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# Comparison of Integrated Pest Management approaches and conventional (non-IPM) practices in late-winter-season cauliflower in Northern India

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ABSTRACT

On-farm research was conducted in Northern India during the late-winter seasons of 2008–2009 and 2009–2010 to develop and validate an Integrated Pest Management (IPM) approach for cauliflower (*Brassica oleracea* var. *Botrytis* L. subvar. *Cauliflora* DC). Cauliflower has traditionally received considerable use of pesticides to manage insect pests, such as the mustard aphid, *Lipaphis erysimi* (Kaltenbach), and diseases such as damping-off and Alternaria leaf spot. This study compared the conventional farmers' practice, which is pesticide-based and is a non-IPM approach, with an IPM approach, which used cultural, chemical and biological methods to manage the insect and two diseases of cauliflower. Yields for both seasons were consistently greater in the IPM treatment, averaging 24 t/ha (10% greater yields) in the IPM treatment than in the non-IPM treatment. Economic analysis showed higher net economic returns (1410 USD/ha) and benefit: cost ratio (3.6:1) than from the non-IPM treatment (1152 USD/ha net return; 2.9:1 benefit: cost ratio). Compared to the non-IPM treatment, growers using IPM reduced the amount (a.i./ha) of pesticide by 63.8% and the number of pesticide applications by more than 50%. In addition, the IPM treatment replaced hazardous pesticides with safer bio-pesticides and reduced-risk pesticides. This study demonstrated that IPM can be cost-effective for managing pests and diseases of cauliflower in late winter.



## 1. Introduction

Cauliflower (*Brassica oleracea* var. *Botrytis* L. subvar. *Cauliflora DC*) is one of the most important vegetable crops cultivated in India, both for nutritional benefits as well as economic return to growers, especially in localities surrounding the major metropolitan areas. Cauliflower is grown throughout the year in India, with different varieties adapted to the seasonal differences. Cauliflower production in recent years in India has averaged 7.5 million tons from 0.40 million hectares, making cauliflower the 7th most-important vegetable crop, after potato (*Solanum tuberosum* L.), onion (*Allium cepa* L.) tomato, (*Lycopersicon esculentum* Mill.), eggplant (*S. melongena L.*), cabbage (*B. oleracea* L. var. *capitata* L.) and tapioca (*Manihot esculentus* Crantz), (Indian Horticulture Database, 2013).

Cauliflower is considered a high-value crop (1.6 USD/kg), although the selling price fluctuates greatly among seasons, with high prices for the crop grown in the rainy season and late winter, making production of the crop economically favorable in those two seasons.

As with many vegetable crops, production of cauliflower is limited by insect pests and diseases, which vary among regions of the country. In Northern India, nine species of insects and four diseases are considered important. Insects limiting cauliflower production include aphids (*Myzus persicae* [Sulzer], *Lipaphis erysimi* [Kaltenbach]), painted bug (*Bagrada hilaris* [Burmeister]) cabbage head borer (*Hellula undalis* F.), diamondback moth (*Plutella xylostella* [L.]), cabbage webworm (*Crocidolomia binotalis* Zeller), tobacco cutworm (*Spodoptera litura* [F.]), pea leaf miner (*Chromatomyia horticola* [Goureau]), and mustard saw fly (*Athalia lugens proxima* [Klug]) (Ahuja et al., 2012, 2013). Four major diseases include Sclerotinia rot (*Sclerotinia sclerotiorum* [Lib.]), Damping off (*Pythium debaryanum* [Hesse]), Alternaria leaf spot (*Alternaria brassicicola* [Schw.]) and Downy mildew (*Peronospora parasitica* = *Hyaloperonospora brassicae*) (Ahuja et al., 2012, 2013). Of those insects and diseases, the three that are

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typically the most limiting are the aphid, *L. erysimi*, and two fungi, *P. debaryanum* and *A. brassicicola* (Ahuja et al., 2012, 2013).

Due to continuous migration and production of winged aphids from nearby maturing mustard plants in the month of February, *L. erysimi* has been considered the most-difficult pest to manage in cauliflower cultivated during the winter season (Muthukumar et al., 2007; Muhammad et al., 1999). One parasitoid, *Diaeretiella rapae* McIntosh (Hymenoptera: Braconidae), and a predator, *Coccinella septempunctata* L. (Coleoptera: Coccinellidae), are common natural enemies of *L. erysimi*, but do not always provide sufficient levels of control (Lokeshwari et al., 2012). Consequently, cauliflower production in India is often subject to large numbers of insecticide applications, generally up to 10–12 sprays/season (Weinberger and Srinivasan, 2009).

Integrated pest management (IPM) has been shown to be effective for sustainable management of insect pests and diseases by using cultural, chemical and biological methods (Trivedi and Ahuja, 2011). Cultural methods for cauliflower production include the use of healthy seeds, soil solarization, raised beds and green manure (Singh et al., 2002; Dabbas et al., 2009), chemical methods include the fungicides carbendazim, mancozeb and neem cake for managing diseases (Singh et al., 2002), and insecticides such as imidacloprid, thiomethoxam and neem oil, for managing mustard aphids (Muthukumar et al., 2007). Biological methods include the use of the fungus *Trichoderma harzianum* Rifai as a soil or seed treatment or seedling dip for disease management, and conservation of beneficial arthropods, such as *D. rapae* and *C. septempunctata*. Trap crops, such as mustard (*Brassica. juncea* L.), can be planted and used to attract insect pests where they can be treated more economically and effectively. Economic returns of 10–30% can be realized from trap crops, due to reduced pest damage and reduced insecticide use (Kambrekar and Kalaghatagi, 2008). Mustard has been shown to be effective as a trap crop to manage a variety of pests including *L. erysimi* in cauliflower and cabbage (Srinivasan and Krishna Moorthy, 1991), due to the apparent greater attractiveness of mustard to *L. erysimi* than either cauliflower or cabbage (Lokeshwari et al., 2012).

One of the goals of IPM is to reduce the risk or vulnerability in net economic return (Hutchison et al., 2006). However, growers in Northern India view using IPM to manage pests for crops grown in the rainy season and late winter as risky, and thus rely on a pesticide-based approach for pest management. The present study, which included direct participation by farmers on their own land, focused on use of available tactics to develop a comprehensive IPM strategy for cauliflower cultivated in late winter in Northern India. We compared a comprehensive IPM program and the conventional farmers' approach based entirely on pesticides (non-IPM approach) to manage insect pests and diseases of cauliflower in growers' fields, by measuring the number of insects and incidence of diseases, as well as the economic costs and returns of the two approaches.

## 2. Materials and methods

### 2.1. Observations on farmers' practice

Field trials to compare use of an IPM strategy for managing cauliflower with the “farmer's practice”, based entirely on application of pesticides (hereafter, non-IPM), were conducted on local farms in Northern India. Trials were conducted in the village of Palri, Sonipat District, in the state of Haryana, during late winter seasons from 2006 to 2007 to 2009–2010. In this village (29° 15′ 52.96″N, 76° 53′ 50.98″E, elevation 230 m), farmers grow cauliflower year-around, using cultivars from different maturity groups appropriate for cultivation as rainy-season, early-rainy-season, winter-season and late-winter crops. The present study was carried out in the late-winter season (November to March) of each year.

Farmers in the village were chosen who were willing to participate in the programme and interviewed using a prepared questionnaire both before initiating the IPM program and at the end of each year. During the 2006–2007 and 2007–2008 seasons, five growers participated on their family farms, and those seasons were used as a pilot project. As the results of the pilot project were shared with growers, local confidence in IPM grew, and so a larger follow-up project was developed. A total of fifty farmers participated during the 2008–2009 and 2009–2010 seasons, with 25 farmers assigned to the IPM treatment and 25 assigned to the non-IPM treatment. Farmers were asked questions related to plant protection practices and other cultural practices that were used to raise their crop. They also were asked to provide the costs of production, which included expenditures incurred on labor for land preparation, nursery sowing, transplanting, applying fertilizer, irrigation, hoeing and weeding, pest scouting and applying pesticides, as well as the material costs for seed, pesticides, bio-control agents, trap crops, fertilizers, irrigation and transportation of their produce. IPM farmers were supplied inputs required for pest management for the entire cropping season.

### 2.2. Observations on socio-economic parameters and farm information

Data relating to farm and other socio-economic variables were collected in 2010 from a sample of 66 farmers, including both the 25 IPM farmers and 25 non-IPM farmers selected for the present comparison studies. Farmers were asked questions related to socio-economic profile, farming educational level, operational size of landholding, experience in vegetable growing, cropping system, and cauliflower cultivation practices (Table 1). The data were collected using pre-tested schedules by personal interview.

### 2.3. Field studies and IPM module

Pest problems encountered in cauliflower vary among seasons

**Table 1**
Descriptive statistics of the selected IPM and non-IPM farm families of village Palri, Sonipat, Haryana.

| Variables | IPM farmers mean (SD) (n = 25) | Non-IPM farmers mean (SD) (n = 25) |
|---|---|---|
| **Family details** | | |
| Age of farmers (years) | 44.22 (3.07)[1] | 44.60 (3.04) |
| Joint family (No.) | 20.00 | 21.00 |
| Nuclear family (No.) | 05.00 | 04.00 |
| Family members (No.) | 05.77 | 05.68 |
| **Educational status (No.)** | | |
| Illiterate | 14.00 | 15.00 |
| Primary school pass | 1.00 | 3.00 |
| Middle school pass | 1.00 | 1.00 |
| Senior secondary certificate | 6.00 | 5.00 |
| Higher secondary certificate | 1.00 | 2.00 |
| Schooling years | 3.48 | 3.40 |
| **Social group (no.)** | | |
| SC (Schedule caste) | 03.00 | 04.00 |
| ST (Schedule tribe) | 01.00 | 01.00 |
| OBC (Other backward caste) | 09.00 | 07.00 |
| General caste | 12.00 | 13.00 |
| **Farm information** | | |
| Total cropped area (ha) | 2.65 (0.25)[2] | 2.51 (0.30) |
| Area under vegetable (ha) | 1.32 (0.56)[3] | 1.48 (0.65) |

Each treatment contained 25 fields (n = 25).
Comparison between treatments showed non-significant differences between means at 5% level of significance ($t = 0.42$, $P = 0.338$)[1], ($t = 1.91$, $P = 0.030$)[2], ($t = 0.93$, $P = 0.178$)[3].

**Table 2**
Non-IPM and IPM pest management practices adopted by growers in Palri village, Sonipat (Haryana, India) during the late-winter season (November–March).

| Month/Stage | Crop stage/Purpose | Non-IPM (Farmers' Practice) | IPM Components |
|---|---|---|---|
| November<br>Nursery stage | Damping-off disease | Flat soil bed<br>No soil solarization<br>No soil application | Raised (~37.5 cm) soil bed<br>Soil solarization for three weeks prior to sowing<br>Soil application of *Trichoderma harzianum* added to farmyard manure at 250 g/100 kg, Neem cake application at 50 g/m$^2$ |
| | | Seed treatment with carbendazim 50 WP at 1 g a.i./kg seed | Seed treatment with *T. harzianum* at 4 g/kg seed and Imidacloprid 70 WS at 3.5 g a.i./kg seed |
| | | Spray plants with carbendazim 50 WP at 300 g a.i./ha | No spray of fungicide |
| December<br>Before Transplanting | Damping-off disease<br>Aphids | Raised (37.5 cm) bed for transplanting<br>No seedling dip<br>No trap crop | Raised (37.5 cm) bed for transplanting<br>Seedling dip in *T. harzianum* at 4 g/l<br>Mustard trap crop every 25 rows and sprayed with methyl demeton 25 EC at 125 g a.i./ha |
| December<br>After Transplanting | *Alternaria* leaf spot<br>Aphids | One spray of mancozeb 45 WP at 500 g a.i./ha and<br>One spray of chlorpyriphos 20 EC at 200 g a.i./ha or endosulfan 35 EC at 500 g a.i./ha or cypermethrin 10 EC at 200 g a.i./ha | No pesticide application |
| January | *Alternaria* leaf spot<br>Aphids | One spray of mancozeb 45 WP at 500 g a.i./ha<br>1–2 sprays of the above insecticides | One spray of mancozeb 45 WP at 500 g a.i./ha<br>As needed of azadirachtin 3000 ppm at 5 ml/l water and imidacloprid 17.8 SL at 20 g a.i./ha |
| February | Aphids | 1–2 sprays of the above insecticides | As needed imidacloprid at 20 g a.i./ha |

(Ahuja et al., 2013). As a result, an IPM strategy was developed with tactics that were specific to the season and local conditions, in addition to information available in the literature. Details of the experimental design and implementation of IPM were similar to our previous studies (Ahuja et al., 2012). Both the IPM and non-IPM production systems were implemented using locally accepted agronomic practices (Table 2). Practices were specific to the two key stages of plant growth: production of seedlings in a common nursery and growth of the plants in the field from transplanting until harvest.

### 2.4. Nursery production

All participating growers were persuaded to raise seedling plants in local nurseries. During November, seed beds were prepared for planting. The non-IPM treatment used flat beds with no soil modification or solarization. For the IPM treatment, raised beds (~37.5 cm height) were prepared. The soil in the raised beds was solarized by covering beds with a transparent sheet of polythene (70 µm thick), for three weeks prior to planting. Soil in the IPM treatment was modified by adding *T. harzianum* ($10^8$ conidia/g) to farmyard manure at a rate of 250 g/100 kg manure, and neem cake was added to the soil at a rate of 50 g/m$^2$ of seed beds. Seeds of the hybrid cauliflower variety, 'Sonia' (Doctor Seeds Pvt. Ltd., Ludhiana, India), from the March maturity group and suitable for the late-winter season, were used by farmers for planting both treatments. Seeds were planted at a rate of 0.3–0.4 kg seed/ha. For the non-IPM treatment, seeds were treated with carbendazim 50 WP at 1 g a.i./kg seed. For the IPM treatment, seeds were treated with *T. harzianum* at 4 g/kg of seed, and by imidacloprid 70 WS at 3.5 g a.i./kg of seed for management of *P. debaryanum* and *L. erysimi,* respectively. In the nursery stage, observations were made on 100 plants from a 1-m$^2$ sampling area just prior to transplanting (~35 days after planting), and the numbers of plants infected with damping off disease were recorded.

### 2.5. Field production

#### 2.5.1. Field preparation

Each treatment (IPM and non-IPM) consisted of 0.4 ha fields, totaling 10 ha per treatment, and all fields were within a distance of approximately 1 km. Each farmer's field consisted of 50 rows, approximately 50 m long. Rows were 45–50 cm apart and plants were spaced ~30 cm apart within rows. In the IPM treatment, there was a row planted to mustard (*B. juncea*) every 25 rows, to serve as a trap crop in the space between the paired rows of cauliflower. All fields were prepared by plowing 3–4 times prior to transplanting. Farmers in both treatment groups were advised to apply fertilizer at 120 kg/ha N, 60 kg/ha P, and 80 kg/ha K. Raised beds (~37.5 cm tall) were prepared for transplanting for both treatments.

#### 2.5.2. Transplanting to harvesting

For the non-IPM treatment, seedlings were transplanted into the prepared beds, with no fungicides applied to the seedlings prior to transplanting. For the IPM treatment, seedlings were dipped into a solution of *T. harzianum* at 4 g/L prior to transplanting. Seedlings from the nursery were transplanted into all fields in the first week of December, to minimize differences in timing of sowing the crop and variability in plant age, thus reducing variability in yield. Only healthy seedlings (showing no symptoms of disease) were selected for transplanting.

The cauliflower plants in both IPM and the non-IPM fields were grown under a similar agronomic schedule, but differed in pest-management inputs. After transplanting, plants in the non-IPM treatment received two sprays of the fungicide mancozeb 45 WP at 500 g a.i./ha to protect against *A. brassicicola*, and 4–5 sprays of either chlorpyrifos 20 EC at 200 g a.i./ha, endosulfan 35 EC at 500 g a.i./ha, or cypermethrin 10 EC at 200 g a.i./ha, to protect against aphids. For the IPM treatment, plants received one spray of mancozeb 45 WP at 500 g a.i./ha, and only need-based (>5 aphids per plant) treatments with azadirachtin (3000 ppm) at 5 ml/l water, and imidacloprid 17.8 EC at 20 g a.i./ha. Aphids colonizing the mustard trap crop were treated with methyl demeton 25 EC at 125 g a.i./ha to prevent them from spreading to the cauliflower. Pesticides were applied through power-operated backpack sprayer of 15-l capacity and the volume of water used was 330 l/ha in both IPM and non-IPM treatments.

Transplanted plants were observed for insect infestation and plant disease. From each field, 100 cauliflower plants were examined for presence of Alternaria leaf spot at approximately 30–40 days after transplanting. Numbers of *L. erysimi* (both nymphs and adults) per plant were counted on 100 plants, 80–90 days after transplanting for all fields in both treatments. In addition, each year, the numbers of aphids per plant and numbers of *C. septempunctata* per plant were counted weekly, from the beginning of January until the end of February.

### 2.6. Economics of production

The material and labor costs (USD/ha) were recorded for pesticides and other pest-management inputs used during the growing season for each plot in both IPM and non-IPM treatments. Mean cost of production, head yield (t/ha; t = 1000 kg), total returns, net returns and costs of pest management were compared between treatments using t-tests (SPSS version 9.0). Benefit: cost ratios, defined as the total returns: cost of production, were calculated for each treatment, in each year.

## 3. Results

### 3.1. Descriptive statistics of the farmers

Comparison of the farmers and families assigned to the two treatments showed the two groups were very similar in personal and family attributes and land resources (Table 1). The average age of farmers in the IPM and non-IPM treatments did not differ significantly ($P = 0.338$). Mean farm sizes of the IPM and non-IPM groups did not differ significantly ($P = 0.030$), nor did the area under vegetable cultivation ($P = 0.178$). Family size, educational status and social group status are presented in Table 1, but were not compared statistically.

### 3.2. Diseases and insects

Damping-off (*P. debaryanum*) was the primary disease influencing cauliflower plants during nursery production. The annual mean percentages of plants infected by damping-off ranged from 3.2 to 3.8% in the IPM plots and from 6.5 to 8.1% in the non-IPM plots (Fig. 1). The mean percent infection was significantly less in the IPM treatment than in the non IPM treatment in both 2008–2009 (t = 6.35, df = 48, $P < 0.001$) and 2009–2010 (t = 6.11, df = 48, $P < 0.001$). Also, the overall mean percentage for the two years in the IPM plots was significantly less than in the non-IPM plots (t = 8.46, df = 99, $P < 0.001$).

After transplanting, Alternaria leaf spot was the primary disease affecting cauliflower production. The mean percentages of plants infected by *Alternaria* ranged from 1.2 to 3.5% in the IPM plots, versus 2.5–10.1% in the non-IPM plots (Fig. 2). The mean percent infection was significantly less in the IPM treatment than in the non IPM treatment in both 2008–2009 (t = 6.31, df = 48, $P < 0.001$) and 2009–2010 (t = 8.47, df = 48, $P < 0.001$). Also, the overall mean percentage for the two years in the IPM plots was significantly less than infection in the non-IPM plots (t = 5.73, df = 99, $P < 0.001$).

Average numbers of aphids sampled 80–90 days after transplant ranged from 3.0 to 3.5 per plant in the IPM treatment versus 7.2–9.4 in the non-IPM treatment (Fig. 3). The mean numbers of aphid per plant were significantly less in the IPM treatment than in the non IPM treatment in both 2008–2009 (t = 7.02, df = 48, $P < 0.001$) and 2009–2010 (t = 5.92, df = 48, $P < 0.001$). The overall mean numbers for the two years for the IPM treatment were also significantly fewer than the non-IPM treatment (t = 8.89, df = 99, $P < 0.001$). The weekly counts of aphids (Fig. 4) in the IPM plots were consistently lower than the counts in the non-IPM plots. In addition, the average weekly numbers (1.52) of *C. septempunctata* collected per plant in the IPM plots were significantly greater than the number (0.47) per plant seen in the non-IPM plots (t = 11.33, df = 48, $P < 0.001$) (Fig. 4). No parasitization by *D. rapae* was observed in either the IPM or non-IPM plots.

### 3.3. Pesticide application

Mean number of pesticide applications in 2008–2009 (t = 15.34, df = 24, $P < 0.001$), 2009–2010 (t = 12.94, df = 24, $P < 0.001$) and the combined average of the two seasons, 2008–2009 and 2009–2010 (t = 14.35, df = 24, $P < 0.001$) were significantly less in the IPM fields than in the non IPM fields (Table 3). Mean pesticide use by weight (a.i. kg/ha) for IPM fields in 2008–2009 (t = 13.17, $P < 0.001$),

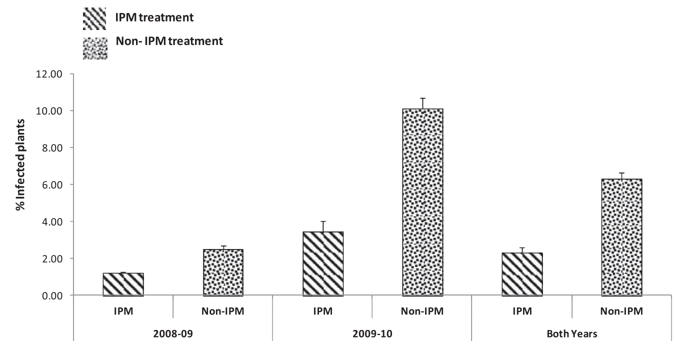


**Fig. 2.** Percent of cauliflower plants infected by Alternaria leaf spot (*Alternaria brassicicola*) in IPM and non-IPM treatments in 2008–2009, 2009–2010 and over both seasons. Shown are means (±SE) of 25 fields per treatment. All comparisons between treatments were significantly different ($P < 0.001$).

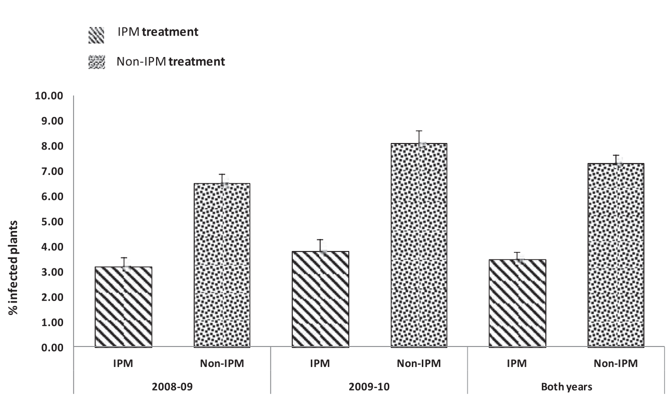


**Fig. 1.** Percent of cauliflower plants infected by damping off (*Pythium debaryanum*) in IPM and non-IPM treatments in 2008–2009, 2009–2010 and over both seasons. Shown are means (±SE) of 25 fields per treatment. All comparisons between treatments were significantly different ($P < 0.001$).

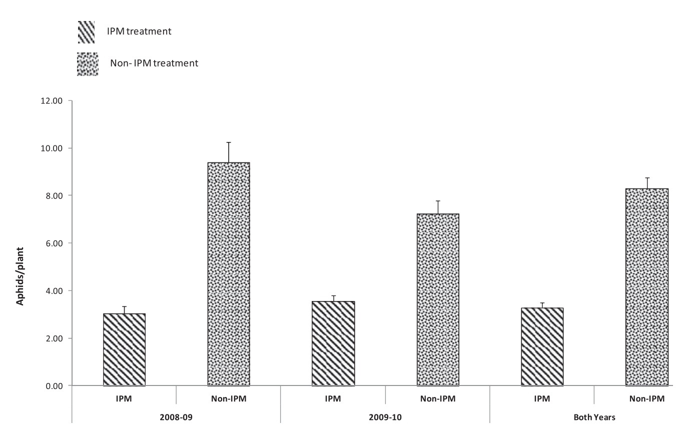


**Fig. 3.** Average numbers of mustard aphids (*Lipaphis erysimi*) per cauliflower plant, sampled 80–90 days after transplanting, in IPM and non-IPM treatments in 2008–2009, 2009–2010 and over both seasons. Shown are means (±SE) of 25 fields per treatment. All comparisons between treatments were significantly different ($P < 0.001$).

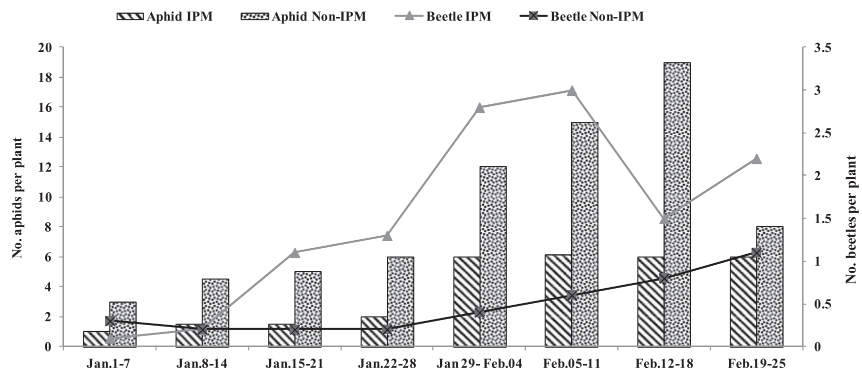


**Fig. 4.** Average numbers of mustard aphids (*Lipaphis erysimi*) and *Coccinella septempunctata* (beetles) per cauliflower plant, sampled weekly, in IPM and non-IPM treatments in January and February, 2008–2009. Comparison for beetle between the IPM and non IPM treatments were significantly different ($P < 0.001$).

2009–2010 (t = 12.30, $P < 0.001$) and over the two years (t = 18.15, $P < 0.001$) was significantly less than the non-IPM fields. More-toxic pesticides, such as carbendazim, endosulfan, cypermethrin and chlorpyriphos, were replaced with biopesticides and reduced-risk pesticides (Table 2).

### 3.4. Economics of production

For both seasons, implementation of IPM resulted in increased head yield, total returns, net returns, and less cost of production due to less expenditure on pest management compared to the farmers who used non-IPM practices (Table 3). Mean yields (Table 3) were significantly greater in the IPM plots than the non-IPM plots in 2008–2009 (t = 8.29, df = 49, $P < 0.001$), 2009–2010 (t = 5.00, df = 49, $P < 0.001$), and over the two seasons combined (t = 8.47, df = 99, $P < 0.001$).

Total costs of production (USD/ha; Table 3) were significantly lower in IPM fields than non-IPM fields in 2008–2009 (t = 61.43, df = 49, $P < 0.001$), 2009–2010 (t = 67.62, df = 49, $P < 0.001$), and in both years combined (t = 15.17, df = 99, $P < 0.001$). Pest management costs were consistently lower in the IPM treatment, and the overall average in the IPM treatment was slightly more than half the cost of the non-IPM treatment. Similarly, the share of total costs represented by pest management over the two seasons was 17.2% for the IPM treatment versus 27.6% for the non-IPM treatment (Table 3).

The mean total (gross) return (USD/ha; Table 3) was significantly greater for IPM fields than non-IPM fields in 2008–2009 (t = 8.29, df = 49, $P < 0.001$), 2009–2010 (t = 4.99, df = 49, $P < 0.001$), and the two years combined (t = 3.82, df = 99, $P < 0.003$). Likewise, net returns (USD/ha; Table 3) were significantly greater for IPM fields than non-IPM fields in 2008–2009 (t = 11.36, df = 49, $P < 0.001$), 2009–2010 (t = 7.10, df = 49, $P < 0.001$), and over the two years (t = 5.64, df = 99, $P < 0.001$). The increase in net return for the IPM treatment ranged from 15.7 to 33.7%, averaging 24.5% (Table 3).

Benefit: cost ratios (Table 3) were greater each year for the IPM fields than the non-IPM fields. Combining the two seasons, the benefit: cost ratios were 3.6:1 for the IPM fields, versus 2.9:1 for the non-IPM fields.

## 4. Discussion

The incidence of both *Pythium* and *Alternaria* was consistently lower in the IPM plots in both years and, on average, was less than half of the average incidence in the non-IPM plots. The combination of tactics used in the IPM plots limited the incidence of both diseases. IPM tactics included healthy seed and solarized soil with raised beds, use of neem cake, as-needed use of fungicides, and use of the beneficial fungus (*T. harzianum*) as a dip for seed, soil and seedlings.

Previous studies have shown that *T. harzianum* was effective for control of *Pythium* damping-off of cauliflower (Mukherjee and Mukhopadhyay, 1995; Sharma et al., 2003) and also against different pathogens in various other crops (Harman et al., 2002; Fourie et al., 2001; Tran, 2010). Dabbas et al. (2009) reported that the disease could also be managed through an integrated approach: seed treatment with carbendazim, soil solarization, soil application of *Trichoderma viride*, neem cake and green manure.

Use of healthy seed, as well as its treatment with *T. harzianum*, likely reduced the incidence of Alternaria leaf spot in both nursery production and after transplanting. However, spread of *Alternaria* spores by wind in later months could only be checked by application of mancozeb in December and later. Still, the IPM plots received at most only one spray of mancozeb, versus two received in the non-IPM plots.

The IPM approach also resulted in consistently fewer aphids than the numbers in the non-IPM plots. Both yearly and overall averages in the IPM plots were less than half the averages seen in the non-IPM treatment. In both treatments, the numbers of aphids increased at the end of January, though numbers did not increase above approximately six per plant during February in the IPM plots, whereas they reached nearly 20 per plant in mid-February in the non-IPM plots. In addition to the differences in numbers of aphids between treatments, the numbers of applications of insecticides differed greatly. Farmers treated the IPM plots at most once each in January and February, whereas farmers treated the non-IPM plots with pesticides as many as seven times, which imposed added costs and had an impact on the numbers of *C. septempunctata*.

Mustard is generally used as an intercrop in cauliflower and other crops, such as wheat, in this region of India. Mustard has been shown to be effective as a trap crop against the aphids, *Brevicoryne brassicae* L. *and L. erysimi* (Muthukumar and Sharma, 2009), and *P. xylostella* (Srinivasan and Krishna Moorthy, 1991), and its effectiveness has been suggested to be due to it being taller and a preferred host plant (George et al., 2009; Lokeshwari et al., 2012). The use of mustard as a trap crop was an important IPM component that reduced the number of aphids in the present study. The mustard plants began flowering in late January when cauliflower heads had begun to form, and were in full flower when the cauliflower heads were maturing. The combination of trap crop and seed treatment reduced the numbers of aphids that moved into the crop and one foliar spray each with imidacloprid 70 WS and azadirachtin 3000 ppm managed aphid numbers later in the season. Our efforts were to educate farmers about the utility of managing pests as well as growing the trap crop in cauliflower and subsequently spraying it with insecticides to prevent migration of aphids to cauliflower.

**Table 3**
Total cost (USD) of production (land preparation, growing period, insect and disease control and post harvest costs) mean head yield, total returns, net returns, frequency of pesticide application and benefit: cost ratio for cauliflower cultivated during winter season at Palri village, Sonipat (Haryana, India) in 2008–2009 and 2009–2010.

| Parameter | 2008–2009 | | 2009–2010 | | 2008–2010 (avg.) | |
|---|---|---|---|---|---|---|
| | IPM | Non IPM | IPM | Non IPM | IPM | Non IPM |
| Operation | | | | | | |
| Land preparation (Ridges, raised beds, nursery) | 41.33 | 43.16 | 47.46 | 50.00 | 44.40 | 46.58 |
| **(A) Growing period cost** | | | | | | |
| Farmyard manure | 44.22 | 50.70 | 44.92 | 45.31 | 44.92 | 48.00 |
| Seed | 87.33 | 87.30 | 91.80 | 91.80 | 89.55 | 89.55 |
| Fertilizer | 52.97 | 54.69 | 53.13 | 53.52 | 53.05 | 54.11 |
| Irrigation | 36.80 | 37.34 | 37.11 | 38.28 | 37.00 | 37.81 |
| Hoeing | 45.70 | 45.16 | 48.83 | 50.39 | 47.27 | 47.38 |
| Manual weeding | 52.97 | 52.07 | 54.69 | 54.69 | 53.89 | 53.38 |
| Harvesting | 24.80 | 25.00 | 27.34 | 27.34 | 26.04 | 26.14 |
| **(B) Disease and insect control cost** | | | | | | |
| Cost of trap crop | 3.28 | 0.00 | 3.28 | 0.00 | 3.28 | 0.00 |
| Polythene sheet | 4.49 | 0.00 | 5.16 | 0.00 | 4.83 | 0.00 |
| Scouting | 5.86 | 0.00 | 7.81 | 0.00 | 6.83 | 0.00 |
| Pesticide cost and its application cost on seed | 3.24 | 1.95 | 3.24 | 1.95 | 3.24 | 1.95 |
| Pesticides (synthetic, biopesticides) and application | 69.73 | 167.70 | 77.73 | 169.92 | 73.73 | 168.81 |
| **(C) Post harvest cost (Transport)** | 45.51 | 47.07 | 48.83 | 48.83 | 47.17 | 47.95 |
| Head Yield t/ha (S.D.) | 24 ± 0.97 | 21 ± 1.52 | 24 ± 1.19 | 23 ± 0.95 | 24 ± 1.08 | 21 ± 1.54 |
| Total cost of production (A + B + C) USD/ha (S.D.) | 518 ± 5.52 | 612 ± 32.29 | 551 ± 3.66 | 632 ± 36.17 | 535 ± 17.35 | 618 ± 34.12 |
| Total cost of pest management(S.D.) | 87 ± 2.33 | 170 ± 6.94 | 97 ± 2.24 | 172 ± 6.95 | 92 ± 5.82 | 171 ± 6.93 |
| % Share of cost of pest management in total cost of production | 16.71 | 27.71 | 17.63 | 27.19 | 17.18 | 27.64 |
| Total return (USD/t) (S.D.) | 1755 ± 70.76 | 1537 ± 111.00 | 2126 ± 103.73 | 1993 ± 83.36 | 1945 ± 206.92 | 1765 ± 250.01 |
| Net return (USD/t) (S.D.) | 1237 ± 70.93 | 925 ± 117.51 | 1575 ± 104.36 | 1361 ± 100.32 | 1410 ± 198.64 | 1152 ± 255.92 |
| Increase in return (%) | 33.72 | – | 15.72 | | 24.45 | – |
| Average Number of pesticide applications(S.D.) | 2.5 ± 0.87 | 6.5 ± 0.96 | 2.1 ± 0.60 | 4.4 ± 0.65 | 2.3 ± 0.77 | 5.5 ± 1.34 |
| Mean pesticide use (a.i. kg/ha) (S.D.) | 0.697 ± 0.02 | 1.894 ± 0.45 | 0.674 ± 0.06 | 1.887 ± 0.49 | 0.685 ± 0.05 | 1.890 ± 0.47 |
| Benefit: cost ratio | 3.4:1 | 2.5:1 | 3.9:1 | 3.2:1 | 3.6:1 | 2.9:1 |
| Selling price (Rs.64 = 1USD) | US $ 0.73/kg | | US $ 0.88/kg | | US $ 0.81/kg | |

Each treatment contained 25 fields (n = 25).
Each comparison between treatments within a year showed significant differences between means.
Significance at $P < 0.05$ for the six parameters compared.

The benefits of using IPM were fewer insecticide applications and replacing more-toxic insecticides with biopesticides and reduced-risk insecticides. The tactic of using trap crops needs further promotion and implementation, due to its important role in IPM.

Earlier studies found *L. erysimi* to be a serious pest when cauliflower plants were transplanted in November or December (Muhammad et al., 1999; Muthukumar et al., 2007; Muthukumar and Sharma, 2009; Kohl et al., 2010; Chavan et al., 2004). In contrast, crops transplanted earlier than November showed no incidence of the aphid (Chavan et al., 2004; Vermora et al., 2010). Because aphids appear in crops at different times, growers have difficulty deciding the timing of application of insecticides. Further, the continuous migration until March of *L. erysimi* results in an extended threat to the crop, leading to unnecessary applications of insecticides that magnify the problem and can negatively affect extant natural enemies. *C. septempunctata* is considered to be the only predator that has the potential to regulate *L. erysimi* on cruciferous crops (Lokeshwari et al., 2012); indiscriminant sprays can negate the levels of natural control already present. Gupta and Rai (2006) reported integration of *C. septempunctata* and judicious use of azadirachtin for effective management of *L. erysimi* in cabbage, thus fitting well with the definition of IPM.

Implementing IPM did not result in higher production costs, which was the preconceived idea of local farmers. Instead, production costs in IPM fields were an average of 83 USD/ha less than in non-IPM fields, due to reduced cost of pest management. The results for net return, gross return and yield indicated consistent economic benefits from adopting IPM. On average, farmers adopting IPM had a net return that was 22.4% greater than the net return for farmers using a non-IPM approach (Table 3). The greater benefit: cost ratios for the IPM fields showed that, regardless of yields or prices, growers benefited by using IPM techniques.

The beneficial effects of IPM practices seen in this study have been verified in a few reports (Ahuja et al., 2011, 2012; 2013; Dabbas et al., 2009; Sahito et al., 2012). In addition to the economic benefit of reduced usage of pesticides (both numbers of applications and a.i./ha), the IPM approach also resulted in replacement of high-dose, toxic pesticides with low-dose, less-toxic and reduced-risk pesticides and biopesticides, which is a robust indicator of the impact of IPM adoption (Peshin and Zhang, 2014). Most other studies of IPM in vegetable crops in India focused only on reducing the frequency of application of pesticides (Sharma et al., 2015), but did not consider the toxicity of the pesticides used. We demonstrated that growers could manage pests more effectively, at lower costs and more safely.

## 5. Conclusion

The effectiveness of implementing IPM tactics in cauliflower directed against mustard aphid (*L. erysimi*), and two fungi, damping-off fungus (*P. debaryanum*) and Alternaria leaf spot (*A. brassicicola*), was demonstrated in this two-year study. The study compared production of the crop by farmers implementing a diverse set of IPM tactics with production by farmers using a non-IPM approach, based on pesticides. IPM tactics used against the fungi included the cultural tactics of healthy seed and appropriate establishment of solarized soil with raised beds; use of neem cake and as-needed applications of fungicides; use of the beneficial fungus, *T. harzianum* as soil, seed and seedling dip; and one foliar spray of mancozeb. Aphid management included a combination of a mustard trap crop and seed treatments of imidacloprid 70 WS, plus one foliar spray each with imidacloprid and azadirachtin later in the season.

The use of IPM tactics resulted in the incidence of *P. debaryanum* and *A. brassicicola* in the IPM plots being less than half the levels seen in the non-IPM plots. Likewise, there were significantly fewer aphids (*L. erysimi*) found on the crop plant in the IPM plots than the non-IPM plots. Presence of mustard as a trap crop attracted the aphids, which were then treated on the trap crop. The result was fewer aphids on the cauliflower plants in the IPM treatment, the outcome of which were 50% fewer insecticide treatments and 63.8% less (a.i./ha) insecticide used, as well as replacement of toxic insecticides with less-toxic biopesticides and lower-risk pesticides.

Implementation of IPM reduced production costs by an average of 83 USD/ha, due to lower costs of plant protection. Pest management as a percentage of the total cost of production was less in IPM plots (17.2%) than in non-IPM plots (27.6%). Net returns were greater for farmers using IPM than for farmers using the non-IPM approach. On average, farmers adopting IPM had a net return that was 24.5% more than the net returns for those farmers not using IPM. The lower costs demonstrated to farmers the economic advantage of using IPM, which contrasted with the preconceived idea, held by farmers that IPM tactics would be too expensive to implement. In addition, the variability of returns was much less in the IPM treatments, meaning reduced risk of adopting IPM. Benefit: cost ratios over the two years averaged 3.6:1 for the growers using IPM, versus 2.9:1 for the non-IPM fields. Regardless of yields or crop prices, growers benefited by using IPM techniques; thus, our recommendation that cauliflower growers should replace the existing pesticide-based plant protection practices via adopting IPM practices.

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