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# Knowledge, Technology Adoption and Production Constraints of Black Pepper Growers in Kolli Hills

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## HIGHLIGHTS

- Nutrient and soil management and marketing practices recorded higher knowledge and adoption.
- Moderate technology adoption highlights the need for stronger extension interventions.
- Labour scarcity, increasing production cost and inadequate institutional support remain the major production constraints.

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## ABSTRACT

Black pepper (*Piper nigrum* L.) is an important spice crop supporting the livelihoods of farmers in Kolli Hills, Tamil Nadu. The study assessed the knowledge and technology adoption levels of black pepper growers and identified the major constraints affecting the adoption of recommended cultivation practices. Primary data were collected from 280 growers using a structured interview schedule during 2025 in Kolli Hills. Twenty-eight knowledge statements and twenty-eight technology adoption statements were constructed to measure on a five-point continuum and grouped into nine indicators. Principal Component Analysis was employed to derive indicator weights and construct composite Knowledge and Technology Adoption Indices. The Kaiser–Meyer–Olkin measure indicated satisfactory sampling adequacy, with values of 0.741 for knowledge and 0.791 for technology adoption. The overall Composite Knowledge Index (0.599) indicated a moderate level of knowledge, whereas the Composite Technology Adoption Index (0.495) indicated comparatively lower adoption of the recommended cultivation practices. Garrett's Ranking Technique revealed that high labour cost, scarcity of skilled labour and high input cost were the major production constraints. The findings highlight the importance of need-based extension services, capacity-building programmes and institutional support in addressing the identified knowledge, technology adoption and production constraints among black pepper growers in Kolli Hills.

## INTRODUCTION

Black pepper (*Piper nigrum* L.), widely recognized as the "King of Spices," is a commercially important spice crop cultivated across the tropical regions of the world. India is among the world's leading producers of black pepper, and the crop contributes significantly to rural livelihoods and employment generation. Cultivated predominantly as an intercrop with perennial vegetation, black pepper forms an integral component of agroforestry-based hill farming systems, with live support trees such as Silver Oak (*Grevillea robusta*) and bamboo providing structural support for the climbing vines. Globally, black pepper production during 2023 was 539 thousand tonnes, while India produced 126,038 metric tonnes during 2023-2024, ranking among the leading pepper-

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producing countries (International Pepper Community, 2024; Spices Board India, 2024). Black pepper productivity is influenced by both biophysical factors and growers' knowledge and timely adoption of recommended production technologies. Studies have shown that technology adoption remains uneven because of production constraints and limited input use.

Kolli Hills of Namakkal district is a predominantly tribal hill region where black pepper cultivation is an important livelihood and income-generating activity for farming households. Although the region possesses favourable agro-climatic conditions for pepper cultivation, productivity remains below its potential because of several production constraints. Agricultural extension services in the region provide technical guidance, demonstrations and farmer-oriented training to support growers in understanding and adopting recommended black pepper cultivation practices. Recent studies have reported that effective extension interventions significantly improve technology adoption and farmers' decision-making capacity (Devi et al., 2024).

In black pepper production, agricultural extension plays an important role in disseminating recommended cultivation technologies, including improved varieties, crop establishment, nutrient and soil management, water and canopy management, pest and disease management, and post-harvest practices through farmer training, field demonstrations and technical advisory services. Improved access to technical information enables growers to make better production decisions, while adoption of recommended technologies contributes to higher productivity, efficient resource use and improved farm income. Besides knowledge, technology adoption is influenced by socio-economic conditions, institutional support, market access and farmers' perceptions of technological benefits. Therefore, evaluating growers' knowledge, technology adoption and production constraints provides useful evidence for planning location-specific extension interventions (Patra et al., 2023; Devi et al., 2024).

Previous studies on black pepper have addressed specific aspects of knowledge, technology adoption and production constraints. Jolly and Mazhar (2023) assessed the knowledge level of black pepper growers in Idukki district of Kerala, while Eliyas and Sumathi (2018) examined factors associated with the adoption of recommended production practices among pepper growers in Wayanad district. Rejula et al. (2018) studied the production system, technology adoption profile and major constraints of black pepper cultivation in Kerala. There is limited evidence on the use of PCA-based weighted composite indices to simultaneously assess knowledge and technology adoption across multiple recommended cultivation domains and to examine the perceived production constraints of growers. The novelty of the present study lies in integrating these dimensions through PCA-based Composite Knowledge and Technology Adoption Indices, together with Garrett's Ranking Technique for production constraints, among black pepper growers in Kolli Hills.

## METHODOLOGY

The study was conducted during 2025 in Kolli Hills of Namakkal district, Tamil Nadu, a prominent tribal region known for black pepper cultivation. Since the variables had already occurred and could not be manipulated by the investigator, an ex-post facto research design was adopted (Devi et al., 2024). Kolli Hills was selected purposively based on its importance in black pepper cultivation, and four major pepper-growing villages, namely Ariyur Nadu, Devanur Nadu, Thinnanur Nadu and Vaalavanthi Nadu, were selected for the study. The respondents comprised 280 black pepper growers. The sample size was determined using Slovin's formula at a 5 per cent precision level, and the sampling procedure followed Kothari (2004). The total sample of 280 growers was distributed among the selected villages in proportion to the number of black pepper-growing households in each village. From each village, the required number of growers was selected using random sampling from the available list of black pepper growers.

$$n = \frac{N}{1 + Ne^2}$$

Where, $n$ = required sample size, $N$ = total population and $e$ = allowable error (0.05). The respondents were selected through proportionate random sampling. Primary data were collected through personal interviews using a pre-tested structured interview schedule.

Knowledge and technology adoption were measured using 28 statements each, grouped under nine indicators covering recommended black pepper cultivation practices. The schedule was developed based on the package of practices of the Spices Board of India and Tamil Nadu Agricultural University and was validated by subject matter experts. Responses were recorded using a five-point continuum, with the response categories defined according to the respective knowledge and technology adoption statements. The same structured schedule was administered to all respondents to ensure consistency in data collection.

The indicator values were normalized using the Min–Max normalization technique (OECD & JRC, 2008):

$$Z_{ij} = \frac{X_{ij} - X_{min}}{X_{max} - X_{min}}$$

Where, $Z_{ij}$ = normalized value, $X_{ij}$ = observed value, $X_{min}$ = minimum value and $X_{max}$ = maximum value. The normalized indicator values therefore ranged from 0 to 1 and were subsequently used in the construction of the Composite Knowledge and Technology Adoption Indices.

Principal Component Analysis was employed to derive empirical weights for each indicator and to construct weighted Composite Knowledge and Technology Adoption Indices. The suitability of the data was assessed using the Kaiser–Meyer–Olkin measure and Bartlett's Test of Sphericity. Components with eigenvalues greater than one were retained, and Varimax rotation was applied to obtain an interpretable factor structure. The eigenvalue of each retained component was used to determine its relative contribution, and the component weights were normalized by dividing each eigenvalue by the sum of the eigenvalues of all retained components. The normalized weights were then combined with the corresponding normalized indicator scores to construct the composite indices. The composite index was computed as:

$$CI = \Sigma (W_i Z_i)$$

Where, CI = composite index, Wi = normalized weight assigned to the $i^{th}$ indicator, $Z_i$ = normalized indicator score and n = number of indicators. Higher composite index values indicate relatively higher levels of knowledge or technology adoption among the respondents. Production constraints were prioritised using Garrett's Ranking Technique (Garrett & Woodworth, 1969). The percent position for each rank was calculated as:

$$\text{Percent Position} = \frac{100(R_{ij} - 0.5)}{N_j}$$

Where, $R_{ij}$ is the rank assigned by the j[th] respondent to the i[th] constraint and $N_j$ is the total number of constraints ranked. The corresponding Garrett scores were obtained from the standard Garrett conversion table. The scores were then summed across respondents and divided by the number of respondents to obtain the mean Garrett score for each constraint. The constraints were ranked according to their mean Garrett scores, with higher scores indicating greater relative importance assigned by the respondents.

## RESULTS

The suitability of the dataset for Principal Component Analysis was assessed to determine whether the data were adequate for PCA using the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's Test of Sphericity (Table 1). The Kaiser-Meyer-Olkin values of 0.741 for knowledge and 0.791 for technology adoption indicated satisfactory sampling adequacy for Principal Component Analysis (Kaiser, 1974). Bartlett's Test of Sphericity was highly significant ($p < 0.001$) for both datasets, confirming adequate intercorrelation among the variables. These results indicated that the selected indicators were appropriate for Principal Component Analysis. Similar findings have been reported by Sathyan et al. (2026) and Thakur et al. (2024).

**Table 1.** Suitability of data for Principal Component Analysis

| Particulars | Knowledge | Technology adoption |
|---|---|---|
| Number of respondents | 280 | 280 |
| Number of variables | 28 | 28 |
| Kaiser–Meyer–Olkin Measure | 0.741 | 0.791 |
| Bartlett's Test of Sphericity ($\chi^2$) | 3898.504 | 11054.004 |
| Significance | <0.001 | <0.001 |

Principal Component Analysis of the 28 knowledge variables related to recommended black pepper cultivation practices resulted in the extraction of nine principal components (Table 2). The

**Table 2.** Principal component loadings and weights of knowledge variables

| Component | Indicator | Knowledge variables | Factor Loading | Eigenvalue | Normalized Weight |
|---|---|---|---|---|---|
| PC1 | High-yielding and disease-free varieties | i. Panniyur-1 | 0.898 | 3.418 | 0.030 |
| | | ii. Panniyur-2 | 0.874 | | 0.029 |
| | | iii. Karimunda | 0.873 | | 0.029 |
| PC2 | Crop establishment | i. Propagation through Serpentine layering method (Rooted Cuttings) | 0.835 | 4.667 | 0.038 |
| | practices | ii. Recommended pit size (50 ×50 × 50 cm) | 0.880 | | 0.040 |
| | | iii. Recommended spacing (3 × 3 m) | 0.837 | | 0.039 |
| | | iv. Recommended planting season (May-June) | 0.856 | | 0.039 |
| PC3 | Live support trees | i. Silver Oak tree | 0.905 | 2.080 | 0.019 |
| | | ii. Bamboo tree | 0.901 | | 0.018 |
| PC4 | Nutrient and Soil Management | i. Farm Yard Manure (10 kg/vine/year) | 0.821 | 5.889 | 0.048 |
| | | ii. Azospirillum | 0.844 | | 0.049 |
| | | iii. Phosphobacteria | 0.859 | | 0.050 |
| | | iv. Azotobacter | 0.825 | | 0.048 |
| | | v. Mulching | 0.867 | | 0.050 |
| PC5 | Water Management | i. Flower Initiation | 0.913 | 2.287 | 0.021 |
| | | ii. Berry development | 0.902 | | 0.020 |
| PC6 | Canopy Management | i. Pruning | 0.911 | 3.209 | 0.029 |
| | | ii. Shade regulation | 0.893 | | 0.028 |
| PC7 | Integrated Management | i. Spraying of Neem Oil for the management of Pollu Beetle | 0.922 | 3.864 | 0.035 |
| | | ii. Phytosanitary measures for the management of Foot rot | 0.874 | | 0.033 |
| | | iii. Weeding | 0.893 | | 0.034 |
| PC8 | Harvest and Post-Harvest Management | i. Harvesting berries at the recommended maturity stage | 0.929 | 2.671 | 0.024 |
| | | ii. Drying of pepper to the recommended moisture content (10-12%) | 0.893 | | 0.024 |
| PC9 | Marketing and Value Addition | i. Quality grading | 0.840 | 5.391 | 0.045 |
| | | ii. Value addition | 0.852 | | 0.045 |
| | | iii. Packaging | 0.837 | | 0.044 |
| | | iv. Market information | 0.839 | | 0.045 |
| | | v. Institutional support | 0.842 | | 0.045 |

PC = Principal Component

retained components had eigenvalues greater than one and collectively explained 93.862 per cent of the total variance. The first component explained 14.095 per cent of the variance, followed by the second component (12.350%), third component (12.036%), fourth component (10.493%), fifth component (10.230%), sixth component (9.833%), seventh component (8.811%), eighth component (8.533%) and ninth component (7.481%). The cumulative variance explained by the nine retained components was 93.862 per cent. Varimax rotation with Kaiser normalization was applied to obtain an interpretable factor structure, and the rotated factor loadings showed strong associations between the variables and their respective components. The extracted components represented key knowledge domains, namely high-yielding and disease-free varieties, crop establishment, live support standards, nutrient and soil management, water management, canopy management, integrated management, harvest and post-harvest management, and marketing and value addition. The normalized indicator weights were subsequently used for constructing the Composite Knowledge Index.

The indicator-wise Composite Knowledge Index of black pepper growers is presented in Table 3. Among the nine knowledge indicators, Nutrient and Soil Management recorded the highest Composite Knowledge Index (0.141) and was ranked first, followed by Marketing and Value Addition (0.139) and Crop Establishment Practices (0.095). Integrated Management ranked fourth with an index value of 0.063, while High-yielding and Disease-free Varieties ranked fifth (0.050). Comparatively lower index values were observed for Canopy Management (0.036), Harvest and Post-Harvest Management (0.028), Water Management (0.024) and Live support trees (0.023). The overall Composite Knowledge Index was estimated at 0.599. Based on the study's normalized 0–1 interpretation scale, this value falls within the moderate category, indicating that the respondents demonstrated an intermediate level of knowledge across the assessed black pepper cultivation practices, with scope for improvement in the comparatively weaker knowledge domains. The indicator-wise assessment highlights the knowledge domains requiring greater extension attention.

Principal Component Analysis of the 28 technology adoption variables related to recommended black pepper cultivation practices resulted in the extraction of nine principal components (Table 4). The retained components had eigenvalues greater than one and collectively explained 94.945 per cent of the total variance. The first component explained 17.700 per cent of the variance, followed by the second component (16.366%), third component (12.820%), fourth component (11.169%), fifth component (10.370%), sixth component (7.769%), seventh component (6.978%), eighth component (6.223%) and ninth component (5.549%). The cumulative variance explained by the nine retained components was 94.945 per cent. Varimax rotation with Kaiser normalization was applied to obtain an interpretable factor structure, and the rotated factor loadings showed strong associations between the variables and their respective components. The extracted components represented the major technology adoption domains, namely high-yielding and disease-free varieties, crop establishment practices, Live support trees, nutrient and soil management, water management, canopy management, integrated management, harvest and post-harvest management, and marketing and value addition. The normalized indicator weights were subsequently used for constructing the Composite Technology Adoption Index.

**Table 3.** Indicator-wise composite knowledge index of black pepper growers

| Component | Indicator | Composite Knowledge Index | Rank |
|---|---|---|---|
| PC4 | Nutrient and Soil Management | 0.141 | I |
| PC9 | Marketing and Value Addition | 0.139 | II |
| PC2 | Crop establishment practices | 0.095 | III |
| PC7 | Integrated Management | 0.063 | IV |
| PC1 | High-yielding and disease-free varieties | 0.050 | V |
| PC6 | Canopy Management | 0.036 | VI |
| PC8 | Harvest and Post-Harvest Management | 0.028 | VII |
| PC5 | Water Management | 0.024 | VIII |
| PC3 | Live support trees | 0.023 | IX |
| Overall Composite Knowledge Index | | 0.599 | |

PC = Principal Component

The indicator-wise Composite Technology Adoption Index of black pepper growers is presented in Table 5. Among the nine technology adoption indicators, Marketing and Value Addition recorded the highest Composite Technology Adoption Index (0.129) and secured the first rank, followed by Nutrient and Soil Management (0.119) and Crop Establishment Practices (0.074). Integrated Management ranked fourth with an index value of 0.047, while High-yielding and Disease-free Varieties ranked fifth (0.045). Comparatively lower index values were observed for Harvest and Post-Harvest Management (0.024), Water Management (0.023), Live support trees (0.019) and Canopy Management (0.016). The overall Composite Technology Adoption Index was estimated at 0.495. Based on the study's normalized 0–1 interpretation scale, this value falls within the moderate category, indicating an intermediate level of adoption across the assessed technologies, with comparatively greater scope for improvement in the lower-ranked technology domains. The indicator-wise assessment suggests that growers adopted production and marketing practices to varying extents, highlighting the need for strengthening extension efforts and technical support for comparatively less-adopted technologies.

The major constraints perceived by black pepper growers are presented in Table 6. High labour cost for field operations and harvesting emerged as the highest-ranked perceived constraint with a mean Garrett score of 72.49, followed by scarcity of skilled labour during peak season (69.51) and high cost of fertilizers and other agricultural inputs (66.39). Limited availability of quality planting materials ranked fourth with a mean Garrett score of 63.54. Among the production-related constraints, foot rot disease incidence (60.95) and unpredictable weather affecting crop productivity (60.63) ranked fifth and sixth, respectively. Inadequate extension and technical advisory services (57.64) and low farm-gate price received during the harvest season (54.75) were also ranked among the major perceived constraints affecting black pepper cultivation. Limited access to institutional credit (51.95) and lack of market information and value addition facilities (49.04) were ranked ninth and tenth, respectively. The Garrett ranking results indicate that labour scarcity,

**Table 4.** Principal component loadings and weights of technology adoption variables

| Component | Indicator | Technology adoption variables | Factor Loading | Eigenvalue | Normalized Weight |
|---|---|---|---|---|---|
| PC1 | High-yielding and disease-free varieties | i. Panniyur-1 | 0.972 | 5.793 | 0.031 |
| | | ii. Panniyur-2 | 0.970 | | 0.031 |
| | | iii. Karimunda | 0.971 | | 0.031 |
| PC2 | Crop establishment practices | i. Propagation through Serpentine layering method (Rooted Cuttings) | 0.973 | 7.162 | 0.038 |
| | | ii. Recommended pit size (50 ×50 × 50 cm) | 0.966 | | 0.038 |
| | | iii. Recommended spacing (3 × 3 m) | 0.967 | | 0.038 |
| | | iv. Recommended planting season (May-June) | 0.972 | | 0.038 |
| PC3 | Live support trees | i. Silver Oak tree | 0.975 | 3.477 | 0.018 |
| | | ii. Bamboo tree | 0.977 | | 0.018 |
| PC4 | Nutrient and Soil Management | i. Farm Yard Manure (10 kg/vine/year) | 0.967 | 9.143 | 0.048 |
| | | ii. Azospirillum | 0.966 | | 0.048 |
| | | iii. Phosphobacteria | 0.969 | | 0.048 |
| | | iv. Azotobacter | 0.964 | | 0.048 |
| | | v. Mulching | 0.969 | | 0.048 |
| PC5 | Water Management | i. Flower Initiation | 0.981 | 4.340 | 0.023 |
| | | ii. Berry development | 0.983 | | 0.023 |
| PC6 | Canopy Management | i. Pruning | 0.970 | 3.100 | 0.016 |
| | | ii. Shade regulation | 0.970 | | 0.016 |
| PC7 | Integrated Management | i. Spraying of Neem Oil for the management of Pollu Beetle | 0.972 | 6.240 | 0.033 |
| | | ii. Phytosanitary measures for the management of Foot rot | 0.973 | | 0.033 |
| | | iii. Weeding | 0.974 | | 0.033 |
| PC8 | Harvest and Post-Harvest Management | i. Harvesting berries at the recommended maturity stage | 0.977 | 3.898 | 0.021 |
| | | ii. Drying of pepper to the recommended moisture content (10-12%) | 0.977 | | 0.021 |
| PC9 | Marketing and Value Addition | i. Quality grading | 0.968 | 9.888 | 0.052 |
| | | ii. Value addition | 0.966 | | 0.052 |
| | | iii. Packaging | 0.966 | | 0.052 |
| | | iv. Market information | 0.969 | | 0.052 |
| | | v. Institutional support | 0.964 | | 0.052 |

PC = Principal Component

**Table 5.** Indicator-wise composite technology adoption index of black pepper growers

| Component | Indicator | Composite Technology Adoption Index | Rank |
|---|---|---|---|
| PC9 | Marketing and Value Addition | 0.129 | I |
| PC4 | Nutrient and Soil Management | 0.119 | II |
| PC2 | Crop Establishment Practices | 0.074 | III |
| PC7 | Integrated Management | 0.047 | IV |
| PC1 | High-yielding and Disease-free Varieties | 0.045 | V |
| PC8 | Harvest and Post-Harvest Management | 0.024 | VI |
| PC5 | Water Management | 0.023 | VII |
| PC3 | Live support trees | 0.019 | VIII |
| PC6 | Canopy Management | 0.016 | IX |
| Overall Composite Technology Adoption Index | | 0.495 | |

PC = Principal Component

increasing production costs, pest and disease incidence, and inadequate institutional and market support were among the major constraints perceived by black pepper growers in Kolli Hills.

## DISCUSSION

The relatively higher knowledge observed in nutrient and soil management, marketing and value addition, and crop establishment may be associated with the greater familiarity of growers with these practices in their routine pepper cultivation and marketing activities. In contrast, the comparatively lower knowledge of canopy management, water management, live support trees, and harvest and post-harvest management suggests areas where growers may require more specialised technical guidance. The overall Composite Knowledge Index of 0.599 indicates a moderate level of knowledge, while the variation across indicators shows that knowledge is not uniform across all recommended practices. Similar patterns have been reported by Chahal et al. (2014); Ravikumar et al. (2015); Jolly and Mazhar (2023); Mishra et al. (2024) and Patra et al. (2023), who observed differences in farmers' knowledge across commonly practised and specialised agricultural technologies. Therefore, extension programmes may give greater attention to the comparatively weaker knowledge domains through practical demonstrations and location-specific advisory services.

The technology adoption pattern follows the knowledge pattern, but the lower overall Composite Technology Adoption

**Table 6.** Major constraints faced by black pepper farmers

| S.No. | Constraints | Total Garrett Score | Mean Garrett Score | Rank |
|---|---|---|---|---|
| 1 | High labour cost for field operations and harvesting | 20,297 | 72.49 | I |
| 2 | Scarcity of skilled labour during peak season | 19,463 | 69.51 | II |
| 3 | High cost of fertilizers and other agricultural inputs | 18,589 | 66.39 | III |
| 4 | Limited availability of quality planting materials | 17,791 | 63.54 | IV |
| 5 | Foot rot disease incidence | 17,065 | 60.95 | V |
| 6 | Unpredictable weather affecting crop productivity | 16,976 | 60.63 | VI |
| 7 | Inadequate extension and technical advisory services | 16,139 | 57.64 | VII |
| 8 | Low farm-gate price received during harvest season | 15,330 | 54.75 | VIII |
| 9 | Limited access to institutional credit | 14,546 | 51.95 | IX |
| 10 | Lack of market information and value addition facilities | 13,730 | 49.04 | X |

*Note:* Mean Garrett Score = Total Garrett Score ÷ Number of respondents (280).

Index suggests that knowledge of recommended practices was not reflected uniformly in field-level adoption. Marketing and value addition, nutrient and soil management and crop establishment practices recorded relatively higher adoption, whereas canopy management, live support trees and water management showed comparatively lower adoption. The difference between the knowledge and adoption indices may reflect the practical challenges associated with implementing certain technologies under hill-farming conditions. Labour availability, production costs, access to inputs, institutional support and technical guidance may be relevant considerations; however, the present study did not statistically establish causal relationships between these factors and technology adoption. Similar observations have been reported by Rejula et al. (2018); Eliyas and Sumathi (2018); Parvathi and Waibel (2015), who highlighted the importance of economic and institutional factors in the adoption of improved black pepper production practices.

The PCA results provide useful evidence on the multidimensional nature of knowledge and technology adoption among black pepper growers. The KMO values of 0.741 for knowledge and 0.791 for technology adoption, together with the significant Bartlett's Test of Sphericity, indicated that the variables were suitable for data reduction and construction of composite indices. The extraction of nine components for both knowledge and technology adoption shows that growers' responses were distributed across distinct domains of recommended black pepper cultivation practices rather than being represented by a single dimension. The relatively high cumulative variance explained by the retained components, 93.862 per cent for knowledge and 94.945 per cent for technology adoption, further indicates that the retained components represented a substantial proportion of the variation in the respective datasets. The use of PCA-based weights therefore provided an empirical basis for combining the indicators into composite measures rather than assigning equal weights to all indicators. Similar applications of PCA-based composite index construction have been reported by Thakur et al. (2024); Kademani et al. (2025); Sathyan et al. (2026), supporting the usefulness of weighted indices for assessing multidimensional behavioural attributes.

Growers identified high labour cost for field operations and harvesting, scarcity of skilled labour during the peak season and high cost of fertilizers and other agricultural inputs as the major perceived constraints affecting black pepper cultivation. Foot rot disease, unpredictable weather conditions, inadequate extension and technical advisory services, low farm-gate prices, limited institutional credit and inadequate market information were also reported as important constraints. The Garrett ranking results describe the relative importance assigned to these constraints by the respondents and do not establish their causal effects on technology adoption or farm profitability. Similar observations have been reported by Maya et al. (2025), who identified labour scarcity and rising cultivation costs as major constraints reported by farmers, while Gireesh et al. (2019); Kumar et al. (2023); Niranjan et al. (2023) and Smija et al. (2025) also emphasised the importance of extension support and market linkage in agricultural development. These findings indicate the need for appropriate extension, input, institutional and market support measures to address the constraints perceived by black pepper growers.

The findings have practical implications for agricultural extension programmes in Kolli Hills. Since knowledge and technology adoption were comparatively lower in areas such as canopy management, live support trees and water management, extension programmes may focus on need-based training, field demonstrations and practical skill development in these areas. The major perceived constraints, particularly high labour cost, scarcity of skilled labour, high input costs and inadequate technical advisory services, also indicate the importance of timely extension support and improved access to production-related information. Regular farmer–scientist interactions, locally relevant training programmes and dissemination of information on recommended cultivation practices can help address the gaps identified in the study. Institutional support for quality planting materials, credit access and market information may further complement extension interventions for black pepper growers.

## CONCLUSION

The study indicates that black pepper growers in Kolli Hills possess a moderate level of knowledge and technology adoption regarding the recommended cultivation practices, with technology adoption remaining comparatively lower than the corresponding knowledge level. Growers recorded higher knowledge and adoption in nutrient and soil management, crop establishment practices and marketing-related activities, whereas comparatively lower values were observed for canopy management, live support trees and water management. High labour cost, scarcity of skilled labour, increasing input prices, disease incidence and inadequate technical support were perceived by respondents as major constraints affecting black pepper cultivation. The PCA-based composite indices provided a systematic approach for assessing the multidimensional knowledge and technology adoption levels of the growers, while Garrett ranking identified the relative importance of perceived production constraints. The findings highlight the need for regular need-based training, field demonstrations, timely technical advisory services and farmer–scientist interactions, together with improved access to quality planting materials, institutional credit and market information.

## DECLARATIONS

Ethical approval and consent to participate: The study involved no invasive procedure on human participants as such the committee of Department of Agricultural Economics SRM College of Agricultural Sciences, SRM Institute of Science and Technology, Baburayanpettai, Chengalpattu District-603201, Tamil Nadu, India waived the ethical approval. Informed consent was obtained from all respondents before data collection. The respondents were informed about the purpose of the study, and their participation was voluntary.

Availability of supporting data: Supporting data are available upon request.

Competing interests: No competing interests were declared.

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