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Principal component analysis of factors influencing livelihood transformation among Flue-Cured Virginia tobacco farmers in Andhra Pradesh

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Abstract

This study aimed to identify the underlying perceived significant dimensions of factors linked with livelihood transformation among Flue-Cured Virginia (FCV) tobacco farmers in the Northern Light Soil (NLS) region of Andhra Pradesh. Understanding these latent factors is essential for designing integrated interventions that enhance livelihood resilience. A multistage sampling technique was employed to select 210 FCV tobacco farmers from five auction floors covering 35 villages in the NLS region of Andhra Pradesh. Principal component analysis (PCA) with Varimax rotation was performed using IBM SPSS Statistics Version 16.0 to identify the underlying factor structure. The Kaiser-Meyer-Olkin (KMO) measure (0.87) and Bartlett's Test of Sphericity (χ^2 = 4293.0, p < 0.001) confirmed the suitability of the data for factor analysis. Five principal components with eigenvalues greater than one were extracted, accounting for 79.51 % of the total variance. The extracted dimensions were crop choice, financial and risk, institutional and governance, market and price and technology and innovation. Crop choice drivers explained the highest proportion of rotated variance (16.41 %), followed by financial and risk (16.12%), institutional & governance (15.98 %), market & price (15.71 %) and technology and innovation (15.26 %). Institutional credit (F_1) (loading = 0.91), profitability (C_1) (0.90), extension services (I_2) (0.90), better price realization (M_3) (0.88) and field demonstrations (T_4) (0.88) emerged as the strongest indicators. The findings, provide empirical evidence for policymakers, extension agencies and development organisations to formulate integrated livelihood enhancement strategies. This study offers a comprehensive empirical assessment of the perceived factors linked with livelihood transformation among FCV tobacco farmers using PCA.

Keywords: components; factors; livelihood; marketing; tobacco

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1. Introduction

The concept of livelihood encompasses the capabilities, assets and activities required to secure a means of living. A livelihood is considered sustainable when it can cope with and recover from stresses and shocks, maintain or enhance its capabilities and assets and provide sustainable livelihood opportunities for future generations (1). Livelihood sustainability is determined by the interaction among five livelihood capitals, namely natural, physical, human, financial and social capital, which collectively shape household resilience and adaptive capacity (2–6). In this study, the term “livelihood transformation” refers to the changes and improvements in the livelihood conditions of Flue-Cured Virginia (FCV) tobacco farmers associated with market access, institutional support, technological adoption, financial and risk and crop choice decisions. The study does not directly measure livelihood transformation as a single outcome variable; rather, principal component analysis (PCA) is used to identify and group the underlying dimensions that influence or contribute to livelihood transformation. Thus, the identified components represent key dimensions associated with the livelihood transformation process among FCV tobacco farmers.

Recent studies have further emphasised that the availability and effective utilisation of livelihood capitals significantly influence the resilience, adaptive capacity and long-term sustainability of rural households under changing socio-economic and environmental conditions (7, 8). Livelihood analysis offers a holistic framework for examining agriculture as a multidimensional socio-economic system (9). The sustainable livelihood framework (10) further recognises the importance of institutional

arrangements, policies, markets and support services in shaping livelihood strategies and outcomes. Contemporary research has also highlighted the critical role of institutional support, market access, extension services and policy interventions in strengthening livelihood outcomes and promoting sustainable rural development (11–13). As livelihood transformation is influenced by multiple interrelated socio-economic, technological and institutional factors, identifying the underlying dimensions influencing this transformation is essential for designing effective interventions that enhance farmers' resilience, improve livelihood security and promote sustainable agricultural development. Livelihood diversification and market participation enhance resilience and reduce poverty (14, 15). Empirical studies have confirmed that diversified livelihood portfolios, improved market integration and access to productive assets contribute significantly to household welfare, income stability and resilience against external shocks (12, 16).

The FCV tobacco is one of India's most important commercial crops, contributing substantially to export earnings, employment generation and rural livelihoods. FCV tobacco production in Andhra Pradesh is concentrated in the Northern Light Soil (NLS), Southern Light Soil (SLS) and Southern Black Soil (SBS) regions. Farmers have continued cultivating FCV tobacco for several decades due to its well-established institutional and marketing support system, including regulated auction platforms, quality-based grading and pricing, assured market mechanisms, technical guidance and strong domestic and export demand, which together provide relatively stable and remunerative returns compared to many competing crops. Limited empirical evidence exists on the multidimensional components influencing livelihood transformation specifically among FCV tobacco farmers. The FCV tobacco was selected because of its distinctive regulated auction system, institutional support, commercial importance and contribution to farm livelihoods in Andhra Pradesh. The present study develops an FCV tobacco-specific perspective by identifying five key components. Recent reports of the Tobacco Board of India and agricultural trade statistics indicate that FCV tobacco continues to be an important source of farm income and export revenue, particularly in major tobacco-growing regions of Andhra Pradesh, where institutional support and organised marketing systems contribute significantly to farmer livelihoods (17–19). The FCV tobacco farming operates within a dynamic external environment shaped by tobacco-control policies, public health concerns, anti-tobacco initiatives and changing market conditions. These external factors may influence farmers' production decisions, market opportunities and livelihood strategies, thereby enhancing the significance of financial resilience, institutional support and livelihood diversification.

Although several studies have focused on the production economics and marketing aspects of FCV tobacco, limited attention has been given to identifying the underlying factors that drive livelihood transformation. In this connection, from a crop-production aspect, these dimensions have direct reliability for FCV tobacco cultivation. Crop-choice considerations namely profitability, agro-climatic suitability, irrigation and input availability effect farmers' decisions to prolong the FCV tobacco cultivation, while technological integration affects the adoption of high yielding varieties, good agricultural practices, mechanisation and post-harvest technologies. Institutional support, financial access and market can further enhance farmers' capability to implement these crop-management practices. Thus, the identified dimensions are appropriate not only to livelihood considerations but also to on-farm activities and technological adoption in FCV tobacco cultivation. Exploratory factor analysis (EFA) with PCA is a widely used statistical method in social sciences, information systems, education and psychology (20). Since livelihood transformation is determined by multiple interrelated socio-economic, technological and institutional factors, multivariate data-reduction techniques can be used to review these relationships into a smaller number of interpretable dimensions. The PCA was selected in the study because the objective was to reduce the 25 observed variables into a smaller set of components while retaining the maximum possible proportion of the total variance in the original dataset. Unlike EFA, which primarily seeks to identify unobserved latent constructs based on common variance, PCA transforms the observed variables into linear combinations that maximise the variance explained by each successive component. As a result, PCA was considered appropriate for the present study, which focused on data reduction and identification of the major dimensions associated with livelihood transformation rather than estimation of latent constructs. In recent years, factor analysis techniques have gained wider acceptance in agricultural and rural development research for identifying latent dimensions, reducing data complexity and examining relationships among socio-economic, institutional and technological variables (21, 22). Unlike previous livelihood studies that mainly examine livelihood elements, the present study provides an FCV tobacco specific empirical framework by integrating into five distinct components. The EFA has been utilised for a variety of purposes including determining relationships among socioeconomic characteristics, livelihood assets, behavioural attributes and institutional factors. Therefore, the present study employed PCA to identify the major components influencing livelihood transformation among FCV tobacco farmers in Andhra Pradesh, thereby generating empirical evidence to support policy formulation and institutional interventions aimed at enhancing livelihood resilience, farm sustainability and farmers' socio-economic well-being.

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The PCA technique was utilised due to its effectiveness in identifying key traits from the mosaic of an overlapping relationship (23) and its suitability for reducing the dimensionality of large and complex datasets while preserving most of the original variability (24). Livelihood transformation refers to the changes in farmers' livelihood strategies and outcomes resulting from the combined influence of different components. The conceptual framework of the study proposes that livelihood transformation among FCV tobacco farmers is a multidimensional process shaped by five interrelated dimensions. Recent methodological studies have reaffirmed that PCA remains one of the most effective multivariate techniques for summarising large datasets, identifying latent structures and improving interpretability without substantial loss of information (25–27). The objectives of factor analysis with PCA are to reduce the number of variables, assess multicollinearity and correlation among factors, evaluate the unidimensionality of constructs, examine construct validity, identify factor relationships, develop meaningful constructs and validate theoretical frameworks (28). Recent applications in agricultural and social science research continue to demonstrate the usefulness of PCA and factor analysis in developing robust empirical models and identifying the key factors for livelihood and development outcomes (26, 29).

2. Materials and Methods

The study was conducted among FCV tobacco farmers in the NLS region of Andhra Pradesh during 2025–26. A multistage sampling technique was adopted for the selection of respondents. Five FCV tobacco auction floors viz., Devarapalli, Koyyalagudem, Gopalapuram, Jangareddy Gudem-I and Jangareddy Gudem-II were selected for the study. From each auction floor, seven representative villages were selected and from each selected village, six farmers were chosen, comprising two small farmers (< 2 ha), two medium farmers (2–10 ha) and two large farmers (> 10 ha). Physiological management practices differ across farm-size categories, primarily due to differences in timely access to labour. Large farmers were generally able to hire labour and complete field operations such as topping and desuckering at the appropriate time, whereas small and medium farmers were relatively more dependent on labour availability and existing wage rates, which sometimes affected the timely completion of these operations. Thus, a total of 42 farmers were selected from each auction floor (14 small, 14 medium and 14 large farmers). Consequently, the overall sample consisted of 210 FCV tobacco farmers drawn from 35 villages across the five selected auction floors. The factor names were assigned systematically based on the conceptual similarity and common characteristics of the variables showing high loadings within each component. Seven villages were selected from each auction-floor jurisdiction to ensure adequate geographical coverage and representation of the diverse FCV tobacco-growing conditions within the NLS region, resulting in a total of 35 villages. A total sample of 210 farmers was considered adequate for PCA, providing a respondent-to-variable ratio of 8.4 : 1 for the 25 variables, which exceeds the commonly recommended minimum ratio of 5 respondents per variable and ensures sufficient observations for reliable factor extraction. The sampling procedure ensured adequate representation of farmers belonging to different farm-size categories, thereby providing a comprehensive assessment of the factors determining livelihood transformation among FCV tobacco farmers. In the NLS region, the commonly adopted FCV tobacco varieties by farmers include Kanchan, CH-1 and LT Kanchan. The recommended nutrient management for NLS includes balanced application of nitrogen, phosphorus and potassium, with additional calcium supplementation where required. The recommended fertiliser schedule is approximately 115–46–150–48 kg ha^{-1} of $N–P_2O_5–K_2O$–Ca under conventional fertilisation, while fertigation recommendations provide approximately 90–35–120–14 kg ha^{-1} of $N–P_2O_5–K_2O$–Ca. However, the present research did not evaluate cultivar-specific physiological traits such as drought tolerance or nutrient-use efficiency. The NLS are predominantly derived from sandstone and are sandy to sandy loamy in texture, moderately acidic, well drained, loose and highly porous, with low cation-exchange and water-holding capacities. The soils are characterised by poor inherent fertility and high nutrient losses through leaching, necessitating efficient nutrient and water management for quality FCV tobacco production. The ideal soil reaction for FCV tobacco generally ranges from pH 5.5 to 6.5, with low nutrient and organic matter status. These soil characteristics influence nutrient availability and uptake and, consequently, leaf development and flue-curing quality. The electrical conductivity (EC) values showed that the soils are free of salts. The EC values ranged from 0.01 to 0.6dS/m. Soils are well within the salt free limits. The mean available of organic carbon content of NLS was 0.29 %, while it varied from 0.24 to 0.31 % among the auction platform areas.

To identify the underlying dimensions influencing livelihood transformation among FCV tobacco farmers, PCA was employed as a multivariate statistical technique. The PCA is widely used to reduce many correlated variables into a smaller set of uncorrelated principal components (30) while retaining the maximum possible variation in the original dataset. This method facilitates the identification of the most influential latent factors explaining livelihood transformation by minimising data redundancy and simplifying interpretation (31). Completed interview schedules were checked for completeness, consistency and coding errors before

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analysis. Incomplete or inconsistent responses were verified and corrected wherever possible and no substantial missing data were observed in the final dataset used for PCA.

Data were collected from FCV tobacco farmers using a structured interview schedule comprising 25 statements related to the 5 potential factors of livelihood transformation, namely crop choice, financial and risk, institutional and governance, market and price and technology and innovation. In the present study, livelihood transformation was operationalised in terms of farmers' perceived importance of factors considered significant to changes in their livelihood conditions. Accordingly, PCA was employed to identify the underlying dimensions among these perceived importance statements. The extracted components should therefore be interpreted as perceived dimensions associated with livelihood transformation. These 25 variables were selected based on relevant literature, expert ratings on the sustainable livelihood framework and their contextual relevance to FCV tobacco farming, ensuring adequate representation of the key dimensions influencing livelihood transformation. Prior to PCA, the variables were standardised to minimise scale-related effects and ensure comparability among the 25 variables included in the analysis. Respondents expressed their level of agreement and perceived importance of each statement on a five-point Likert scale, with Very High = 5, High = 4, Moderate = 3, Low = 2 and Very Low = 1. The internal consistency of the 5 dimensions was examined using Cronbach's alpha. The reliability coefficients were 0.94 for crop choice, 0.93 for financial and risk, 0.93 for institutional and governance, 0.93 for market and price and 0.92 for technology and innovation, representing suitable internal consistency among all dimensions. All statistical analyses were performed using IBM SPSS Statistics (Version 16.0).

3. Results and Discussion

Livelihood transformation among FCV tobacco farmers was examined through five major factors: namely crop choice, financial and risk, institutional and governance, market and price and technology and innovation. These factors were measured using 25 statements of 5 each under the factors. Crop choice factors consisted of profitability (C_1), agro-climatic suitability (C_2), family labour utilisation (C_3), farming experience (C_4) and irrigation and input availability (C_5). Financial and risk factors included institutional credit (F_1), reduced dependence on informal credit (F_2), financial returns (F_3), financial resilience (F_4) and cost management (F_5). Institutional and governance factors covered policy support (I_1), extension services (I_2), technical guidance (I_3), quality monitoring (I_4) and farmer registration systems (I_5). Market and price factors included assured auction marketing (M_1), transparent price discovery (M_2), better price realisation (M_3), timely market information (M_4) and export demand (M_5). Technology and innovation factors comprised improved varieties (T_1), scientific cultivation practices (T_2), mechanisation (T_3), field demonstrations (T_4) and post-harvest technologies (T_5).

Kaiser-Meyer-Olkin and Bartlett's test of sphericity

Principal component analysis was performed using Varimax rotation (32). The adequacy and suitability of the data for PCA were assessed using the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy (33) and Bartlett's test of sphericity (34, 35). The results are presented in Table 1.

The results (Table 1) showed that the KMO value was found to be 0.87, which is well above the recommended threshold value of 0.60. According to previous researchers, KMO values between 0.80 and 0.90 indicate meritorious sampling adequacy, suggesting that the data are appropriate for extraction (25, 33). Bartlett's test of sphericity produced a Chi-square value of 4293.0 with 300 degrees of freedom and was statistically significant at the 1 % level ($p < 0.001$). Another study stated that a significant result indicates that the correlation matrix is not an identity matrix and that substantial correlations exist among the variables included in the study (34).

The high KMO value indicates that the selected variables relating to market, institutional, financial, technological and crop-choice factors share sufficient common variance for factor analysis (6, 35, 36). The significant Bartlett's test further confirms that meaningful relationships exist among the variables, thereby justifying the application of factor analysis to identify the underlying dimensions influencing livelihood transformation among FCV tobacco farmers. Similar studies employing PCA in agricultural and rural livelihood research have reported that high KMO values and significant Bartlett's statistics provide strong evidence for extracting meaningful latent dimensions from socio-economic datasets (24, 25).

Communality of variables

Communality analysis was performed to assess the extent to which the variance of each observed variable is explained by the extracted factors (25, 36, 37). It provides an indication of the adequacy of variables in representing the extracted component structure. Variables with higher communality values are considered to have stronger representation within the extracted components and contribute more effectively to the component solution (6, 38). The communalities obtained for the variables included in the study are presented in Table 2.

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Table 1. Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and bartlett's test of sphericity

Test	Statistic	Value
KMO measure of sampling adequacy	KMO	0.87
Bartlett's test of sphericity	Approx. Chi-square	4293.0
	Degrees of freedom (df)	300
	Significance (p-value)	0.000*

*Significant at $p < 0.001$.

Table 2. Initial and extracted communalities of the study variables using principal component analysis (PCA)

Communalities		
	Initial	**Extraction**
M_1	1.00	0.79
M_2	1.00	0.75
M_3	1.00	0.79
M_4	1.00	0.79
M_5	1.00	0.78
I_1	1.00	0.79
I_2	1.00	0.82
I_3	1.00	0.79
I_4	1.00	0.77
I_5	1.00	0.79
F_1	1.00	0.83
F_2	1.00	0.76
F_3	1.00	0.81
F_4	1.00	0.80
F_5	1.00	0.80
T_1	1.00	0.74
T_2	1.00	0.77
T_3	1.00	0.76
T_4	1.00	0.78
T_5	1.00	0.76
C_1	1.00	0.83
C_2	1.00	0.81
C_3	1.00	0.83
C_4	1.00	0.81
C_5	1.00	0.81

C_1–C_5: crop choice; F_1–F_5: financial and risk; I_1–I_5: institutional and governance; M_1–M_5: market and price; T_1–T_5: technology and innovation. Source: Primary survey data (2025–26), analysed by the authors in IBM SPSS Statistics (Version 16.0).

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The results presented in Table 2 indicate that communality values indicate the proportion of variance in each variable explained by the extracted factors. The extracted communalities for all variables were found to be above the acceptable threshold level of 0.50, indicating that the selected variables were adequately represented by the extracted factors (25, 38). Similar studies reported that higher communalities improve the stability and interpretability of factor structures by ensuring that a substantial proportion of variance is explained by the retained components (39, 40). The communalities obtained in the present study revealed that the variables associated with market, institutional, financial, technological and crop-choice dimensions are well represented within the factor solution. The high factor loadings and absence of substantial cross-loadings showed a well-defined factor framework and indicate that farmers perceive crop-choice, financial, institutional, marketing and technological dimensions as major aspects linked with transformation of livelihood. A previous study, supported by other researchers observed that high communalities indicate that the extracted components effectively summarise the original dataset with minimal loss of information (24, 41, 42). This indicates that the extracted factors effectively capture the information contained in the original variables. The satisfactory communalities further validate the appropriateness of retaining the selected variables for understanding the factors for livelihood transformation of farmers (2, 14, 43).

Computation of total variance: The total variance explained presents the amount of variance accounted for by each extracted component in the PCA. It indicates the relative contribution of each component to the total variance in the dataset. Components with eigenvalues greater than one were retained for interpretation, as they explain a substantial proportion of the total variation in the data (6, 33, 36, 38, 40, 44).

The results presented in Table 3 revealed that five principal components had eigenvalues greater than one and were therefore retained for further analysis. The relative importance of the five components was assessed based on their eigenvalues and proportion of variance explained, with crop choice drivers emerging as the leading component. The first component viz., crop choice, recorded an eigenvalue of 4.80 and explained 19.22 % of the variance. The second component, viz., financial and risk, had an eigenvalue of 4.77 and accounted for 19.11 % of the variance. The third component, institutional and governance, explained 15.46 % of the variance with an eigenvalue of 3.86. The fourth component namely, market and price, explained 13.68 % of the variance with an eigenvalue of 3.42, while the fifth component, technology and innovation, explained 12.02 % of the variance with an eigenvalue of 3.00. Collectively, these components accounted for 79.51 % of the cumulative variance, indicating that the retained components adequately represented the original dataset comprising 25 variables. The remaining 20 components had eigenvalues below one and individually explained only 0.55 to 1.73 % of the total variance, suggesting that they contributed little additional information and were therefore excluded from further interpretation. Similar findings have been reported by previous researchers, who emphasised that components with eigenvalues greater than one generally capture meaningful variation and enhance the interpretability of multivariate datasets (38). Likewise, another study retained components with eigenvalues exceeding one to identify the principal factors influencing pulse crop productivity through PCA (6).

The total variance explained graph (Fig. 1) revealed that the five extracted components (n = 5) collectively accounted for 79.51 % of the total variance in the dataset. The cumulative variance exceeding the recommended threshold of 60–70 % indicates that the extracted components adequately represent the underlying structure of the data (25, 36). The extracted components varied in their contribution to explaining the total variance. Crop choice (component 1) showing a minimal difference of 0.11 % points with financial and risk (component 2) which indicates nearly equal explanatory power. Institutional and governance (component 3) representing a decline of 3.65 % points from financial and risk (component 2). Similarly, market and price (component 4) was 1.78 % points lower than institutional governance (component 3), while technology and innovation (component 5) showed a further decrease of 1.66 % points compared to component 4. The cumulative variance increased from 19.22 % for the first component to 79.51 % for all five components combined. This demonstrates that the five-component solution adequately captures the underlying structure of the data and provides a comprehensive representation of the factors influencing livelihood transformation. These findings confirm that the five-component solution provides a robust and parsimonious representation of the factors influencing livelihood transformation consistent with recent applications of PCA in agricultural and socio-economic research (6, 38).

To enhance interpretability, the extracted components were subjected to Varimax rotation with Kaiser normalisation. Although rotation did not alter the cumulative variance explained (79.51 %), it redistributed the variance more evenly across the retained components. The rotated solution explained 16.41, 16.12, 15.98, 15.71 and 15.26 % of the total variance for crop choice to technological integration (components 1 to 5), respectively. This redistribution resulted in a simpler and more interpretable factor structure by maximising high loadings within components while minimising cross-loadings among variables (6, 32, 36, 38).

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Table 3. Total variance explained by extracted factors

Components	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	4.80	19.22	19.22	4.80	19.22	19.22	4.10	16.41	16.41
2	4.77	19.11	38.34	4.77	19.11	38.34	4.03	16.12	32.54
3	3.86	15.46	53.80	3.86	15.46	53.80	3.99	15.98	48.53
4	3.42	13.68	67.49	3.42	13.68	67.49	3.92	15.71	64.24
5	3.00	12.02	79.51	3.00	12.02	79.51	3.81	15.26	79.51
6	0.43	1.73	81.24	-	-	-	-	-	-
7	0.39	1.56	82.81	-	-	-	-	-	-
8	0.36	1.45	84.26	-	-	-	-	-	-
9	0.33	1.34	85.61	-	-	-	-	-	-
10	0.32	1.30	86.91	-	-	-	-	-	-
11	0.31	1.25	88.16	-	-	-	-	-	-
12	0.29	1.19	89.36	-	-	-	-	-	-
13	0.27	1.10	90.46	-	-	-	-	-	-
14	0.25	1.03	91.50	-	-	-	-	-	-
15	0.25	1.01	92.51	-	-	-	-	-	-
16	0.24	0.99	93.50	-	-	-	-	-	-
17	0.23	0.92	94.43	-	-	-	-	-	-
18	0.21	0.87	95.30	-	-	-	-	-	-
19	0.19	0.78	96.08	-	-	-	-	-	-
20	0.18	0.74	96.83	-	-	-	-	-	-
21	0.17	0.69	97.52	-	-	-	-	-	-
22	0.16	0.66	98.19	-	-	-	-	-	-
23	0.16	0.65	98.84	-	-	-	-	-	-
24	0.15	0.60	99.44	-	-	-	-	-	-
25	0.13	0.55	100.00	-	-	-	-	-	-

Extraction method: Principal component analysis

Source: Primary survey data (2025–26), analysed by the authors in IBM SPSS Statistics (Version 16.0).

The interpretation and naming of the retained components were subsequently performed using the rotated component matrix (Table 4), where variables with high factor loadings were grouped into meaningful latent dimensions.

The high cumulative variance (79.51%) shows that the five components adequately explain the major variations in livelihood transformation among FCV tobacco farmers. In a previous study, PCA extracted four principal components explaining 71–81 % of the total variance, with land characteristics, income diversification and farmer education emerging as the key factors of agricultural performance (6). Recent methodological studies have emphasised that cumulative variance exceeding 60–70 % generally indicates the reliability and interpretability of the extracted components in multivariate analysis (36, 38).

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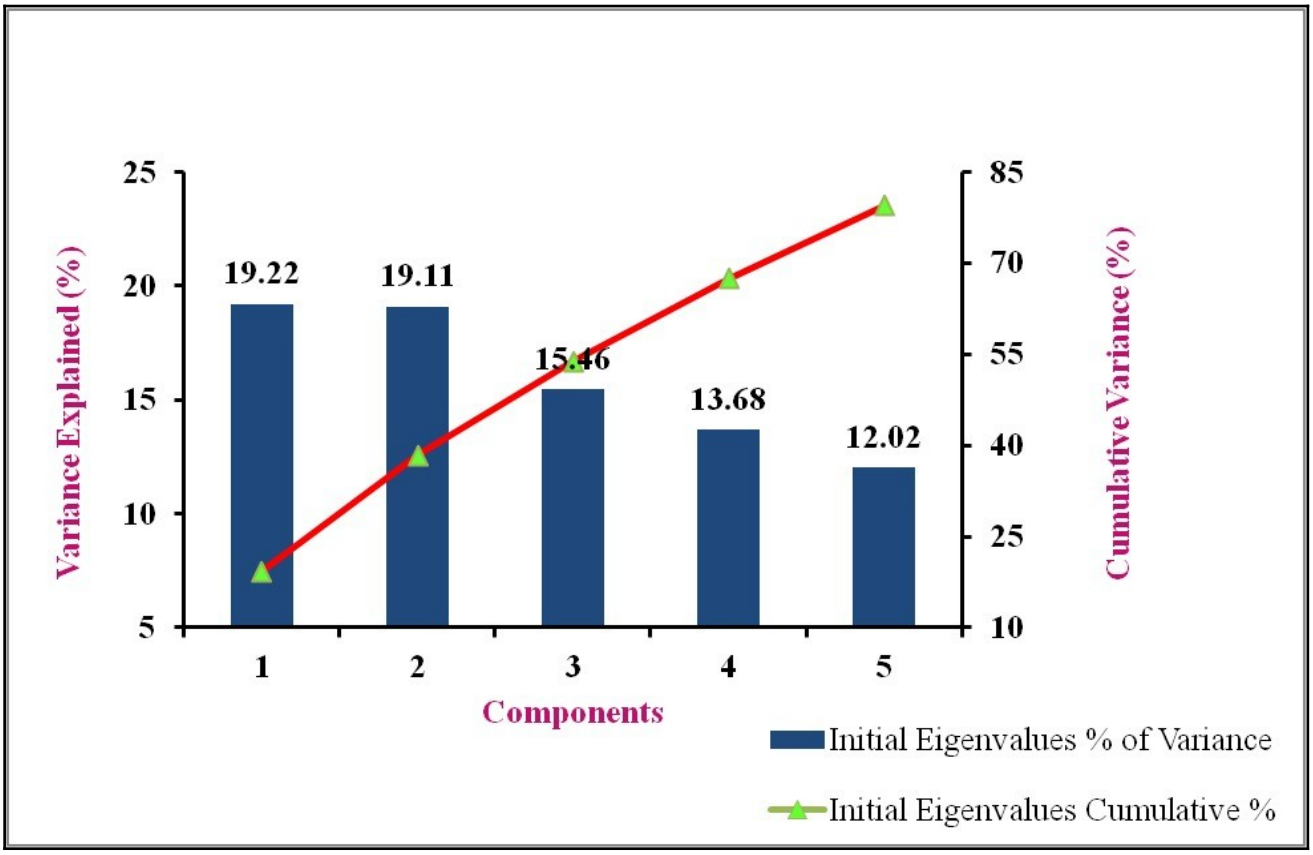

Fig. 1. Total variance explained by five extracted components.

Table 4. Rotated component matrix of variables using varimax with Kaiser normalisation

Rotated component matrix[a]					
	Component				
	1	2	3	4	5
C_1	.90				
C_3	.90				
C_4	.89			-.10	
C_5	.89				
C_2	.89		.12		
F_1		.91			
F_3		.90			
F_4		.89			
F_5		.89			
F_2		.87			
I_2			.90		
I_3			.89		
I_1			.88		
I_5			.88		
I_4			.87		
M_3				.88	
M_4				.88	

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M_5		.88	
M_1		.88	.10
M_2		.86	
T_4			.88
T_3			.87
T_2	-.12		.86
T_5			.86
T_1			.85

a. Rotation converged in 5 iterations.

C_1–C_5: crop choice; F_1–F_5: financial and risk; I_1–I_5: institutional and governance; M_1–M_5: market and price; T_1–T_5: technology and innovation. Source: Primary survey data (2025–26), analysed by the authors in IBM SPSS Statistics (Version 16.0).

Another study reported that cumulative variance exceeding 60 % is generally considered satisfactory in behavioural and social science research (25), while earlier researchers stated that higher cumulative variance reflects a robust and reliable factor solution capable of representing the original variables with minimal information loss (24). The cumulative variance of observed in the present study is consistent with earlier agricultural studies, which reported 71.5 % variance among smallholder farming systems in the Indo-Gangetic Plains (45–51) and 87 % among integrated farming households in Kerala (52).

Scree plot: The scree plot is a graphical representation of the eigenvalues associated with each extracted component in PCA. It is commonly used to determine the optimal number of factors to be retained for further interpretation. A previous review introduced the scree test as a graphical approach for identifying the number of meaningful components in a dataset (45), while another studies emphasised that the scree plot provides a visual assessment of component retention by distinguishing substantial factors from trivial ones (6, 24, 38). The point at which the slope of the curve begins to level off, commonly referred to as the "elbow," indicates the number of meaningful components that adequately explain the variation present in the dataset in Fig. 2.

The scree plot displayed a distinct break after the technological integration (component 5), indicating that the first five factors contributed significantly to explaining the total variance in the data. The eigenvalues of the first five components were substantially higher than those of the subsequent components, demonstrating their greater explanatory power. Beyond the fifth component, the curve gradually flattened and the remaining components exhibited relatively small eigenvalues, indicating a minimal contribution to the overall variance. Similarly, a study noted that components occurring before the flattening of the scree curve generally account for most of the systematic variation in the data (25). Researchers reported that components with larger eigenvalues capture the dominant patterns present in multivariate datasets, whereas components with very small eigenvalues contribute little additional information (24).

The scree plot clearly supports the retention of five factors for further analysis. The sharp decline in eigenvalues from the first to the fifth component followed by a noticeable flattening of the curve suggests that additional components contribute little meaningful information. This finding is consistent with previous studies and Kaiser's criterion, which recommends retaining components with eigenvalues greater than one (33, 44, 45). Therefore, the five-factor solution was considered appropriate for identifying the major components influencing livelihood transformation among FCV tobacco farmers. The retained factors were subsequently interpreted as marketing performance, institutional governance, financial resilience, technological integration and crop choice drivers. Together, these five factors captured most of the variation in the dataset and provided a meaningful representation of the multidimensional nature of livelihood transformation among FCV tobacco farmers.

Rotated component matrix of variables: The rotated component matrix is an important output of PCA and provides a clearer and more interpretable component structure. Varimax rotation was employed to maximise the loading of each variable on a single factor while minimising its loading on other factors. According to literature, Kaiser proposed Varimax rotation as an orthogonal rotation technique that maximises the variance of factor loadings, thereby improving the interpretability of extracted factors (32). This rotation technique facilitates the identification of underlying dimensions by grouping variables with similar characteristics under common factors (25, 28). A factor loading of ≥ 0.50 was considered the threshold for retaining and interpreting variables, while a secondary loading of ≥ 0.30 on another component was considered a meaningful cross-loading. Variables with component loadings greater than 0.50 were considered significant and were used for naming and interpreting the extracted components (38, 42).

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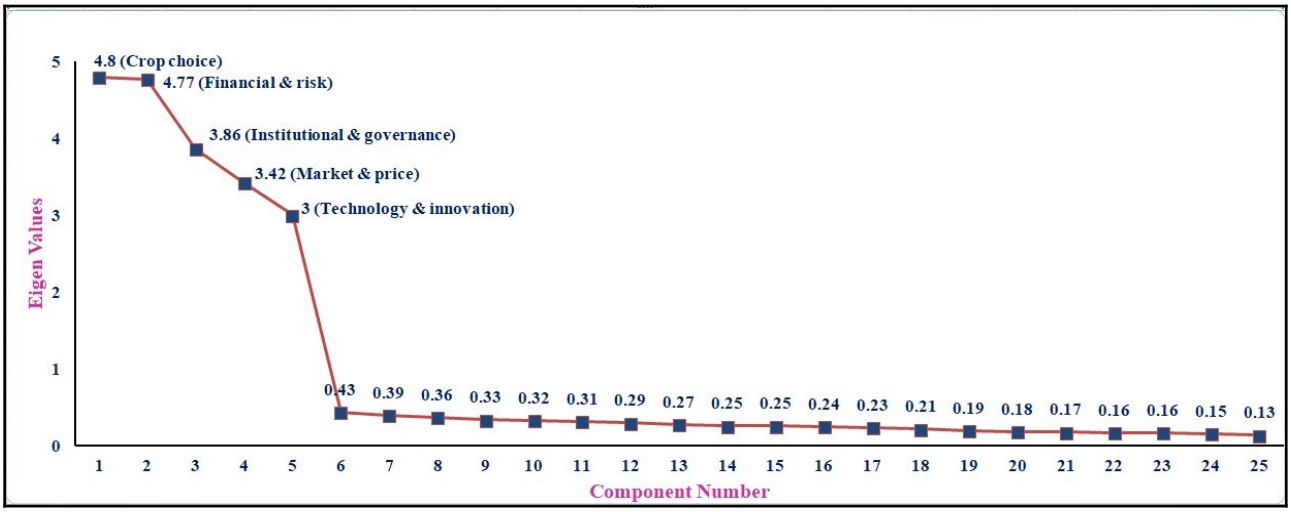

Fig. 2. Scree plot showing principal component retention.

The above results indicate that the rotation clearly classified the 25 observed variables into five distinct components, with high component loadings and negligible cross-loadings, indicating a clear and interpretable component structure (29, 39, 41). It is notable that the 5-component framework mainly confirmed the a priori conceptual organisation of the 25 items, as the items were primarily developed under the same 5 domains of crop choice, financial and risk, institutional and governance, market and price and technology and innovation. Entire items loaded strongly on their relevant components, without any substantial cross-loadings necessitating reassignment to another dimension. Thus, the PCA mainly provided empirical support for the conceptual framework of the instrument while also demonstrating a strong and interpretable component framework. Crop choice (component 1) consists of five variables (C_1–C_5), namely profitability (C_1), agro-climatic suitability (C_2), family labour utilisation (C_3), farming experience (C_4) and irrigation and input availability (C_5), with component loadings ranging from 0.89 to 0.90. Among these, profitability (C_1) exhibited the highest loading (0.90), indicating that expected economic returns are the strongest indicator influencing farmers' crop selection decisions. The high loadings suggest that crop choice is primarily determined by economic viability, resource availability and production suitability. The high Cronbach's alpha coefficients (0.92–0.94) demonstrated major internal consistency of the 5 dimensions. In the study conducted by researchers (46) reported that agricultural diversification and commercialisation is closely linked to farmers' crop selection behaviour. Crop profitability, climatic suitability, market opportunities and input availability loaded strongly on the crop choice factor, suggesting that crop selection decisions play a critical role in shaping livelihood outcomes (47).

Financial and risk (component 2) comprised variables (F_1–F_5) related to financial stability, including institutional credit (F_1), reduced dependence on informal credit (F_2), financial returns (F_3), financial resilience (F_4) and cost management (F_5), with loadings ranging from 0.87 to 0.91. Institutional credit (F_1) recorded the highest loading (0.911), representing the strongest individual indicator in the entire rotated matrix. Access to institutional credit can enable farmers to make timely investments in essential inputs, irrigation, balanced nutrient management and other recommended crop management practices. Such investments may strengthen farmers' capacity to manage moisture and nutrient-related production risks, which are particularly important in the light-textured NLS where water-holding capacity is low and nutrient losses through leaching are high. Although the present study did not directly measure physiological responses or leaf-quality parameters, timely access to credit may indirectly support the maintenance of crop growth and the production of quality FCV tobacco leaves. This finding highlights the critical role of formal financial access in strengthening farmers' livelihood resilience and their capacity to manage production and market-related risks. The previous findings similarly emphasised that financial inclusion significantly enhances rural livelihood security (14, 48) and agricultural sustainability (49, 50). This finding is consistent with previous studies, which reported that access to institutional credit significantly increased net farm income and household consumption expenditure among Indian farm households (53).

Institutional and governance (component 3) represents five variables (I_1–I_5), included policy support (I_1), extension services (I_2), technical guidance (I_3), quality monitoring (I_4) and farmer registration systems (I_5), with factor loadings varying from 0.87 to 0.90. Among these variables, extension services (I_2) showed the highest loading (0.90), demonstrating the importance of institutional support, technical advisory services and policy interventions in facilitating livelihood transformation. Recent studies

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have demonstrated that effective agricultural extension systems enhance overall livelihood outcomes by strengthening linkages between research, extension and farming communities. Similar findings were reported by previous researchers, who observed that agricultural advisory services, particularly frontline demonstrations and capacity-building interventions, significantly enhanced knowledge transfer and adoption of improved agricultural technologies among smallholder farmers (54).

Market and price (component 4) consists of five variables (M_1–M_5), comprising assured auction marketing (M_1), transparent price discovery (M_2), better price realisation (M_3), timely market information (M_4) and export demand (M_5), with factor loadings ranging from 0.86 to 0.88. Better price realisation (M_3) exhibited the highest loading (0.88), indicating that favourable prices and efficient marketing systems are major factors of farmers' economic performance. The findings are consistent with previous findings, which reported that farmers' choice of marketing channels, access to market information and communication networks significantly influenced producer price realisation in India (55).

Technology and innovation (component 5) includes five variables (T_1–T_5), improved varieties (T_1), scientific cultivation practices (T_2), mechanisation (T_3), field demonstrations (T_4) and post-harvest technologies (T_5), with loadings ranging from 0.85 to 0.88. Among these, field demonstrations (T_4) showed the highest loading (0.88), emphasising the importance of practical learning, technology dissemination and innovation adoption in improving farm productivity. The field demonstrations (T_4) primarily focused on practical agronomic practices, including improved varieties, scientific cultivation, nutrient and pest management and post-harvest practices. Physiological parameters such as stomatal conductance and transpiration rates were not specifically demonstrated or measured, as the demonstrations were designed to emphasise farmer-observable and field-applicable cultivation practices. Recent studies have further shown that technology adoption enhances farmers' income by facilitating the uptake of climate-smart and sustainable agricultural practices (6, 19).

Overall, the rotated component matrix demonstrated that the 25 observed variables were successfully grouped into five meaningful principal components, namely crop choice, financial and risk, institutional and governance, market and price and technology and innovation. The high factor loadings and absence of substantial cross-loadings indicate excellent construct validity and confirm that livelihood transformation among FCV tobacco farmers is a multidimensional process influenced by production decisions, financial security, institutional support, efficient marketing systems and technological advancement. These five dimensions collectively explained 79.51 % of the total variation in the dataset, confirming the robustness and reliability of the extracted component structure (25, 38, 41). The identified factors should also be interpreted within the broader tobacco-specific context. Changes in tobacco-control policies, enhancing health concerns and anti-tobacco initiatives and shifts in domestic and export demand may influence the relative significance of crop choice, financial and risk market and price over time. Under such circumstances, institutional and governance and technology and innovation become predominantly significant in helping farmers access timely information, get better production efficiency and explore appropriate diversification opportunities. Strengthening these dimensions can increase farmers' capability to adapt to regulatory and market uncertainties and support more sustainable livelihood pathways in the long term.

4. Conclusion

The present study employed principal component analysis (PCA) to identify the underlying factors influencing livelihood transformation among Flue-Cured Virginia (FCV) tobacco farmers in the Northern Light Soil (NLS) region of Andhra Pradesh. The high Kaiser–Meyer–Olkin (KMO) value (0.87) and statistically significant Bartlett's test of sphericity confirmed the suitability of the dataset for factor analysis. Five principal components were extracted, collectively explaining 79.51% of the total variation. The findings demonstrate that livelihood transformation is a multidimensional process requiring integrated policy interventions rather than isolated measures. In the context of tobacco control and diversification pressures; Tobacco Board, policymakers, research institutes and allied extension agencies should strengthen access to institutional credit, organise regular field demonstrations and extension programmes, enhance timely market information and price transparency and promote the adoption of appropriate production and post-harvest technologies. Such coordinated actions can increase farmers' resilience, competitiveness and long-term livelihood sustainability. Differences among farmer categories and the effects of socio-economic characteristics on component scores were beyond the scope of the present PCA-based study. The absence of additional inferential analyses has been acknowledged as a limitation and examination of these relationships has been suggested for future research. Future research should examine these dimensions across other FCV tobacco growing areas and farming systems to assess their wider applicability, while longitudinal and mixed-method studies may further explore how changes in policies, markets, technologies and institutional support shape livelihood transformation and farmers adaptive strategies over time.

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Authors' contributions

BH, MSM and VS contributed to conceptualisation of the study. YS contributed to methodology. VJ and LKP contributed to validation. BH and VS contributed to investigation and resource collection. BH and VS contributed to writing the original draft. BH and LKP contributed to visualisation. MSM contributed to supervision. All authors have read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest

Authors do not have any conflict of interests to declare.

Ethical issues

None

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