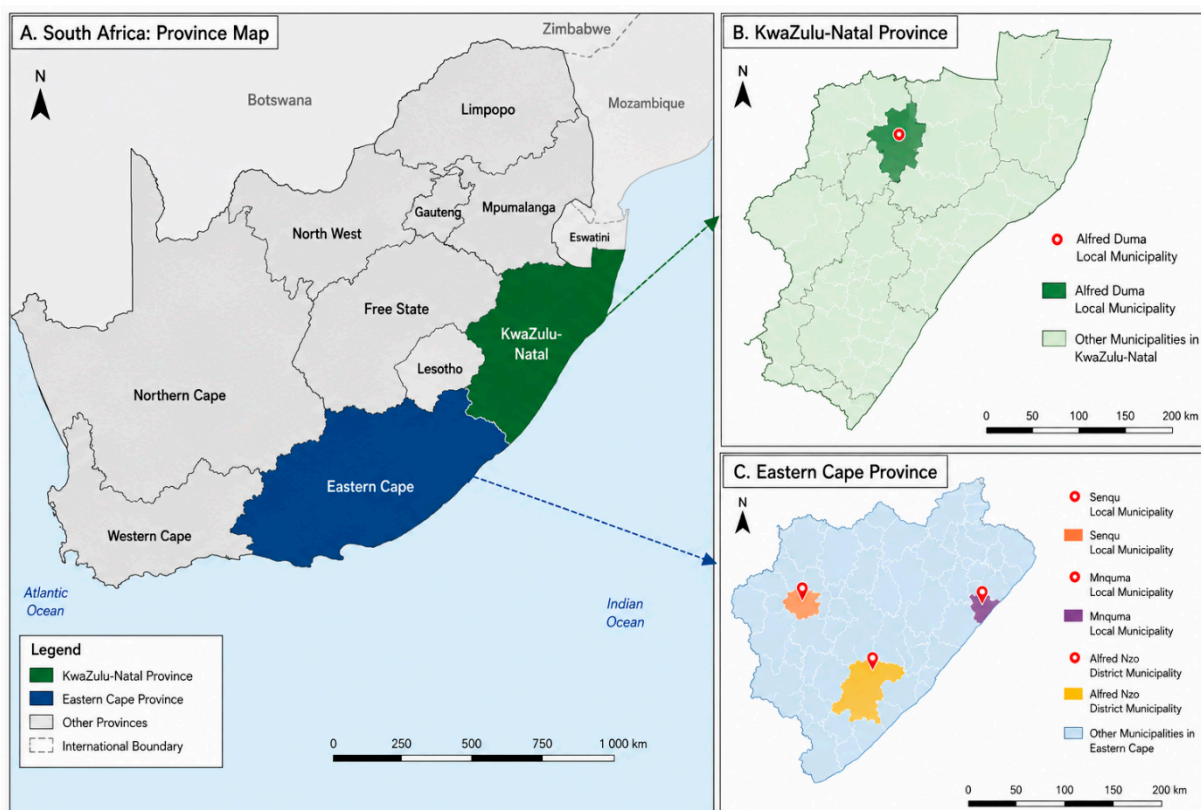


Figure 2. Study area. Source: Author's compilation using QGIS version 3.40 (QGIS Development Team, <https://qgis.org/>) and municipal boundary data obtained from the Municipal Demarcation Board, South Africa municipal boundary data.

Sampling proceeded in three stages. First, study municipalities were purposively selected based on their relevance to the study objectives. Second, initial respondents were identified through agricultural extension officers and subsequently used as entry points for snowball sampling to identify additional UIC farmers. Finally, stratified sampling was applied to ensure representation across study locations. A total of 205 farming households were surveyed: 85 from Alfred Duma Local.

Municipality in KwaZulu-Natal, and 120 from Senqu, Mnquma, and Alfred Nzo municipalities in the Eastern Cape (Table 1). Primary data were collected through structured

questionnaires administered via face-to-face interviews between November 2025 and March 2026 by trained enumerators fluent in isiZulu and isiXhosa. The questionnaire captured household socio-economic characteristics, farming practices, institutional support, water access, and KAP indicators relating to UICs (Supplementary File S1). Ethical approval was obtained from the University of the Free State Research Ethics Committee (Reference No. UFS-HSD2025/1260). All respondents provided written informed consent.

Table 1. Distribution of Sampled Households across Study Areas.

Province	Municipality/District	Number of Households
KwaZulu-Natal	Alfred Duma	85
Eastern Cape	Senqu, Mnquma and Alfred Nzo	120
Total		205

Source: Author's compilation (2026).

3.3. Variable Operationalisation and Measurement

Table 2 summarises the operationalisation of all key variables, including construct definitions, indicator items, measurement scales, and analytical roles. Knowledge was measured using five Likert-scale statements evaluating ability to identify UICs, understand nutritional and agronomic benefits, recognise food security contributions, and comprehend crop-specific management practices (1 = Strongly Disagree to 5 = Strongly Agree) [38–40]. Attitudes toward UICs were measured using six five-point Likert-scale statements capturing perceptions regarding dietary value, climate resilience, income potential, and overall livelihood relevance. Practices were operationalised as a binary adoption variable (1 = cultivating at least one UIC; 0 = non-adopter) [7]. Composite indices for knowledge and attitudes were constructed by computing mean Likert-scale item scores, consistent with established empirical practice [38,40,41]. Composite scores were calculated as the mean of retained items following confirmation of internal consistency and construct validity. Standardisation was not applied, as all indices used the same scale, ensuring comparability [42]. Retaining the original scale allows more intuitive coefficient interpretation [41].

Table 2. Operational definition and measurement of variables used in the analysis.

Variable	Construct	Scale	Role
Knowledge Index	KAP—Knowledge	5-point Likert (mean of 5 items)	Mediator/Independent
Attitude Index	KAP—Attitude	5-point Likert (mean of 6 items)	Mediator
UIC Adoption (Practices)	KAP—Practice	Binary: 1 = Adopter, 0 = Non-adopter	Dependent
Extension Frequency	Extension Access	Ordinal (reversed; higher = less frequent)	Explanatory
Extension UIC Info	Extension Content	Binary: 1 = Yes, 0 = No	Explanatory
Water Sufficiency	Water Management	Binary: 1 = Sufficient, 0 = Insufficient	Explanatory
Water Comparison	Water Management	Ordinal: 1 = Less, 2 = Same, 3 = Not sure	Explanatory
Irrigation Use	Water Management	Binary: 1 = Uses irrigation, 0 = No	Explanatory
Age	Socio-economic	Continuous (years)	Explanatory
Education Level	Socio-economic	Ordinal (1–4)	Explanatory
Household Size	Socio-economic	Continuous (persons)	Explanatory
Land Size	Socio-economic	Continuous (hectares)	Explanatory
Farming Experience	Socio-economic	Continuous (years)	Explanatory
Gender	Socio-economic	Binary: 1 = Male, 0 = Female	Explanatory

Source: Author's compilation (2026).

3.4. Data Analysis and Analytical Framework

All quantitative data were coded and analysed using IBM SPSS Statistics for Windows, Version 30.0 (IBM Corp., Armonk, NY, USA, 2023). Publication-quality figures and graphical visualisations were produced in R version 4.6.0 (R Foundation for Statistical Computing, Vienna, Austria, 2026) using the ggplot2 and related packages. Descriptive

statistics, including frequencies, percentages, means, and standard deviations, were used to summarise respondents' socio-economic characteristics, water management practices, and KAP indicators. The reliability and dimensionality of the knowledge and attitude constructs were assessed using Cronbach's Alpha and Exploratory Factor Analysis (EFA), with the Kaiser-Meyer-Olkin (KMO) statistic and Bartlett's Test of Sphericity used to confirm suitability for factor analysis. Factor extraction used Principal Axis Factoring with Varimax rotation. Composite indices derived from validated items were subsequently used in the econometric analyses, as described in Section 3.3 [42,43].

Three interconnected econometric models were estimated. Model 1 (OLS) examined determinants of the Knowledge Index:

$$K_i = \beta_0 + \beta_1 X_i + \beta_2 W_i + \beta_3 E_i + \varepsilon_i \quad (1)$$

where

- K_i = Knowledge index
- X_i = socio-economic characteristics (e.g., age, education, household size)
- W_i = water management variables
- E_i = extension-related variables

Model 2 (OLS) examined determinants of the Attitude Index, including the Knowledge Index to test the $K \rightarrow A$ pathway (H1). Attitudes were modelled as a function of knowledge and other explanatory variables:

$$A_i = \gamma_0 + \gamma_1 K_i + \gamma_2 X_i + \gamma_3 W_i + \gamma_4 E_i + u_i \quad (2)$$

where

- A_i = Attitude index
- K_i = Knowledge index

Model 3 (binary logistic regression) estimated the probability of UIC adoption. To further evaluate the behavioural pathways proposed by the KAP framework, a formal bootstrap mediation analysis was subsequently conducted using R (Version 4.6.0) with the mediation package [44] to rigorously test H3, whether attitudes mediate the knowledge-adoption association. Bootstrapped standard errors were estimated using 1000 simulations and the percentile method. Significance thresholds of $p < 0.01$, $p < 0.05$, and $p < 0.10$ were applied. All associations are interpreted as correlational rather than causal, given the cross-sectional design. Model 3 (Binary Logistic Regression) estimated the probability of UIC adoption.

$$\text{logit}(P_i) = \alpha_0 + \alpha_1 K_i + \alpha_2 A_i + \alpha_3 X_i + \alpha_4 W_i + \alpha_5 E_i + \eta_i \quad (3)$$

where

- P_i = Probability of adoption (1 = adopter; 0 = non-adopter)
- K_i = Knowledge index
- A_i = Attitude index

4. Results

4.1. Socio-Economic Characteristics of Respondents

Male respondents constituted most of the sample (56.1%). The average age of respondents was 56 years (range: 21–84 years), with an average farming experience of 10 years (range: 1–50 years). The sample is characterised by moderate educational attainment (52.7% secondary; 41% primary). Household size averaged six members (range: 1–14). The low

mean annual income (R20,553; range: R3000–R120,000) reflects significant income inequality. Income was mainly derived from farming (43.9%) and government grants (37.6%). Market access was constrained, with 54.8% travelling more than 10 km to markets and 60.4% relying on informal marketing channels. Primary crops cultivated by respondents included maize, sorghum, cowpeas, amaranth, pumpkin, sweet potato, cassava, and okra, with limited commercial fertiliser and pesticide use (Table 3).

Table 3. Socio-economic characteristics of the respondents.

	Category/Measure	Total <i>n</i> (%)	Mean	Min	Max
Gender	Male	115 (56.1)			
	Female	90 (43.9)			
Age (years)	Continuous		56	21	84
Education level	No formal education	8 (3.9)			
	Primary	84 (41.0)			
	Secondary	108 (52.7)			
	Tertiary	5 (2.4)			
Household size	Continuous		6	1	14
Farming experience (years)	Continuous		10	1	50
Main income source	Farming	90 (43.9)			
	Formal employment	36 (17.6)			
	Informal trading	2 (1.0)			
	Government grants	77 (37.6)			
Household income (R/year)	Continuous		20,553	3000	120,000
Distance to market	<10 km	89 (45.2)			
	>10 km	108 (54.8)			
Market type	Informal market	119 (60.4)			
	Formal market	17 (8.6)			
	Direct sales	61 (31.0)			

Source: Author's compilation (2026).

4.2. Water Management Practices

Rainwater constituted the dominant water source (70.2%), followed by river/dam water (57.1%), borehole water (30.7%), and municipal water (26.8%). Approximately 60% of respondents used some form of irrigation, predominantly manual watering using buckets or bottles (51.7%). A major constraint was water insufficiency: 60.5% reported that water was not available year-round. Slightly more than half (50.7%) indicated that water management affected their ability to cultivate UICs. Most respondents (62%) perceived UICs as requiring less water than conventional crops. The major challenges identified were limited water availability (36.3%) and lack of knowledge on water management practices (34.8%) (Table 4).

Table 4. Water Management Practices of Surveyed Farmers.

Water Management Variable	Category	Frequency	Percentage (%)
Water sources used	Rainwater	144	70.2
	River/dam water	117	57.1
	Borehole water	63	30.7
	Municipal water	55	26.8
Use of irrigation system	Yes	123	60.0
	No	82	40.0

Table 4. Cont.

Water Management Variable	Category	Frequency	Percentage (%)
Main irrigation method	Manual-watering (buckets/bottles)	106	51.7
	Sprinkler irrigation	61	29.8
	Drip irrigation	11	5.4
	Furrow irrigation	9	4.4
Water sufficient throughout year	Yes	81	39.5
	No	124	60.5
Water management affects ability to grow UICs	Yes	104	50.7
	No	101	49.3
Perception of UIC water requirements	UICs require less water	127	62.0
	UICs require the same amount	20	9.8
	Not sure	58	28.3
Main water management challenge	Limited water availability	73	36.3
	Lack of knowledge	70	34.8
	Poor soil moisture retention	30	14.9
	High cost of water storage	10	5.0
	None	18	9.0

Source: Author's compilation (2026).

4.3. Agricultural Extension Services

Extension services were the primary information source (51.7%), followed by farmer groups/cooperatives (34.6%) and radio (13.7%). Monthly extension contact was most common (48.8%). However, only 23.9% of respondents received UIC-specific information from extension officers, and only 1.9% received UIC-specific training. Extension dissatisfaction was high at 75.1%. Figure 3 illustrates the critical gap between general extension contact (88.3%) and UIC-specific service delivery (23.9%) in the study area (Table 5).

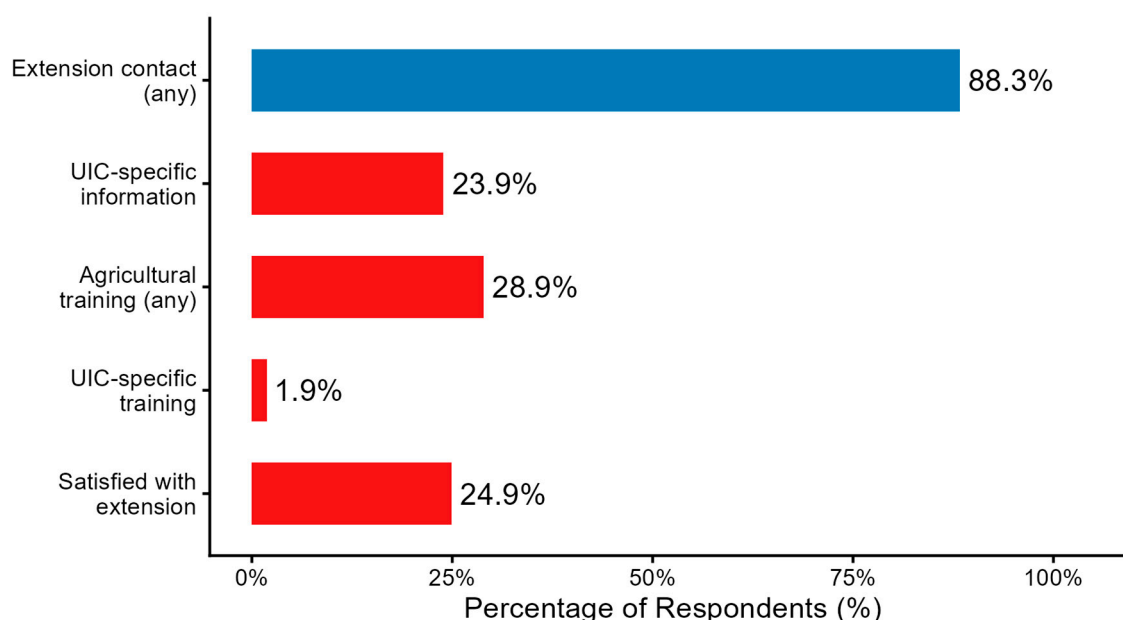


Figure 3. Extension Service Engagement and UIC-Specific Support. Source: Author's compilation (2026).

Table 5. Agricultural Extension Services Characteristics.

Extension Variable	Category	Frequency	Percentage (%)
Primary method of accessing agricultural information	Extension services	106	51.7
	Farmer groups/cooperatives	71	34.6
	Radio	28	13.7
Frequency of extension support	Weekly	81	39.5
	Monthly	100	48.8
	Quarterly	19	9.3
	Annually	5	2.4
Extension officers provide UIC information	Yes	49	23.9
	No	156	76.1
Participation in agricultural training	Yes	57	28.9
	No	140	71.1
Training specifically on UICs	Yes	2	1.9
	No	102	98.1
Satisfied with extension services	Yes	49	24.9
	No	148	75.1

Source: Author's compilation (2026).

4.4. Measurement of the Determinants

The Knowledge construct demonstrated acceptable internal consistency (Cronbach's Alpha = 0.765). The KMO value (0.807) and Bartlett's Test ($p < 0.001$) confirmed suitability for factor analysis. EFA yielded a single factor explaining 40.95% of variance, with factor loadings ranging from 0.593 to 0.707. The Attitude construct showed strong internal consistency (Cronbach's Alpha = 0.868). The KMO statistic (0.901) and Bartlett's Test ($p < 0.001$) confirmed factorability. A single factor explained 60.23% of variance with loadings between 0.688 and 0.745. Both constructs are unidimensional and appropriate for composite index construction [42].

4.5. Adoption of UICs

Results indicate a strong level of adoption within the study areas, with 70% of farmers classified as UIC adopters compared to 30% non-adopters. This indicates that UICs are well-integrated into local farming systems and are no longer marginal crops for most households in the surveyed municipalities. However, the presence of 30% non-adopters shows that adoption is not universal and that barriers persist. Figure 4 illustrates this distribution; it should be noted that adoption was operationalised as a binary variable and does not capture variation in adoption intensity or species diversity among adopters.

4.6. Determinants of Farmers' Knowledge of Underutilised Indigenous Crops

Table 6 presents the Ordinary Least Squares (OLS) regression results for determinants influencing farmers' knowledge regarding UICs. The regression model was statistically significant ($F = 4.317$; $p < 0.001$), indicating that the explanatory variables jointly influenced farmers' knowledge levels regarding UICs. The model explained approximately 57.2% of the variation in the Knowledge Index ($R^2 = 0.572$), while the adjusted R^2 was 0.541, suggesting relatively strong explanatory power within the context of behavioural and perception-based research.

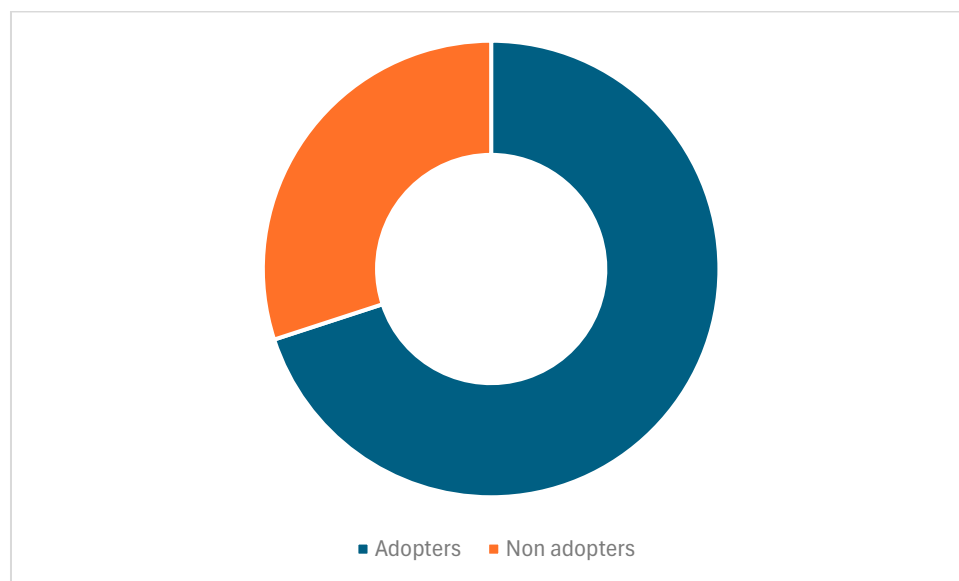


Figure 4. The level of UICs adoption among farmers. Source: Author's compilation (2026).

Table 6. Determinants of Farmers' Knowledge of Underutilised Indigenous Crops.

Determinants	Coefficient	Std. Error	p-Value
Age group of respondents	0.206	0.087	0.019 **
Education level	−0.090	0.098	0.360
Use of irrigation system	0.070	0.123	0.570
Water sufficient throughout year	0.134	0.124	0.281
Water management affects ability to grow UICs	0.141	0.116	0.222
Frequency of extension support	−0.214	0.080	0.008 ***
Participated in agricultural training	0.071	0.131	0.589
Extension officers provide information on UICs	−0.016	0.139	0.908
Water needs of UICs vs. conventional crops	−0.159	0.044	<0.001 ***
Constant	3.959	0.493	<0.001 ***
Model Statistics			
Statistic	Value		
N	197		
R ²	0.572		
Adjusted R ²	0.541		
F-statistic	36.317 ***		

Notes: *** $p < 0.01$, ** $p < 0.05$. Source: Author's calculations from survey data.

The regression results indicate that age group, frequency of extension support, and perceptions regarding the water requirements of UICs significantly influenced farmers' knowledge regarding UICs. Among these determinants, perceptions regarding the water needs of UICs emerged as the strongest predictor of knowledge levels. The variable was statistically significant at the 1% level ($\beta = -0.159$, $p < 0.001$). The negative coefficient reflects the coding structure of the variable, where lower values represented the perception that UICs require less water relative to conventional crops. This suggests that farmers who recognised the lower water requirements of UICs possessed higher levels of knowledge regarding indigenous crops. This finding supports existing literature which positions UICs as climate-resilient and drought-tolerant crops suitable for water-scarce environments [5].

Frequency of extension support also showed a statistically significant relationship with knowledge ($\beta = -0.214$, $p = 0.008$). The negative coefficient must be interpreted within the coding structure of the variable, where lower numerical values represented more frequent

extension contact (e.g., weekly and monthly support). The findings therefore indicate that farmers receiving more regular extension support possessed relatively higher knowledge levels regarding UICs. This highlights the importance of sustained institutional interaction in facilitating knowledge dissemination among smallholder farmers. However, descriptive findings presented earlier revealed that only 23.9% of respondents indicated that extension officers provide information specifically related to UICs. This suggests that while extension contact generally enhances agricultural knowledge, UIC-specific content within extension systems remains limited and insufficiently prioritised.

Age group of respondents positively and significantly influenced knowledge levels at the 5% significance level ($\beta = 0.206$, $p = 0.019$). Older farmers were more likely to possess higher knowledge levels regarding UICs compared to younger farmers. This may reflect accumulated farming experience, long-term exposure to indigenous agricultural systems, and intergenerational knowledge transmission within rural communities. Indigenous crop knowledge is often embedded within traditional farming practices and household food systems, which may explain the relatively higher knowledge levels among older respondents.

4.7. Determinants of Farmers' Attitudes Towards Underutilised Indigenous Crops

Table 7 present results of the multiple linear regression for determinants of farmers' attitudes towards UICs. The regression model was statistically significant ($F = 32.197$; $p < 0.001$), indicating that the explanatory variables jointly explained variations in farmers' attitudes towards UICs. The model explained approximately 53.4% of the variation in the Attitude Index ($R^2 = 0.534$), suggesting relatively strong explanatory power within the context of behavioural and perception-based research.

Table 7. Determinants of Farmers' Attitudes Towards Underutilised Indigenous Crops.

Variables	Coefficient (B)	Std. Error	Beta	p-Value
Knowledge Index	0.352	0.029	0.643	<0.001 ***
Frequency of extension support	0.210	0.025	0.425	<0.001 ***
Extension officers provide information on UICs	0.219	0.066	0.164	0.001 ***
Water needs of UICs vs. conventional crops	−0.028	0.021	−0.072	0.167
Water sufficient throughout year	−0.344	0.147	−0.177	0.020 **
Age of respondent	−0.004	0.002	−0.123	0.017 **
Gender of respondent	0.004	0.056	0.003	0.949
Education level	−0.010	0.019	−0.026	0.603
Constant	0.782	0.180		<0.001
Model Statistics				
Statistic	Value			
N	205			
R^2	0.534			
Adjusted R^2	0.517			
F-statistic	32.197 ***			

Notes: *** $p < 0.01$, ** $p < 0.05$. Source: Author's calculations from survey data.

The regression results indicate that the Knowledge Index, frequency of extension support, provision of UIC-specific information by extension officers and age of the respondent significantly influenced farmers' attitudes towards UICs. Among these determinants, the Knowledge Index emerged as the strongest predictor of attitudes towards UICs, as reflected by the relatively large, standardised beta coefficient ($\beta = 0.643$) and high level of statistical significance ($B = 0.352$, $p < 0.001$). The results indicate that farmers possessing greater knowledge regarding indigenous crop identification, nutritional value, food secu-

rity contribution and production practices were more likely to express positive attitudes towards UICs.

This finding supports the Knowledge–Attitude relationship proposed within the KAP framework, which argues that increased awareness and understanding positively influence behavioural orientation and perceptions towards agricultural innovations. Farmers with improved knowledge regarding UICs may better appreciate the agronomic, nutritional and climate-resilience benefits associated with indigenous crops, thereby shaping more favourable perceptions towards their cultivation and utilisation.

Frequency of extension support also positively and significantly influenced farmers' attitudes towards UICs ($B = 0.210, p < 0.001$). Farmers receiving more regular extension support were more likely to exhibit favourable attitudes towards indigenous crops. This finding highlights the important role played by agricultural extension services in shaping farmers' perceptions, confidence and awareness regarding alternative and underutilised farming systems. Consistent interaction with extension officers may increase exposure to technical information, demonstrations and awareness campaigns relating to indigenous crops.

Similarly, the provision of UIC-related information by extension officers significantly increased the likelihood of positive farmer attitudes towards UICs ($B = 0.219, p = 0.001$). Farmers who received information regarding indigenous crops from extension personnel were more likely to express favourable attitudes towards cultivating and utilising these crops. These findings are consistent with the Diffusion of Innovations theory, which emphasises the importance of communication systems, advisory services and institutional support in facilitating behavioural change and innovation adoption among farmers.

Age of the respondent was negatively associated with attitudes towards UICs and statistically significant at the 5% level ($B = -0.004, p = 0.017$). The negative beta coefficient ($\beta = -0.123$) suggests that older farmers were relatively less likely to express positive attitudes towards indigenous crops compared to younger farmers. This may reflect stronger attachment among older farmers to conventional farming systems and reduced willingness to embrace alternative or underutilised agricultural practices. Younger farmers may be comparatively more receptive to agricultural diversification, innovation and climate-smart farming approaches involving UICs.

Water sufficiency throughout the year had a statistically significant negative relationship with attitudes at the 5% significance level ($\beta = -0.344, p = 0.020$). The negative coefficient suggests that farmers experiencing adequate water availability throughout the year were relatively less likely to express positive attitudes towards UICs. This finding may reflect the perception that farmers with secure water access are less dependent on drought-tolerant or climate-resilient crops and may therefore prefer conventional crops that are often more commercially established. Conversely, households facing water constraints may perceive UICs more favourably due to their adaptability to water-scarce conditions.

4.8. Determinants of UIC Practices (Adoption and Utilisation)

Figure 5 illustrates the distribution of Knowledge and Attitude Index scores by adoption status, confirming that adopters tend to score somewhat higher on the Knowledge Index than non-adopters, while Attitude Index scores show greater overlap between groups, consistent with the weak attitude-to-adoption pathway established in the regression results below.

Binary logistic regression analysis was conducted to identify the factors influencing farmers' adoption and utilisation of UICs (Table 8). The dependent variable was binary, where respondents were classified as either adopters or non-adopters of UICs. Explanatory variables included behavioural, institutional, and resource-related factors derived from the KAP framework and broader agricultural extension literature.

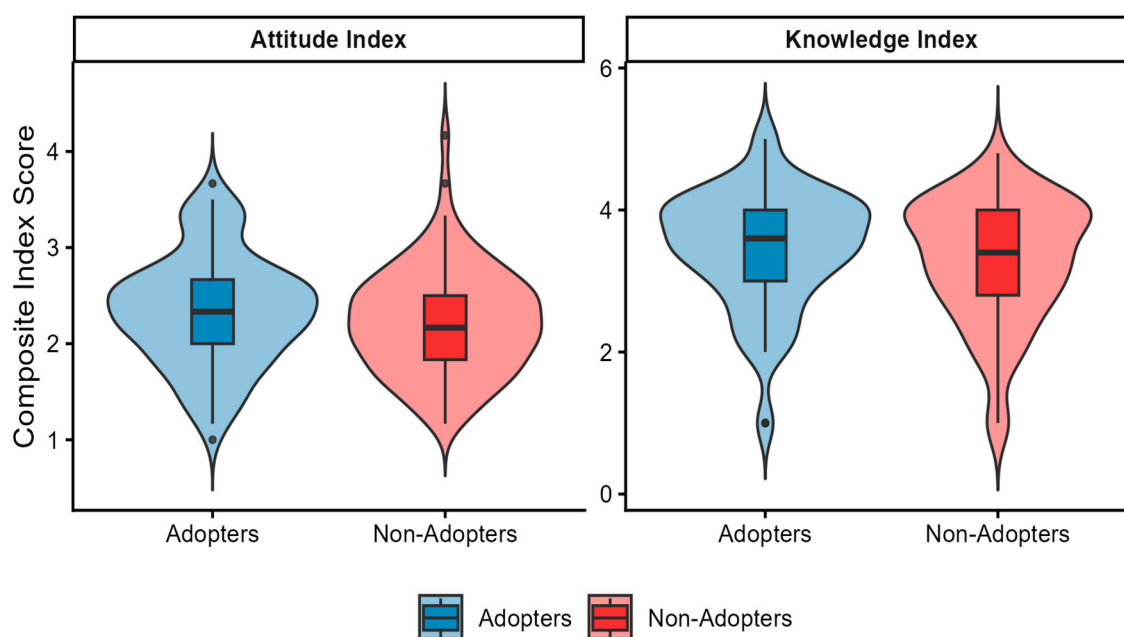


Figure 5. Distribution of Knowledge and Attitude Indices by UIC Adoption Status. Source: Author's compilation (2026).

Table 8. Determinants of UIC Adoption and Utilisation.

Variables	Coefficient (B)	Std. Error	Wald	p-Value	Exp(B)
Knowledge Index	0.364	0.171	4.534	0.033 **	1.439
Attitude Index	0.287	0.214	1.794	0.180	1.333
Water sufficient throughout year	0.731	0.305	5.741	0.017 **	2.077
Extension officers provide information on UICs	0.592	0.286	4.280	0.039 **	1.808
Use of irrigation system	0.281	0.294	0.912	0.340	1.325
Total land size available for farming	0.097	0.049	3.918	0.048 **	1.102
Constant	−1.284	0.681	3.557	0.059 *	0.277
Model Statistics					
Statistic	Value				
N	205				
Cox & Snell R ²	0.174				
Nagelkerke R ²	0.199				
Hosmer–Lemeshow Test	5.982 ($p = 0.648$)				
Omnibus Test	15.842 ($p = 0.015$)				
Overall prediction accuracy	63.4%				

Notes: ** $p < 0.05$; * $p < 0.10$. Source: Author's calculations from survey data.

The overall logistic regression model was statistically significant, suggesting that the included explanatory variables jointly influenced farmers' adoption behaviour (Omnibus Test: $\chi^2 = 15.842$, $df = 6$, $p = 0.015$). The Cox and Snell R^2 (0.174) and Nagelkerke R^2 (0.199) indicate that the model explained between 17.4% and 19.9% of the variation in adoption behaviour. Although the explanatory power remained modest, such values are considered acceptable in behavioural and smallholder agricultural adoption studies where farmer decision-making is shaped by multiple socio-economic and contextual factors. The Hosmer–Lemeshow goodness-of-fit test was non-significant ($\chi^2 = 5.982$, $p = 0.648$), indicating satisfactory model fit. In addition, the classification results showed that the model correctly predicted 63.4% of adoption outcomes, with stronger predictive accuracy among adopters than non-adopters.

The regression results indicate that water availability throughout the year was one of the strongest determinants of UIC adoption and utilisation. The positive and statistically significant coefficient ($\beta = 0.731$, $p = 0.017$) suggests that households with reliable year-round water access were more likely to cultivate indigenous crops. The odds ratio further indicates that farmers with sufficient water availability were approximately 2.1 times more likely to adopt UICs than those facing water constraints. This finding highlights the continued importance of water security within smallholder farming systems. Although UICs are commonly promoted as drought-tolerant and climate-resilient crops, successful cultivation may still depend on minimum levels of water access, particularly during crop establishment and periods of prolonged dry conditions.

The Knowledge Index also positively and significantly influenced adoption behaviour ($\beta = 0.364$, $p = 0.033$). Farmers with higher levels of knowledge regarding the nutritional, agronomic, and livelihood benefits of UICs were more likely to adopt these crops. The odds ratio suggests that a one-unit increase in the knowledge index increased the likelihood of adoption by approximately 44%. This finding supports the central proposition of the KAP framework that cognitive awareness plays an important role in shaping behavioural outcomes. However, the Attitude Index was not significantly associated with adoption ($B = 0.287$, $p = 0.180$), which does not support H2. Figure 6 presents the odds ratios visually.

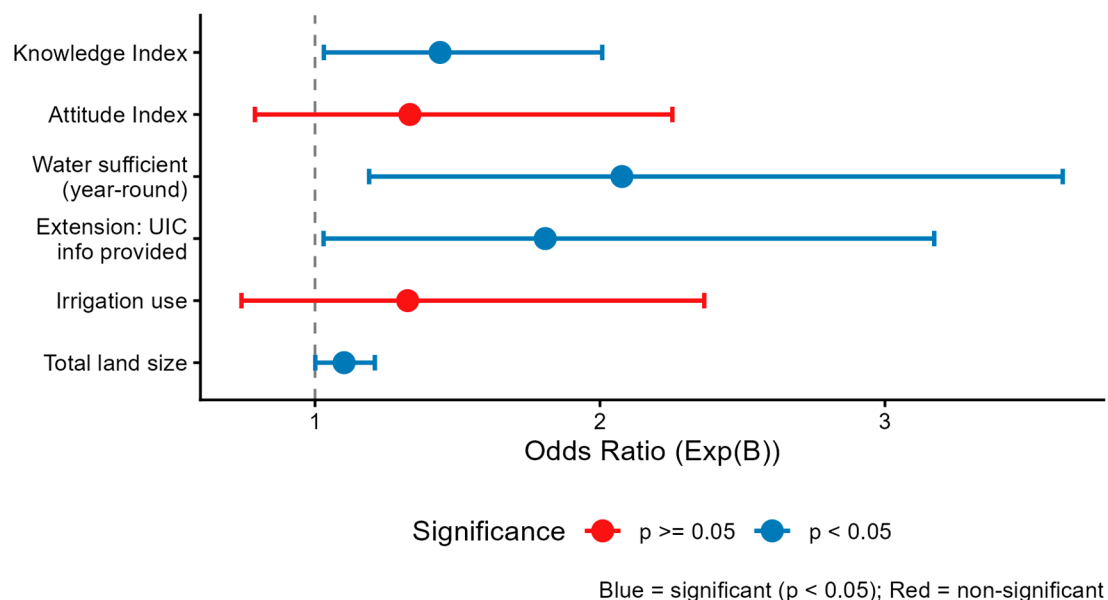


Figure 6. Determinants of UIC adoption. Source: Author's compilation (2026).

Furthermore, extension exposure significantly influenced adoption behaviour ($\beta = 0.592$, $p = 0.039$). Farmers receiving information on UICs from extension officers were approximately 1.8 times more likely to adopt indigenous crops compared to those without extension exposure. This finding underscores the importance of agricultural advisory services in facilitating information dissemination, technology awareness, and behavioural change among smallholder farmers.

Land size also exerted a positive and statistically significant influence on adoption ($\beta = 0.097$, $p = 0.048$), suggesting that farmers with relatively larger landholdings were more willing to allocate land toward alternative or underutilised crops. Larger landholdings may reduce production risk associated with experimentation and diversification.

4.9. Formal Bootstrap Mediation Analysis

A formal bootstrap mediation analysis was conducted to test H3 (Table 9). Results show that the Average Causal Mediation Effect (ACME: indirect effect of knowledge on adoption via attitudes) is not statistically significant (ACME = -0.007 , 95% CI: -0.079 to 0.059 , $p = 0.802$). The Average Direct Effect (ADE = 0.067 , 95% CI: -0.040 to 0.143 , $p = 0.176$) is also non-significant on the marginal (probability) scale. H3 is therefore not supported by formal mediation testing. These results indicate that attitudes do not mediate the knowledge-adoption association in the study area. Knowledge appears to be associated with adoption through mechanisms other than attitudinal change, possibly through direct informational triggers, experiential learning, or social observation. The non-significant indirect effect is itself theoretically informative and is discussed in Section 5.2.

Table 9. Bootstrap Mediation Analysis: Indirect Effect of Knowledge on UIC Adoption via Attitudes. Notes: $n = 205$; 1000 simulations; percentile bootstrap CIs. ACME = Average Causal Mediation Effect; ADE = Average Direct Effect. Source: Author’s calculations using R mediation package [44].

Pathway	Estimate	95% CI Lower	95% CI Upper	<i>p</i> -Value	Interpretation
ACME—Indirect effect (K → Attitude → Adoption)	-0.007	-0.079	0.059	0.802	Not significant— mediation not supported
ADE—Direct effect (K → Adoption)	0.067	-0.040	0.143	0.176	Not significant on probability scale
Total Effect (K → Adoption)	0.059	-0.024	0.096	0.152	Not significant on probability scale
Proportion Mediated	-0.125			0.838	Not significant

5. Discussion

5.1. Adoption of Underutilised Indigenous Crops

Within the study municipalities of Alfred Duma, Senqu, Mnquma, and Alfred Nzo, UICs remain embedded within smallholder farming systems and continue to contribute to household food production and livelihood resilience. The 70% adoption rate observed in the study areas is comparatively higher than findings from Sri Lanka, where Chamara et al. [16] documented high awareness but lower actual adoption due to institutional and market barriers. It is also higher than many sub-Saharan African adoption estimates reported by Ndlovu et al. [8] and Omotayo and Aremu [7] and may reflect the deeper cultural integration of indigenous crops such as taro, amaranth, cowpeas, and pumpkin within isiZulu- and isiXhosa-speaking communities. Nevertheless, these findings should be interpreted cautiously given the non-probability sampling approach and the binary measurement of adoption, which may overestimate engagement by capturing even minimal or irregular cultivation.

The findings contribute to ongoing debates regarding the role of UICs within South Africa’s agricultural transformation agenda. Historically, indigenous crops have remained marginal within formal agricultural policy, research, and extension systems despite their recognised nutritional, environmental, and socio-economic importance [10–12]. However, recent developments within the Department of Agriculture signal increasing institutional recognition of the sector. In 2025, the Minister of Agriculture approved the inclusion of indigenous crops and medicinal plants in the list of officially declared agricultural products under the Marketing of Agricultural Products Act. This policy shift formally recognises indigenous crops within South Africa’s agricultural economy and provides an enabling environment for strengthening market development, institutional support, and commercialisation.

Furthermore, farmers in the study areas adopted UICs because of their resilience under climate variability, lower water requirements, and contribution to household food security. These findings are consistent with those reported by Omotayo et al. [32], Shelembe et al. [2,45], and Nkambule and Agholor [46], all of whom documented the central role of institutional support and extension access in shaping adoption behaviour among smallholder farmers in South Africa. Moreover, Mendi et al. [9] identified indigenous crops as important components of climate-resilient farming systems. At the same time, the findings suggest that policy recognition alone may be insufficient to transform the sector. Constraints related to weak market development, limited extension support, low consumer awareness, and inadequate seed systems continue to constrain wider adoption and commercialisation, reinforcing concerns raised in previous studies [7,12,13,47,48].

5.2. Knowledge, Attitudes, and the Limits of Attitudinal Mediation

The finding that knowledge was positively associated with attitudes ($B = 0.352$, standardised beta = 0.643, $p < 0.001$) in the study population supports H1 and is consistent with the KAP pathway. Farmers possessing greater awareness regarding indigenous crop identification, nutritional value, and production practices were more likely to express positive attitudes. This aligns with Ntawuruhunga et al. [25] and Light et al. [29] in African contexts, and with Mulugeta et al. [30] and Mweke et al. [31], who also found knowledge-attitude relationships to be robust across diverse agricultural KAP applications.

However, the formal bootstrap mediation analysis does not support attitudinal mediation of the knowledge-adoption association in the study area. The ACME was not statistically significant ($p = 0.802$), and neither the direct nor total effects were significant on the marginal probability scale. The ‘partial mediation’ interpretation sometimes derived from sequential regression is therefore not supported by formal testing. Three explanations are proposed for the attitude-practice gap. First, structural and resource barriers suppress attitude-to-practice translation regardless of attitudinal orientation: 60.5% of respondents lacked year-round water access and 75.1% were dissatisfied with extension services. Byfuglien et al. [23] systematically demonstrates that the intention-behaviour gap in farming is consistently explained by structural constraints rather than motivational deficits, findings echoed by Rurii & Nzengya Daniel [49] in a recent scoping review of CSA adoption in sub-Saharan Africa. Second, perceived behavioural control may be low even among farmers holding favourable attitudes, consistent with the Theory of Planned Behaviour [19]. Third, social stigma associated with UICs as ‘poverty crops’ may deter adoption even among motivated farmers [12,32,47]. These mechanisms explain why H2 and H3 (mediated) are not empirically supported.

5.3. Water Availability and UIC Adoption

Water availability throughout the year was the strongest predictor of adoption in the study area ($\text{Exp}(B) = 2.077$, $p = 0.017$), indicating that households with reliable water access were approximately 2.1 times more likely to cultivate UICs. This association is consistent with Zhou et al. [14], who identified water scarcity as a primary constraint to smallholder agricultural productivity in semi-arid South Africa, and with Ncube and Shoko [1], who documented water access conflicts among smallholder farmers. Although UICs are commonly promoted as drought-tolerant crops [5], the findings in the study area suggest that successful cultivation depends on minimum levels of water security, particularly during crop establishment. Mnukwa et al. [44] similarly found that water access was a significant enabling condition for climate-smart agricultural adoption in sub-Saharan African contexts. The negative association between water sufficiency and attitudes ($B = -0.344$, $p = 0.020$) reflects an apparent paradox explained by economic substitution: farmers with secure

water access are less constrained and may prefer commercially established conventional crops, while water-constrained farmers may perceive UICs more favourably due to their drought adaptability [12,32].

5.4. Extension Readiness and the UIC Knowledge Gap

The findings suggest that agricultural extension systems in the study areas are not yet adequately equipped to support the large-scale promotion and commercialisation of underutilised indigenous crops (UICs). While extension contact frequency was positively associated with farmers' knowledge and attitudes towards UICs, crop-specific advisory support remained extremely limited. Although 88.3% of respondents reported contact with extension services, only 23.9% received UIC-specific information and a mere 1.9% had participated in UIC-related training. As illustrated in Figure 5, these findings reveal a substantial gap between general extension engagement and the provision of specialised technical support for indigenous crops.

These findings support the observations of Cele and Mkhize [13] and Vilakazi et al. [11], who argue that agricultural extension systems in South Africa continue to prioritise conventional commercial crops, while indigenous crops receive limited institutional attention. Consequently, extension officers are often trained, monitored, and incentivised based on mainstream crop production indicators, reflecting historical policy priorities that have marginalised UICs within formal agricultural advisory services [48]. This institutional bias limits farmers' access to crop-specific production knowledge, technical support, and market-related information necessary for expanding indigenous crop cultivation.

Effective mainstreaming of UICs will require extension systems capable of supporting seed access, production training, climate adaptation practices, market development, and value chain integration [10,13]. Zhang and Dannenberg [50] similarly documented that indigenous food plant farmers in Cape Town face structural barriers to agri-food value chain integration, including limited market infrastructure, inadequate institutional linkages, and low consumer demand, challenges directly mirrored in the study findings.

Furthermore, the findings reveal an important gap between recent policy ambitions and implementation capacity. While the 2025 declaration of indigenous crops and medicinal plants under the Marketing of Agricultural Products Act represents a significant institutional milestone, effective mainstreaming of UICs will require extension systems capable of supporting seed access, production training, climate adaptation practices, market development, and value chain integration [26,34]. Recent evidence further demonstrates the potential contribution of agricultural advisory services, with Mnukwa et al. [44] reporting that extension services increased climate-smart agriculture adoption by approximately 2.8 times across sub-Saharan Africa. These findings highlight the transformative potential of well-targeted extension services in accelerating the adoption and commercialisation of UICs.

From a behavioural perspective, the pathway analysis demonstrated that knowledge exerted a stronger influence on adoption behaviour than attitudes alone. Although extension services positively influenced both knowledge and attitudes, the absence of a significant mediation effect suggests that improving farmers' perceptions alone may be insufficient to stimulate widespread adoption. Rather, adoption decisions appear to be shaped by a combination of cognitive, institutional, and resource-related factors, including access to technical knowledge, extension support, water resources, and market opportunities [6,28]. Consequently, strengthening extension systems will require moving beyond awareness creation towards comprehensive support that facilitates knowledge acquisition, farmer training, seed availability, market access, and institutional linkages capable of translating positive attitudes into sustained adoption and commercialisation of UICs.

5.5. Limitations of the Study

Several limitations should be considered. First, the cross-sectional design cannot establish causal directionality. The observed associations may reflect reverse causation, for example, farmers who have adopted UICs may accumulate greater knowledge through practice. Longitudinal or instrumental variable approaches are needed to resolve this endogeneity. Second, the binary operationalisation of adoption masks substantial heterogeneity in adoption intensity, species diversity, and continuity. Third, the non-probability sampling approach limits statistical generalisability beyond the four study municipalities. The sample contains a larger proportion of Eastern Cape respondents (120 vs. 85), which should be noted when comparing provinces. Fourth, market-specific demand-side variables (consumer demand, market prices, value chain integration) were not included in the regression models, reflecting the behavioural focus of the study, though they are discussed as contextual factors. Fifth, self-reported KAP data may be subject to recall and social desirability bias. Sixth, the Nagelkerke R^2 of 0.199 indicates that approximately 80% of variation in adoption remains unexplained, consistent with comparable adoption studies [24], and policy implications should therefore be treated as indicative rather than definitive.

6. Conclusions

This study examined farmers' KAP regarding UICs and assessed factors associated with their adoption among smallholder farmers in selected municipalities of KwaZulu-Natal and Eastern Cape provinces of South Africa. Within the study areas, UICs remain embedded in local farming systems and contribute to household food production, dietary diversity, and climate resilience. Farmers generally possessed positive knowledge and attitudes toward these crops, particularly regarding their adaptability to harsh climatic conditions, low input requirements, and nutritional importance. However, positive knowledge and attitudes do not automatically translate into widespread adoption. Formal bootstrap mediation analysis does not support attitudinal mediation of the knowledge-adoption association ($ACME = -0.007$, $p = 0.802$), indicating that structural and resource-related barriers, not attitudinal deficits, are the primary obstacles to adoption in the study communities.

The study contributes empirical evidence supporting the 2025 legislative recognition of indigenous crops as agricultural products under South African national legislation, reinforcing arguments that UICs can contribute to climate-resilient agriculture and food system transformation in the study areas. However, there is a significant gap between policy recognition and implementation capacity, particularly regarding extension readiness and market development. UICs possess substantial potential to contribute to food and nutrition security and climate adaptation in the surveyed communities; realising this potential requires coordinated institutional support, investment in extension systems, research and seed development, and stronger integration into formal markets.

7. Recommendations

7.1. Strengthen Agricultural Extension Support for UICs

Extension systems should be reoriented to include UIC-specific crop training, demonstration plots, and technical support. Concretely: (a) develop standardised UIC extension packages and production manuals for at least five priority species in each agroecological zone; (b) establish demonstration plots in each study municipality; and (c) revise extension officer performance monitoring to include UIC advisory delivery as a measurable indicator.

7.2. Improve Seed Systems and Research Investment

Government and research institutions should: (a) establish provincial seed banks for priority UIC species; (b) fund agronomic trials to develop locally adapted varieties;

and (c) invest in post-harvest processing, storage, and value addition research to improve market readiness.

7.3. Support Implementation of the Indigenous Crops Policy

The 2025 declaration under the Marketing of Agricultural Products Act should be supported through: (a) dedicated funding programmes for UIC value chain development; (b) inter-departmental coordination across Agriculture, Health, and Trade; (c) consumer awareness campaigns addressing the ‘poverty crop’ stigma; and (d) inclusive participation of smallholder farmers in policy design and implementation.

7.4. Address Water Access as a Prerequisite for Wider Adoption

Water security interventions should be integrated into UIC promotion strategies, including support for small-scale rainwater harvesting, community water storage, and affordable drip irrigation systems in water-constrained municipalities.

7.5. Directions for Future Research

(1) Longitudinal panel studies to establish causal direction of the knowledge-adoption relationship. (2) Mixed-methods research to explore structural barriers to attitude-to-practice translation. (3) Models of adoption intensity (ordered logit, Tobit) to examine depth of engagement. (4) Consumer-side demand studies to complement the supply-side focus. (5) Comparative provincial studies to test the generalisability of the KAP-UIC model across all nine South African provinces.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/agriculture16161742/s1>, Supplementary File S1: Research Questionnaire.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author due to privacy and confidentiality considerations related to survey respondents.

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