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THE PRACTICE OF IMIDAZOLINONE-RESISTANT RICE PRODUCTION IN THE IRRIGATED RICE FIELDS OF KG SUNGAI LEMAN

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ABSTRACT
Rice is an important crop and a staple food in Malaysia. Herbicides are used extensively to control weeds, which represent a major constraint to yield production. Although the introduction of Imidazolinone-resistant Rice with its management system (IRPS) has greatly improved both yields and weed control, the system is designed to be used for only a short term before transitioning to local varieties. Thus, a survey was conducted among 115 farmers to obtain information on their general knowledge on weed control and IRPS. The results showed that the majority of the farmers use herbicides to control all types of weed presented, with a small minority still using manual control. The majority of farmers using IRPS were applying the herbicide imidazolinone when soil condition were right, and only once per season, which is the recommendation. Most of the farmers still utilized imidazolinone to control weedy rice but would not use it on other weeds. However, many of the farmers perceived imidazolinone as becoming more ineffective and expensive and were willing to change to other herbicides if there was a viable alternative. Although herbicide is the main method employed in controlling weeds when using IRPS, farmers still regard imidazolinone as an ineffective herbicide. The reason IRPS is still in use is due to the high yields provided. This study shows a better understanding of knowledge on weeds and IRPS among farmers. Nonetheless, the IRPS will become a redundant system due to the ineffectiveness of imidazolinone and a new system should be introduced to replace it.

Contribution/Originality: This study is one of very few studies to have investigated the imidazolinone-resistant rice system and weed-related knowledge of farmers in Malaysia.

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1. INTRODUCTION

Rice is considered a staple food in Malaysia and the second most important crop after wheat (Rajamoorthy, Rahman, & Munusamy, 2015). The current self-sufficiency level for Malaysia is only around 70% (Sharif, 2013). Because of this, the government has outlined plans to attain a 100% self-sufficiency level (Rajamoorthy et al., 2015). However, rice has many limitations to achieving a high yield. Weeds are the major pest for rice, accounting for an average of up to 50% yield losses (Tshewang, Sindel, Ghimiray, & Chauhan, 2016). The major pest is weedy rice, which has almost the same morphological traits and thus can be very difficult to spot in the early planting stage (Sudianto et al., 2016). Therefore, the Imidazolinone-resistant Rice Production System (IRPS) has been introduced to control weedy rice. The system comes in a package of imidazolinone-resistant rice seeds and the herbicide imidazolinone, which contains imazapic and imazaphyr as the active ingredients. Imidazolinone-resistant rice was first introduced in Malaysia at FELCRA Seberang Perak (Azmi, Azlan, Yim, George, & Chew, 2012). Two varieties were introduced, namely MR220-CL1 and MR220-CL2, both high-yielding varieties able to produce up to 1.5 times more than local types (Adedoyin, Shamsudin, Radam, & AbdLatif, 2016). The planting of imidazolinone-resistant rice comes with certain recommendations, such as the number of seasons over which it can be planted, time of planting, soil conditions during imidazolinone application, and the number of imidazolinone applications per season (BASF, 2010). Following the IRPS method can reduce weedy rice infestation but, at the same time, it can increase the risk of gene flows due to their genetic similarities and inheritance of the same resistance towards the herbicide (Sudianto. et al., 2013). In fact, there are several gene flows reported from nations that utilize imidazolinone-resistant rice (Engku et al., 2016; Kaloumenos, Capote, Aguado, & Eleftherohorinos, 2013; Roso, Merotto Jr, Delatorre, & Menezes, 2010). Imidazolinone-resistant rice has been planted for several years now, but there are no studies regarding the practice of IRPS by farmers. This study aims to gain an insight into farmers' general knowledge of weeds and the practice of IRPS after years of using this system.

2. MATERIALS AND METHODS

The study consisted of personal interviews with rice farmers who planted imidazolinone-resistant rice in Kampung Sungai Leman, Sekinchan, Selangor. A total of 115 farmers were interviewed in the area based on their willingness to co-operate. The survey was conducted in a direct interview using a structured questionnaire, which included three sections of open-ended questions, closed-ended questions, and a section on Likert scale-based question. The interviews were conducted in Bahasa Malaysia. The interviewees were asked about their socio-demographic information, knowledge on IRPS, classification of common weeds in rice fields, and knowledge on imidazolinone. The data were analyzed using several methods. Descriptive analysis was used to describe the farmers' socio-demographic background, knowledge on IRPS, and classification of common weeds in rice fields. Meanwhile, Chi-square was used to investigate the relationship between farmers' education levels and the general practice of the IRPS system. Factor analysis was used on the Likert scale questions to reduce variable groups according to their underlying characteristics. A value of Kaiser–Meyer–Olkin (KMO) at 0.60 or higher was considered to determine whether the variables were accepted for further factor analysis. Factors with eigenvalues >1 were considered significant for the analysis. For factor loading, the cut-off point was >0.5. For each factor extracted, reliability testing was conducted and Cronbach's alpha coefficient of >0.6 was considered acceptable.

3. RESULTS AND DISCUSSION

3.1. Farmers' Background

In total, 115 farmers participated with all of them being Malays, consisting of 114 males and only one female. Table 1 shows that >80% of the farmers were >40 years of age and only a very small percentage <40 years. In terms of educational attainment, 16 and 80% of the farmers had received education up to primary and secondary school, respectively. Only one farmer (0.87%) had not received any formal education, while four (3.48%) had received their education to college or university level. The mean number of people per farming household in the area was 5.09. One-fifth of the farmers had >31 years of rice planting experience, which constituted the lowest percentage. The highest percentage consisted of farmers with experience <10 years and 21–30 years (28.70%). A total of 89.57% of the farmers were primarily rice farmers while the remainder were farmers with jobs in the private (7.82%) or government sector (1.74%), as well as one pensioner (0.87%). Most of the farmers gained revenue per season in the range RM4001–6000 (32.2%). The lowest percentage was in the range >RM10,000 (2.61%). More than half of the average yield in the area was around 8–9 tonnes per hectare (56.52%), while the second-highest value was 6–7 tonnes per hectare (24.35%). Other average yield ranges were 4–5 tonnes per hectare (9.57%), >10 tonnes per hectare (5.21%), and 2–3 tonnes per hectare (4.35%).

3.2. IRPS Knowledge among Farmers

Of all the farmers interviewed, around 73% expressed their knowledge about IRPS while the remainder had no information at all. This result can be seen in Table 2. The major source of information obtained by these farmers was from the agriculture extension officer of the Department of Agriculture (DOA) (20.87%), followed by the farmers' organization (16.52%). Only 15.65% of farmers had obtained information about IRPS from their friends, while the remainder had obtained their information from seed companies (11.30%), rice seed agents (7.82%), or pesticide retailers (0.87%). From the total of 84 farmers who had knowledge of IRPS, 90.48% mentioned that they had followed the IRPS recommendations whereas the remainder (9.52%) had not. For those farmers who had not followed procedures, 50.00% stated that the reason for this was due to high yields, while the remainder noted the ease of weed control (25.00%) or ease of use (25.00%).

Table-1. Farmers' socio-demographic profile.

Profile	Frequency (n = 115)	Percentage
Age (years)		
≤30	3	2.61
31–40	15	13.04
41–50	46	40.00
51–60	43	37.39
≥61	8	6.96
Education attainment		
No formal education	1	0.87
Primary	18	15.65
Secondary	92	80.00
College/university	4	3.48
Number of households		
≤2	23	20.00
3–4	24	20.87
4–5	25	21.74
5–7	28	24.35
≥8	15	13.04
Experience in rice planting (years)		
≤10	33	28.70
11–20	26	22.60
21–30	33	28.70
≥31	23	20.00
Primary work		
Rice farmer	103	89.57
Private sector	9	7.82
Government sector	2	1.74
Pensioner	1	0.87
Revenue per season (RM/ha)		
≤2000	8	6.96
2001–4000	31	26.96
4001–6000	37	32.17
6001–8000	23	20.00
8001–10,000	13	11.30
≥10000	3	2.61
Average yield (tonnes/ha)		
2–3	5	4.35
4–5	11	9.57
6–7	28	24.35
8–9	65	56.52
≥10	6	5.21

Table-2. Farmers' IRPS knowledge.

Profile	Frequency	Percentage
IRPS source of information	n = 115	
Agent	9	7.82
DOA	24	20.87
Seed company	13	11.30
Farmers' organization	19	16.52
Friend	18	15.65
Pesticide retailer	1	0.87
No knowledge on IRPS	31	26.97
Follow IRPS (n = 84)		
Yes	76	90.48
No	8	9.52
Reason did not follow (n = 8)		
Weedy rice control	2	25.00
High yield	4	50.00
Ease of usage	2	25.00

3.3. Types of Weed in Rice Fields

A total of nine types of weed were found to be most commonly encountered by the farmers in Kampung Sungai Leman, and are shown in Figure 1. Among the nine weeds mentioned, some were considered as major weeds: *Eleusine indica*, *Cyperus iria*, *Echinochloa crus-galli*, *Oryza* sp., and *Ischaemum rugosum*. The most common type of weed was *E. indica*, which accounted for 39.73% of the total. The second-highest weed mentioned by farmers was *I. rugosum* (17.81%), with weedy rice or *Oryza* sp. the third most mentioned weed (9.59%). Other weeds that mentioned by the farmers were *Sagittaria guyanensis* (8.22%), *C. iria* (6.85%), *Limnophila erecta* (6.16%), *Scirpus grossus* (4.79%), *E. crus-galli* (4.79%), *Leptochloa chinensis* (3.85%), and *Eleocharis dulcis* (2.05%).

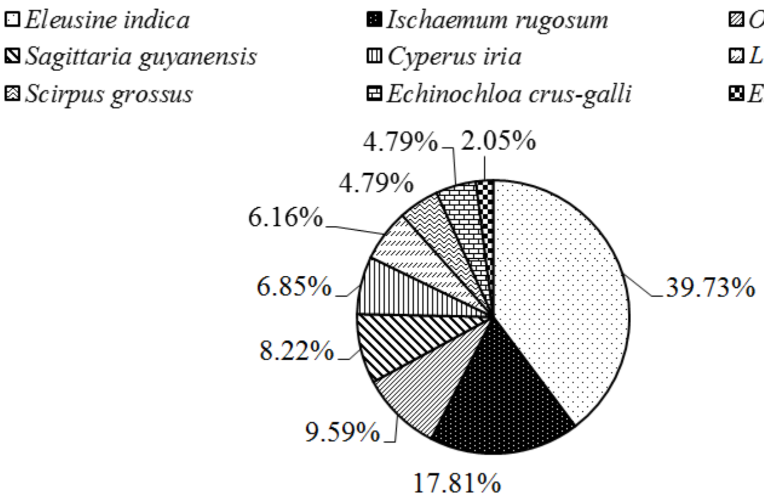

Figure-1. Common weeds found in rice fields.

3.4. Infestation Period of Weeds

The infestation period is the time when the weed is most prominent during the whole of the planting season, based on farmers' knowledge and experience. Most weeds had an infestation period during the early planting season at around 0–30 days after planting (DAP). All weeds had an infestation period at 30–60 DAP. Only five types of weed had an infestation period from 60 DAP to harvesting stage, namely *Oryza* sp. (16.66%), *E. crus-galli* (20.00%), *S. grossus* (14.29%), *E. indica* (1.96%), and *I. rugosum* (10.53%). The critical period for weed control under flood conditions varies according to the season: 2–98 days after seeding in the main season and 15–73 days after seeding in the off season (Juraimi et al., 2009). As such, all of these weeds have the potential to affect rice yield if no weeding is done during the critical period.

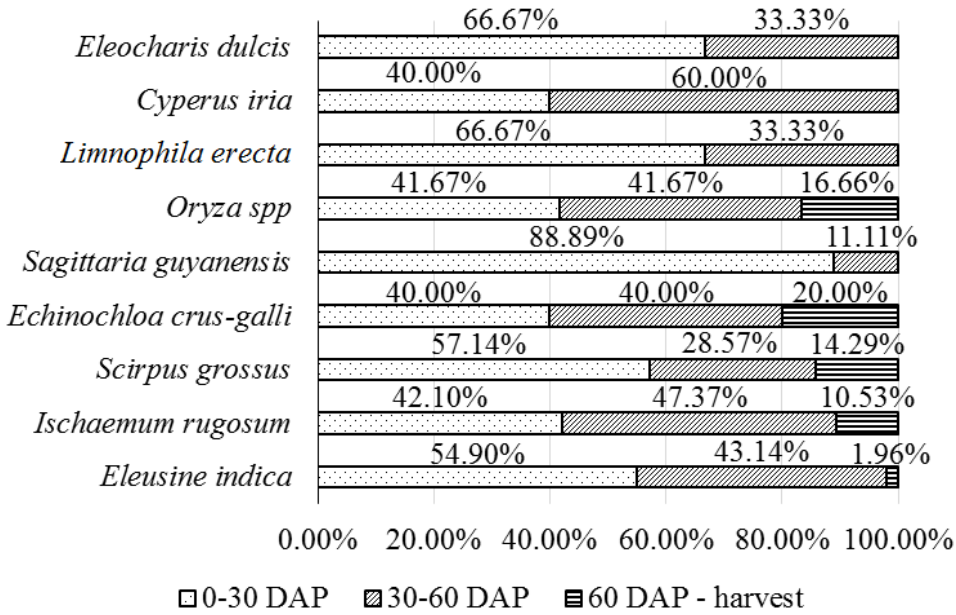

Figure-2. Infestation period for weeds present in Sungai Leman.

3.5. Infestation Level

The infestation level of weeds was determined by the number of herbicide applications per season. Low-level infestation weeds required no herbicide application while serious invaders required one or two application. For very serious infestation levels, more than two applications were required. According to the data gathered from farmers, although all of the weeds were associated with a serious infestation level, 2.08 and 11.76% of the farmers considered *E. indica* and *I. rugosum*, respectively, as not serious. Interestingly, the following weeds were considered very serious: *Oryza* sp. (54.55%), *E. crus-galli* (20.00%), *E. indica* (14.59%), and *I. rugosum* (23.53%). In particular, *E. indica* and *I. rugosum* have been documented as being among weeds that cause massive loss due to their competition with commercial rice. Weeds can cause losses of 35–100% if not properly managed (Ismaila, Wada, Daniya, & Gbanguba, 2013). Moreover, *Oryza* sp. has been confirmed to hybridize with imidazolinone-resistant rice and to develop resistance to the herbicide (Engku et al., 2016). These three weeds (*I. rugosum*, *E. indica* and *Oryza* sp) have previously been studied and confirmed to have developed resistance to certain herbicides (Heap, 2018). This developing resistance will reduce the capability of these herbicides to control weeds, thus increasing management costs and reducing the income of farmers.

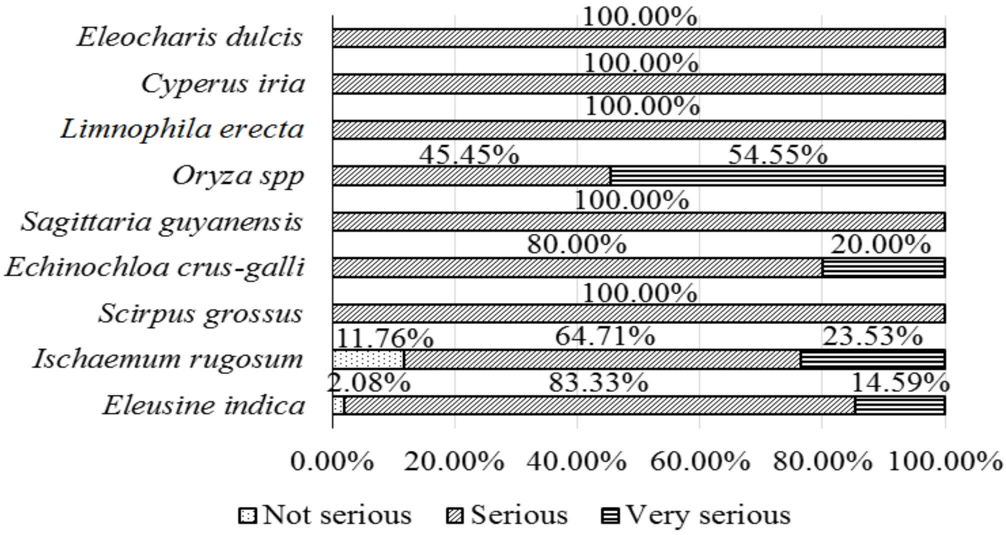

Figure-3. Infestation levels of weeds present in Sungai Leman.

3.6. Weed Control

Many types of herbicide were applied by the farmers to control weeds. Using herbicide to control weeds can increase the yield of rice – it was observed that some weeds, such as *Oryza* sp. and *E. indica*, were controlled with many types of herbicide. Among herbicides used to control both of these weeds included pendimethalin, pretilachlor, 2,4 D-amine, thiobencarb + propanil, cyhalofop-butyl, and pretilachlor + pyribenzoxim. The usage of 2,4-D amine in controlling this weeds is somewhat puzzling as this is a selective herbicide for broadleaf weeds. This shows that some farmers do not understand the correct way to use herbicides. The results for weed control can be observed in Table 3 which shows the percentage of the farmer's based on their experience. For *E. dulcis*, the farmers used only 2,4 D-amine-based herbicide for control. For *S. grossus*, 50.00% of the farmers used pendimethalin while the remaining 50.00% used bendioxide to control this weed. *E. crus-galli* was commonly controlled using cyhalofop-butyl (50.00%) and pendimethalin (50.00%), whereas *S. guyanensis* was controlled by three types of herbicide, namely bispyribac sodium (20.00%), lufenuron (20.00%), and 2,4 D-amine (60.00%). *C. iria* was controlled mainly by 2,4 D-amine (50.00%), benoxide (33.33%), and pendimethalin (16.67%). For *L. erecta*, three types of herbicide were used, namely pretilachlor + pyribenzoxim (20.00%), pendimethalin (20.00%), and 2,4 D-amine (40.00%). Similarly, *I. rugosum* was controlled by five types of herbicide: lufenuron (8.33%), bendioxide (8.33%), bispyribac sodium (25.00%), pendimethalin (25.00%), and pretilachlor + pyribenzoxim (33.34%). *E. indica* was controlled by eight herbicides: thiobencarb + propanil (2.86%), pretilachlor + pyribenzoxim (5.71%), penoxulam (5.71%), 2,4 D-amine (8.57%), bispyribac sodium (8.57%), pretilachlor (11.43%), pendimethalin (22.86%) and cyhalofop-butyl (31.43%), and also by manual control (2.86%). For *Oryza* sp., the controls implemented were imazapyr + imazapic (66.09%), pendimethalin (14.78%), pretilachlor + pyribenzoxim (9.56%), pretilachlor (4.35%), penoxulam (0.87%), 2,4-D amine (0.87%), thiobencarb + propanil (0.87%), and cyhalofop-butyl (0.87%). Surprisingly, imidazolinone was still considered the most utilized herbicide to control weedy rice after years of applying the IRPS technique. One study indicated that farmers have low confidence in following the IRPS system due to strict guidelines and procedures (Terano, Mohamed, & Din, 2016). Imidazolinone is a low-application-rate herbicide, which carries a higher risk of causing resistance in weeds. Only 1.74% of the farmers controlled their weeds manually in paddy fields, where it is is a labour-intensive effort. Therefore, the most cost-effective and practical option for controlling weeds is the application of herbicides (Juraimi et al., 2013). Some of the weeds featured in this study are being controlled solely using herbicides without any input of manual labor. Using herbicides also has its downside, as certain examples are toxic and have carcinogenic properties, including 2,4 D-amine, pendimethalin, and pretilachlor (Ahmad, Zafeer, Javed, & Ahmad, 2018; Loomis et al., 2015; Soni & Verma, 2018). Imidazolinone, which is the main element in IRPS, is not known to be carcinogenic.

Table-3. Weed control.

Weed	Herbicide	Percentage
Eleochoris dulcis	2,4 D-amine	100.00
Scirpus grossus	Pendimethalin	50.00
	Bendioxide	50.00
Echinochloa crus-galli	Cyhalofop-butyl	50.00
	Pendimethalin	50.00
Sagittaria guyanensis	Bispyribac sodium	20.00
	Lufenuron	20.00
	2,4 D-amine	60.00
Cyperus iria	2,4 D-amine	50.00
	Benoxide	33.33
	Pendimethalin	16.67
Limnophila erecta	Pretilachlor	20.00
	Pendimethalin	20.00
	2,4 D-amine	60.00
Ischaemum rugosum	Lufenuron	8.33
	Bendioxide	8.33
	Bispyribac sodium	25.00
	Pendimethalin	25.00
	Pretilachlor	33.34
Eleusine indica	Thiobencarb + propanil	2.86
	Penoxulam	5.71
	2,4 D-amine	8.57
	Bispyribac sodium	8.57
	Pretilachlor	17.14
	Pendimethalin	22.86
	Cyhalofop-butyl	31.43
	Manual	2.86
Oryza sp	Imazapyr + imazapic	66.09
	Pendimethalin	14.78
	Pretilachlor	13.91
	Penoxulam	0.87
	2,4-D amine	0.87
	Thiobencarb + propanil	0.87
	Cyhalofop-butyl	0.87
	Manual	1.74

3.7. Farmers' Application of IRPS

In the IRPS system, a set of guidelines should be used by farmers to ensure that weeds cannot develop resistance due to hybridization and mutations. Farmers' usage of IRPS is shown in Table 4. The maximum frequency of planting for imidazolinone-resistant rice should be limited to only two consecutive seasons. The result from this study found that 30.43% of farmers followed the guidelines while 69.57% planted more than two seasons continuously or every other season, which does not comply with the recommendations. The recommended period of imidazolinone herbicide application on imidazolinone-resistant rice should be 0–7 days after planting; however, only 38.26% of farmers sprayed herbicide during this period: 48.70% sprayed after 7 days of planting while 13.04% sprayed before planting. Regarding soil conditions during the application of imidazolinone, the soil must be saturated with water. A total of 68.70% of farmers applied herbicide following the suggested soil conditions, while 29.56% sprayed when the soil was in a dry condition. Only 1.74% of farmers sprayed when the soil was flooded with water. Regarding the frequency of imidazolinone application, 80.87% of farmers sprayed only once per season, 10.43% sprayed twice per season, and the remainder sprayed three times or more in one season. The major reason mentioned by farmers for spraying imidazolinone more than once per season was the lack of effect of herbicide on imidazolinone-resistant rice. As mentioned above, imidazolinone remained the main herbicide used to control weedy rice by farmers in the study, at 66.09%.

3.8. IRPS Practice by Farmers

Chi-square analysis was carried out to determine the relationship between farmers' level of education and their practice in following this system. The hypotheses for the analysis are as follows:

H_o: There is no significant relationship between farmers' level of education and their practice of IRPS.

H_a: There is a significant relationship between farmers' level of education and their practice of IRPS.

Table-4. Farmers' application of IRPS.

Criterion	Frequency (n = 115)	Percentage
Frequency of imidazolinone-resistant rice planting		
Two seasons consecutively	35	30.43
Every other season	31	26.96
Continuous	49	42.61
Time of imidazolinone spraying		
Before planting	15	13.04
0–7 days after planting	44	38.26
7 days after planting	56	48.70
Soil conditions when spraying imidazolinone		
Dry	34	29.56
Water-saturated	79	68.70
Flooded	2	1.74
Frequency of spraying imidazolinone herbicide		
Once	93	80.87
Twice	12	10.43
Three times or more	10	8.70
Herbicide used to control weedy rice		
Imizaphyr + imizapic	76	66.09
Pendimethalin	17	14.78
Pretilachlor + pyribenzoxim	11	9.56
Pretilachlor	5	4.35
Manual	2	1.74
Penoxulam	1	0.87
2,4-D-amine	1	0.87
Thiobencarb + propanil	1	0.87
Cyhalofop-butyl	1	0.87

From Table 5, there is no significant relationship shown between farmers' level of education with their practice in following IRPS at the 5% level of significance. The table shows that education level had no effect on farmers' IRPS practices. The same result was obtained by Meiguran and Basweti, who found that the level of education obtained by farmers did not influence their agricultural practices. Some studies have stated that extension officers and friends are usually among the main sources of information for farmers (Bachhav, 2012; Mattah, Mattah, & Futagbi, 2015). This can explain why more than half of the farmers knew of the IRPS system from government agencies, organizations, and even friends.

Table-5. Relationship between farmers' level of education and their usage of IRPS.

Variable	Chi-square	d.f.	Significance	Decision
Frequency of planting	3.922	6	0.687	Fail to reject H_o
Time of spraying	10.176	6	0.117	Fail to reject H_o
Soil condition	1.761	6	0.940	Fail to reject H_o
Frequency of spraying	3.814	6	0.702	Fail to reject H_o

3.9. Farmers' Knowledge of Imidazolinone Herbicide

Based on the KMO test the sampling adequacy was 66.9%, which was considered acceptable for conducting the factor analysis. Bartlett's test of sphericity showed that the overall matrix was not an identified matrix. It showed that it was significant at the 0.000 probability level with approx. Chi-square = 616.477 and degree of freedom (d.f.) of 136. Four factors were extracted using principal component analysis (PCA), which collectively explained 63.21% of the total variance (Table 6). The four factors were 'effectiveness', 'recommendations and labeling', 'price', and 'information. For factor loading, the strength of correlation is greater when the score nears 1.0; values close to 1 are the most significant (Fernandes, Amaral, & Varajão, 2018).

Factor 1 (i.e., effectiveness) consisted of six items with eigenvalues of 2.723, which indicated that imidazolinone was losing its effectiveness and that farmers would use other types of herbicide if these could kill the weeds. This can explain why a small percentage of farmers sprayed imidazolinone more than once. Factor 2 (i.e., recommendations and labeling) had an eigenvalue of 2.355, with three items. This factor explains why farmers spray the herbicide as recommended and are more likely to trust products that have labels that give them a sense of security. For Factor 3 (i.e., price) the eigenvalue was 1.965, with three items. This factor explains that farmers have a tendency to use cheap herbicides providing these are effective and easy to use. Lastly, Factor 4 (i.e., information) had an eigenvalue of 1.806, with two items. This factor explains that the farmers trust government agencies that provide them with information regarding imidazolinone. However, at the same time, they also rely on information relayed from their friends on the effectiveness of other herbicides.

As shown in Table 6, all eigenvalues are >1.0 and indicate that the factors can explain more than one item. To demonstrate the internal consistencies of a multiple-item scale, Cronbach's alpha was computed by the reliability test. The alpha value for 'effectiveness' and 'recommendations and labeling' was >0.7, which indicated that the items formed a scale with reasonable internal consistency. For 'price' and 'information', the alpha value was >0.6, which indicated that the scale formed had minimally adequate reliability.

Table-6. Summary of factor loadings on farmers' knowledge of imidazolinone.

Items	Factor loading			
Factor 1 (Effectiveness)				
Imidazolinone is no longer effective	0.720			
Imidazolinone is more expensive.	0.693			
Resistance to imidazolinone made me change to another herbicide	0.611			
Price may be the reason I use herbicides other than imidazolinone	0.597			
I care about herbicides that do not damage the environment	0.584			
I will consider other herbicides besides imidazolinone herbicide if they work	0.542			
Factor 2 (Recommendations and labeling)				
I use the recommended rate and spraying method		0.886		
I sprayed the herbicide according to what that was recommended		0.815		
I choose herbicides that have a complete label as these are safe to use		0.697		
Factor 3 (Price)				
I buy only cheap herbicides			0.841	
I value price over effectiveness			0.733	
I prefer to use a cheap herbicide providing it is easy to use			0.706	
Factor 4 (Information)				
I am confident with information from government agencies relating to the effectiveness of this herbicide				0.851
I refer to other farmers about the effectiveness of other herbicides				0.774
Eigenvalues	2.723	2.355	1.965	1.806
% of variance explained	19.450	16.821	14.035	12.899
Cumulative % variance explained	19.450	36.271	50.307	63.206
Cronbach's alpha	0.743	0.784	0.674	0.660

4. CONCLUSIONS

The study concluded that some farmers did not follow the guidelines, with around 73% of them having some knowledge of IRPS prior to the interview. They also had good knowledge of common weeds in the rice fields, with the majority using chemicals to eradicate them. However, certain herbicides that were used are potentially carcinogenic, which can have negative effects for farmers. A small proportion of them also had no knowledge of IRPS. Regarding the five criteria investigated in terms of the usage of IRPS, two (i.e., planting frequency and time of spraying) were not followed by the majority of farmers. Regarding those criteria that the majority of farmers followed (i.e., soil conditions, spraying frequency, and types of herbicide), nearly one third of the remaining farmers do not follow them. It is very important that farmers know how to use this system correctly, to avoid damaging the environment. Although there is evidence of gene flow due to usage of IRPS, not following the guidelines can also contribute to increased ineffectiveness of imidazolinone. The DOA should increase its monitoring efforts and educate farmers. Regulations are essential to curb incorrect usage of the system. This study further concluded that the farmers perceived imidazolinone as expensive and no longer effective. They were also willing to change to other, cheaper alternatives. However, imidazolinone was still the main herbicide used to control weedy rice when this study was undertaken. An alternative to this system must be researched, because farmers have started to use herbicides that are carcinogenic, as opposed to imidazolinone which is less harmful.

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