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Impact of Insecticide Resistance Management (IRM) Strategy on Insecticide Use Pattern during Different Growth Stages of Irrigated Cotton in Punjab

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The Insecticide Resistance Management (IRM) strategy was devised and followed at farmers' fields in 20 villages each in Bathinda, Mansa and Ferozepur districts of Punjab during 2004 and 2005 on cotton crop. Various resistance management strategies were disseminated to the farmers throughout the crop season. Its impact was studied on the pattern of use and reduction in insecticidal applications in IRM villages compared to non-IRM ones. The whole crop season was divided into 4 window period. In window I, endosulfan was used as first spray in IRM villages in both the years as it is safe to natural enemies while farmers in non-IRM villages used other insecticides also in addition to it. In window II, chloronicotinyls such as imidacloprid, acetamiprid and thiamethoxam were mainly used against sucking pests. Triazophos/ethion, carbaryl/thiodicarb were used for the control of whitefly, American bollworm and tobacco caterpillar while synthetic pyrethroids were used against spotted bollworms. Farmers showed more preference for spinosad/indoxacarb for the control of American bollworm. No insecticidal mixtures were used in IRM villages in both the years but in non-IRM. The total number of applications remained lower in IRM than non-IRM villages. In window III, the use of chloronicotinyls, organophosphates and synthetic pyrethroids declined. However, the use of spinosad/ indoxacarb showed an increasing trend. Applications of mixtures were reported only in non-IRM villages. The total number of applications remained lower in IRM than non-IRM villages. In window IV, endosulfan, imidacloprid/ thiamethoxam, triazophos/ethion, acephate/chlorpyriphos, spinosad/indoxacarb and emamectin benzoate were commonly used insecticides in IRM villages whereas in non-IRM villages other insecticides and mixtures were also used in addition to these. The pattern of insecticidal application showed maximum application of imidacloprid/ thiamethoxam followed by endosulfan, spinosad and acephate/chlorpyriphos. The implementation of IRM strategy resulted in 46.9 and 34.5% reduction in insecticidal applications in IRM villages over non-IRM ones in 2004 and 2005, respectively.

Keywords: Cotton, Insecticide Resistance Management, sucking pests, bollworms, tobacco caterpillar

The present day hue and cry situation in cotton is the result of unwise and indiscriminate use of insecticides by farmers. Farmers depend heavily on insecticidal chemicals for the control of insect-pests in cotton, as it is the most effective and easily available option for pest control. However, during the last two decades heavy reliance on these chemicals has resulted in several problems such as resistance in insects, resurgence of secondary pests and destruction of natural enemies besides environmental pollution and health hazards. Of the 96,000 metric tones of technical grade pesticides currently produced in India, more than 60% is used in agriculture sector especially cotton crop alone[1]. Thus, at present, there is an urgent need to reduce the dependence on toxic chemicals and explore the possibility of developing new strategies for pest management. Keeping this in mind, the Insecticide Resistance Management (IRM) strategy was devised and followed at farmers' level to prevent selection for resistance based on rational use of insecticides, restriction of treatments and alteration of chemicals with different modes of action[2]. The impact of adoption of IRM strategy was evaluated by studying the pattern of insecticide use by farmers and reduction in number of sprays.

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MATERIALS AND METHODS

The Insecticide Resistance Management (IRM) strategy was devised, followed and evaluated in farmers' fields of 20 villages each in Bathinda, Mansa and Ferozepur districts of Punjab for studying its impact on insecticide use pattern and reduction in number of applications for management of cotton insect-pests during 2004 and 2005

crop seasons. In addition, 3 villages in each district were taken as non-IRM during both the years. Cotton crop in these villages was grown by farmers at their own level without the supervision and guidance of IRM staff. From each of IRM and non-IRM villages, 10 farmers were selected at random in order to record data on number of insecticide sprays. The following window based IRM strategy was implemented[3].

Window I (Sucking pests management, Sowing – 1st week of July) — i) Selection of varieties resistant to sucking pests and cotton leaf curl virus to avoid early sprays. It also helps in conservation of natural enemies. ii) Destruction of alternate hosts of cotton leaf curl virus and whitefly. iii) Timely sowing, judicious use of fertilizers and irrigation, proper spacing and clean cultivation to prevent early build up of pests. iv) Seed treatment with Gaucho/Cruiser against jassid attack in susceptible cultivars. v) To avoid sprays of any insecticide in this window to conserve natural enemies. vi) No spray against attack of thrips and black semilooper, as they do not cause any economic damage to the crop.

Window II (Sucking pests and bollworms management, 2nd week of July-First week of August) — i) Use of endosulfan against bollworms infestation, as it is less toxic to natural enemies. It gives moderate control of cotton jassid also. ii) To avoid the use of synthetic pyrethroids for the control of spotted bollworms. They were used when endosulfan failed to give satisfactory control. iii) To avoid the use of nitroguadine compounds against jassid as these are toxic to natural enemies. iv) To avoid use of organophosphates/carbamates against bollworms.

Window III (Bollworms and tobacco caterpillar management, Mid to end August) — i) Use profenophos/quinalphos/carbaryl in alteration with synthetic pyrethroids for the control of bollworms. ii) Use acephate for the control of grown up larvae of American bollworm. It also provides effective control of tobacco caterpillar. iii) Use spinosad only in case of severe infestation of American bollworm.

Window IV (Bollworms and tobacco caterpillar management, September-October) — i) Use profenophs/triazophos/quinalphos/thiodicarb for younger larvae of American bollworm. Prefer chlorpyriphos for grown up larvae. Chlorpyriphos, thiodicarb and quinalphos also provide effective control of tobacco caterpillar. ii) Use indoxacarb/spinosad in case American bollworm is serious. iii) Use triazophos/ethion for the management of whitefly. It also provides effective control of pink bollworm and spotted bollworms.

The data regarding number of insecticidal sprays by cotton growers throughout the crop season were recorded. The mean number of insecticidal applications of different chemicals in each window and in the whole crop season was calculated. The data so obtained were subjected to statistical analysis by Student's t-test.

RESULTS AND DISCUSSION

The data on insecticide use pattern during different period of crop season in IRM and non-IRM villages during 2004 and 2005 are presented in Table 1.

Window I (Sowing-1st week of July) — Endosulfan is recommended as first spray as it is relatively safe to natural enemies. It was used as the first spray in IRM villages during 2004 and 2005, and no other insecticide was used. On the other hand, farmers in non-IRM villages used many insecticides in addition to endosulfan. The use of endosulfan remained higher (0.3 and 0.1 sprays) in IRM than that in non-IRM villages (0.1 and 0.0 sprays) in 2004 and 2005, respectively. Despite its higher use, the total number of sprays was significantly lower in IRM (0.3 and 0.1) than non-IRM villages (0.9 and 0.1) in 2004 and 2005, respectively.

Window II (2nd week of July-first week of August) — The chlornicotinyls such as imidacloprid, acetamiprid and thiamethoxam were used for the control of sucking pests especially jassid. Their use was relatively more in this window both during 2004 and 2005 as is evident from the relatively higher number of applications of this group compared to other groups. But still their use was significantly less in IRM than non-IRM villages.

In organochlorines group, use of endosulfan was reported in both IRM and non-IRM villages. While its use was less in IRM villages in 2004, it was at par with that in non-IRM villages in 2005.

Among the organophosphates, the maximum use of triazophos/ethion was reported in 2004 targeted against whitefly (*Bemisia tabaci*) and/or younger larvae of American bollworm (*Helicoverpa armigera*). However, the number of applications of these chemicals was lower in IRM (0.3 and 0.1) than non-IRM villages (0.5 and 0.2) in 2004 and 2005, respectively. No use of monocrotophos was reported in

Table 1. Insecticide use pattern in cotton belt of Punjab during different periods

Insecticide used	Target pest	Average number of sprays with different insecticides															
		Window-I*				Window-II				Window-III				Window-IV			
		2004		2005		2004		2005		2004		2005		2004		2005	
		IRM	Non-IRM	IRM	Non-IRM	IRM	Non-IRM	IRM	Non-IRM	IRM	Non-IRM	IRM	Non-IRM	IRM	Non-IRM	IRM	Non-IRM
Endosulfan	BW complex	0.3	0.1	0.1	0.0	0.1	0.2	0.1	0.1	0.3	0.1	0.1	0.0	0.0	0.1	0.2	0.0
Imidacloprid/ Thiamethoxam	Sudking pests	0.0	0.0	0.0	0.1	0.6	0.7	0.4	0.5	0.1	0.5	0.2	0.3	0.2	0.1	0.2	0.2
Acetamiprid		0.0	0.1	0.0	0.1	0.3	0.5	0.2	0.3	0.1	0.0	0.1	0.1	0.0	0.2	0.0	0.0
Triazophos/ Ethion	BW/ Whitefly	0.0	0.1	0.0	0.0	0.3	0.5	0.1	0.2	0.1	0.4	0.1	0.1	0.1	0.2	0.0	0.0
Monocrotophos	BW complex	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.1
Quinalphos/ Profenophos	BW Complex	0.0	0.0	0.0	0.1	0.1	0.3	0.2	0.0	0.1	0.1	0.2	0.3	0.0	0.0	0.0	0.1
Acephate/ Chlorpyriphos	ABW/ TCP	0.0	0.1	0.0	0.1	0.3	0.2	0.3	0.3	0.1	0.1	0.2	0.3	0.0	0.0	0.1	0.1
Carbaryl/ Thiodicarb	BW complex/ TCP	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0
Cypermethrin/ Alphamethrin/ Deltamethrin/ Fenvalerate	SBW†	0.0	0.1	0.0	0.0	0.2	0.4	0.1	0.2	0.1	0.2	0.0	0.1	0.0	0.0	0.0	0.1
Spinosad/ Inodxacarb	ABW	0.0	0.0	0.0	0.0	0.1	0.3	0.0	0.0	0.4	0.2	0.3	0.2	0.2	0.1	0.0	0.1
Emamectin benzoate	ABW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.0
SP+ Monocrotophos	ABW	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0
SP+Quinalphos/ Profenophos	BW complex	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.2	0.0	0.0	0.0	0.1	0.0	0.0
SP+ Acephate/ Chlorpyriphos	BW complex	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
SP+Triazophos/ Ethion	ABW	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
SP+Endosulfan	BW complex	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total		0.3	0.9	0.1	0.5	2.0	3.8	1.5	2.4	1.4	2.4	1.3	1.6	0.6	1.0	0.5	0.7
t (p=0.05)		0.04		0.04		0.03		0.05		0.05		0.04		0.06		0.05	

* Window I (Sowing to first week of July); Window II (Second week of July-First week of August); Window III (Mid to end August); Window IV (September-October)

BW: Bollworms, ABW: American bollworm, SBW: Spotted bollworms, TCP: Tobacco caterpillar

IRM villages in both the years as it is highly toxic to natural enemies. On the other hand, its use was reported in non-IRM villages (0.2 and 0.1 sprays in 2004 and 2005). The number of applications of quinalphos/profenophos for the control of bollworms was significantly less (0.1) in IRM than non-IRM villages (0.3) in 2004. However, their use was not reported in non-IRM villages in 2005. The sprays of acephate/chlorpyriphos targeted against American bollworm, *H. armigera* and tobacco caterpillar, *Spodoptera litura* were more in IRM villages (0.3) compared to non-IRM ones in 2004, while in 2005, these were at par with each other.

In carbamates group, carbaryl and thiodicarb were used against bollworms and tobacco caterpillar. An equal number of applications of these chemicals (0.1) were recorded in IRM and non-IRM villages in 2005 with no reports in 2004.

The use of synthetic pyrethroids for the control of spotted bollworms (*Earias* spp.) was significantly less being 0.2 and 0.1 sprays in IRM than non-IRM villages (0.4 and 0.2) in 2004 and 2005, respectively. In 2004, the use of indoxacarb/spinosad for the control of *H. armigera* was reported in 2004 with 0.1 and 0.3 applications in IRM and non-IRM villages, respectively. However, no spray of these chemicals was reported in 2005 in this window. It was important to note that farmers in non-IRM villages used various mixtures of insecticides for the control of bollworms while the use of mixtures is not recommended in Punjab. On the other hand, no use of insecticidal mixtures was reported in IRM villages.

The total numbers of insecticidal applications were significantly lower in IRM being 2.0 and 1.5 than that in non-IRM villages (3.8 and 2.4) in 2004 and 2005, respectively.

Window III (Mid to end August) — The use of chloronicotinyls (imidacloprid, acetamiprid and thiamethoxam) declined from the previous window. Moreover, their use was lower in IRM than non-IRM villages in 2004 and 2005. Among the organophosphates, average number of sprays of triazophos/ethion against *B. tabaci* and younger larvae of *H. armigera* were lower in IRM (0.1) than non-IRM villages (0.4) in 2004 while these were at par with each other in 2005. The use of monocrotophos was also recorded in non-IRM villages during this period in 2004 and 2005 while no such use was recorded in IRM villages. An equal number of sprays of quinalphos/profenophos, acephate/chlorpyriphos for the control of bollworms and *S. litura* were used in both IRM and non-IRM villages in 2004, however in 2005, these were significantly less in IRM villages than non-IRM ones. Further, a declining trend in the use of these chemicals was observed in this window from the previous one in both years except in non-IRM villages in 2005.

In case of carbamates an equal number of sprays of carbaryl/thiodicarb for the management of bollworms and *S. litura* were reported in 2004 and 2005, respectively. The insecticidal applications of synthetic pyrethroids for the control of spotted bollworms decreased in this window from the previous one in both the years of study. Further, their use was significantly more in non-IRM (0.2 and 0.1 sprays) compared to IRM villages (0.1 and 0.0) in 2004 and 2005, respectively.

The use of indoxacarb/spinosad increased in this window from the previous one in both the years with exception in non-IRM villages in 2004. This could be attributed to population build up of *H. armigera* in reproductive phase of cotton. Contrary to the other insecticides, applications of these chemicals in IRM villages were more (0.4 and 0.3) than that in non-IRM ones (0.2 and 0.2) in 2004 and 2005, respectively. In 2004, 0.1 applications of emamectin benzoate for the management of *H. armigera* were reported in non-IRM villages with no spray in IRM ones. The trend of use of insecticide mixtures was similar to that observed in window II.

The total number of applications of different insecticides in this window remained lower in IRM than non-IRM villages in 2004 and 2005.

Window IV (September-October) — The use of endosulfan, imidacloprid/thiamethoxam, triazophos/ethion, acephate/chlorpyriphos, indoxacarb/spinosad and emamectin benzoate was most common during this period, but their average number of applications in IRM villages never exceeded those in non-IRM ones except for imidacloprid in 2004 and endosulfan in 2005. Moreover, acetamiprid, monocrotophos, quinalphos/profenophos, synthetic pyrethroids and insecticidal mixtures were commonly used in non-IRM villages in addition to the insecticides used in IRM villages.

Insecticide use pattern — The overall pattern of insecticide use (Table 2) revealed that the use of

Table 2. Overall insecticide use pattern in cotton belt of Punjab

Insecticide used	Target Pest	Total number of sprays with different insecticides			
		2004		2005	
		IRM	Non-IRM	IRM	Non-IRM
Endosulfan	BW complex	0.7	0.5	0.5	0.1
Imidacloprid/ Thiamethoxam	Sudking pests	0.9	1.3	0.8	1.1
Acetamiprid		0.4	0.8	0.3	0.5
Triazophos/ Ethion	BW/ Whitefly	0.5	1.2	0.2	0.3
Monocrotophos	BW complex	0.0	0.3	0.0	0.4
Quinalphos/ Profenophos	BW Complex	0.2	0.4	0.4	0.5
Acephate/ Chlorpyriphos	ABW/ TCP	0.4	0.4	0.6	0.8
Carbaryl/ Thiodicarb	BW complex/ TCP	0.1	0.1	0.2	0.2
Cypermethrin/ Alphamethrin/ Deltamethrin/ Fenvalerate	SBW†	0.3	0.7	0.1	0.4
Spinosad/ Inodxacarb	ABW	0.7	0.6	0.3	0.3
Emamectin benzoate	ABW	0.1	0.2	0.0	0.0
SP+ Monocrotophos	ABW	0.0	0.3	0.0	0.3
SP+Quinalphos/ Profenophos	BW complex	0.0	0.4	0.0	0.1
SP+ Acephate/ Chlorpyriphos	BW complex	0.0	0.6	0.0	0.1
SP+Triazophos/ Ethion	ABW	0.0	0.3	0.0	0.0
SP+Endosulfan	BW complex	0.0	0.0	0.0	0.1
Total		4.3	8.1	3.4	5.2
t (p=0.05)		*0.03*		*0.03*	

BW: Bollworms, ABW: American bollworm, SBW: Spotted bollworms, TCP: Tobacco caterpillar

endosulfan in 2004 and 2005 was significantly more in IRM (0.7 and 0.5 sprays) than that in non-IRM (0.5 and 0.1 sprays). It reflects the increased awareness among the farmers in IRM villages about the use of chemicals safe to natural enemies and importance of natural enemies in cotton ecosystem. The total number of sprays of imidacloprid/thiamethoxam was significantly less being 0.9 and 0.8 in IRM as against 1.3 and 1.1 in non-IRM villages in 2004 and 2005, respectively. Similar trend was observed for acetamiprid with 0.4 and 0.3 sprays in IRM as against 0.8 and 0.5 sprays in non-IRM villages in 2004 and 2005, respectively. Among organophosphates, use of triazophos/ ethion was significantly less (0.5 and 0.2 sprays) in IRM compared to non-IRM villages (1.2 and 0.3 sprays) in 2004 and 2005, respectively. No spray of monocrotophos was recorded in IRM villages in both the years, whereas in non-IRM 0.3 and 0.4 sprays were done in 2004 and 2005, respectively. The use of quinalphos/profenophos and acephate/chlorpyriphos followed the similar trend as that of triazophos/ethion.

In carbamates, an equal number of carbaryl/thiodicarb sprays were done in both IRM and non-IRM villages against *H. armigera* and *S. litura* i.e. 0.1 in 2004 and 0.2 in 2005. In 2004, there were 0.3 applications of synthetic pyrethroids against spotted bollworms in IRM as against 0.7 in non-IRM villages. It further declined to only 0.1 and 0.4 applications in IRM and non-IRM villages, respectively, in 2005. In case of new chemistries, the use of indoxacarb/ spinosad for the control of *H. armigera* was more in IRM (0.7 sprays) than non-IRM villages (0.6) in 2004, whereas, in 2005 their use was equal. The use of emamectin benzoate against *H. armigera* was reported only in 2004 with significantly higher number of applications in non-IRM (0.2) than IRM villages (0.1). The use of insecticide mixtures for the control of bollworms was more popular in non-IRM villages with no reports from IRM villages.

The data on the number of sprays targeted toward a particular pest complex are presented in Table 3. In 2004, out of total 4.3 applications of insecticides, 1.2 and 3.1 were done for sucking pests and bollworms, respectively while no spray was done against *S. litura*. On the other hand in non-IRM villages, out of 8.1 applications, 2.2 and 5.9 were done sucking pests and bollworms, respectively being significantly higher than IRM villages. Similar trend

Table 3. Number of insecticidal applications for the management of different insect-pests of cotton

District	Number of insecticidal applications															
	Year 2004								Year 2005							
	IRM villages				Non-IRM villages				IRM villages				Non-IRM villages			
	SP	BW	TCP	**Total**	SP	BW	TCP	**Total**	SP	BW	TCP	**Total**	SP	BW	TCP	**Total**
Bathinda	1.1	2.0	0.0	3.1	2.7	6.3	0.0	9.0	1.7	0.0	1.2	2.9	1.8	0.0	1.4	**3.2**
Mansa	1.3	2.1	0.0	3.4	1.9	4.8	0.0	6.7	1.5	0.2	1.6	3.3	2.9	1.3	2.1	**6.3**
Ferozepur	1.3	5.1	0.0	6.4	2.1	6.5	0.0	8.6	1.6	0.9	1.5	4.0	1.2	1.4	3.5	**6.1**
Mean	1.2	3.1	0.0	4.3	2.2	5.9	0.0	8.1	1.6	0.4	1.4	3.4	2.0	0.9	**2.3**	**5.2**
t (p=0.05)	0.009	0.009	0.0	0.008					0.203	0.049	0.053	0.025				

SP: Sucking Pests, BW: Bollworms, TCP: Tobacco caterpillar

of higher number of insecticidal applications in non-IRM than IRM villages was observed in 2005.

The implementation of IRM strategy resulted in 46.9 and 34.6% reduction in insecticidal applications in IRM villages over non-IRM ones in 2004 and 2005, respectively. In China, the adoption of IPM strategy resulted in a 3-4 times reduction in insecticidal application and 80 kg ha^{-1} increase in lint cotton yield[4]. The inclusion of new chemicals such as imidacloprid, acetamiprid, thiamethoxam, spinosad and indoxacarb in IRM strategy is a healthy sign as it will lead to the reduced selection pressure on the limited number of efficacious products[5]. Further, the use of indoxacarb will help in managing pyrethroid resistant populations of *H. armigera* as it exhibits negative cross-resistance between indoxacarb and pyrethroids[6]. However, optimized use of these new molecules through monitoring of field pest tolerance is needed to prolong their lifespan[7].

Thus, it can be concluded that implementation of IRM strategy was successful in reducing the insecticidal applications and hence, plant protection costs in addition to reducing the risk of undesirable effects of excessive use of chemicals.

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