The Influence of Partial UV-blocking Films in the Insect Infestation and in the Growth of Broccoli and Turnip Seedlings

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Authors' contributions

This work was carried out in collaboration between all authors. Author AHMS designed the experiment, wrote the protocol and wrote the first draft of the manuscript. Author TN corrected proof and revised the draft. Authors SMAA and MDS performed the statistical analysis of the study. Author MMR contributed in identifying and counting the insects and author MS managed the literature searches. All authors read and approved the final manuscript.

ABSTRACT

The present work study the effect of partially UV-blocking films on the promotion of growth and insect control as well as the herbivores/sucking insects-predators proportion in the tunnels of Broccoli and Turnip seedlings is provided. During the experiment six treatments were tested: outdoor, UV-transmitting, and partial UV-blocking (UVs shorter than 340, 350, 360 and 400 nm) in three replications. Also a tunnel covered with UV-transmitting polyolefin film was also prepared.
and the results were compared with the seedlings that were grown, outdoors. The plant height, leaf number and leaf area increased in Turnip, while Broccoli was not affected. The number of insects invaded into the tunnels were trapped using blue and yellow adhesive films, and Eight different insects including mosquitoes were listed viz.: Aphid (Brevicoryne brassicae), brown plant hopper (Nilparvata lugens), short horn grass hopper (Melanoplus femurrubrum), white backed plant hopper (Sogatella furcifera), dipteran fly, mirid bug (Heteroptera: Miridae), up to 30 days after planting. Aphid was found as the most predominant insect followed by mosquito, dipteran fly, and white baked plant hopper. The largest feeding damage was found in outdoor with 26% in Broccoli and 22.5% in Turnip. The ratio of the herbivores and predators was also influenced by the films and it was remarkable in both Broccoli (35-65%) and Turnip (25-75%) seedlings, respectively. The partial UV-blockings effectively reduced the feeding damage compared with the outdoors, irrespective of seedling. Therefore, the sticky traps were found to be effective, and partial UV-blocking films showed different effects in controlling insect pests. Hence, the partial UV-blocking films can be an effective component for the IPM system rather than fully UV-blocking films.

Keywords: Insect infestation; partial UV-blocking films; pest management; predators.

1. INTRODUCTION

The accumulation of residual agricultural chemicals in vegetables is now widely recognized as a factor for inducing serious health problems [1]. Nevertheless, this problem has not yet been improved, because many farmers easily use chemical pesticides for vegetable production [2]. Among the vegetables, Brassicaceae plants such as broccoli and turnip are well known to be easily attacked by phytophagous insects, and if they leave a trail of feeding damage, their market values are largely reduced [3]. Perhaps, young seedlings are more sensitive to herbivory than mature plants, and seedling sizes are more prone in biomass removing to insects [4,5]. Considering the uncontrolled use of chemical pesticides and subsequent environmental hazards, the introduction of integrated pest management (IPM) should come into light [2,6].

Photo-selective plastics which affect not only the radiation use efficiency but also the mode of insect behavior are often used in vegetable production for obtaining the specific benefit of sunlight [7,8]. Among them, ultraviolet (UV)-blocking plastics have been commercially used mainly for reducing the number of phytophagous insects in greenhouses [8-10].

Although standard plastic films contain UV light-absorbing compounds to prolong the life of plastics and absorb some amount of UV radiation, the invasion of phytophagous insects into greenhouses cannot be well blocked by these films [11]. On the other hand, invasion of some species of phytophagous insects such as aphids, thrips and whiteflies is effectively blocked by high UV-blocking films which can block UV-light shorter than 400 nm (<400 nm), because they utilize UV-A light to orient themselves toward plants and to recognize plant species [10,12-13]. In contrast, the use of high UV-blocking films may disturb the ecological balance between herbivorous vermins and their natural enemies, because high UV-blocking films also inhibit the invasion of parasitoids [14]. These results provided a notion that partial UV-blocking conditions may be more appropriate for minimizing the number of phytophagous insects. In fact, less number of some arthropods was found on traps when the tunnels were covered with <385 nm rather <400 nm film [14]. In this study, therefore, Broccoli and Turnip seedlings were grown under different UV-blocking conditions and the number of captured insects and the feeding damage on the seedlings were compared with those grown under UV-transmitting conditions for assessing the effectiveness of UV-blocking films on its inclusion as IPM component.

2. MATERIALS AND METHODS

2.1 Plant Cultivation and UV-blocking

The experiment was carried out in 36 raised seedbeds (length × breadth × height = 100 cm × 100 cm × 50 cm) which were prepared at the experimental field of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh. Half of them were used for the cultivation of Broccoli (Brassica oleracea var. italica cv. KB superstar) and other half for Turnip (B. rapa var. rapa cv. Ledia). Seeds were sown in each bed at a spacing of 10 × 5 cm (200 seedlings per bed). The experiment was conducted in dry season from October to December, 2013. Fertilizer applications, irrigation and other operations were done following the procedure suggested in FRG [15].
Plastic tunnels (140 cm × 140 cm × 60 cm) were placed on the beds after germination (7 days) of the seeds, and two of each beds were covered with different polyolefin films (0.13 mm thickness) which had ability to block UV-lights shorter than <400, <360, <350, and <340 nm respectively (Mitsubishi Plastics Agri Dream, Tokyo, Japan). At 10 cm (17%) from the soil level of each tunnel remained open for the ventilation and allowing for insects invasion. The remaining two beds were not covered by plastic films and used as uncovered control. After 30 days of sowing (DAS), the seedlings were harvested and growth parameters measured.

2.2 Measurement of Environmental Conditions

Temperature, humidity, and visible- and UV-light irradiations were measured daily during the experiment. Temperature and humidity were recorded at 8:00, 12:00 and 24:00, while visible- and UV-light irradiations were measured at 12:00.

2.3 Measurement of Invaded Insects and Feeding Damage

In November, two (blue and yellow) sticky trap films (18 × 5 cm) were suspended at the middle position of the tunnels to collect the invasive insects. The adhesives were replaced every week, the kind and the numbers of captured insects were counted daily until December. During the 30 days of cultivation under different UV-blocking conditions, leaves of some seedlings showed feeding damages by herbivores/sucking insects. Therefore, the feeding damages of the seedlings were evaluated by two different ways as follows:

1. Rate of damaged seedlings (%) = Number of damaged seedlings per plot/Total number of seedlings per plot × 100
2. Rate of damaged leaf area (%) = Damaged area/Total leaf area × 100

Rate of damaged leaf area was calculated using open access software (Image J, NIH, MD, USA).

2.4 Statistical Analysis

Data were subjected to analysis of variance and significant differences of the means among treatments were analyzed using MSTAT-C software (East Lansing, MI, USA). The differences among treatment means were evaluated by Duncan’s multiple range test (DMRT).

3. RESULTS AND DISCUSSION

During the experiment, mean temperature in the tunnels at 20:00 and 24:00 was 20.3-21.9°C and there was no significant difference among the treatments (Table 1). However, mean temperature at 12:00 was higher (up to 2-4°C) inside tunnels than in outdoors. It is natural that films raise the temperature inside tunnels during day and night time. In our experiment, day temperature differed significantly but night temperature shows no significant difference. The experiment was conducted during dry season and the mean humidity in the tunnels at 12:00 was 53.1%. However, the mean humidity at 20:00 and 24:00 was 87.8% and 91.5%, respectively and the value in the tunnels was often significantly higher than that of the outdoors, especially when UV-blocking rate was high (Table 1). Similar findings on non-significant changes in temperature have been reported by Kittas et al. [16].

Although visible radiation was blocked 18-33% by the films, there was no significant difference among the tunnels. On the other hand, more than 50% of UV-irradiation was blocked even under UV-transmitting film, and the blocking rate increased gradually as UV-blocking increased, reaching only 14.3% of the outdoors under <400 nm (Table 1). Previous experiments by other researchers showed that at below 20°C, a few insects such as white fly, *T. vaporarium* and *B. tabaci* restrict or stop flight behavior inside greenhouses [17,18]. Flight activity of insects strongly coincides with light and temperature during morning [17,19-20]. In accordance with these results, our investigation showed that temperature ranged mostly at around 20°C, though at 12:00 and 20:00 it went down below 20°C during at the last two weeks (19 to 26 December, data not shown).

The growth parameters such as plant height, fresh weight and leaf areas of both Turnip and Broccoli increased by 20-30% in the <400 nm tunnels than in outdoors, as well as in UV-transmitting tunnels (Table 2).

It is already established in earlier findings that UV-blocking can promote the plant growth [11]. But in this study, it was discovered that partial UV-blocking also could also promote the growth significantly, which can be prescribed for the farmers to use partial UV-blocking films rather
than full UV-blocking films. Contrary to results of this study, <380 nm showed the minimum growth or no remarkable difference for some flowers (Lisianthus, Solidago, Chrysanthemum) [13]. In a study with cucumber and tomato seedlings, partial UV-A blocking films did not affect the plant growth [11]. Therefore, effect of partial UV-A blocking on plant growth would be highly species-specific as shown in Sinapis alba and Nasturtium officinale [21].

Plant biomass production was affected by partial UV-blocking. When compared with outdoor the fresh weight of the plant inside the tunnels increased by 50-70% (Table 2) while the dry weight did not follow similar trend. For Broccoli seedlings, maximum dry matter (%) was recorded inside the tunnels of <340 nm but for Turnip it was highest in outdoor plants (Table 2). Unlike UV transparent film, the accumulation of dry matter was increased (47% higher) with continuous growing of plants under UV-blocking films which is also in the agreement with [22]. For young plants, dry matter partitioning can be appraised by the stem-leaf ratio [16].

In the case of Broccoli seedlings, highest total number of insects was trapped maximum in outdoors than tunnels and the number of insect trapped in outdoors are significantly different from other blocking types (Fig. 1). In the yellow traps, insect number was non-significant in UV-transmitting and partial UV-blocking but in blue, it was almost similar in respect to the number of trapped insects. In the case of Turnip, trapped insect number decreased with increasing UV-blocking and for yellow and blue traps, insect trapping was affected same as the total

Table 1. Effect of partial UV-blocking films on the recorded mean temperature and RH% (daily, 3 times), light intensity, UV reading (12 pm) inside and outside tunnels during the period of experiment

| UV-blocking          | Mean temperature (°C) | Mean Relative humidity (%) | Light intensity (W cm⁻²) | UV average (mW cm⁻²) | % of outdoors | % of outdoors |
|----------------------|-----------------------|----------------------------|--------------------------|---------------------|---------------|---------------|
|                      | 12:00 | 20:00 | 24:00 | 12:00 | 20:00 | 24:00 | 12:00 | % of outdoors | 12:00 | % of outdoors |
| Outdoors             | 31.9 c | 21.7 | 20.5 | 53.6 | 85.4 b | 89.1 c | 20.6 a | 100 | 721.6 a | 100 |
| UV-transmitting     | 33.9 b | 21.9 | 20.4 | 53.5 | 85.4 b | 89.7 bc | 17.6 bc | 85.5 | 449.2 b | 48.7 |
| Partial UV-blocking  |<340 nm | 34.8 ab | 21.4 | 20.3 | 54.3 | 88.0 a | 90.9 bc | 18.2 bc | 88.4 | 309.0 c | 33.5 |
|<350 nm               | 35.8 a | 21.5 | 20.7 | 53.0 | 89.1 a | 91.6 b | 16.1 c | 78.4 | 250.5 c | 27.2 |
|<360 nm               | 35.4 ab | 21.5 | 20.9 | 53.5 | 92.2 a | 93.8 a | 17.0 bc | 82.6 | 219.3 cd | 23.8 |
|<400 nm               | 35.4 ab | 21.5 | 20.5 | 50.8 | 89.7 a | 93.8 a | 17.6 bc | 85.4 | 132.1 d | 14.3 |
| Significance         | ns | ns | ns | ns | ** | ** | ** | ** | ** | ** |

ns-non significant, *- significant at P≤ 0.01; **- significant at P≤ 0.05. Different uppercase letters beside the mean value indicate significant at P≤ 0.05 or 0.01. The differences among treatment means were evaluated by Duncan’s multiple range test (DMRT)

Table 2. Effect of partial UV-blocking films on different growth parameters of Broccoli and Turnip seedlings

| UV-blocking          | Turnip | Broccoli |
|----------------------|---------|----------|
|                      | Plant height (cm) | Number of leaves | Leaf area (cm²) | Fresh weight (g) | Dry matter (%) | Plant height (cm) | Number of leaves | Leaf area (cm²) | Fresh weight (g) | Dry matter (%) |
| Outdoors             | 24.5 e | 5.1 | 146.7 c | 4.5 d | 17.8 a | 18.7 a | 3.7 b | 45.4 b | 4.4 ab | 23.93 c |
| UV-transmitting     | 32.9 ab | 5.4 | 226.3 a | 6.9 a | 11 b | 23.1 a | 4.4 a | 74.7 a | 4.9 a | 16.47 d |
| Partial UV-blocking  |<340 nm | 27.0 d | 5 | 162.1 c | 5.7 b | 16 a | 20.8 bc | 4.2 ab | 57.7 ab | 3.4 c | 32.87 a |
|<350 nm               | 30.7 bc | 5 | 178.9 bc | 5.1 c | 17.7 a | 22.1 ab | 4.2 ab | 56.1 ab | 3.66 c | 32.07 ab |
|<360 nm               | 30.1 c | 5.1 | 170.8 bc | 6.2 b | 12.3 b | 23.6 a | 4.4 a | 62.8 ab | 3.7 bc | 25.84 bc |
|<400 nm               | 33.0 ab | 5.2 | 198.5 ab | 7.3 a | 11.5 b | 24.0 a | 4.5 a | 59.6 ab | 5.1 a | 14.23 d |
| Significance         | ns | ns | ns | ** | ** | ** | ** | ** | ** | ** |

ns-non significant, *- significant at P≤ 0.01; **- significant at P≤ 0.05. Different uppercase letters beside the mean value indicate significant at P≤ 0.05 or 0.01. The differences among treatment means were evaluated by Duncan’s multiple range test (DMRT)
number (Fig. 1). From the Figure, it can be concluded that partial UV-blocking films can be effective for trapping insects equally than full UV-blocking films.

The extent of feeding damage by insects was significantly influenced by the partial UV-blocking films for both vegetables (Fig. 2). The minimum number of plants (2-5%) was attacked inside the tunnels where partial UV-blockings were applied rather than outdoors (10%) and UV-transmitting (9%). So, it is evident from our experiment that less number of insects invaded inside the tunnels which can be an effective tool for minimizing the attack of plants rather than fully UV-blocking. On the other hand, the fed areas (%) showed significant variation among the treatments by which it can be said that if the number of insects maximize, it does not mean that the area of fed would be the maximum (Fig. 3). Among the trapped insects, all of them are not detrimental for the plants. Some beneficial insects were also trapped by the adhesives inside or outside tunnels. This type of variations may hamper ecological balance and in that case some predators will be killed and the insect pest invasion will be maximized. Insects fed areas were significantly influenced by the types of

Fig. 1. Total number of insects trapped by adhesives (blue and yellow) inside or outside tunnels during 30 days of the Broccoli and Turnip seedlings (A- Broccoli, B- Turnip seedlings). Yellow- Insect trapped in yellow adhesives, blue- Insect trapped in blue adhesives and total-

Total number of insects trapped inside and outside tunnels during the 30 days

Lowercase letters above the vertical error bar lines indicate significant (P ≤ 0.05). The error bars represent the standard deviation of the values.
Brassica species, Broccoli seedlings were attacked more than Turnip seedlings inside the tunnels where both of them were seeded at same time. The maximum leaf area fed by insects, inside the tunnels covered with <340 nm UV-blocking for both species. The fed area can be influenced by both the seedling densities and the area of the leaves; maybe that’s why insects attacked mostly in Broccoli seedlings [11].

In this study, tunnels with low height and a small opening with 10 cm were used which might interfere with the flying behavior of different insects. The plant growth was also influenced by the infestation of insects as in <400 nm tunnels, plants grew vigorously than other tunnels. For some insects, maximum numbers of insects were trapped under <400 nm tunnels than others, whereas, in previous experiment with tomato and cucumber [11] trapped number was maximum in <360 nm. Broccoli and Turnip seedlings are only seedlings, no flowering and also the leaves and stems were more succulent than other plants inside the <400 nm tunnels.

In this experiment, several species of insects were trapped but eight species were identified as follows: mirid bug (Cyrtothrinus lividipennis, Heteroptera: Miridae), aphid (Brevicoryne brassicae), brown plant hopper (BPH) (Nilaparvata lugens), dipteran fly, mosquito (Toxorhynchites sp.), short horn grass hopper (SHGH) (Melanoplus femurrubrum, Acrididae), white backed plant hopper (WBPH) (Sogatella furcifera, Hemiptera: Delphacidae). We also counted the other insects that were trapped by blue and/or yellow adhesive films which were not classified or found only in few numbers.

Further, we distinguished the insects as predators and herbivores/sucking insects. For both Broccoli and Turnip 10-20% predators or parasitoids were trapped and significantly controlled the herbivores/sucking insects with the use of partial UV-blocking films (Fig. 4). Predators are also important in environmental balance and also for the control of pest or herbivores/sucking insects by the predators or parasitoids that might be an influential agent for bio-control of herbivores/sucking insects. That's why; we differentiated the proportion of predators and herbivores/sucking insects that was trapped in blue or yellow adhesives inside or outside tunnels. It is evident that partial UV-blocking films can inhibit the insects invasion and beneficial insects were also trapped along with pests that was also considered in this experiment. In this experiment, we observed that significant number of beneficial insects have been trapped inside and or outdoors (Fig. 4). For parasitoid in Turnip seedlings, about 25% of the predators were trapped inside tunnels and on the other hand, 32% predators were trapped inside the tunnels of Broccoli seedlings (Fig. 4). Especially for Broccoli seedlings, more than 35% beneficial insects were trapped in the tunnels with partial UV-blocking films. This proportion should be considered whether the blue or yellow adhesives were used for catching insect-pest as a tool for control. In this experiment, partial UV-blocking of <350 or <360 nm captured almost the same as the full UV-blocking films rather than outdoors. In that case, it would be commercially acceptable to use partial UV-blocking films than full UV-blocking films to control insect pests [11].

This is expected that sticky traps captured only the winged and sometimes walking insects, but insect pest counts on plants included both adult and immature. However, a lot of other factors could contribute differences and plant height could reduce the invasion density of insects inside the tunnels. On the contrary, though the Brassica seedlings did not produce any flowers, the insects’ invasion may have migrated inside and outside tunnel, but the difference showed significant minimization inside the tunnel than outside, where the tunnels were opened at the bottom. Aphid prefers the color of background mainly by the contrast of green (plant) and soil as background to land [23]. Different secondary compounds of the plants might influence members of the next trophic level by affecting host plant, feeding and oviposition behavior of herbivores/sucking insects and their performance in different degree [24-26]. This might be a reason for trapping more insects inside the tunnels covered with <400 nm. In addition the duration of plant growth was only 30 days, the invasion numbers could vary with the duration of the experiment. Scientists showed that UV-blocking materials have properties to filter the UV radiation (280-400 nm) interfering with the vision of insects and in consequence, their behavior related with movement, host location ability and their population parameters [27]. They also stated that once the invading insects' enter into the protected crop; they must recognize and locate their host plants. As a result, insects begin the second phase of the process of host plant infestation, which is primary infestation. Especially, dipteran fly and aphids showed significant invasion inside the tunnel and for the WBPH it was remarkable in YSTs only whereas,
BSTs showed non-significant effect (Fig. 5). The dipteran fly invaded 3 times more in outdoors than inside tunnel and it was gradually decreased as the UV-blocking rate increased (UV-blocking shorter than 340, 350, 360, and 400 nm were 50, 33, 17 and 17%, respectively). In the case of aphid (Brevicoryne brassicae), invasion was 50% in UV-transmitting film than outdoors and it was decreased as 28, 13, 18, and 20% with the increasing rate of UV-blocking (Fig. 6). The YSTs were influential for the control of WBPH where it significantly trapped most number of insect inside the tunnel. The number of insects' invasion was not too much might be due to the smaller size of the tunnels and smaller opening of the tunnels for invading. The trap counts were also correlated with the densities with tomato and cucumber seedlings [11,28-29] that supported sticky traps as an influential tool for estimating population densities.

Fig. 2. Feed damage (% number of attacked seedlings) by insects in each plots as influenced by partial UV-blocking films (A-Broccoli, B-Turnip seedlings)

Fig. 3. Mean value of leaf fed area (%) by insects at harvest as influenced by partial UV-blocking films (A-Broccoli, B-Turnip seedlings)

Lowercase letters above the vertical error bar lines indicate significant ($P \leq 0.05$). The error bars represent the standard deviation of the values

Fig. 4. Cumulative number of predators and herbivores/sucking insects that were trapped by adhesive films during the experiment. Predator: Mirid bug, Herbivores/sucking insects: Aphid, BPH, Dipteran fly, mosquito, SHGH, WBPH and miscellaneous insects

Different lowercase letters above the vertical bar lines indicate significant ($P \leq 0.05$). The error bars represent the standard deviation of the values
Fig. 5. Mean numbers of major insect pest trapped in adhesives (Blue, yellow) inside and outside tunnels during the experiments (Broccoli seedlings). Here, BPH - Brown plant hopper, WBPH - White backed plant hopper, SHGH - Short horn grass hopper. Here, Predators- Mirid bug, Herbivores/sucking insects- Aphid, BPH, Dipteran fly, mosquito, SHGH, WBPH and miscellaneous insects- unclassified and only few numbers. Different lowercase letters above the vertical bar lines indicate significant ($P \leq 0.05$). The error bars represent the standard deviation of the values.
Fig. 6. Mean numbers of major insect pest trapped in adhesives (blue, yellow) inside and outside tunnels during the experiments (Turnip seedlings). Here, BPH - Brown plant hopper, WBPH - White backed plant hopper, SHGH - Short horn grass hopper. Here, Predators- Mirid bug, Herbivores/sucking insects- Aphid, BPH, Dipteran fly, mosquito, SHGH, WBPH and miscellaneous insects- unclassified and only few numbers

Different lowercase letters above the vertical bar lines indicate significant ($P \leq 0.05$). The error bars represent the standard deviation of the values.
4. CONCLUSION

It is possible to conclude that the partial UV-blocking films (<340, <350, <360 and <400 nm) had significant effect on the growth promotion and can be an important tool in IPM system for Brassica seedlings specifically against aphid, dipteran fly and white baked plant hopper. The plant height, fresh weight and dry weight was enhanced by using partial UV-blocking films, so that it is commercially acceptable not to use full UV-blocking films rather than partial UV-blocking films. For both Broccoli and Turnip 10-20% predators or parasitoids were trapped and significantly controlled the herbivores/sucking insects with the use of partial UV-blocking films. During the experiment, the proportion of insect-pest and parasitoids-predators balance was hampered because of the UV-blocking films. On the other hand, the effects of UV-blocking materials on predators, such as syrphid flies, mirid bugs, Orius spp., lady-beetles and lacewings have never been well described in the literature. The effectiveness of using partial UV-blocking films on the pest-predator proportion inside the controlled cultivation techniques was observed in the present study. It is clear that the cost effectiveness, timing, and nature of crops might also be the effective points to consider for successful IPM system in Bangladesh.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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