



## Determinants of Farmers' Knowledge and Safe Pesticide Utilisation Behaviour: Artificial Neural Network Approach

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### HIGHLIGHTS

- Socioeconomic, informational and perceptual factors have a major impact on farmers' knowledge and safe pesticide use practices.
- There is a clear knowledge-practice gap whereby information about safe pesticide use does not necessarily result in safe behaviour.
- Promoting safe pesticide use practices is greatly aided by extension services, media coverage and training initiatives.
- Artificial Neural Networks (ANNs) analysis successfully captured non-linear interactions and determined the relative significance of influencing factors.

### ARTICLE INFO

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### ABSTRACT

Pesticides are increasingly being used to enhance agricultural productivity, but the risks of unsafe pesticide application to both human health and the environment can be severe. In this study, Artificial Neural Network (ANN) analysis along with traditional statistical techniques were used to analyze factors influencing farmers knowledge and pesticide use behaviour. The study was carried out in 2025-26 in Kakinada district of Andhra Pradesh, utilizing ex-post facto research design. A sample of 240 farmers were selected by means of multistage random sampling. Information was collected with the help of a well-structured and pre-tested interview schedule. Correlation and multiple regression analysis were used to determine the association of socio-economic, communication and behaviour variables with farmers knowledge and use behaviour. ANN model was developed to determine non-linear relationship and variable importance. The results clearly indicated that, education, extension contact, mass media exposure and risk orientation had significant role in farmer knowledge and pesticide use behaviour. From ANN, mass media exposure was most influential independent variable followed by risk orientation and social participation that implies the communication-based extension efforts are the right way to disseminate the safe pesticide application techniques for intensive pesticide use production systems.

### INTRODUCTION

Pesticides have an important place in modern agriculture in enhancing productivity, protecting crop from disease and pests and contributing to food security in the developing countries like India

(Bhandari et al., 2018). However, improper and unsafe use of pesticides has generated serious environmental pollution, loss of bio-diversity and unfavourable health impact on the farming population (Damalas & Koutroubas, 2016). Majority of the farming communities have strong dependency on the use of chemical

pesticides as production challenges mount up to prevent the losses and farmers have no enough knowledge on safe storage, usage and disposal of the pesticides, posing great occupational health risks along with environmental pollution and chronic health hazards in the rural areas (Thorat et al., 2023; Yaseen et al., 2024).

The use behaviour and the knowledge among the farmers regarding pesticide are one of the most important determining factors for safe and sustainable use of pesticides. Factors influencing farmers' use behaviour and their decision-making behaviour towards pesticides include many socio-economic factors (e.g., level of education, extension services, communication exposure, social participation) and behaviour-related factors (e.g., knowledge, risk perception) (Naghavi et al., 2024). Many of the farmers possess the knowledge about negative effects on human health and the environment due to pesticide use, but are not utilizing them into their behaviours and a significant knowledge-practice gap exists among the farmers (Sai et al., 2019). Farmers generally use the information gained through informal sources like the local dealers and other fellow farmers that possibly induce unsafe practices for the increased use of pesticides (Okoffo et al., 2016). Other attitudes, perceived use utility and behavioural intention affect usage of safety equipment, as well as method of disposal of pesticides (Kaur et al., 2022). Perceived occupational dangers, training exposure and awareness levels all have a significant impact on farmers' pesticide handling behaviours and safety procedures (Jallow et al., 2017).

In earlier studies pesticide knowledge and behaviour have been analyzed by the use of ordinary statistical methods such as correlation and regression analysis in order to find relation among socio-economic parameters with behavioural patterns of the farmers (Choudhary et al., 2022). These studies offer significant information, but failed to account for and represent the multiple and non-linear interactions among behavioural, perceptual and communicative variables, which affects behaviour related to the pesticide application. The application of artificial neural network models in analyzing multi-dimensional behavioural relationships has emerged recently in agricultural research due to their abilities in exploring the non-linear underlying patterns and relationship between the variables which is better than traditional linear models (Liakos et al., 2018). There are few researches done on pesticide knowledge and utilization behaviour by farmers using ANN approach, and this has not yet been explored in Andhra Pradesh, especially in Kakinada district, which also involves a lot of pesticides. The objective of this research was to examine the factors affecting farmers' level of knowledge and behaviour in relation to pesticide use through ANN analysis and to ascertain the relative significance of the socio-economic, communication and behavioural variables on the safe pesticide usage behaviour.

## METHODOLOGY

The present study was carried out in Kakinada district of Andhra Pradesh during the year 2025-2026 since the district was having tremendous horticultural activities and the farmers use the pesticides widely. For the selection of the respondents, multistage sampling technique was used. In the first stage eight mandals were purposively selected basing on the maximum area where vegetables are grown. In the second stage, three villages were randomly selected

from each mandal in the selected mandals, i.e., twenty-four villages in total. In the last stage, 10 farmers were randomly selected from each of the selected villages, thus giving 240 respondents in total.

An organised, pre-tested interview schedule was used to collect data. A two-point continuum (Yes = 2 and No = 1) is used for knowledge level. Previous approaches for evaluating farmers' agricultural and environmental knowledge levels served as a foundation for the development and standardisation of knowledge measuring processes (Sharma, 2023). A three-point continuum (Always = 3, Sometimes = 2, Never = 1) is used to quantify utilisation behaviour. The relationships between independent and dependent variables were studied through correlation analysis and the contribution of individual independent variable to the farmers' knowledge and use of pesticides was measured through multiple regression analysis.

Artificial Neural Network (ANN) modelling and suitable statistical methods were used to examine the gathered data. ANN is a computer model built using the ANN technique that draws inspiration from the architecture and operations of biological neural networks (Gupta & Raza, 2019). Because ANN models can examine multidimensional interactions among variables and increase prediction efficiency in complicated farming systems, they have recently become more significant in agricultural behavioural studies (Pradhan et al., 2025). Correlation and regression analyses were used to detect relations between variables, whereas ANN was used to capture complex non-linear interactions and determine the relative relevance of influencing elements.

The study took into consideration two sets of variables: two dependent variables (Y) and ten independent variables (X) that represented socioeconomic and communicative factors.

$$X = x_1, x_2, x_3, \dots, x_9 \text{ and } Y = y_1, y_2$$

$x_1$  = age,  $x_2$  = education,  $x_3$  = experience,  $x_4$  = no. of crops,  $x_5$  = annual income,  $x_6$  = total landholding,  $x_7$  = access to extension services,  $x_8$  = social participation,  $x_9$  = risk orientation,  $x_{10}$  = mass media exposure,  $y_1$  = knowledge level towards pesticides,  $y_2$  = utilisation behaviour of pesticides

Two sets of variables were considered for the study: ten independent variables (X) representing socio-economic and communication characteristics and two dependent variables (Y). An input layer with ten independent variables, a hidden layer with seven neurones using a hyperbolic tangent activation function and an output layer with two dependent variables using an identity function made up the Artificial Neural Network model.

## RESULTS

### Correlation co-efficient (r) of independent variables and dependent variables

In Table 1, the correlation analysis revealed that education, extension contact, mass media exposure, social participation and risk orientation are positively and significantly related to farmers' knowledge and pesticide utilisation behaviour, but age was negatively related and means that older farmers were less responsive to adopt improved pesticide practices. The results shows that information and communication related variables are significantly related to farmers' adoption behaviour of improved pesticide practices.

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

| Variables                    | Knowledge level towards pesticides | Utilisation Behaviour of pesticides |
|------------------------------|------------------------------------|-------------------------------------|
| Age                          | -.644**                            | -.641**                             |
| Education                    | .703**                             | .608**                              |
| Experience                   | .774**                             | .801**                              |
| No. of crops                 | 0.004                              | 0.030                               |
| Annual Income                | .843**                             | .864**                              |
| Total landholding            | .805**                             | .793**                              |
| Access to Extension Services | .816**                             | .804**                              |
| Social Participation         | .723**                             | .784**                              |
| Risk Orientation             | .878**                             | .923**                              |
| Mass Media Exposure          | .869**                             | .893**                              |
| Knowledge Level              | 1                                  | .941**                              |
| Utilisation Behaviour        | .941**                             | 1                                   |

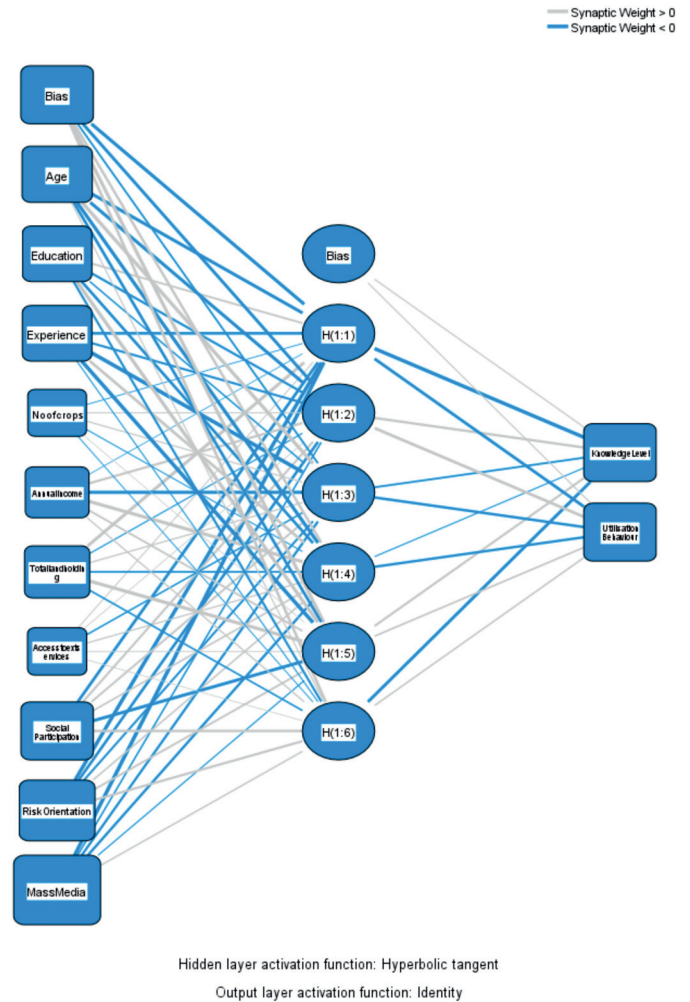
\*Significant at 5% \*\* Significant at 1%

**Multiple linear regression analysis of independent variables with both dependent variables**

The multiple linear regression analysis in Table 2 shows that the identified independent factors account for 87.7% of the variance in farmers' knowledge level (R = 0.877) and 91.7% of the variance in farmers' use of pesticides (R = 0.917). While beta values (standardised coefficients) indicate the degree to which one variable can influence the dependent variable in relation to the others, B values (unstandardised coefficients) display the actual change in dependent variables for each unit change in the independent variable. While mass media exposure (= 0.433), access to extension services (= 0.173) and risk orientation (= 0.143) have the greatest influence on pesticide utilisation behaviour, access to extension services (= 0.351) and exposure to the media (= 0.230) had a favourable impact on knowledge level. Sig. values indicate statistical significance, while T values indicate the strength of each variable's contribution. The variable significantly affects the dependent variable when the values are less than 0.05. The independent variables used in the study did not indicate substantial multicollinearity, according to the VIF values, which ranged from 1.844 to 7.463. The fact that variables like mass media exposure (7.463), risk orientation (7.215) and access to extension services (7.010) displayed relatively higher VIF values but stayed within the acceptable limit confirmed the statistical reliability of the regression and ANN models for analysing farmers' knowledge level and pesticide usage behaviour.

**Neural network architecture for farmers knowledge level and utilisation behaviour of pesticides**

Figure 1 ANN model successfully incorporated all 10 independent factors through a hidden neural layer to predict the two dependent variables, farmers' knowledge level and pesticide usage behaviour. The chart shows that, in comparison to structural farm variables, communication and behavioural variables had a greater impact on the outputs. Risk orientation also showed strong correlations with knowledge (r = 0.878) and utilisation behaviour (r = 0.923), while mass media exposure demonstrated a very high



**Figure 1.** Developed neural network architecture for farmers knowledge level and utilisation behaviour of pesticides

positive correlation with knowledge level (r = 0.869) and utilisation behaviour (r = 0.893). These findings provide strong support for this. Mass media exposure had the highest standardised beta value for pesticide use behaviour in the regression model (β = 0.433), followed by risk orientation (β = 0.143) and access to extension services (β = 0.173), suggesting that these factors had a stronger influence on behavioural outcomes within the ANN architecture. Therefore, the ANN figure confirms that communication exposure, behavioural orientation, and institutional support systems all interacted to influence farmers' pesticide behaviour through interconnected neurones rather than a single element acting alone.

The high R<sup>2</sup> values for knowledge level (0.877) and pesticide usage behaviour (0.917) in Figure 1 ANN architecture also demonstrate the model's outstanding predictive capabilities. The model was able to capture intricate non-linear interactions that traditional regression was unable to adequately explain thanks to the hidden layer's 10 neurones and hyperbolic tangent activation function. The ANN structure shows that even smaller contributing variables interacted with stronger predictors to influence behavioural outcomes collectively, despite the fact that variables like annual income, number of crops, and landholding showed weaker regression contributions. The independent variable important results are further

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

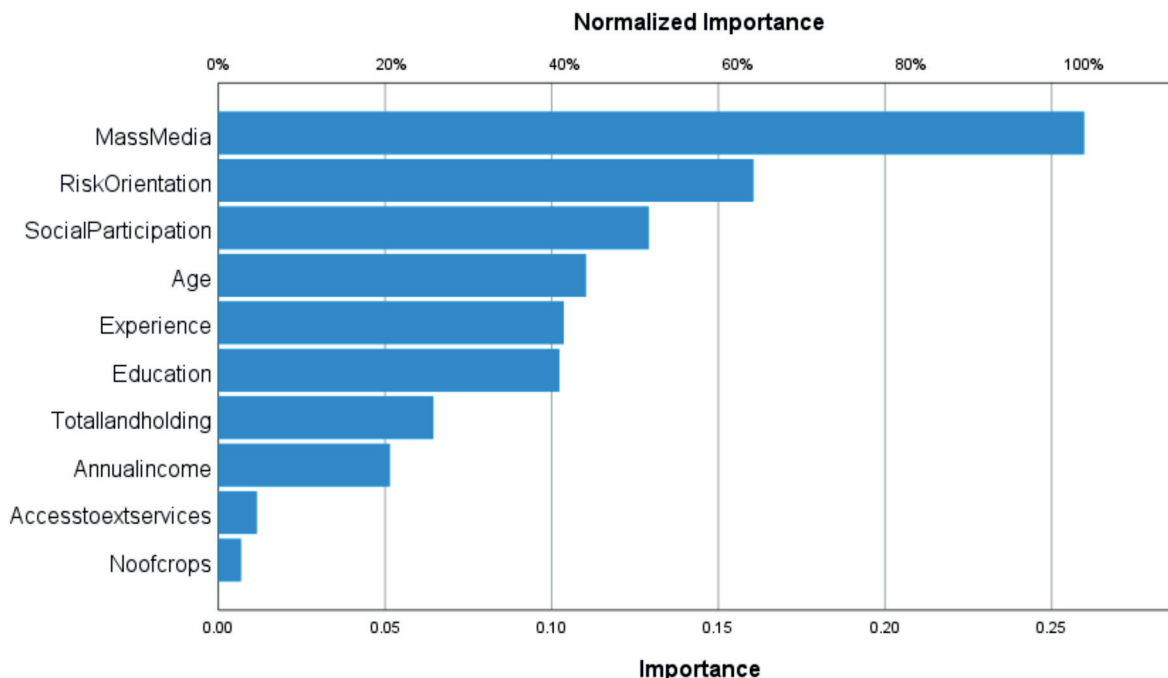
| Variables                    | Knowledge level towards Pesticides<br>(R <sup>2</sup> =0.877) |               |                              |        |       | Pesticide Utilisation Behaviour<br>(R <sup>2</sup> =0.917) |       |                              |        |       | Collinearity<br>Statistics |
|------------------------------|---|---------------|------------------------------|--------|-------|--|-------|------------------------------|--------|-------|----------------------------|
|                              | Unstandardized<br>Coefficients                                |               | Standardized<br>Coefficients | t      | Sig.  | Unstandardized<br>Coefficients                             |       | Standardized<br>Coefficients | t      | Sig.  | VIF                        |
|                              | B   | Std.<br>Error | Beta                         |        | B     | Std.<br>Error  | Beta  |                              |        |       |                            |
|                              |   |               |                              |        |       |  |       |                              |        |       |                            |
| Age                          | 23.192  | 2.510         |                              | 9.240  | 0.000 | 6.994  | 1.799 |                              | 3.888  | 0.000 | 2.789                      |
| Education                    | -1.207  | 0.576         | -0.081                       | -2.096 | 0.037 | -1.050   | 0.413 | -0.081                       | -2.546 | 0.012 | 3.624                      |
| Experience                   | 0.451   | 0.232         | 0.086                        | 1.942  | 0.053 | -0.544   | 0.167 | -0.119                       | -3.267 | 0.001 | 4.721                      |
| No. of Crops                 | -0.821  | 0.448         | -0.092                       | -1.830 | 0.069 | -0.725   | 0.321 | -0.093                       | -2.256 | 0.025 | 1.913                      |
| Annual Income                | -0.039  | 0.146         | -0.009                       | -0.266 | 0.791 | -0.035   | 0.105 | -0.009                       | -0.331 | 0.741 | 1.844                      |
| Total landholding            | 0.349   | 0.194         | 0.057                        | 1.804  | 0.073 | 0.172  | 0.139 | 0.032                        | 1.241  | 0.216 | 3.810                      |
| Access to Extension Services | 2.977   | 0.383         | 0.351                        | 7.768  | 0.000 | 1.274  | 0.275 | 0.173                        | 4.637  | 0.000 | 7.010                      |
| Social Participation         | -0.034  | 0.130         | -0.016                       | -0.262 | 0.794 | -0.010   | 0.093 | -0.006                       | -0.111 | 0.911 | 3.046                      |
| Risk Orientation             | 0.453   | 0.427         | 0.043                        | 1.061  | 0.290 | 1.313  | 0.306 | 0.143                        | 4.294  | 0.000 | 7.215                      |
| Mass Media Exposure          | 0.210   | 0.057         | 0.230                        | 3.698  | 0.000 | 0.343  | 0.041 | 0.433                        | 8.449  | 0.000 | 7.463                      |

supported by the figure, which shows that mass media exposure had the highest importance value of 0.26 (100% normalised importance), followed by risk orientation (0.16; 61%) and social participation (0.13; 49%). Therefore, the ANN figure verifies that behavioural traits and communication-based variables were the main factors impacting vegetable producers’ awareness of and use of safe pesticides in the research area.

**Independent variable importance**

According to Figure 2, mass media was the most influential variable, with an important value of 0.26 (100% normalised importance). This suggests that media exposure, including television, radio, newspapers and the internet, had a significant impact on the dependent variable’s extent. Risk orientation has an importance

score of 0.16 (61% normalised importance), making it the second most influential variable. It suggests that those who take a lot of risks are more influential. Social Participation ranked third with an importance value of 0.13 (49% normalised relevance). It suggests that individuals who participate in social organisations and other social activities at a high level have a favourable influence on the dependent variable. The moderate contributing variables include age (0.11; 42%), experience (0.10; 40%) and education (0.10; 39%), suggesting that individuals with high levels of age, experience and education are comparatively higher influencing variables. With an importance value of 0.06 (26%) for total landholding and 0.05 (20%) for annual income, these factors were shown to have lower influencing power on the model. Access to extension services (0.01; 4%) and the number of crops (0.007; 2%) were two of the extremely



**Figure 2.** Independent Variable Importance

**Table 3.** Neural Network Information Summary

| Neural Network Information Summary |                 |  |                       |                              |
|------------------------------------|-----------------|--|-----------------------|------------------------------|
| A.                                 | Input Layer     | Covariates                                     | 1                     | Age                          |
|                                    |                 |  | 2                     | Education                    |
|                                    |                 |  | 3                     | Experience                   |
|                                    |                 |  | 4                     | No. of crops                 |
|                                    |                 |  | 5                     | Annual income                |
|                                    |                 |  | 6                     | Total landholding            |
|                                    |                 |  | 7                     | Access to extension services |
|                                    |                 |  | 8                     | Social Participation         |
|                                    |                 |  | 9                     | Risk Orientation             |
|                                    |                 |  | 10                    | Mass Media Exposure          |
| B.                                 | Hidden Layer(s) | Number of Units <sup>a</sup>                   | 10                    | Standardized                 |
|                                    |                 | Rescaling Method for Covariates                |                       |                              |
|                                    |                 | Number of Hidden Layers                        | 1                     |                              |
|                                    |                 | Number of Units in Hidden Layer 1 <sup>a</sup> | 10                    |                              |
| C.                                 | Output Layer    | Activation Function                            |                       | Hyperbolic tangent           |
|                                    |                 | Dependent Variables                            | Knowledge Level       | Knowledge Level              |
|                                    |                 |  | Utilisation Behaviour | Utilisation Behaviour        |
|                                    |                 | Number of Units                                |                       | 2                            |
|                                    |                 | Rescaling Method for Scale Dependents          |                       | Standardized                 |
|                                    |                 | Activation Function                            | Identity              |                              |
|                                    | Error Function  | Sum of Squares                                 |                       |                              |

low influencing variables since they had very little bearing on the dependent variable. Overall, it was discovered that behavioural traits and communication variables were more significant than economic and other farm-related variables.

#### Neural network information summary

According to Table 3, the ANN had two dependent variables farmers' knowledge and their use of pesticides and ten input variables. The intricate relationships between socioeconomic, informational and behavioural aspects were captured by a single hidden layer consisting of ten nodes. The ANN technique successfully investigated these connections between farmers' behavioural dimensions and their socioeconomic traits, informational and behavioural features, where risk orientation, education, extension contacts and the media all contributed to a better understanding of farmers' behaviours. Additionally, it demonstrated that the ANN method could accurately simulate relationships between factors to comprehend farmers' pesticide application practices. ANN is a useful model to explain the interactive nature of relationships between various determinants in farmers' knowledge and safety of pesticide application, as the results demonstrated that communication and information variables have a stronger impact in

**Table 4.** Comparative Performance of Regression and ANN Models

| Parameter                                | Regression Model | ANN Model |
|--|------------------|-----------|
| R <sup>2</sup> (Knowledge Level)         | 0.877            | Higher    |
| R <sup>2</sup> (Utilisation Behaviour)   | 0.917            | Higher    |
| Prediction Accuracy                      | Moderate         | High      |
| Capability to capture non-linear effects | Limited          | Strong    |
| Variable interaction modelling           | Weak             | Strong    |

predicting the behavioural outcomes than structural farm characteristics.

#### Comparison between regression and ANN models

Table 4 demonstrates that the ANN model performed better than the regression model in forecasting farmers' knowledge level and pesticide use patterns. Regression analysis yielded good R<sup>2</sup> values (0.877 for knowledge level and 0.917 for utilisation behaviour), however ANN showed better prediction efficiency with values and higher accuracy. Although regression analysis was useful for finding direct correlations between variables, it was not very good at capturing intricate behavioural interactions. ANN, on the other hand, was able to identify nonlinear and interrelated effects among behavioural, socioeconomic and communication variables, leading to a greater capacity for prediction. The results thus validate that, in comparison to traditional regression analysis, ANN offers a more dependable and thorough knowledge of farmers' behavioural responses regarding pesticide use.

## DISCUSSION

The discussion shows that rather than being influenced by a single independent factor, farmers' awareness of and use of pesticides are influenced by interrelated informational, socioeconomic and perceptual elements. Respondents' knowledge of pesticide application techniques and safety precautions was moderate, but it did not always convert into safe usage practices. Vegetable producers use of agricultural information is greatly influenced by their access to trustworthy information sources and extension contacts, suggesting that knowledge alone cannot guarantee behavioural adoption in the absence of effective communication mechanisms (Choudhary et al., 2022). Previous research has also shown that farmers continue to handle pesticides hazardously and apply them excessively even when they are aware of the negative

effects since their knowledge of these risks is still incomplete (Gupta et al., 2010).

These conclusions were reinforced by the ANN analysis, which found latent non-linear correlations between behavioural orientation, institutional support systems and communication exposure. In contrast to regression models, ANN successfully captured threshold effects and the combined influence of variables influencing the behaviour of pesticide use. Mass media exposure was found to be the most significant predictor in the ANN significance analysis, followed by risk orientation and social engagement. This indicates that communication and perception-oriented variables have a greater influence on behavioural adaptability than economic parameters. Attitudes, beliefs and perceived utility have a significant impact on their behavioural choices regarding pesticide safety procedures and usage habits (Kaur et al., 2022). The adoption of safe pesticide handling procedures is strongly influenced by vegetable growers' perceptions regarding pesticide safety measures (Singh et al., 2025). Despite being aware of the risks involved, farmers frequently prioritise crop protection and financial benefits, which leads to overuse or misuse of pesticides.

ANN showed that farmer's impact increased when they interacted with behavioural orientation and communication exposure factors. Extension programs that include demonstrations and tailored advisories significantly improve farmers' capacity to make decisions and promote safer pesticide use practices (Saha et al., 2024). Behavioural adaptation was also greatly influenced by socioeconomic factors like education and access to information sources. Farmers' attitudes and actions regarding agricultural technologies and safety procedures are significantly influenced by socioeconomic circumstances and information accessibility (Bharat et al., 2022). Media exposure, education and extension contact have a favourable impact on farmers' attitudinal orientation and knowledge development (Kumari et al., 2025).

Interactive and experiential learning strategies significantly enhance safe pesticide use practices. Farmer field schools and hands-on training programs increase farmers' proficiency with safe pesticide handling techniques (Davis et al., 2018). Despite knowledge of the hazards associated with pesticides, production pressure and a lack of training opportunities continue to promote improper pesticide usage (Paine et al., 2021). Farmers' learning retention and behavioural adaptation are greatly enhanced by communication-based treatments such dramatised presentations and interactive extension activities (Sahar et al., 2020). Digital apps, mobile-based information systems and AI-enabled advisory platforms increase farmers' access to timely ideas and encourage their behavioural adoption (Kumar et al., 2025; Mittal et al., 2016). Social information networks and communication systems had a major impact on farmers' learning outcomes and behavioural adaptation (Ogheneakoke et al., 2025). Additionally, applications of ANN and machine learning techniques showed exceptional proficiency in the analysis of hidden variable interactions and multidimensional agricultural behavioural systems (Liakos et al., 2018; Suman et al., 2025). Through intelligent predictive frameworks, advanced AI-based modelling techniques have also shown great analytical potential in comprehending intricate behavioural and infrastructural systems (Sharma & Dehalwar, 2026).

## CONCLUSION

This study discovered that farmers' use of pesticides is influenced not only by knowledge level but also by communication exposure, behaviour orientation and institutional support. Respondents' adoption of waste disposal, storage and safety precaution procedures was found to be low, despite their modest level of understanding of pesticide use. The results of the ANN analysis show that the variables mass media exposure, risk orientation and extension contact have non-linear relationships with behavioural outcomes. The findings suggest that extension services should prioritise behaviour adoption above information dissemination. Additionally, there is a need for hands-on training sessions that cover all aspects of safe handling, waste disposal and protective measures. Farmers' perceptions of risk would be improved by better extension services and media attention, which would encourage safe practices. According to several farmer groups, interventions are necessary to support environmentally sound agriculture.

## DECLARATIONS

**Ethical approval and informed consent:** No ethical approval is needed for this study.

**Conflict of interest:** Authors have no conflict of interest.

**Authors contribution:** Pandiri Neha Pragnya: paper plan execution and manuscript preparation; Peddi Naga Harsha Vardhan and Vaishnavi Pulletikurthi: Monitoring, paper planning and manuscript editing; Ashok Kumar, Nihal R and Tumma Mounika: Monitoring, manuscript editing and manuscript correction.

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