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A Mathematical Model for Pesticide Recommendations in Contemplation of Alternative and Variable Threshold Combinations of Insect Pests in the Paddy Field

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Abstract: Pesticides though have ecological adverse effects are still the prime way for pest control. Selection of the pesticide formulation is based upon mostly on a single pest economic threshold level (ETL). But field insect pests represent a more complex and heterogeneous association as it characterizes an admixture of different species of variable life-stages. As, pesticide of a single brand is not equally effective to all insect pests, a broadly defined insecticide application strategy based on a single pesticide application cannot not be taken in *toto* for paddy insect pest control. Side by side re-validation of the presently running ETL system in consideration of threshold limit is required. Brown plant hopper (BPH), yellow stem borer (YSB), gall midge (GM) and paddy bug (PB) are four major paddy insect pests in the northern parts of West Bengal, India. A mathematical model of pest occurrence was proposed after conducting the field experiment for five consecutive years (2003-2007) at three blocks of the district Uttar Dinajpur, West Bengal. In the present model four incidence grades of YSB, BPH and GM and three grades of PB was considered. Gradation was done either depending on the incidence of the individual species or the damage symptoms. During gradation, the nationally advocated economic threshold level (ETL) of each of the pest species was considered as the maximum indices for all the pests. Multiple mutual combination between the grades of all the four pests showed that the pests could occur in 192 combinations. But at a given growth stage of paddy only one pest combination occurs. Depending on the key insect pest in a combination, 192 combinations were again grouped in 12 cultivation modules (CMs) for practical applicability. Each CM was named in consideration of key insect pest species of that group and accordingly application strategy of pesticides for particular CM was recommended.

Key words: Threshold levels · Cultivation module · Pesticide formulations · Action pathway

INTRODUCTION

A pest management system, its consistency and honesty in decision-making and hence the output accruing from management actions and approach, depend to a large extent on 'threshold values' for action decisions [1, 2]. The use of chemical pesticides in Indian agriculture has seen a sharp increase in recent years and in some areas has reached alarming levels [3, 4]. Inspite of that, pesticides as prime pest control 'input' are still used by a number of farmers [5]. Modern IPM's focus on pest suppression using effective, least toxic methods which is practical to apply and cost effective to operate [6-8]. As pest management is a complicated process, it is not simply a matter of substituting 'good' pesticides for 'bad' pesticides. It is rather an improved way to select and apply the pesticide in judicious mode in consideration of the incidence of insect pest population [9, 10].

Out of the 12 important paddy insect pests, 7 are economically more injurious in the northern parts of West Bengal, India [11]. These are yellow stem borer (YSB), brown plant hopper (BPH), gall midge (GM) and paddy

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bug (PB). Considerable differences of bio-ecology, numerical abundance, extent of infestation and nature of damage by these four pests were noted [12]. Accordingly the pesticide application strategy should be befitted [13]. Incidence of YSB was noted throughout the paddy growth stages [14]. Abundance of BPH increases as the growth stage of paddy advances and attains the maximum at early grain maturation stage [13]. Activity of gall midge was mostly restricted to the tillering stage [15]. PB is mainly injurious to the developing grains [16]. Selection of a single pesticide brand is not equally effective to all these four pests in relation to the particular paddy growth stage [17]. Systemic pesticide is effective for YSB, BPH and GM while both contact and systemic pesticide is favoured for PB. However Further in a field peak abundance of all the four insect pests differs considerably. So a more reliable method of pesticide application which is based on based on multiple pest threshold level instead of single pest assessment is urgently required [18].

Presently, the terms economic threshold (ETL), damage threshold level (DTL), injury threshold level (ITL) and action threshold (ATL) were used to explain the insect pest status of the field. DTL are more realistic [19] and can easily be used in examination of varying level of pest infestation [20]. Sogawa *et al*. [21] have commented that most economic thresholds for insects are numerical and not based on damage functions. So selection of pesticides in consideration of single pest threshold level is less applicable to check the crop damage since the pests occur at multiple threshold combination [8]. Prophylactic application of single pesticide formulation is still widely practiced in the southern parts of Asia.

Experiment on the relative superiority of the pesticide formulation on a particular pest species was carried out by various authors [22-24]. But hardly any author advocates the application of pesticide in consideration of variable grades of pest occurrence. Under this situation the presently available ETL limit should be graded in to sub-ETL levels and accordingly should be redefined. This paper quantifies the nature of pesticide application in relation to action threshold of four major insect pest populations.

MATERIALS AND METHODS

Selection of Pests: Only four major insect pests were considered in the present mathematical model. These are yellow stem borer (YSB), brown plat hopper (BPH), gall midge (GM) and paddy bug (PB).

Underlying Principle of Categorization: Let us consider a set of n groups X_1, X_2, X_3,…….., X_n. Any ordered arrangement (X_{i1}, X_{i2}, X_{i3},………, X_{ir}), $1 \leq i \leq n$ of r symbols is called an ordered sample of size r. If groups are selected one by one and repetitions are permitted then clearly there are n^r samples of size r. Gradation were done depending on the field incidence of the four insect species. Again, if X_1, X_2, X_3,……., X_n groups having n_1, n_2, n_3,….., nr represents the incidence of insect pests respectively, then there are ordered sequences or samples (permutation with repetition) are $n_1 \times n_2 \times n_3 \times$ ……….. x_{nr}. In our case, We have considered four grades (1,2,3,4) for YSB, BPH, GM and three grades (1,2,3) for PB respectively, then the total number of different ordered arrangements of the groups is 4(YSB) x 4(BPH) x 4(GM) x 3(PB) = 192.

Categorization of Insect Damage Depending on National Protocol: Economic threshold level (ETL) as described in the national protocol for these four pests was taken as the uppermost limit during gradation (………..). A limit of 20 individuals/hill, 1 egg mass/m^2, 1 silver shoot/m^2 and 1 individual/hill were recognized as the national ETL limit of BPH, YSB, GM and PB respectively. Depending on these values, the pests or the damage symptoms are divided into four (for YSB, BPH and GM) or three (for PB) tolerant grades. Collective contemplation of the four grades for YSB, BPH and GM and three grades for each of PB reflected that in relation to the four growth stages of paddy the pests could occur in a total of 192 matrix combination matrices (Table 1). Each combination indicated its relative occurrence and the potential of damage. Combinations which were supposed to require the same pattern of prophylactic or corrective measures were taken in one group, regarded as *Cultivation Module* (CM).

RESULTS AND DISCUSSION

Redefining the Pest Action Threshold Level: ETL value described in the national protocol is more or less fixed. It explains the incidence either of insect individuals or the damage symptoms numerically. Decisions to apply pesticide are taken only when the pest indices crosses the limit. But such pest management strategy disregards the heterogeneity of the pest complexes. Most of the pesticide based paddy insect pest control module is prepared in consideration of the economic injury level (EIL) of a single pest. But dynamics of insect pest is more complex and heterogeneous as it represents an

Table 1: Categorization of the major pests into different grades depending on the observable field threshold

Pests with unit of observations	Symbol	ETL limit given in national protocol	Gradation of ETL limit with threshold value: Nomenclature	Grade(s)	Threshold level(s) Individuals/damage symptoms
Brown plant hopper Individual(s)/hill	A	20 individuals/hill	PT	A1	0.0-5.0
			FT	A2	5.1-10
			AT	A3	10.1-20
			BT	A4	20.1<
Yellow stem borer Egg mass(s)/m^2	B	1 egg mass/m^2	PT	B1	0.0-0.5
			FT	B2	0.6-1.0
			AT	B3	1.1-1.9
			BT	B4	2.0<
Gall midge Individual(s)/m^2	C	1 silver shoot /m^2	PT	C1	0.0-0.4
			FT	C2	0.5-0.9
			AT	C3	1.0-1.4
			BT	C4	>1.5
Paddy bug Individual(s)/hill	D	1 individual/m^2	PT	D1	0.0-0.4
			FT	D2	0.5- 1.5
			AT	D3	1.6<

1: Permissible threshold (PT), 2: Functional threshold (FT), 3: Action threshold (AC), 4: battle threshold (BT)

admixture of different pest population of variable life-stages. The objective of the modern IPM is to suppress the pest rather than its abolition. When the individual number of a pest approaches the ETL limit, control of population by pesticides is more crucial. So gradation of abundance of insect individuals or the damage symptoms were done taking the nationally defined ETL level as working limit. Naming of each grade was done according to the necessity of management procedure. There were four grades for YSB, BPH and GM and three grades for PB. No special attention to the field is required in case of '*permissible threshold* (PT) as the pest status is far below ETL. At '*functional threshold'* (FT) the pest status approached to the limit of ETL and the situation could be managed only after taking special attention to some cultural practices including pesticide application. '*Action threshold'* (AT) required the steady prophylactic alteration of the cropping practices while in '*battle threshold'* (BT) (absent in case of PB) immediate pesticidal input together with the adoption of the corrective measures at local level for future crop cultivation was given priority.

Naming of the CM Domain: Multiple mutual combination between all the grades (four grades of YSB, BPH and GM and three grades of PB) of all the four pests showed that the pests could occur in 192 combinations. But only one combination can occur at a time. Depending on the key insect pest, 192 pest-combinations were again grouped in 12 cultivation modules (CMs) for practical applicability. Each CM was named in consideration key insect pest species and accordingly pesticides for particular CM were recommended. A total of 12 CMs were formed of which 6 were found to be economically and ecologically more important (indicated by * in the Table 2) in the northern parts of West Bengal. Probability of occurrence of each CM was determined after observation on 50 plots in each block for five consecutive years. After assessing the pest status in the field, farmers would be able to follow the appropriate group combination and adopt suitable prophylactic or corrective measures. Each of the 12 domains has its individuality and is characterized by the presence or absence of the activity of pest(s) (indicated in the Table 1). Threshold combinations under the same domain have nearly same pest intensity and accordingly require more or less same pesticidal treatment.

Application Protocol of Different Pesticides in Consideration of Single Pest Attack: CMs have shown that some pesticides were equally effective to more than one insect pest (Table 3). Pest combinations under CM2, CM4, CM5, CM6, CM7 and CM8 were more common in the northern parts of Bengal. Farmers may select a single pesticide among the batches in consideration of particular CM. But mode of application of single pesticide under different CM may differ.

Generic name of the pesticides was recommended depending on only the gazette of Government of India Ministry of Agriculture Department of Agriculture and Cooperation, Directorate of Plant Protection, Quarantine

Table 2: Multiple threshold combinations of the four major pests from the paddy fields and their categorization into cultivation modules (CMs).

CMs and probability of its occurrence	Threshold Combinations (TC)
CM1 (Nil)	A1B1C1D1, A1B2C1D2, A1B1C2D1
*CM2 (BPH+YSB)	A2B2C1D1, A2B2C1D2, A2B2C1D3, A2B2C2D1, A2B2C2D2, A2B2C2D3, A2B2C3D1, A2B2C3D2, A2B2C3D3, A2B3C1D1, A2B3C1D2, A2B3C1D3, A2B2C2D1, A2B3C2D1, A2B3C2D2, A2B3C2D3, A2B3C3D1, A2B3C3D2, A2B3C3D3, A3B2C1D1, A3B2C1D2, A3B2C1D3, A3B2C2D1, A3B2C2D2, A3B2C2D3, A3B2C3D1, A3B2C3D2, A3B2C3D3, A3B3C1D1, A3B3C1D2, A3B3C1D3, A3B3C2D1, A3B3C2D2, A3B3C2D3, A3B3C3D1, A3B3C3D2, A3B3C3D3, A4B1C2D2, A4B2C1D1, A4B2C1D2, A4B2C1D3, A4B2C2D1, A4B2C2D2, A4B2C2D3, A4B2C3D1, A4B2C3D2, A4B2C3D3, A4B3C1D1, A4B3C1D2, A4B3C1D3, A4B3C2D1, A4B3C2D2, A4B3C2D3, A4B3C3D1, A4B3C3D2, A4B3C3D3
CM3 (BPH+GM)	A3B1C2D1, A3B1C2D2, A3B1C2D3, A3B1C3D1, A3B1C3D2, A3B1C3D3, A3B2C2D1, A3B2C2D2, A3B2C2D3, A3B2C3D1, A3B2C3D2, A3B2C3D3, A3B3C3D1, A3B3C3D2, A4B1C2D3, A4B1C3D2, A4B1C3D3,
*CM4 (GM+PB)	A1B1C2D2, A1B1C2D3, A1B1C3D2, A1B1C3D3, A1B2C2D2, A1B2C2D3, A1B2C3D2, A1B2C3D3, A1B3C2D2, A1B3C2D3, A1B3C3D2, A1B3C3D3, A2B1C2D3, A2B1C3D2, A2B1C3D3, A2B2C2D3, A2B3C2D2, A2B3C2D3, A3B3C3D3, A4B1C2D3, A4B1C3D1, A4B1C3D2, A4B1C3D3, A4B3C3D3
*CM5 (YSB+PB)	A1B2C1D2, A1B2C1D3, A1B3C1D2, A1B3C1D3, A2B2C1D2, A2B2C1D3, A3B3C1D2, A3B3C1D3, A3B3C2D2, A3B3C2D3, A4B2C1D2, A4B3C1D2, A4B3C1D3
*CM6 (BPH+PB)	A2B1C1D2, A2B1C1D3, A2B1C2D2, A2B3C1D2, A2B3C1D3, A3B1C1D3, A3B1C2D2, A3B1C2D3, A3B1C3D2, A3B1C3D3, A3B2C1D2, A3B2C1D3, A3B2C2D2, A3B2C2D3, A3B2C3D2, A3B2C3D3, A4B1C1D2, A4B1C1D3, A4B1C2D3, A4B2C1D3, A4B2C3D3, A4B3C2D2, A4B3C2D3
*CM7 (BPH+GM+PB)	A2B1C2D1, A2B1C2D2, A2B1C2D3, A2B1C3D1, A2B1C3D2, A2B1C3D3, A2B3C3D1, A2B3C3D2, A2B3C3D3, A3B3C3D3, A4B1C1D1, A4B1C2D2, A4B3C3D2, A4B3C3D3
*CM8 (YSB+GM+PB)	A1B2C2D1, A1B2C2D2, A1D2C2D3, A1B2C3D1, A1B2C3D2, A1B2C3D3, A1B3C2D1, A1B3C2D2, A1B3C2D3, A1B3C3D1, A1B3C3D2, A1B3C3D3, A2B2C2D1, A2B2C2D2, A2B2C3D2, A2B2C3D3, A2B3C2D1, A2B3C2D2, A2B3C2D3, A3B3C2D1, A3B3C2D2, A3B3C2D3, A4B1C2D2, A4B2C2D1, A4B2C2D2, A4B2C2D3, A4B2C3D1, A4B2C3D2, A4B2C3D3, A4B3C2D1, A4B3C2D2, A4B3C2D3, A4B3C3D1
CM9 (YSB)	A1B2C1D1, A1B3C1D1, A2B3C1D2
CM10 (BPH)	A2B1C1D1, A3B1C1D1, A3B1C1D2, A4B1C1D1
CM11 (GM+PB)	A1B1C2D1, A1B1C3D1, A1B2C3D1
CM12 (PB)	A1B1C1D2, A1B1C1D3, A1B2C2D3

* Major insect pest domains in the northern parts of Bengal

Table 3: Multiple threshold combinations of the four major pests from the paddy fields and their categorization into cultivation modules (CMs)

CMs	Recommended pesticides
CM1 (Nil)	lindane, monocrotophos, phosalone, phorate, quinalphos, etofenprox, fipronil
*CM2 (BPH+YSB)	carbaryl, carbofuran, diazinon, endosulfan, ethion, fenthion, lindane, methamidophos, monocrotophos, phorate, phosphalone, phosphamidon
CM3 (BPH+GM)	carbaryl, carbofuran, chlopyriphos, cypermethrin, decamethrin, diazinon, fenitrothion, monocrotophos, phosphamidon, fenthion, phorate, etofenprox
*CM4 (GM+PB)	carbofuran, chlopyriphos, diazinon, fenthion, mephosfolan, phorate phosphamidon, quinalphos
*CM5 (YSB+PB)	aldrin,carbaryl, chlopyriphos, dichlorvos, endosulfan, fenthion, malathion, methyl parathion, phosphamidon,quinalphos,trichlorphon
*CM6 (BPH+PB)	acephate, bromophos, carbaryl, carbofuran, cartap, chlorpyriphos, endosulfan, ethion, fenitrothion, etofenprox
*CM7 (BPH+GM+PB)	acephate, carbaryl, carbofuran, cartap, chlopyriphos, fenthion, fenvalerate, monocrotophos, permethrin, phosphamidon, quinalphos, triazophos
*CM8 (YSB+GM+PB)	carbaryl, carbofuran, chlopyriphos, cypermethrin, decamethrin, diazinon, fenitrothion, monocrotophos, phosphamidon, fenthion, phorate
CM9 (YSB)	carbofuran, chlopyriphos, diazinon, Fenthion, mephosfolan, phorate phosphamidon, quinalphos, phosphamidon
CM10 (BPH)	carbaryl, carbofuran, chlopyriphos, cypermethrin, carbofuran decamethrin, diazinon, fenitrothion, monocrotophos, phosphamidon, fenthion, phorate, etofenprox, cartap hydrochloride
CM11 (GM+PB)	carbofuran, chlopyriphos, diazinon, fenthion, mephosfolan, phorate phosphamidon, quinalphos, imidacloprid
CM12 (PB)	fenthion, malathion, phosphamidon, carbaryl

*major domains

and Storage, Central Insecticide Board and Registration Committee, Faridabad [25]. Application strategies of some selected pesticides in consideration of four important pests are delineated below:

For brown plant hopper (BPH):

- Spraying of carbaryl @ 0.75 kg a.i./ha during early growth stage of paddy.
- Application of etofenprox, moncrotophos, phosalone or chlorpyrifos @ 0.5 kg a.i./ha or lindane 20 EC at 1 liter/ha in the early stages of the crop growth.
- Application of granular insecticides such as phorate or cartap hydrochloride or carbofuran at 1 kg a.i./ha.
- Application of fipronil 0.3% G at 25 kg/ha during mid growth stage.

- Application of granules of carbofuran at 0.75 kg a.i./ha or phorate at 1.25 kg a.i./ha at maximum vegetative growth stage.
- Spray application of phosalone or etofenprox or chlorpyriphos or carbaryl, at 0.5 kg a.i./ha or fipronil at 50 g a.i./ha.
- Application of resurgence causing insecticides like quinalphos, chlorpyriphos, methyl parathion, deltamethrin and cypermethrin should be restricted in application.

For yellow stem borer (YSB):

- Application of fipronil 5% SC at 1 liter/ha if the incidence of dead heart crosses 10% limit at early vegetative stage.
- Spraying of fenthion or fenitrothion or endosulfan or phosalone or monocrotophos or etofenprox or cartap hydrochloride or chlorpyriphos at 0.5 kg a.i./ha.
- Seedlings root dip treatment for 10-12 hours before transplanting in 0.02% chlorpyriphos gives protection up to 35 days against stem borer.
- Seed treatment with fipronil @ 25g/kg seed.

If the pest crosses economic threshold level (ETL) then apply cartap hydrochloride 4G @ 20kg/ha or fipronil 0.3G –25kg/ha

- Phorate 10G @ 10kg/ha or carbofuran @ 33 kg/ha or carbosulfan 3G @ 16kg/ha in the main field.
- Alternately spray with cartap hydrochloride 50 SP - 500g/ha.
- Fipronil 5 SP –1 lit/ha/ monocrotophos/ quinalphos/ chlorpyriphos/ phosphamidon / triazophos / profenophos – 1 lit/ha.

For gall midge (GM):

- Seed treatment with chlorpyriphos 0.2% solution for $2^{1}/_{2}$ hours or seed mixing with either chlorpyriphos (0.75 kg a.i./100 kg seeds) or imidacloprid (0.5 kg a.i./100 kg seeds) provide protection for 35-day in the nursery.
- Seedling root dip in 0.02% chlorpyriphos emulsion before transplanting for 10 -12 hours gives protection for 35 days.
- Sprouted seed soaked with imidacloprid 200SL @ 0.05% (2.5ml/lit) for $2^{1}/_{2}$ hours – then shade dried and broadcasted on raised nursery bed give protection against gall midge.

For paddy bug (PB):

- Dusting carbaryl 10% and repeat it depending upon the extent of infestation.

- Carbaryl – 2 kg/ha/ abamectin – 500ml/ha/ phosphamidon 40SP –1 lit/ha or dusting with malathion 5% @ 25kg/ha.

Determination of Action Pathway: Decision to follow a particular CM mostly comes from a serial observation in an area on a particular pest species in relation to the growth stage of paddy. After extensive observation for five consecutive years (2003-2007) on the relative occurrence of the four major pests in the three administrative blocks of Raiganj, Uttar Dinajpur, West Bengal a comprehensive pest incidence table (Table 4) for the farmers was prepared.

Utility of modern IPM in rice cropping system has emerged as a multi-factorial cropping system approach known as 'component technology' of rice production

Table 4: Relative threshold level of four insect pests in relation to the paddy growth stages in the three blocks of the district Uttar Dinajpur, West Bengal, India

Growth stage of paddy crop		Threshold level of pest species*											
		Raiganj				Hemtabad				Itahar			
Major stage	Sub stages	YSB	BPH	GM	PB	YSB	BPH	GM	PB	YSB	BPH	GM	PB
Nursery	-	PT	PT	PT	PT	PT	PT	PT	PT	PT	PT	PT	PT
Seedling	early	FT	PT	PT	PT	PT	FT	PT	PT	PT	PT	PT	PT
	late	FT	FT	PT	PT	FT	AT	PT	PT	PT	FT	PT	FT
Vegetative	early	FT	FT	PT	PT	FT	AT	PT	PT	FT	AT	FT	FT
	middle	AT	FT	FT	PT	FT	AT	FT	PT	FT	AT	FT	FT
	late	AT	AT	FT	FT	AT	AT	FT	FT	FT	AT	AT	AT
Reproductive	early	AT	AT	FT	FT	AT	AT	FT	FT	FT	BT	AT	AT
	late	FT	AT	FT	FT	AT	AT	FT	FT	AT	BT	AT	AT
Ripening	early	FT	BT	PT	FT	AT	BT	AT	FT	AT	BT	AT	PT
	late	FT	BT	PT	PT	AT	BT	PT	FT	PT	BT	AT	PT

*Permissible threshold (PT), Functional threshold (FT), Action threshold (AC), battle threshold (BT)

[26, 27]. No mathematical model is presently available which suggests the pesticide application based on the probable multiple combinations of pest occurrence. In the present study, only four major insect pests were considered simultaneously. But more than seven species was economically significant in the northern parts of Bengal. Further predators and parasitoids play significant suppressive role for pest control [28, 29]. So during the formulation of the final pest management decision-making system based on pesticide application, the population status of natural enemies should also be considered separately and pesticide application strategy should be constructed depending on only pest: defender value [30, 31]. The success of the present model lies on the extensive field survey, enlisting the pests and natural enemy population at regional level, assessing the maximum probable combinations of pest occurrence and finally to adopt the action taken path way [26]. So any bias involved in management action/no-action decisions based on the superficial field observation of both pests and natural enemies will underscore the practical utility of the model.

The design of IPM programs is influenced by researcher/policymaker perceptions of pest-related yield losses [6, 12]. Where perceived and actual yield losses diverge widely, recommended economic thresholds for spraying are too low, thus reducing the usefulness of IPM [2, 5, 9]. Necessity of multiple threshold definitions like 'permissible threshold', 'functional threshold', 'action threshold' and 'battle threshold' could have described the field pest situation in better way. So, uncorrected application dosages may exacerbate the post application problem. Farmer normally either tends to under-dose or over-dose, using low or high than the recommended amount of chemicals per application. Upon complete implementation of the present 'application module', most of them adjust their dosages. An ill-conceived IPM program could thus lead farmers to spray more often and with heavier concentrations than before.National IPM recommendations, unless adapted to local conditions with fine tuning, could overstate the case for applying pesticides and could cause amplify in pesticide applications in cases where a natural control strategy would be more effective.

The present recommended 'area-specific' cultivation management or 'precision farming' compensates the shortcomings of the broadly defined 'national protocols' and protect environment by rationalizing of the chemical inputs. Undoubtedly the level of usefulness of these action thresholds lies in actual testing when implementing pest management operations on large, medium and small acreage rice fields. However, it is admitted that the method of determination of action threshold used here does not include pertinent variables such as damage, plant compensation, yield potential, economic and marketing considerations.. Present site-specific village level farming involves the measurement and analysis of within-field yield variability only to the variety *Swarna mashuri* (MTU 7029) and targetting the four major insect pests. Based on this future mathematical model may focus on multiple pest constraints on all the cultivars by 'computer based monitoring system' that will help the decision makers to evolve the appropriate cultivation strategy.

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