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Research Article

Efficacy of different bagging techniques for the management of litchi fruit borer (*Conopomorpha sinensis*)

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ABSTRACT

The bagging of fruits is widely used to provide a physical barrier between the fruits and insect pests. Litchi can easily be bagged to keep them safe from oviposition of litchi fruit borer, *Conopomorpha sinensis* Bradley (Lepidoptera: Gracillariidae). Efficacies of different bagging alone or in combination with insecticides to control litchi fruit borer were evaluated in a commercial litchi orchard in Bangladesh. The study consisted of five treatments: mosquito net sheets, mosquito net bags, white waxed-paper bags, mosquito net bags combined with Novastar 56 EC (bifenthrin + abamectin) and mosquito net bags combined with neem leaf extracts. Treatments were set at 10, 20 and 30 days after fruit settings (DAFS). Regardless of the bagging method and setting times, all the treatments significantly reduced *C. sinensis* infestations compared to the control trees. Earlier bagging of fruits (within the 10 days of fruit settings) provided the best protection (100%) from *C. sinensis* infestations. In cases of late bagging of fruits (at 20 and 30 DAFS), better defenses against *C. sinensis* were found from the white waxed-paper bagging and mosquito net bags + Novastar 56 EC treatments. Irrespective of the bagging times, higher pest-free fruits (>95%) and benefit-cost ratios (BCR) were achieved from the bagging with white waxed-paper bags (8.25:1) and the mosquito net bags + Novastar 56 EC (5.18:1). Among the treatments, the mosquito net bags, or sheets were less effective. However, mosquito net bags combined with neem leaf extracts provided better outcomes. Therefore, any of the treatments used in the trial can be recommended for the early bagging (within 10 days of fruit settings). For the late bagging, white waxed-paper bags or the mosquito net bags in combination with Novastar 56 EC (preferred) or neem leaf extracts might be suggested.

Introduction

Litchi [*Litchi chinensis* Sonn. (Sapindaceae: Sapindales)] are attractive, tasty, highly nutritive (Singh et al.; 2012, Srivastava et al., 2015) and worldwide cultivated fruits (Vercammen and Schmitz, 2001, Singh et al., 2019). In Bangladesh, the greater Dinajpur, Rangpur, and Pabna districts are known for commercial litchi production, although it is cultivated throughout the country (FAO., 2001, Ahad et al., 2010). Commercial litchi cultivation has become widespread because of its increasing demands in the local and international markets. In 2019, over eighty thousand metric tons of litchi were produced from over thirty one thousand acres of litchi orchards in Bangladesh (BBS., 2020). However, the quality production of marketable litchi is greatly hampered by the attack of the litchi fruit borer, *Conopomorpha sinensis* Bradley (Lepidoptera: Gracilariidae) (Alam et al., 2004, Kumar et al., 2014).

Conopomorpha sinensis females lay one or few (Waite and Hwang, 2002) eggs on the tender shoots (when fruits are not available) and young fruits (DAF., 2003, Schulte et al., 2007). The larvae mine near the fruit stalk, move to seeds and feed on the seed kernels (Taher et al., 2022). Usually, one larva develops in one fruit (Waite and Hwang, 2002). Earlier infestations may result in immature fruit droppings (Kumar et al., 2011). The severe infestations occur during the colour-changing stages of the fruits (Bhatia et al., 2000, Tuat et al., 2012, Taher et al., 2022). However, the peaks may vary temporally and spatially (Zhang et al., 1997). The affected fruits have reduced commercial values and often become unfit for human consumption (Sarma, 2003, Alam, 2011, Ishwarkar, 2020). Spraying of chemical insecticides is the conventional way to control litchi fruit borer in Bangladesh (Alam, 2011, Taher,

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2020, Taher et al., 2022), but they are widely criticized for health and environmental safety concerns (Islam, 2012, Jallow et al., 2017).

One of the pesticide-free management approaches is to keep the pests away from their host plants by providing physical barriers (Debnath and Mitra, 2008, Sharma et al., 2014, Sultana et al., 2017). Insect-proof netting of whole litchi orchard is practised in many countries (Rigden, 2008). However, covering the entire orchard is expensive and requires year-round management and specialised knowledge (Manja and Aoun, 2019, Johnson et al., 2020). Alternatively, localised bagging is more accessible and inexpensive for *C. sinensis* management. To date, detailed studies on the feasibilities and effectiveness of different techniques of litchi fruit bagging have not been done in Bangladesh. Similarly, efforts have not been made to develop efficient management options by combining bagging techniques with other control options. In this experiment, the effectiveness of bagging techniques and their combinations with conventional control strategies (chemical and botanical) were evaluated.

Materials and Methods

Experimental site

The experiment was conducted in a commercial litchi orchard in Gopalpur, Tangail, Bangladesh during the fruiting seasons (March to June) in 2015-2016. The weather of the experimental sites can be described as subtropical (19-34°C; 67-80% R.H. and 19-311 mm precipitations) (Meteorological Parameter, 2016) with silty alluvium soil having ≈6.5 pH level (BARC, 2012).

Bagging of fruits

Five bagging techniques of different nets and their associations with Novastar 56 EC (bifenthrin + abamectin) and neem leaf extracts were compared with the control trees. Treatments were mosquito net sheets (2 mm mesh), mosquito net bags (45 cm × 36 cm), white waxed-paper bags, mosquito net bags in combination with 0.4% neem leaf extract @ 20 ml/L of water (Mordue and Nisbet, 2000, Taher et al., 2022), and mosquito net bags in combination with Novastar 56 EC @ 1 ml/L of water (Taher et al., 2022). Treatments were set at 10 days, 20 days and 30 days after fruit settings (DAFS) following the techniques used by Sharma et al. (2014) and Chand et al. (2020). On the chosen day, the treatments including controls were laid out in a randomised complete design (CRD) on separate trees maintaining three replications of each. The insecticides were applied twice, during bagging of fruits and 15 days after bagging. In the cases of mosquito net bags (Figure 1b) and waxed-paper bags (Figure 1c), bunches of fruits were tied together to fit them inside the bags.

Data collection and analysis

On harvesting, 50-100 fruits per observation were selected randomly, and the number of *C. sinensis* infested and healthy fruits were recorded. The collected data were compiled and analysed using the software MSTAT-C (MSTAT-C., 1991) and Microsoft Excel (Microsoft Corporation, 2016). The one-way ANOVA (analysis of variance) followed by DMRT (Duncan's Multiple Range Test) were performed to differentiate the levels of the predictors. The residual plots of models were visually observed to check the distribution of the data. Log transformed data were used in the analysis when data were not normally distributed. The benefit-cost ratio (BCR) of litchi produced was calculated for acres of land to compare the economic returns by the treatments.

Figure 1. Covering/bagging fruit bunches with a (a) mosquito net sheet, (b) mosquito net bag and (c) white waxed-paper bag

Results

Compared to the control trees, all the treatments effectively reduced the fruit infestations by *C. sinensis* ($P<0.01$, Figure 2). Over half of the fruits (57.22%) were infested by the *C. sinensis* in the controlled trees. For the treatments set after 10 days after fruit settings (DAFS), no difference among the treatments was observed (DMRT; $P>0.05$), and only a negligible portion of fruits (0.33%) were affected by the *C. sinensis* in the treatments covered with the mosquito net sheets. Nearly 100% reduction of fruit infestations was found in the covered/bagged bunches (Table 1).

For the trees where the treatments were set at 20 DAFS, mosquito net bags associated with Novastar 56 EC spray and the white waxed-paper bagging were the most efficient (DMRT; P<0.05, Figure 2). The mosquito net bags with neem leaf extract spray and the mosquito sheets were the second most effective for reducing fruit borer infestations. However, no difference was found between the mosquito net sheet and bags (DMRT; P>0.05). Compared to the control trees, the treatments reduced over 95% to 100% fruit infestations (Table 1).

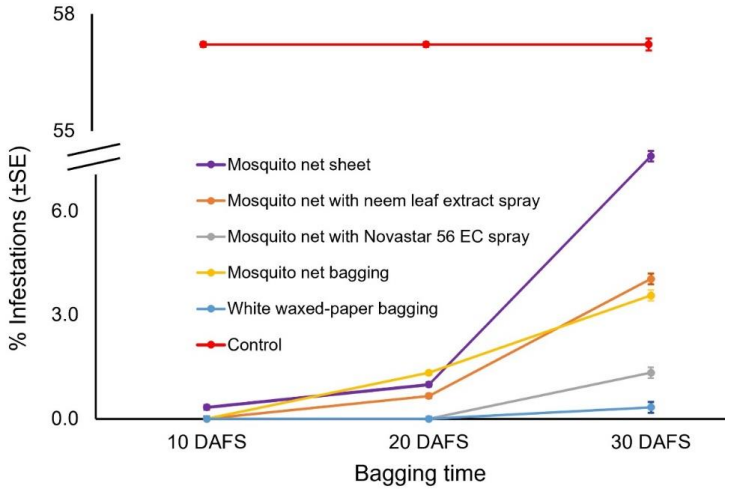

Figure 2. Percent fruit infestations (±SE) under different treatments set at 10 days after fruit settings, DAFS (ANOVA: P<0.01, CV (%) = 6.80, $DMRT_{0.05}$ = 0.207), 20 DAFS (ANOVA: P<0.01, CV (%) = 6.0, $DMRT_{0.05}$ = 0.199) and 30 DAFS (ANOVA: P<0.01, CV (%) = 11.4, $DMRT_{0.05}$ = 0.484).

Ninety percent or more uninfested and quality fruits were harvested from the treated trees than the control trees (Table 1). Considering the quality fruit production, the treatments can be ranked as waxed-paper bagging (99.67%) followed by mosquito net bagging combined with Novastar 56 EC spray (98.67%), mosquito net bagging combined with neem leaf extract spray (95.30%), mosquito net bagging (95.11%), mosquito net sheet (91.10%) and control trees (42.78%) (Table 1). The benefit-cost ratio (BCR) varied depending on the cost of treatments and the number of fresh fruits obtained (Table 1). The highest BCR was for the waxed-paper bagging (8.25:1), followed by the mosquito net bagging spray with Novastar 56 EC (5.18:1), and mosquito net bagging (5.05:1), mosquito net bagging spray with neem leaf extract (4.89:1) and mosquito net sheet (2.89:1) (Table 1).

Table 1. Percent reduction of fruit infestations, production of healthy fruits (ANOVA: P<0.001, CV (%) = 23.7, $DMRT_{0.05}$ = 4.604) and benefit-cost ratios (BCR) under different treatments set at 10, 20, 30 days after fruit settings (DAFS)

Treatments	Reduction of infestations over control (%)			Healthy fruits (%)	Benefit-cost rations
	10 DAFS	20 DAFS	30 DAFS		
Mosquito net sheet	99.42	98.27	86.75	91.10 b	2.89:1
Mosquito net with neem leaf extract	100	98.85	92.94	95.30 ab	4.89:1
Mosquito net with Novastar 56 EC	100	100	97.68	98.67 a	5.18:1
Mosquito net bagging	100	97.68	93.78	95.11 ab	5.05:1
White waxed-paper bagging	100	100	99.42	99.67 a	8.25:1
Control	-	-	-	42.78 c	-

The values marked with the same letter in a column are not significantly different (DMRT; P>0.05)

Discussion

Bagging techniques used in the trial significantly reduced *C. sinensis* infestations irrespective of the setting times and bagging materials compared to the control trees (Figure 2). Among treatments, white waxed-paper bags were the most effective in producing pest-free fruits and reducing *C. sinensis* infestations. The results align with many researchers who reported that the bagging was efficient for a higher number of pest-free fruit productions (Chand et al., 2020). White waxed-paper bags are cost-effective (Wang et al., 2003, Kawabata and Nakamoto, 2013, Purbey and Kumar, 2015, Singh et al., 2019) and provided higher benefit-cost ratios in the current study (Table 1). Notably, the

white waxed-paper bags let sunlight through, providing better support for the growth and development of the fruits. However, keeping fruits in the white waxed-paper bags for longer durations (>40 days) may deteriorate the fruit quality (Purbey and Kumar, 2015). Considering the fruit quality, mosquito net bags combined with Novastar 56 EC spray would be the better option (Figure 2).

The mosquito net bag combined with the spray of Novastar 56 EC worked better than the bagging with the mosquito net bag alone. The insecticide Novastar 56 EC was found effective in controlling *C. sinensis* in the previous trials (Upadhyay et al., 2020, Taher et al., 2021, Taher et al., 2022). Therefore, synergistic effects (Hwang and Hung, 1993) of mosquito net bags and Novastar 56 EC were achieved. The mosquito net bags kept the moths away from oviposition, and Novastar 56 EC provided further protection. Similarly, mosquito nets bags combined with the neem leaf extracts offered better results than the solo bagging with mosquito nets. Neem leaf extracts and neem oils have been reported as an efficient management tool for many pests (Rahman et al., 2013, Majlish et al., 2015, Rahman et al., 2016, Sultana et al., 2017, Barmon et al., 2021, Saha et al., 2021, Taher et al., 2022). The neem leaf extract spray on the mosquito net bags offered combined impacts of a physical barrier and deterrent impacts for lowering *C. sinensis* infestations. Among the treatments, mosquito sheets were comparatively less influential (Figure 2), possibly because it was difficult to seal the fruits completely (Figure 1a).

All the bagging techniques were equally effective at the earlier bagging of fruits (10 days after fruit settings) (Figure 2). Different fruit infestations were found for the trials set after 20 days and 30 days after fruit settings (Figure 2). The young fruits may have egg laying by the time of bagging of fruits when bagging was done lately. Combining the bagging of fruits with other control options may provide synergistic impacts to have reduced fruit infestations (Debnath and Mitra, 2008). Further studies on the efficacies of the different netting/bagging materials in the lab or controlled field conditions would provide better outcomes with minimum errors.

Bagging fruits/bunches are safer for consumers and environment friendly (Lal, 2020, Ali et al., 2021, Kumar et al., 2021, Zhi et al., 2021) but labour intensive. The costs associated with the bagging can be cut down by reusing the bagging materials. Fruits produced from the bagging procedures are healthy and appealing, resulting in increased market values. Likewise, reduced fruit dropping with bagging can significantly enhance profits (Debnath and Mitra, 2008, Kawabata and Nakamoto, 2013, Chand et al., 2020). Therefore, bagging with white-wax paper bags and mosquito net bags associated with Novastar 56 EC or neem leaf extracts can be recommended for litchi fruit borer management. It is also suggested not to keep fruits in white waxed-paper bags for an extended period (>40 days).

Competing interests

The authors have declared that no competing interests exist.

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