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RESEARCH ARTICLE

Socio-economic determinants of the adoption of improved weed management technologies in rice-wheat system: Evidence from central India

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ABSTRACT

The Rice-Wheat Cropping System (RWCS) is one of the most widely adopted systems by farmers in Punjab, Bihar, Haryana, Uttar Pradesh, and Madhya Pradesh. Weed menace is a major challenge in this system, limiting production capacity per unit area and causing significant losses to farmers. However, the adoption of Improved Weed Management Technologies (IWMTs) enables farmers to effectively manage weed flora in the RWCS, allowing them to maximize the production potential of their land. The present study aims to offer a social science perspective on IWMT adoption within the rice-wheat system, focusing on identifying the socio-economic determinants influencing farmers' adoption. Jabalpur and Katni districts in the Madhya Pradesh state were selected for the study, and primary data were collected from a sample of 240 farmers. The major weed flora observed in rice fields included *Anagallis arvensis*, *Cynodon dactylon*, *Cyperus iria*, *Cyperus rotundus*, *Echinochloa colona*, *Echinochloa crusgalli*, and *Eclipta alba*. In wheat fields, the prominent weeds identified by farmers were *Avena fatua*, *Chenopodium album*, *Convolvulus arvensis*, *Cyperus rotundus*, *Parthenium hysterophorus*, and *Phalaris minor*. The study further revealed that 62% of the surveyed farmers had adopted *IWMT*, while the remaining 38% had not. Key factors influencing IWMT adoption among farmers included extension contact, participation in improved weed management training, and attendance at IWMT field demonstrations. Shortage of labourers during peak seasons for hand weeding and the absence of skilled workers for herbicide application was identified as the top-ranked constraints to adoption.

Keywords: Rice-wheat system, Improved weed management technologies, Adoption, Determinants

INTRODUCTION

The rice (*Oryza sativa* L.) - wheat (*Triticum aestivum* L.) cropping system (RWCS) spans approximately 18 million hectares in Asia, with 10 million hectares in the Indo-Gangetic Plains (IGP) of India, and it is the most adopted system by the farmers of IGP as rice and wheat constitute staple food for millions of Indians (Farooq *et al.* 2007, Saharawat *et al.* 2010). Regarding states, the RWCS is predominantly practiced in Punjab, Bihar, Haryana, Uttar Pradesh, and Madhya Pradesh (Debangshi and Ghosh 2022). In north-western India, Punjab and Haryana collectively supply approximately 50% of the rice and 85% of the wheat procured by the Indian government (Deep *et al.* 2018).

The diverse climatic conditions in India facilitate the prevalence of the most commonly adopted weeds, leading to significant crop yield losses (Rao *et al.* 2020). According to available estimates, weeds contribute to approximately one-third of the overall crop yield loss caused by agricultural pests, in addition to problems like diminishing quality of produce, increasing production costs, and acting as the alternate hosts for various insect pests and diseases (Directorate of Weed Research, 2015). Overall, weeds are responsible for the highest potential loss (34%), with animal pests (18%) and pathogens (16%) being comparatively less significant (Oerke 2006).

Indian farmers have long relied on their experience to combat weeds through a combination of chemical and non-chemical methods. Hand weeding, the most ancient practice, persists even today alongside modern herbicide-based strategies, which have been the primary focus of Indian researchers. Herbicides are extensively used across more than 20 million hectares in India, approximately 10% of the total cropped area (DWR 2015), and constitutes nearly 20% of total pesticide usage. Wheat (28%), rice (20%), soybean (9%), and sugarcane (7%) are the major crops utilizing herbicides (Yaduraju 2012), with Punjab leading in consumption followed by Uttar Pradesh, Andhra Pradesh, Maharashtra, and West Bengal (Rao *et al.* 2020). Non-chemical methods include various ecological approaches such as weed-free seed

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sowing, adjusting sowing times, seed rate, cultivating competitive cultivars, and employing techniques like soil solarization, stale seed-bed technique, scientific crop rotations, laser land levelling (Kumar *et al.* 2021).

Weed seeds and seedlings are spatially clustered across agricultural landscapes, even though the fields are typically managed more-or-less similarly (Johnson *et al.* 2015). The variation in weed populations over space and time is influenced by various interactions between plants and their environment. Factors such as changes in topography, soil type, and drainage patterns contribute to the variability in weed density and composition within fields. In this context, improved weed management technologies play crucial role for the effective weed management at field level. However, relying solely on one method, whether it be mechanical, chemical, biological, or cultural control tactics, presents challenges due to the aggressive, adaptive, and persistent nature of weeds. Therefore, effective weed management necessitates a holistic and integrated approach for sustainable crop production.

Weed management technologies are critical for addressing weed-related challenges in the Rice-Wheat Cropping System (RWCS). Over the years, research institutions across various regions have developed and disseminated numerous IWMTs to farmers, aiming to improve weed control and minimize crop yield losses. However, the effective implementation of these technologies' hinges on their successful dissemination from scientific institutions to end users. In this context, farmers' awareness and socio-economic characteristics play a vital role in influencing the adoption of these technologies. Research highlights those factors such as education level, farming experience, training, access to farm machinery, extension contacts, and innovativeness significantly shape farmers' knowledge and their capacity to adopt new technologies (Rajashekhar *et al.* 2017). Despite these insights, there is a notable lack of socio-economic survey-based studies that specifically analyse the adoption of IWMTs and their determinants. Moreover, weed management technologies are often tailored to regional conditions, requiring continuous efforts from research and extension agencies to effectively disseminate these innovations and promote sustainable agricultural practices. Therefore, farmers' survey-based studies that explore the determinants of adoption are critically important from a policy perspective. They serve as valuable feedback mechanisms to refine and enhance the dissemination of technologies based on insights into the factors influencing adoption. In this context, the present study seeks to identify the key socio-economic factors that determine the adoption of IWMTs by farmers.

MATERIALS AND METHODS

Katni and Jabalpur districts in Madhya Pradesh (**Figure 1**) were deliberately chosen as the study area, taking into account the extensive extension activities conducted by ICAR-DWR over the years to disseminate Integrated Weed Management Technologies (IWMTs) in these regions. Primary data for the study were collected from November to February 2022-23 through a well-structured, pre-tested interview schedule from a comprehensive sample of 240 farmers**,** comprising 120 farmers from each of the two districts, who cultivate rice and wheat crops. Details on the socio-economic characteristics, weed flora, technology adoption, yield etc. were collected from the farmer respondents.

We classified farmers as adopters of IWMT if they applied at least one pre-emergent herbicide and one post-emergent herbicide in rice, and if at least one post-emergent herbicide was used in wheat. Subsequent survey results highlighted Pendimethalin and bispyribac-sodium as the predominantly used herbicides in rice, whereas metsulfuron-methyl + clodinafop-propargyl emerged as the predominant choice for wheat cultivation.

Descriptive statistics, such as percentages and means, were employed to describe different variables under study. Further, t-tests were conducted for continuous variables such as age, annual income, farming experience etc. to ascertain significant differences between adopter and non-adopter groups. Conversely, the chi-square (χ^2) test was utilized for categorical variables such as gender, education, social group *etc.* to know any significant difference

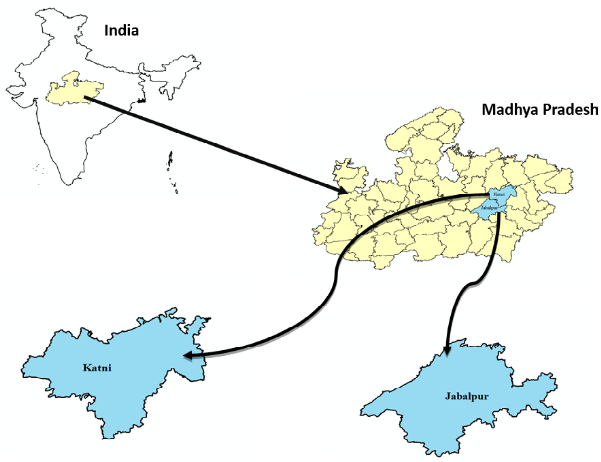

Figure 1. Study area map: Jabalpur and Katni districts in Madhya Pradesh

between the groups. Five-point continuum-based scoring technique was used to rank and prioritize the constraints.

We employed a linear probability model (LPM) to analyze the determinants of adoption, with the adoption of IWMT captured as a binary dummy variable. Our interest lies in measuring the marginal effects of independent variables on the probability of adoption. In this context, the linear model is preferable to logit and probit models, which provide estimates in index form (Angrist and Pischke 2009, Friedman 2012). The general form of the model used is as follows:

$$D_i = \propto + \beta_1 X_{1i} + \beta_2 X_{2i} \dots \dots \dots \dots + \beta_j X_{ji} + \varepsilon_i$$

Where,

D_i is the dummy for adoption (=1 if the farmer has adopted IWMT, 0 otherwise)

X_j is vector of independent variables used in the model

ε_i is the error term

RESULTS AND DISCUSSION

This particular section of the paper is discussed under different headings as given below;

Major weeds reported by the farmers

Open-ended questions were asked to farmers about major weeds observed and makes serious menace in their respective fields. The figure 2 depicted the weeds composition as percentage share of farmers' responses. *Anagallis arvensis*, *Cynodon dactylon*, *Cyperus iria*, *Cyperus rotundus*, *Echinochloa colona*, *Echinochloa crus-galli* and *Eclipta alba* were the weed flora observed in rice fields. *Avena fatua*, Chenopodium *album*, *Convolvulus arvensis*, *Cyperus rotundus*, *Parthenium hysterophorus* and *Phalaris minor* were the weed flora observed in wheat fields. It is noteworthy that *Cyperus rotundus* was reported as one of the most problematic weeds in both rice and wheat fields. Upon examining comparisons between districts, it becomes clear that *Echinochloa colona* is the most prevalent weed in rice fields across both districts though. Nevertheless, when considering percentage distributions, it was found that over 50% of farmers in Katni identified this as the major weed, whereas 31% of farmers in Jabalpur acknowledged this. Maun and Barret (1986) highlighted *Echinochloa crus-galli* as the most problematic weed in rice ecosystems, with just 9 plants per square meter causing a 50% reduction in rice yield. Furthermore, losses exceeding

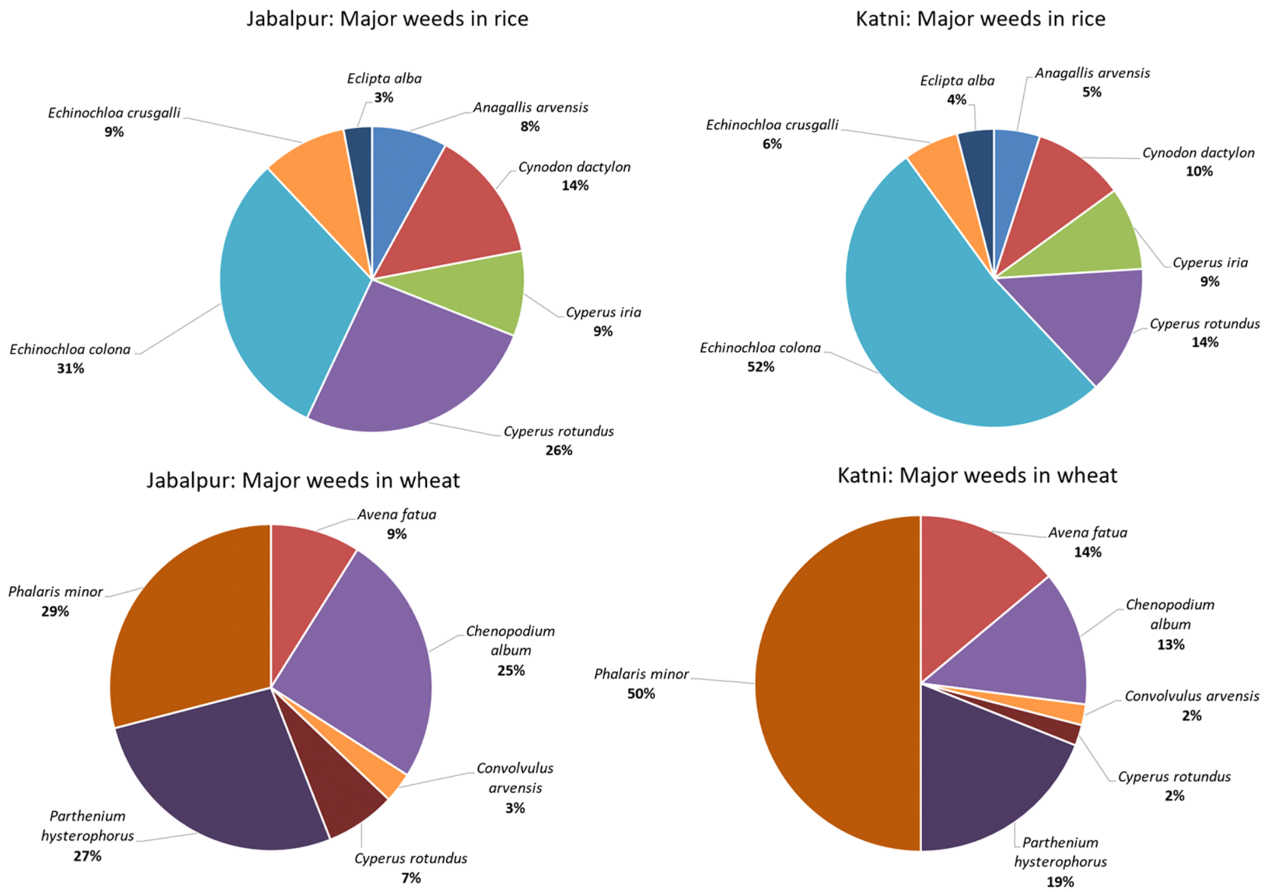

Figure 2. Percentage share of major weeds in the rice-wheat system as reported by the farmers

75% were observed with *Echinochloa colona* densities reaching 280 plants per square meter (Mercado and Talatala 1977). *Cyperus rotundus* was the second most prevalent weed in rice, with 26% and 14%, respectively, for Jabalpur and Katni. Similarly, *Cynodon dactylon* occupied the third position, registering respective percentage share of 14% in Katni and 10% in Jabalpur.

In the context of wheat crop, six weeds, namely, *Avena fatua*, *Chenopodium album*, *Convolvulus arvensis*, *Cyperus rotundus*, *Parthenium hysterophorus*, and *Phalaris minor* were identified as highly infested in the wheat fields. Notably, the composition varied between the two districts in terms of percentage distribution. In Katni, approximately 50% of farmers reported *Phalaris minor* as the most severe weed in wheat, while in Jabalpur, this figure stood at 29%. Several weed species significantly impact wheat productivity, with *Phalaris minor* being among the most prominent (Jat *et al.* 2003). The noxious weed *Parthenium hysterophorus* emerged as the second most severe weed in both districts, but the percentage distribution was significantly higher in Jabalpur (27%) compared to Katni (19%). *Avena fatua*, recognized as the third most important weed in wheat, exhibited a higher incidence in Katni (14%) compared to Jabalpur (9%).

From 2003 to 2014, India suffered a wheat production loss of US$ 3376 million across 18 states due to weeds (Gharde *et al.* 2018). Weeds like *R. dentatus* and *C. arvense* pose challenges in harvesting and threshing operations, while heavy infestations of *P. minor* during the maturity period cause severe lodging of the crop (Chhokar *et al.* 2012).

Adoption status and profile characteristics of sample farmers

Post-survey classification was done to know the adoption status of the farmer respondents. **Table 1** indicated that around 64% of farmers in Katni districts were adopters and 36% did not adopt the technology. While in Jabalpur, it was 59% adopters and 41% non-adopters. Overall, around 62% of farmer respondents adopted the IWMT while 38% of respondents fall under the non-adopter category.

The **Table 2** presents a comprehensive comparison of different demographic and socio-economic variables between adopters and non-adopters. The mean age of adopters was 44 years while it was 45 years for non-adopters. Each category exhibits similar size of house hold, that is on an average 5 members family. Farming experience also more or less similar 20.26 years and 20.54 years) in both groups. The gender distribution between the groups is not significant, similar to the caste category, and no significant difference was shown between adopters and non-adopters. Variables such as annual income, landholding, education, and credit availing exhibit significant differences between adopters and non-adopters. The average size landholding for adopters

Table 1. Post-survey classification of sample respondents (n=240)

District	Adopters	Non-adopters	% of adoption	% of non-adoption
Katni	77	43	64.17	35.83
Jabalpur	71	49	59.17	40.83
Total	148	92	61.67	38.33

Table 2. Profile characteristics of sample respondents

Variables	Adopters (N=148) Mean/%	Non- adopters (N=92) Mean/%	t-statistic/Chi-square statistic	P value
Age	44.49	45.47	-0.8544	0.3939
Household size	5.22	5.15	0.3116	0.7557
Farming experience (years)	20.26	20.54	-0.2636	0.7923
Annual income (Rs.)	89547.28	77347.83	2.0892	0.0380
Landholding (acres)	4.09	3.27	1.9983	0.0472
Gender			1.7175	0.1900
Male	63.06	36.94		
Female	44.44	55.56		
Education			6.5757	0.0103
Illiterate	47.69	52.31		
Literate	66.86	33.14		
Social group (caste)			4.35	0.1136
General	70.00	30.00		
OBC	65.13	34.87		
SC/ST	51.47	48.53		
Credit			20.658	0.000
Availed	76.47	23.53		
Not-availed	47.11	52.89		

was higher (4.09 acres) for adopters as compared to non-adopters (3.27 acres). Similarly, annual income of adopter groups was significantly higher (Rs. 89,547) compared to non-adopters (Rs. 77,347).

Determinants of adoption of improved weed management technologies

Description of the variables used in the LPM estimation is given in the table 3. Age, farming experience, and annual income were the continuous variables; rest of the variables were in the form of dummy variables, which took the value of either 0 or 1. The dependent variable was adoption which takes value 1 if the farmer adopted IWMT, 0 otherwise. Average age of the farmer respondents was 45 years, farming experience was 20 years and average annual income was Rs. 84871/-. The average area under cultivation was around 3.8 acres and as high as 49 per cent of farmers fall under below poverty line. Around 60 per cent of farmers had contact with extension institutions, while only 6 per cent of farmers became part of the IWM related field demonstrations.

Table 4 revealed the results of the linear probability model estimation. The variable extension contact was found to be highly significant (at 1% level) in order to determine the adoption of IWMT by the farmers. We specifically queried farmers about their engagement in extension contacts, focusing on whether they sought information on improved weed management technologies from ICAR-DWR or KVKs. This inquiry was motivated by the geographical proximity of these institutes to the study area and their concerted efforts in disseminating IWMTs. Participation in the improved weed management trainings and participation in the field demonstrations of IWMTs were the other significantly determining factors for the adoption of IWMTs. ICAR-DWR have been conducting field demonstrations on IWMTs in different localities of these study districts since many years and every year KVKs and ICAR-DWR do organize trainings on IWMTs in different crops and cropping systems (Prasad *et al.* 2018, Annual Report 2022. ICAR-DWR, Jabalpur). Therefore, as expected, the aforementioned two variables found to be a significant determinant of adoption of IWMTs in rice-wheat system. In a study by Singh *et al.* (2018) on IWM practices adoption among 108 farmers in Jabalpur district, Madhya Pradesh, most exhibited moderate adoption rates for rice (56%), soybean

Table 3. Summary of key variables used in the linear probability model

Variable	Mean	Unit
Age	44.87	Years
Farming experience	20.37	Years
Annual income	84871	Rupees (INR)
Area under cultivation	3.77	acres
Lower caste	0.92	Dummy (=1 if SC/ST/OBC, 0 otherwise)
Below poverty line	0.49	Dummy (=1 if BPL, 0 otherwise)
Credit	0.50	Dummy (=1 if availed credit, 0 otherwise
Membership in social organization	0.17	Dummy (=1 if has membership in any registered organization, 0 otherwise
Crop insurance	0.25	Dummy (=1 if subscribed PMFBY, 0 otherwise
Literacy	0.73	Dummy (=1 if literate, 0 otherwise)
Extension contacts	0.60	Dummy (=1 if has contact with KVK/ICAR-DWR, 0 otherwise)
Participation in the field demonstrations of IWMT	0.06	Dummy (=1 if participated, 0 otherwise)
IWM training participation	0.58	Dummy (=1 if participated, 0 otherwise)
Adoption	0.62	Dummy (=1 if adopted IWMT, 0 otherwise)

Table 4. Factors determines the adoption of improved weed management technologies

Dependent variable: Dummy for adoption			
Explanatory variable	Coefficient	Std. Error	Probability
Constant	-0.0408	0.0360	0.2591
Age	-0.0004	0.0007	0.5829
Farming experience	0.0014	0.0014	0.2988
Lower caste	0.0222	0.0158	0.1610
Annual income	0.0000	0.0000	0.1891
Below poverty line	0.0097	0.0150	0.5203
Credit	-0.0068	0.0131	0.6041
Membership in social organization	0.0151	0.0222	0.4965
Crop insurance	-0.0323	0.0233	0.1676
Area under cultivation	0.0015	0.0014	0.3046
Literacy	0.0193	0.0127	0.1314
Extension contacts	0.7029***	0.1330	0.0000
Participation in the field demonstrations of IWMT	0.2168**	0.1040	0.0382
IWMT training participation	0.2714**	0.1288	0.0363

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

(49%), greengram (50%), and wheat (55%). Significant positive correlations were found between adoption levels and factors such as age, education, farm size, training, extension contacts, media exposure, input availability, and innovativeness. Rajashekar (2018) also reported similar results in Mahaboobnagar district, Telangana.

We employed Heteroskedasticity consistent robust standard errors in estimating the linear probability model. Notably, when predicted probabilities fall within the range of 0.2 to 0.8, the model yields consistent results (Hausman *et al.* 1998; Horrace and Oaxaca 2006). In our study, predicted probabilities ranged from 0.21 to 0.84 (**Figure 3**), reinforcing the model's suitability. Given the purpose of the analysis and the uncertainty about the cumulative distribution function of the error term, adhering to the linear model is advantageous (Hippel and Workman 2016, Ochalibe *et al.* 2015, Aditya *et al.* 2018).

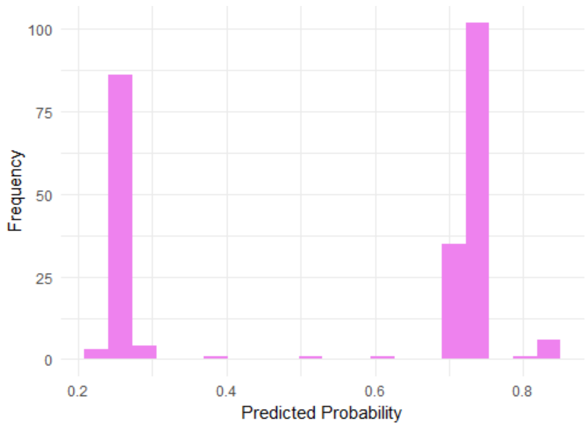

Figure 3. Histogram of predicted probabilities in the LPM estimation

Constraints faced by farmers in adopting weed management technologies

In the next stage of the study, we attempted to prioritize the adoption constraints faced by farmer respondents. In fact, we posed questions on various components of Integrated Weed Management Practices, considering IWMTs as part of the same, in order to obtain a holistic picture of the constraints in weed management in the rice-wheat system. For this, firstly we have identified important constraints through literature review and pilot survey. Subsequently, we included these constraints in the survey schedule. The responses were collected on a five-point continuum *viz.* strongly agree, somewhat agree, unsure, somewhat disagree and strongly agree. The scores were assigned as 5, 4, 3, 2 and 1, corresponding to strongly agree, somewhat agree, unsure, somewhat disagree and strongly disagree. Based on the total score, the average score for each constraint was calculated to ascertain the seriousness of each constraint, and finally, the ranking was done.

The results (**Table 5**) indicated that the non-availability of laborers during the peak season for hand weeding ranked as the top constraint, with a total score of 701 and an average score of 2.92. The non-availability of skilled laborers for herbicide application appeared as the second-ranked constraint with an average score of 2.72, while the lack of knowledge about sprayers and nozzles was the third-ranked constraint, having an average score of 2.66. Interestingly, awareness-related constraints, such as the lack of awareness about chemical weed management technologies and mechanical weed management technologies, were found at the bottom of the table. This clearly indicates that farmers are aware of improved technologies through various extension activities; however, other constraints hinder their widespread adoption. Moreover, since labour availability is identified as the most significant constraint among others, it reinforces the importance of herbicide-based chemical weed management practices to achieve better productivity and profitability for farmers. Gharde and Singh (2021) identified key constraints in the adoption of weed management technologies by farmers, including a lack of technical expertise concerning herbicides, inadequate awareness regarding improved weed management technologies, and lack of knowledge about the precautions during spray of herbicides.

Table 5. Constraints faced by the respondents to adopt improved weed management technologies

Constraints	Total score	Average score	Rank
Non-availability of labourers during peak season for hand weeding	701	2.921	1
Non-availability of trained/skilled labourers for herbicide application	653	2.721	2
Lack of knowledge about sprayer and nozzle	639	2.663	3
Lack of proper technical knowledge about recommended dose of herbicides and its application	576	2.410	4
Lack of awareness about cultural methods of weed management	568	2.367	5
Non-availability of required spraying equipment and nozzles	562	2.342	6
Non-availability of herbicides at local level	558	2.325	7
Supply of spurious/adulterated herbicides	531	2.213	8
Lack of awareness about chemical weed management technologies	522	2.175	9
Lack of awareness about mechanical weed management technologies	519	2.163	10
Fear about the use of herbicides	503	2.096	11

Conclusion

The findings of the present study provide a micro-level insight into the adoption behavior of farmers concerning improved weed management technologies in the rice-wheat system. While the major weed flora found in both studied districts were the same, their composition differed. *Echinochloa colona* emerged as the most prevalent weed in rice fields, while *Phalaris minor* was reported as the most severe weed in wheat fields. Notably, *Cyperus rotundus* was identified as one of the most problematic weeds in both rice and wheat fields. Approximately 62% of farmer respondents adopted IWMT, while 38% did not. Socio-economic variables such as annual income, landholding, education, and access to credit exhibited significant differences between adopters and non-adopters. Extension contacts emerged as a highly significant variable determining the adoption of IWMT by farmers. Participation in improved weed management trainings and field demonstrations of IWMTs were other influential factors affecting adoption. Constraints related to labor availability, such as the unavailability of laborers during peak seasons for hand weeding and the absence of skilled laborers for herbicide application, were identified as the top-ranked constraints for adoption. Conversely, awareness-related constraints, such as the lack of knowledge about chemical and mechanical weed management technologies, were perceived as less significant barriers hindering the adoption of weed management technologies. This underscores the importance of improved weed management technologies, particularly chemical methods, for effective weed management in the rice-wheat system, leading to reduced yield losses and enhanced productivity.

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