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Socio-economic Determinants of Environmental Risk and Safe Pesticide Use: A Canonical Correlation Analysis

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HIGHLIGHTS

- Growers' perceptions and socio-economic factors were found to be strongly correlated by canonical correlation analysis.
- The first canonical function, which was dominated by attitude, knowledge, education and the perception of safe pesticide usage, explained 81.72% of the shared variance.
- Attitude and knowledge emerged as key predictors shaping growers' perceptions of pesticide safety and environmental risk.
- Second canonical function showed moderate association, highlighting area under chilli crop and environmental risk perception.

ARTICLE INFO

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ABSTRACT

The study was conducted in 2025-26 at Guntur District of Andhra Pradesh and examines the significant impact on socio-economic factors of chilli growers and their perceptions of environmental risk and safe pesticide use in the study area. Canonical correlation analysis (CCA) was used to identify the connection between independent variables with dependent variables of chilli growers. A multistage sampling technique was used to choose 160 chilli growers from four mandals in the Guntur district. Perceptions of environmental risk and safe pesticide use were regarded as dependent variables, while eleven socioeconomic factors were classified as independent variables. The first canonical pair of variates showed stronger canonical correlation of 81.72 per cent with high Eigen values. It was mainly influenced by attitude, knowledge, education, age and information source. The second function, showed 37.58 per cent of the shared variance was mostly determined by structural characteristics that influenced perceptions of environmental risk, specifically the area under chilli cultivation. The findings suggest how cognitive, attitudinal and resource-based socioeconomic factors significantly influence growers' perspectives. Promoting ecologically safe pesticide practices requires bolstering extension interventions that emphasize knowledge, attitude and risk communication.

INTRODUCTION

Chilli (*Capsicum annuum*) belongs to the Solanaceae family. It is an important horticultural crop with commercial and nutritional importance (Delai et al., 2024; Goddu et al., 2025). In 2023, there were 18.03 lakh hectares of chilli cultivation worldwide, with an average productivity of 3,229 kg per hectare and a production of 58.22 lakh tonnes. India is the world's largest producer, consumer, and exporter of chillies, followed by China, Thailand, Ethiopia, and Indonesia (Daravath et al., 2025). In 2023–2024, 8.09 lakh hectares of chilli cultivation were grown in India, with an average productivity of 3273 kg/ha and an expected production of 29.13

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lakh tonnes. 33% of the nation's total spice exports are chillies alone (Singh et al., 2024). Andhra Pradesh tops the states in chilli production with 14.44 lakh tons (49.57%), grown on 2.47 lakh hectares (27.75%) with a productivity of 5846 kg/ha, followed by Telangana, Madhya Pradesh, Karnataka and West Bengal (Janaki et al., 2023). Guntur is the most productive district for chilli farming, with a yield of 8354 kg/ha, grown on 19,000 hectares, producing 159,000 tonnes (Centre for Agriculture and Rural Development Policy Research, 2023). The state of Andhra Pradesh as a whole contributes 40% of India's chilli production, while Guntur alone contributes 15% of the total (One District One Product, 2024). Guntur exports Rs. 100 crore worth of chillies annually to the United States, the United Kingdom, Japan, France, Sri Lanka, and other countries (Kumari & Nahatkar, 2021). Despite having significant export potential, the chilli crop is severely impacted by a wide range of pests and viral diseases (Prabhavathi et al., 2025). However, thrips (*Scirtothrips dorsalis*) is a common pest of chillies and is present throughout the growing season. The incidence of flower thrips (*Thrips parvispinus*) has been documented for the first time in India's chilli ecosystem (Sireesha et al., 2021). Despite its economic significance, Guntur's chilli faces intense pest pressure, forcing many growers to rely heavily on chemical pesticides. This led to pesticide-residue issues that harmed export shipments and raised concerns about environmental risks and human health (Sharma et al., 2020; Sahar et al., 2020). Over half of the world's pesticides are used in Asia, with India ranking third in Asia after China and Turkey and 12th overall (Yadav, 2024; Das et al., 2025). Andhra Pradesh accounts for 22.5% of the nation's pesticide use (Prabhavathi et al., 2020). Guntur District spends Rs. 450–500 crore a year, mostly on cotton and chilli cultivation, making it the district with the highest pesticide use. Previous research on farmers' perceptions of environmental risk and pesticide use has mostly relied on univariate or bivariate methods. Furthermore, there is limited combined evidence particularly from pesticide-intensive chilli-growing regions like Guntur district because environmental risk perception and safe pesticide usage are frequently examined independently. To fill the gap, the study uses Canonical Correlation Analysis to concurrently analyze eleven socioeconomic variables and two perceptual dimensions, providing an integrated understanding and supporting data for targeted extension initiatives and policy creation.

METHODOLOGY

The study was carried out in Guntur District, Andhra Pradesh, due to its dominance in chilli cultivation and high pesticide use intensity. The respondents were chosen using a multistage sampling process. In the initial stage, four mandals were purposively chosen based on the extreme availability of chilli cultivation. At the second stage, two villages were randomly selected from each mandal, for a total of eight villages. In the final stage, 20 chilli farmers were randomly selected from each village, yielding a sample of 160 respondents. A pre-tested, well-structured interview schedule was used to gather data from the respondents. While knowledge was evaluated using objective items scored dichotomously (correct = 1, incorrect = 0), attitudes toward safe pesticide use and perceptions of environmental risk and safe pesticide usage were measured using five-point Likert-type scales, with responses ranging from strongly disagree (1) to strongly agree (5). The data were analysed in SPSS and R-Studio software using Pearson's correlation, Multiple Linear Regression and Canonical Correlation Analysis to investigate the relationships between the independent variables and both perceptions of chilli growers. Variance Inflation Factor (VIF) was used to assess multicollinearity between the independent variables before Canonical Correlation Analysis. Even while some socioeconomic factors had higher VIF values, these factors were conceptually different and logically pertinent to research on farmers' perceptions.

In this work, a multivariate analysis was performed using Canonical Correlation Analysis (CCA), a well-known technique for identifying the correlations between two sets of variables X and Y (Sahoo et al., 2024). The linear function of one set of variables that is closely related to that of another can be identified using CCA (Akour et al., 2023).

Two sets of variables were considered in the study: eleven independent variables (X) representing socioeconomic factors and two dependent variables (Y).

$$X = x1, x2, x3,\ldots\ldots\ldots x11 \text{ and } Y = y1, y2$$

Where, x1 = age, x2 = education, x3 = experience , x4 = l and holding, x5 = area under chilli cultivation, x6 = income, x7 = source of information, x8 = risk orientation, x9 = economic motivation and x10 = knowledge, x11 = attitude, y1 = perception towards environmental risk, y2 = Perception towards safe usage of pesticides.

Since the number of canonical correlation pairs is equal to the number of characters in the smallest set, two canonical correlation pairs U_1, V_1, and U_2, V_2 were evaluated in the present study.

RESULTS

The correlation coefficient analysis of Table 1 reveals that education, knowledge, attitude, source of information and land holding showed highly significant at 0.001% level, while age exhibited negative significance with perception towards environmental risk and perception towards safe usage of pesticides.

Table 1. Correlation co-efficient (r) of independent variables and dependent variables

Variables	Pearson Correlation	
	Perception towards environmental risk	Perception towards safe usage of pesticides
Age	-.525**	-.680**
Education	.694**	.727**
Experience	-0.030	-0.023
Land holding	0.144	.364**
Area under chilli crop	-0.022	.326**
Income	0.068	.261**
SOI	.422**	.537**
RO	.245**	.178*
EM	.303**	.170*
Knowledge	.654**	.754**
Attitude	.658**	.818**

*Significant at 5%; ** Significant at 1%

Table 2. Multiple Linear Regression analysis of independent variables with both dependent variables

Variables	Perception towards environmental risk (R^2 =0.788)					Perception towards safe usage of pesticides (R2 =0.615)					Collinearity Statistics
	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	
	B	Std. Error	Beta			B	Std. Error	Beta			VIF
Age	-4.678	5.308	-0.105	-0.881	0.38	3.764	1.8	0.334	2.091	0.038	9.846
Education	-10.395	2.504	-0.658	-4.152	0	3.571	0.849	0.898	4.206	0	17.526
Experience	-2.924	1.544	-0.084	-1.894	0.06	-0.621	0.524	-0.071	-1.187	0.237	1.380
Land holding	6.641	2.562	0.297	2.592	0.01	-0.543	0.869	-0.097	-0.625	0.533	9.194
Area under chilli crop	4.227	1.413	0.171	2.992	0.003	-1.247	0.479	-0.2	-2.603	0.01	2.283
Income	-5.827	3.177	-0.203	-1.834	0.069	2.058	1.077	0.284	1.91	0.058	8.531
SOI	-1.396	0.816	-0.136	-1.711	0.089	-0.351	0.277	-0.136	-1.268	0.207	4.399
RO	0.278	0.366	0.034	0.758	0.449	0.323	0.124	0.156	2.602	0.01	1.384
EM	-0.483	0.961	-0.024	-0.503	0.616	1.012	0.326	0.196	3.108	0.002	1.532
Knowledge	1.729	0.74	0.381	2.335	0.021	0.332	0.251	0.291	1.324	0.187	18.593
Attitude	2.982	0.323	1.059	9.231	0	-0.08	0.11	-0.113	-0.729	0.467	9.187

The regression analysis Table 2 of perception towards environmental risk accounted for 78.8 per cent of the variation among chilli growers. Attitude ($\beta = 1.059$, $p < 0.01$) and knowledge ($\beta = 0.381$, $p < 0.05$) showed positive significance, while education ($\beta = -0.658$, $p < 0.01$) showed negative significance. The dependent variable, perception of safe pesticide use, showed that 61.5 per cent of the variation occurred among chilli growers. Education ($\beta = 0.898$, $p < 0.01$) and age ($\beta = 0.334$, $p < 0.05$) showed positive, significant relationships, while area under chilli crop ($\beta = -0.200$, $p < 0.05$) showed a negative significant relationship. The Variance Inflation Factor (VIF) shows that several independent variables exhibit multicollinearity. Knowledge (VIF = 18.593) and education (VIF = 17.526) exhibit severe multicollinearity, beyond the critical threshold of 10. Strong interrelationships are suggested by the high but acceptable multicollinearity of age (9.846), landholding (9.194), attitude (9.187), and income (8.531). On the other hand, low multicollinearity (VIF < 5) indicates steady and independent contributions to the model for experience, area under chilli crop, source of information (SOI), risk orientation (RO), and economic motivation (EM).

The statistical canonical correlation analysis displayed in Table 3 indicates that both canonical functions were statistically significant at the 0.00 level. With a low Wilks' statistic (0.114), the first canonical pair, U_1 and V_1, showed a very strong canonical correlation (0.904) with a high eigenvalue (4.479), explaining 81.72% of the shared variance between socioeconomic characteristics and growers' perceptions of environmental risk and safe pesticide use. Despite having a higher Wilks' statistic (0.625), the second canonical pair, U_2 and V_2, likewise had a significant but somewhat mild connection (0.613) with an eigenvalue of 0.601, accounting for 37.58% of the shared variance.

From Table 4, canonical loadings indicate that attitude (-0.948), knowledge (-0.890), education (-0.879), age (0.780) and source of information (-0.619) all had stronger correlations with U1 in the first canonical function U_1 and V_1, whereas perception of the safe use of pesticides (-0.966) had a strong correlation with V_1. In the second canonical function, U_2 and V_2, Area under chilli crop (0.506) had a comparatively larger association with U_2, whereas perception of environmental risk (-0.676) had the strongest correlation with V_2.

Table 4. Canonical loadings and cross-loadings analysis of socio-economic characteristics with different perceptions of growers

Independent variables	Canonical loadings		Canonical cross-loading	
	U_1	U_2	U_1	U_2
Age	.780	.013	.706	.008
Education	-.879	-.260	-.795	-.159
Experience	.030	.025	.027	.015
Landholding	-.371	.250	-.336	.153
Area under chilli crop	-.281	.506	-.254	.310
Income	-.255	.244	-.230	.150
SOI	-.619	-.023	-.559	-.014
RO	-.241	-.205	-.218	-.125
EM	-.253	-.324	-.229	-.198
Knowledge	-.890	-.147	-.805	-.090
Attitude	-.948	-.065	-.857	-.040
Dependent Variables	V1	V2	V1	V2
perception towards environmental risk	-.737	-.676	-.666	-.414
Perception towards safe usage of pesticides	-.966	.258	-.874	.158

Table 3. Canonical correlation analysis of socio-economic characteristics and different perceptions of growers

Pair of canonical	Canonical correlation	Square of canonical correlation	Eigenvalue	Wilks Statistic	Probability
U_1 V_1	0.904	0.817216	4.479	0.114	<0.000
U_2 V_2	0.613	0.375769	0.601	0.625	<0.000

In the canonical cross-loading analysis, it was shown that attitude (-0.857), knowledge (-0.805), education (-0.795) and age (0.706) had stronger cross-loadings with U_1 in the first canonical function U_1 and V_1, showing their substantial association with the dependent canonical variate. Perception of the safe use of pesticides (-0.874) showed high cross-loadings with V_1 among the dependent variables. Cross-loadings were very modest in the second canonical function, U_2 and V_2, which showed an area under chilli crop (0.310), indicating a moderate correlation with U_2. However, perception of environmental risk (-0.414) had the largest cross-loading among dependent variables with V_2.

Table 5. Standardised and unstandardised canonical coefficients analysis of socio-economic characteristics and different perceptions of growers

Independent variables	Standardised Canonical Correlation Coefficients		Unstandardised Canonical Correlation Coefficients	
	U_1	U_2	U_1	U_2
Age	-.020	-.775	-.041	-1.572
Education	.280	-2.617	.201	-1.878
Experience	.099	.013	.156	.020
Landholding	-.231	.605	-.234	.613
Area under chilli crop	-.084	.619	-.094	.694
Income	.084	-.821	.109	-1.071
SOI	.166	.060	.078	.028
RO	-.083	-.244	-.031	-.091
EM	-.045	-.400	-.042	-.373
Knowledge	-.436	-.001	-.090	.000
Attitude	-.901	1.721	-.115	.220
Dependent Variables	V1	V2	V1	V2
perception towards environmental risk	-.306	-1.146	-.055	-.207
Perception towards safe usage of pesticides	-.802	.874	-.036	.040

From Table 5, standardised canonical coefficients, attitude (-0.901) had a stronger correlation with U_1 among independent variables in the first canonical function U_1 and V_1, although perception of safe pesticide usage (-0.802) dominated the dependent side with V_1. Education (-2.617) and attitude (1.721) had a greater correlation among independent factors with U_2 in the second canonical function U_2 and V_2. Perception of environmental risk (-1.146) had the greatest correlation with V_2 among the dependent variables.

In unstandardized canonical correlation coefficients, land holding (-0.234) and education (0.201) had comparatively greater correlations with U1 among independent factors, from the first canonical function U_1 and V_1. Perception of environmental danger (-0.055) contributed slightly more to the dependent variable (V_1) than perception of safe pesticide use (-0.036). Education (-1.878) and age (-1.572) had a better association with U_2 in the second canonical function U_2 and V_2, whereas perception of environmental risk (-0.207) demonstrated a stronger correlation with V_2 among dependent factors.

DISCUSSION

The correlation showed that education, knowledge, attitude, and source of information were positively associated with both perceptions, while age was negatively associated with perceptions of environmental risk. It shows that younger, educated farmers take environmental issues more seriously. The multiple regression analysis shows that, while age, education, economic motive, and risk orientation encourage safer pesticide use, attitude, knowledge, and risk awareness significantly affect farmers' perceptions of environmental risk (Sahar et al., 2020). It suggests that experienced, knowledgeable, and financially motivated farmers implement safe methods to reduce environmental risk and use pesticides safely. According to the multicollinearity pattern, farmers' perceptions of pesticides are influenced by an interconnected socio-cognitive cluster that includes education, knowledge, attitude, age, income and landholding. The canonical correlation analysis revealed a high association between the socioeconomic characteristics of chilli growers and their perceptions of environmental risk and safe pesticide use. The presence of two statistically significant canonical functions indicates that growers' perceptions are influenced by several underlying socioeconomic factors. With a low Wilks' Lambda value and a very high canonical correlation (0.904), the first canonical function (U_1V_1) accounted for 81 per cent of the shared variance. This implies a strong, consistent primary link between socioeconomic determinants and perception variables. According to canonical loadings, the most significant factors influencing U_1 were attitude, knowledge, education, age and source of information (Pujitha et al., 2024). Growers with more positive attitudes and higher levels of knowledge tend to have stronger perceptions of safe pesticide use, as indicated by the strong negative loadings of attitude and knowledge (Uikey et al., 2025). Another important factor that surfaced was education, emphasising how formal education shapes awareness and appropriate pesticide use (Paine et al., 2021). Age showed a positive loading, indicating that older farmers may have more life experience, which influences their perception of pesticide safety (Nurika et al., 2022). Perception of safe pesticide use on the dependent side with V_1 showed very high loadings and cross-loadings in the first canonical function, indicating that growers' cognitive and attitudinal characteristics account for the majority of this perception dimension (Afandi & Irfan, 2024).

Strong cross-loadings further confirm that these socioeconomic indicators do not reflect misleading associations but rather are substantially linked to views of safer pesticide use. The second canonical function (U_2V_2) only accounted for 37% of the shared variance. Area under chilli crop emerged as the most influential independent variable, indicating that the farm size devoted to chilli cultivation plays an important role in shaping growers' perceptions in this dimension. Farmers may be more sensitive to environmental risks if a larger area is planted with chilli crops, as this could increase production risks and pesticide use (Nehul, 2025). The dependent side of the second function, where perception of environmental risk showed the highest loadings and cross-loadings, lends credence to this argument. By identifying variables that specifically contributed to each canonical variate after adjusting for intercorrelations, standardised canonical coefficients further improved interpretation. The first function was dominated by attitude, highlighting its crucial role in shaping opinions about the safe use of pesticides. Education and attitude demonstrated significant but conflicting standardised effects in the second function, indicating a more intricate relationship between behavioural orientation and cognitive awareness regarding environmental risk perception (Vandenberg et al., 2025). The unstandardized coefficients highlighted the importance of economic ability and farming experience in shaping perception patterns, showing that landholding, age and education had significant practical impacts. The findings show that U, is largely defined by farm structural characteristics influencing V_2, which represents perceptions of environmental risk, while U_2 is primarily defined by cognitive and attitudinal socio-economic variables influencing V_1, which represents perceptions of safe pesticide use.

CONCLUSION

The most important variables affecting farmers' perceptions of environmental risk and safe pesticide use are attitude, knowledge, education, and source of information. The canonical correlation analysis indicates that socio-economic characteristics are significantly related to chilli growers' perceptions of environmental risk and safe pesticide use. The first canonical pair (U_1V_1) was strongly significant in influencing growers' perceptions with attitude, knowledge, education, age and source of information. This suggests that cognitive and attitudinal factors play a key role in promoting safer pesticide practices. The second pair (U_2V_2) revealed that socioeconomic factors were strongly associated with perception towards environmental risk, indicating that larger-scale growers are more sensitive to environmental hazards. The study recommends that extension and policy interventions be differentiated and CCA-guided, with a primary focus on growers' knowledge and attitudes through education and information-based approaches to improve safe pesticide use.

DECLARATIONS

Ethical approval and informed consent: No ethical approval is needed for this study, however, the informed consent was sought from participants.

Conflict of interest: Authors have no conflict of interest.

Authors contribution: Vaishnavi Pulletikurthi: paper plan execution and manuscript preparation; Peddi Naga Harsha Vardhan, Ajay Kumar Prusty: Monitoring, paper planning and manuscript editing; Rama Lakshmi Vecmalapu, Tumma Mounika: Monitoring, manuscript editing and manuscript correction.

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