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Comparison of biorational management approaches against mango fruit fly (*Bactrocera dorsalis* Hendel) in Bangladesh

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ABSTRACT

Mango (*Mangifera indica* L.) is a major fruit crop throughout the tropical and sub-tropical regions of the world including Bangladesh. The Oriental fruit fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) is a major pest of mango causing both quantitative and qualitative losses as well as export barriers. We compared the efficacy and economic benefits of several prophylactic and remedial tactics against *B. dorsalis* during the 2017 mango cropping season in pursuit of the development of a mango IPM program to produce fruit fly-free and residue-free mango fruits. Several non-chemical approaches, such as bagging fruits with double-layer brown paper bags, cloth bags, polythene bags, and installing methyl eugenol kairomone traps and protein hydrolysate bait lures, were evaluated and compared with conventional Profenofos + cypermethrin (Shobicron 425 EC) management. Among the treatments, bagging mangos with double-layer brown paper bags at forty-two days before harvest showed the best performance. Fruit infestation was reduced to zero, marketable yields were significantly higher than with conventional pesticide management, and the marginal benefit cost ratio of bagging mangos with double-layer brown paper bags was nearly twice as high as any other treatment. The strong economic return from bagging fruits with double-layer brown paper bags results from high fruit quality and being able to use the bags for two growing seasons. The positive results from this study indicate that double-layer brown paper bagging is effective at controlling the oriental fruit fly in mango and should be integrated into a full IPM package for mango production.

1. Introduction

Mango (*Mangifera indica* L.) is one of the most popular and important fruit crops among all fruits grown in Bangladesh. The total production of mango is about 1,018,112 metric tons and it ranks second in terms of production after banana (BBS, 2015). The area under mango cultivation is increasing every year because consumers prefer this fruit due to its delicious taste and nutritive value (Hossain, 1989). As Bangladesh is geographically situated in the tropical and sub-tropical climatic zones, many insect pests and diseases attack mango and contribute to the low yield and poor quality of mango fruits.

The mango fruit fly, *Bactrocera dorsalis* Hendel (Tephritidae: Diptera), is the most serious pest of mango in all production regions in Bangladesh, but especially in the high rainfall and hilly areas (Karim, 1989). This pest also attacks carambola (*Averrhoa carambola* L.) and guava (*Psidium guajava* L.). The female fruit flies puncture the skin of the mature mango with their ovipositors and lay eggs in the fruit's flesh (Fletcher, 1987; Allwood, 1997). After hatching, the maggots tunnel through the flesh, spoiling the ripe mango fruit, which becomes unfit for consumption. Infested fruits begin to rot due to secondary infection by fungi and bacteria (Bose, 1985). An infested fruit may not always show clear signs of attack, but when cut open, numerous white maggots can be seen wriggling in the pulp. A huge quantity of mango fruits is annually lost due to fruit fly infestations. In general, the yield loss due to fruit flies varies between 40 and 70%, depending on the mango variety and the availability of susceptible fruits during different parts of the season.

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Farmers mainly use chemical insecticides to control the mango fruit fly, and these pesticides are often used indiscriminately to the extent that mixtures of two or three insecticides are sprayed at very high frequencies (15–62 times in a season) (Uddin and Reza, 2017). Misuse of insecticides has undesirable effects including the killing of pollinators, and predators and parasitoids, which can result in the resurgence of other pest populations (Debach and Rosen, 1991; Pedigo, 1999). It can also result in the development of resistant insect biotypes (Whalon et al., 2012), and pesticide residues on marketable fruits (Hussain et al., 2002).

Integrated pest management (IPM) techniques, including the use of kairomones, protein baits, and fruit bagging, may prove effective in controlling the mango fruit fly, while reducing conventional pesticide use (Vargas et al., 2008; Sharma et al., 2014). Methyl eugenol (ME), a kairomone produced by over 450 species of plants, is highly attractive to male *B. dorsalis*. It has been used successfully in government-sponsored, area wide management and eradication programs of *B. dorsalis* in Hawaii and Mariana Islands, respectively (Vargas et al., 2014). While ME can be used to control male *B. dorsalis*, females can also be targeted through the use of protein lures. Females need protein to successfully produce eggs and protein-starved females are highly attracted to protein baits (Vargas and Prokopy, 2006). Bagging fruits is another important control option as previous studies have reported up to 100% control of *B. dorsalis* infestations by covering the fruits at least 30 days prior to harvest (Sarker et al., 2009). However, bagging fruits is labor intensive and can be cost prohibitive (Sharma et al., 2014). While some studies of fruit bagging in developing countries indicate that it can be profitable (Abbasi et al., 2014; Leite et al., 2014), that will ultimately depend on the particulars of a growing locale including pest pressures, labor costs, and farmgate prices.

To determine their efficacy and economic costs and benefits, five IPM tactics, as alternatives to chemical insecticides, were tested against *B. dorsalis* in several commercial mango plantings in Bangladesh during the 2017 harvest season. IPM tactics included the use of the plant kairomone ME plus soapy water to attract and kill males, protein bait plus carbaryl to attract and kill females, and physical barriers including cloth, polythene and double-layer paper fruit bags. These tactics were compared with a standard pesticide regime (Shobicron foliar sprays) and a no-spray control.

2. Materials and methods

2.1. Study sites

Multi-site field studies were conducted in farmers' fields at three locations: Gazipur (23^{0}59'.37″N and 90^{0}24'.46.27″E), Rajshahi (24^{0}22'.57.02″N and 88^{0}33'.45.04″E), and Chapainawabgonj districts (24^{0}35'.32.78″N and 88^{0}16'.46.45″E) of Bangladesh (Sultana et al., 2018). These three sites represent the commercial production areas as well as different climatic zones for mango production in Bangladesh.

2.2. Plot layout and data collection

Studies were conducted during the mango growing season spanning 2016–17 following a randomized complete block design with seven treatments and three replications per location. One tree (8–10 years' old) served as a single experimental unit with 200 randomly selected fruits measured per tree. The variety of mango was BARI Aam-4 (the only BARI [Bangladesh Agricultural Research Institute] released hybrid mango variety). The treatments were: T_1 = Methyl eugenol traps; T_2 = Protein hydrolysate bait traps; T_3 = Bagging by cloth bag; T_4 = Bagging by Polythene bag; T_5 = Foliar spray of Profenofos 40% + Cypermethrin 2.5% (Shobicron 425 EC) @ 1.5 ml/L of water, three times at 10 day intervals; T_6 = Bagging by double-layer brown paper bag; and T_7 = Untreated control. All treatments were begun 42 days before fruit harvest.

The methyl eugenol treatment was composed of methyl eugenol (4-allyl-1,2-dimethoxybenzene-carboxylate) (Ispahani Agrobiotech, Dhaka, Bangladesh) contained in rubber septa and hung in a water trap. The trap contained soap water to wet the fruit fly and ensure drowning. The water was changed at 7-day intervals and the number of trapped fly adults were counted at each change.

Protein hydrolysate bait was made with the mixture of rice bran, molasses (sugarcane by-product) and yeast powder in a ratio of 10:5:1. An insecticide, carbaryl (Sevin 85SP), was added (2 g per bait) to the mixture to act as a killing agent of the attracted flies (Vargas et al., 2002). Three bait traps were used per plant per site. To avoid the effect of other treatments, the mango trees selected for the bait and kairomone trap treatments were located at a minimum of 50 m from the other treatments. The bait was changed at 5-day intervals.

The three different bagging treatments were applied as follows. Locally made 4″ X 8″ size Markin cloth bags were placed over the developing fruit and tied at the petiole. Similarly, 4″ X 8″, 20 mm thick polythene bags were tied over the fruit. Both bottom corners of the polythene bag were cut to drain the deposited water inside during bagging period. Double-layer brown paper bags (4″ X 8" size) (Chapai Agro company, Bangladesh) were attached by a built-in wire. A fungicide, Propiconazole (Tilt250EC) @ 0.2 ml/L of water, was sprayed at 2 h prior to bagging to kill pathogens that may be present on the mango surface. All bags were attached six weeks before harvest of the fruit and removed at harvest.

The conventional insecticide treatment provided a comparison for the IPM treatments with prevailing production techniques. Shobicron 425 EC (Profenofos (40%) + Cypermethrin (2.5%) insecticide foliar applications were made three times, at 10 day intervals, with a foot pump sprayer, starting at 42 days before harvest. To minimize drift caused by winds and therefore conserve natural enemies and honey bees, foliar applications were made in the late afternoon.

Harvestable fruits were collected and sorted into infested and healthy ones and weighed. A fruit was designated infested when we found a puncture or oozing caused by oviposition injury on fruit. The percent infestation reduction was calculated by averaging percent infestation for each treatment across the three study locations, subtracting that number from the average infestation of the untreated controls and then dividing by the average infestation of the untreated controls. The marketable yield was calculated by weighing only ripe, uninfested fruit. The percent marketable yield increase over control was calculated by averaging the marketable yield for each treatment across the three study locations, subtracting that number from the average marketable yield of the untreated controls and then dividing by the average marketable yield of the untreated controls. A full economic analysis was conducted for the Gazipur site. The monetary returns from the harvests were calculated at the prevailing market price of mango at that location. Costs of all treatments including treatment and labor costs were recorded. Adjusted net return of treatment was calculated as: Net return of treatment - Net return of untreated control. The Marginal Benefit Cost Ratios (MBCR) were calculated for each treatment as follows:

$$\text{Marginal BCR} = \frac{\text{Adjusted net return of treatment}}{\text{Cost of treatment}}$$

where, Cost of treatment = Price of insecticide/botanical + labor and spraying cost (Yadav et al., 2000).

2.3. Data analysis

Treatment results were analyzed using ANOVA (MSTAT-C, Michigan State University) with each study location analyzed separately. Data were arcsin square root transformed prior to analyses to meet model assumptions of normality and equal variance. Means were compared using an LSD test (Gomez and Gomez, 1984; Seman-Varner et al., 2017).

Table 1
Effects of different treatments on the incidence of mango fruit fly across Bangladesh*.

Treatment**	Locations				
	Gazipur	Rajshahi	Chapainawabgonj	Average Across Locations	Average Across Locations
	% fruit infestation	% fruit infestation	% fruit infestation	% fruit infestation	% infestation reduction
Methyl eugenol kairomone trap	26.33b	30.00b	25.83b	27.39	34.35
Protein hydrolysate bait trap	28.80b	32.00b	25.67b	28.82	30.92
cloth bag	5.50d	7.75c	3.00c	5.42	87.01
Polythene bag	3.05d	5.50cd	2.33c	3.63	91.30
Shobicron 425 EC	26.80b	31.67b	30.00b	29.49	29.31
double-layer brown paper bag	0.00d	0.00d	0.00c	0.00	100
Untreated control	40.83a	45.67a	38.67a	41.72	–
Level of significance	<0.01	<0.01	<0.01		
%CV	15.82	13.47	15.59		

*Means having the same letter(s) within columns did not significantly differ.
**Treatments: T_1 = Setting of methyl eugenol kairomone trap at six weeks before mango harvest; T_2 = Protein hydrolysate bait trap at six weeks before mango harvest; T_3 = Bagging by cloth bag at six weeks before mango harvest; T_4 = Bagging by Polythene bag at six weeks before mango harvest; T_5 = Foliar spray of Shobicron 425 EC @ 1.5 ml/L of water, three times at 10 day intervals, starting at 42 days before harvest; T_6 = Bagging by double-layer brown paper bag at six weeks before mango harvest and T_7 = Untreated control.

Table 2
Effects of different treatments for the mango fruit fly on marketable yield of mango across Bangladesh*.

Treatment**	Locations				
	Gazipur	Rajshahi	Chapainawabgonj	Average Across Locations	Average Across Locations
	Marketable yield/plant (kg)	Marketable yield/plant (kg)	Marketable yield/plant (kg)	Marketable yield/plant (kg)	% marketable yield/plant increase over control
Methyl eugenol	37.79bc	36.29c	32.64b	35.57	17.66
Protein hydrolysate bait trap	38.75bc	34.98c	32.56b	35.43	17.20
cloth bag	53.77a	47.61b	45.32a	48.90	61.76
Polythene bag	55.76a	47.33b	43.69a	48.93	61.86
Shobicron 425 EC	41.56b	35.11c	32.02b	36.23	19.85
double-layer brown paper bag	58.60a	52.70a	46.27a	52.52	73.73
Untreated control	35.69c	28.52d	26.48c	30.23	–
Level of significance	<0.01	<0.01	<0.01		
%CV	4.66	4.97	5.08		

*Means having the same letter(s) within columns did not differ significantly.
**Treatments: T_1 = Setting of methyl eugenol kairomone trap at six weeks before mango harvest; T_2 = Protein hydrolysate bait trap at six weeks before mango harvest; T_3 = Bagging by cloth bag at six weeks before mango harvest; T_4 = Bagging by Polythene bag at six weeks before mango harvest; T_5 = Foliar spray of Shobicron 425 EC @ 1.5 ml/L of water, three times at 10 day intervals, starting at 42 days before harvest; T_6 = Bagging by double-layer brown paper bag at six weeks before mango harvest and T_7 = Untreated control.

3. Results

3.1. Fruit infestation

Fruit fly pressure was similar among the sites with infestation levels ranging from 38% to 45% in control treatments (Table 1). Overall, there were highly significant reductions in infestation levels of fruit fly (100% reduction compared with the untreated control) in the bagging of mango with double-layer brown paper bag relative to other treatments across study sites. The bagging with polythene bags and cloth bags reduced infestations by 91.30% and 87.01% fruit infestation, respectively (Table 1). The kairomone, protein, and conventional insecticide treatments performed similarly and were more effective than no treatment but much less effective than bagging. The highest infestation was recorded in untreated control treatments (41.72%).

3.2. Marketable yield

Bagging of mango with double-layer brown paper bag provided the maximum increase of marketable yield (73.73%) followed by bagging with polythene bag (61.86%) and cloth bags (61.76%). The kairomone, protein, and conventional insecticide treatments performed similarly but not as well as bagging and only significantly better than the untreated control at two of the three sites. The minimum marketable yield was obtained from the untreated control treatment (30.23kg/plant) (Table 2).

3.3. Economic analysis

The double-layer brown paper bag provided the highest marginal benefit cost ratio MBCR (1.49) since the same bag could be used two successive seasons. The polythene paper bagging performed as the second highest treatment with a MBCR of 0.82. The lowest MBCR was found in bagging by cloth bag (−0.28) (Table 3).

4. Discussion

Results of this study show that bagging mango fruits was the most effective means of preventing fruit fly damage. Of the bagging technologies tested, the double-layer brown paper bag proved to be superior, providing 100% control of the fruit fly, with results consistent across the three growing regions studied. These findings add new insights into the cost effectiveness of bagging mango fruits in Bangladesh and support previous studies that also reported bagging mango fruits can provide

Table 3
Economic analysis of different treatments against mango fruit fly management at Gazipur*.

Treatment**	Marketable yield (Kg/plant)	Gross return (Tk/plant)	Cost of treatment (Tk/plant)	Net return (Tk/plant)	Adjusted net return (Tk/plant)	Marginal Benefit Cost Ratio (MBCR)
Methyl eugenol	37.79	1889.50	150.00	1739.50	−45.00	−0.30
Protein hydrolysate bait trap	38.75	1937.50	125.00	1812.50	28.00	0.22
cloth bag	53.77	2688.50	1250.00	1438.50	−346.00	−0.28
Polythene bag	55.76	2788.00	550.00	2238.00	453.50	0.82
Shobicron 425 EC	41.56	2078.00	450.00	1628.00	−156.50	−0.35
double-layer brown paper bag	58.60	4395.00	1050.00	3345.00	1560.50	1.49
Untreated control	35.69	1784.50	0	1784.50	–	–

*Cost of all bagged treatments include cost of materials and labor.
Cost of Tilt Fungicide: 160.00Tk/100 ml.
Cost of Shobicron Insecticide @ Tk 1600.00/L.
Cost of kairomone trap: @ Tk 80.00/trap.
Cost of protein hydrolysate trap: @ Tk 50.00/trap.
Cost to spray: Two laborers/spray/ha @ Tk 450.00/day. Spray volume required: 20L/plant.
Cost of polythene bag: Tk.0.50/piece.
Cost of cloth bag: Tk.4.50/piece (bag is used two years).
Cost of double-layer brown paper bag: Tk.4.00/piece (bag is used two years).
Farm gate price of mango: Tk 50/kg (June–July, 2017).
Farm gate price of paper bagged Mango: Tk 75/kg (June–July, 2017).
**Treatments: T_1 = Setting of methyl eugenol kairomone trap at six weeks before mango harvest; T_2 = Protein hydrolysate bait trap at six weeks before mango harvest; T_3 = Bagging by cloth bag at six weeks before mango harvest; T_4 = Bagging by Polythene bag at six weeks before mango harvest; T_5 = Foliar spray of Shobicron 425 EC @ 1.5 ml/L of water, three times at 10 day intervals, starting at 42 days before harvest; T_6 = Bagging by double-layer brown paper bag at six weeks before mango harvest and T_7 = Untreated control.

100% protection from fruit fly infestations (Uddin and Reza, 2017; Sarker et al., 2009).

Bagging mango fruits with double-layer brown paper bags is effective against mango fruit flies because it prevents adult females from contacting the fruits and ovipositing eggs. While the upfront cost of double-layer paper bags was relatively high, considering the high labor cost of bagging individual fruits, the net return was still the highest among all the IPM technologies tested, and was nearly twice that of conventional pesticide use. Bagging mango fruits with double-layer paper bags provided high gross returns on investment because it provided the highest numeric marketable yields across all three study sites and high per unit prices. A further benefit is that the same double-layer brown paper bag could be used for two consecutive seasons if it is kept carefully after harvest. In addition to just providing protection against mango fruit flies, the paper bags can improve post-harvest fruit quality because they also protect the fruit from other insect and disease damage as well as from scratches and scars, making the fruits spotless (Uddin and Reza, 2017). Bagging also can increase the mango's shelf-life while increasing fruit mass and total soluble solids, and improving color (Sarker et al., 2009; Haldankar et al., 2015; Islam et al., 2017a, b). These qualities contributed to the price of bagged mangos being nearly double that of non-bagged mango and the high-quality fruits may be exported to earn foreign currency.

In this study, the methyl eugenol and protein hydrolosate bait IPM treatments provided some level of control but still resulted in one quarter to one third damaged fruits. This damage was similar to the conventional insecticide treatment, and less than the untreated control, but nowhere near as good as the 100% control provided by the double-layer brown paper bag. While these technologies have worked very well in controlling fruit fly populations and fruit damage in other situations (Vargas et al., 2008), the method of technology deployment in this study may explain the low efficacy. For example, male annihilation technology such as the deployment of methyl eugenol traps is most effective over large spatial scales. Since the technology's effectiveness is based on reducing the population of males, which therefore causes a reduction of gravid females, the technology is most effective over a spatial extent that exceeds the dispersal ability of the pest (Vargas et al., 2014). This was not the case in this experiment. The protein hydrolosate bait might also have been more effective if it had been deployed as a spray rather than as a lure. In the Hawaii fruit fly area-wide pest management program, baited lures such as those deployed in this experiment are most effective for population monitoring while liquid bait sprays mixed with conventional or organic insecticides are applied to crops and surrounding vegetation for crop protection (Vargas et al., 2017).

Based on this study, bagging mangos with double-layer brown paper bags is recommended for commercial mango production throughout Bangladesh. When mangoes reach an age of 40–55 days (i.e. 42 days before harvest), each fruit should be covered with a bag until the mango is harvested. No additional pesticide is needed once the fruits are covered. Bagging should be done properly on a sunny day. Care should be taken so that no opening remains near the fruit stalk after bagging. Pesticide costs, farmer exposure, and residues on fruit would all be reduced if this technology is disseminated and adopted among mango growers. Although this technology is laborious, it is safer and easier to practice than using conventional insecticides and is more effective.

In conclusion, this study has demonstrated effective control of fruit fly damage to mangos. Double-layer brown paper bag technology has potential for expansion in mango growing areas of Bangladesh. Where bagging with polythene bags is already implemented for guava fruit fly control (Rahman et al., 2017), the technology effectively manages the devastating pest and farmers have a positive perception of the technology. These factors indicate the potential stability and resilience of fruit bagging technology, and confirms that it is an ecologically sustainable and socially acceptable approach to pest management for safe mango production.

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