-Article 2-

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Efficacy of Mosquito Netting for Sustainable Small Holders' Cabbage Production in Africa

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ABSTRACT The efficacy of a mosquito netting to protect cabbages, *Brassica oleracea* L., against pests was investigated in field trials in Benin, West Africa. A polyester net covered the plants at night by using a wood armature. The net was removed during the day to prevent overheating and excessive shade, both problems of insect-proof screens used under tropical conditions. The number of all lepidopteran larvae with netting protection and foliar insecticide sprays was significantly lower than the unprotected control. The number of diamondback moth, *Plutella xylostella* (L.), was significantly lower with netting protection compared with foliar insecticide sprays and control. Netting treated with deltamethrin gave total protection of young plants against the aphid *Lipaphis erysimi* (Kaltenbach). At harvest, the number of marketable cabbages protected with untreated netting was significantly higher compared with the production with foliar insecticide sprays. The protection of cabbages with netting can be an economically viable method. Considering the price of cabbages on local markets (US\$1/unit), the net returns per 100 m^2 were US\$247 by using netting, US\$149 by using insecticides, and US\$117 for controls. The net returns for using netting are based on replacing the netting each crop cycle. But netting can be reused several times, depending upon conditions, increasing the profit margin. The netting protection may be an alternative to the growing unsustainable practices of vegetable cropping in peri-urban areas of tropical countries.

KEY WORDS vegetable protection, mosquito netting, insecticide treated net, *Plutella xylostella*, cabbage

Farmers in Sub-Saharan Africa use a large amount of pesticides on vegetables, and the use is exacerbated by insecticide resistance. Small-scale producers rarely have access to training in pesticide use and have only limited, or no access, to advice on the management of pesticides (Dinham 2003). Without a thorough knowledge of alternatives, farmers often assume that the only solution to pest problems is to increase dose and spray frequency. Moreover, the reentry periods after spraying and withholding periods are not known. The insecticides used are often very hazardous to human health, affecting users, produce consumers, and the environment. Pesticide residues from agricultural use select for resistance in mosquitoes, threatening the efficiency of those insecticides that also are used for mosquito control such as malaria vectors (Diabate et al. 2002). These unsustainable pesticide use practices are increasing with the demand for vegetables in expanding African cities.

To reduce insecticide pollution, a solution is to replace foliar insecticide sprays with an insect-proof net covering vegetables. This technique has been used with success in China to protect cabbage and in the Netherlands on various vegetables (Ester et al. 1994, Chen et al. 1998). In West Africa, insect-proof nets and particularly insecticide-treated nets, have only been used as bed-nets in public health to prevent malaria morbidity and mortality (Hougard et al. 2002). Therefore, these nets, treated or untreated, and netting fabrics are readily available in local markets.

The aim of this study was to adapt netting techniques to small-scale farming practices, testing insect-proof netting (insecticide treated or untreated), for the protection of cabbage, *Brassica oleracea* L., crops in peri-urban areas of Cotonou, Benin. Insecticide-treated netting was used to protect seedling plants, and untreated netting was used to protect cabbage crops after planting-out. Insecticide-treated net was limited to young plants to protect from harmful attacks of small pests. Results were compared with the local foliar insecticide protection recommended by the National Research Institute of Agriculture of Benin (INRAB). Cabbage was chosen because it is one of the most important cash crops among vegetables in Africa, and it attracts a wide range of pests, leading to important yield losses (Goudegnon et al. 1998). Cabbages are therefore heavily treated by insecticides and often with inappropriate and hazardous chemicals. We planned to remove the net during hot periods of the day when the flight activities of pests were reduced to suppress the problems of overheating and

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Table 1. Number of all caterpillar species, percentage of aphid-infested plants and percentage of damaged plants in seedling cabbage nurseries with insecticide-treated netting and untreated netting compared with foliar insecticide sprays and unprotected controls

Treatment	Caterpillars/10 plants[a]	% aphid-infested plants[b]	% damaged plants[c]
Control	6.3 ± 1.9d	20.0 ± 18.7ab	16.6 ± 7.1c
Foliar insecticide sprays	4.2 ± 1.2c	22.5 ± 25.2ab	21.1 ± 10.3c
Untreated netting	1.7 ± 1.0b	52.5 ± 36.7b	6.6 ± 5.1b
Insecticide-treated netting	0.0 ± 0.0a	0.8 ± 2.0a	2.0 ± 2.8a

Means ± SEM in the same column with the same letter are not significantly different ($P < 0.01$).
[a] Cumulative number for the total of all caterpillar species from five samples, including *H. undalis*, *S. littoralis*, *P. xylostella*, *T. ni*, and *Agrotis* spp.
[b] Average of three samples.
[c] Percentage of damaged plants just before planting-out (100 plants observed per plot).

excessive shade with insect-proof screens used in tropical conditions (Desmarais 1996).

Materials and Methods

Seedling Cabbage. The trial with a local variety of cabbage was implemented in the Research Centre of Agonkanmey of INRAB. Four treatments with three replicates were compared: insecticide-treated net, untreated net, foliar insecticide sprays, and unprotected control. The plots (1 by 2 m) were randomized in a complete randomized block design. Four rows of cabbages were sowed in each plot in November at the beginning of the dry season. Insecticide-treated nets and untreated nets were simple white bed-nets from local market in knitted polyester, 30 g/m^2 and 25 holes per cm^2. Six bed-nets (1 by 2 by 1.5 m) were cut down to be 75 cm in height. Three treated nets were insecticide impregnated 2 d before use, by dipping in deltamethrin formulation at a rate of 50 mg (AI)/m^2. Four wood pickets at each corner kept the nets at a height of 50 cm over seedling plants.

Planting-Out. Cabbages were planted-out in the field 20 d after sowing in nine plots of 6 m^2 (1.2 by 5 m) randomized in complete randomized block design with three replicates. Plots were three rows of 12 plants that have been previously protected by an insecticide-treated net. Three treatments were compared: untreated netting, foliar insecticide sprays, and unprotected control. Three untreated nets (2 by 6 m) were made from white mosquito netting fabric. The nets were put on a light wooden frame above the cabbage plots to protect young plants. Nets were used only at night to avoid plant overheating problems and to facilitate manual watering. Nets were put in place every day at 5 p.m. and removed the next morning at 9 a.m.

Pesticides. Cabbage seeds were treated with a formulation of Super Homai 70 DS (thiophanate-methyl thiram diazinon used at 50 g [AI]/kg seeds) from Nippon Soda (Tokyo, Japan) for a protection against soil insects, nematodes, and fungus. Deltamethrin 25 EC from ALM (Abidjan, Côte d'Ivoire) was used for foliar sprays and net impregnation. In keeping with local recommendations, deltamethrin was used at 12 g (AI)/ha for foliar sprays. Two foliar insecticide sprays were applied on seedling cabbage. Then, 10 foliar insecticide sprays were applied on cabbages twice a week after planting-out. Foliar sprays ceased 2 wk before harvesting.

Sampling. In seedling cabbage, the number of caterpillars was counted on two samples of 10 plants per plot, twice a week. Individual species counted were *Hellula undalis* (F.), *Spodoptera littoralis* (Boisduval), *Trichopulsia ni* (Hübner), *Plutella xylostella* (L.), and *Agrotis* spp. The number of infested plants by the aphid *Lipaphis erysimi* (Kaltenbach) was recorded from two samples of 10 plants, twice a week. Before planting-out, the percentage of damaged plants was noted on 200 plants per replication. After planting-out, the same sampling was done once a week. The number of *P. xylostella* adults was counted on two samples of 20 plants per plot. The number of vegetables of good quality (with no or few damage) also was recorded during the sixth, seventh, and eighth week after planting-out on 20 plants per plot. Harvesting was done, row by row, separating out marketable cabbages, which were used for the yield calculations. The other cabbages were considered as losses because of poor quality.

Analysis. MINITAB software (Minitab, Inc., State College, PA) was used for statistical analysis. Analysis of variance (ANOVA) was done on cumulated data for caterpillars and on average data for aphids. Fisher and Mann–Whitney *U* tests were used for comparisons of means with 0.05 error rate.

Results

The major pests of seedling cabbage were the larval stages of Lepidoptera. The first caterpillar attack was observed around 15 d after sowing, principally on plots without netting. In unprotected control plots, the caterpillars were largely *H. undalis* (33%) and *S. littoralis* (33%); less abundant caterpillars were *T. ni* (15%), *P. xylostella* (10%), and *Agrotis* spp. (5%). Protection with netting, either treated or untreated, against caterpillar infestations was significantly more effective than foliar insecticide sprays and the unprotected control (Table 1). There were significant differences in cumulative sampled caterpillars per 10 plants between the four treatments with the greatest number on untreated controls, intermediate numbers on netted and sprayed cabbage, and no caterpillars detected on

Table 2. Number of larvae for each lepidopteran species, number of *P. xyllostella* adults, and percentage of aphid-infested plants in cabbage plots with untreated netting compared with foliar insecticide sprays and unprotected controls

Treatment	*H. undalis* larvae/10 plants[a]	*S. littoralis* larvae/10 plants[a]	*P. xylostella* larvae/10 plants[a]	*T. ni* larvae/10 plants[a]	*Agrotis* larvae/10 plants[a]	*P. xylostella* adults/10 plants[b]	% aphid-infested plants[c]
Control	14.2 ± 2.4b	3.3 ± 0.6b	0.8 ± 0.4	8.0 ± 4.9	0.7 ± 0.3	20.3 ± 3.1b	4.4 ± 1.8
Foliar insecticide sprays	4.2 ± 1.2a	1.0 ± 0.2a	1.5 ± 0.8	0.8 ± 0.5	0.2 ± 0.2	14.0 ± 3.2b	1.9 ± 0.4
Untreated netting	3.2 ± 1.6a	1.0 ± 0.0a	0.2 ± 0.2	0.5 ± 0.5	0.3 ± 0.2	4.5 ± 1.4a	5.8 ± 3.2

Means ± SEM in the same column with the same letter are not significantly different ($P < 0.001$).
[a] Cumulative numbers of each caterpillar species from nine samples.
[b] Cumulative numbers of *P. xylostella* from seven samples.
[c] Average of six samples.

plants covered with insecticide-treated net. No caterpillars or aphids were found on seedling cabbage protected with insecticide-treated netting (Table 1). Although untreated netting was effective against caterpillars, it did not protect against aphids. Thus, the percentage of infested plants by aphids was significantly higher with untreated nets than with insecticide-treated nets. The beneficial effects of treated and untreated nets on seedling cabbage quality before planting-out compared with foliar insecticide sprays and unprotected control were significant (Table 1). The percentage of damaged plants was significantly lower with insecticide-treated netting than with untreated netting. There was no significant difference between the foliar insecticide sprays and unprotected control.

After 20 d in seedling nurseries, the young cabbages were planted-out in plots. The infestation of caterpillars began 2 wk later and increased until harvest. The caterpillar species observed on cabbage leaves were *H. undalis* (54%) and *P. xylostella* (20%) with some *S. littoralis* (13%), *T. ni* (11%), and *Agrotis* spp. (2%). The number of caterpillars per 10 plants was significantly lower with netting and foliar insecticide sprays compared with the unprotected control (Table 2), confirming results obtained with netting in seedlings nurseries. The number of *P. xylostella* adult per 10 plants was significantly lower with netting protection compared with foliar insecticide sprays (Table 2). Except at the beginning of the infestation, the number of *P. xylostella* adult was always lower on cabbages protected by netting than on cabbages with foliar insecticide sprays or in the unprotected control. The percentage of good-quality cabbage (not damaged or slightly damaged) grown under netting protection was significantly higher at 6 (68%), 7 (70%), and 8 wk (53%) after planting-out than with foliar insecticide sprays (28, 7, and 12%, respectively). The untreated control plots produced no good-quality cabbage at the last sampling date. Statistical analysis of cabbage production showed significantly two-fold higher production of marketable cabbages per 100 m^2 with netting protection compared with foliar insecticide sprays (Table 3). The local insecticide protection with 10 sprays of deltamethrin did not produce more marketable cabbages than untreated control. The yield, in terms of weight of marketable cabbages, was significantly greater for the netting protection than with untreated control and intermediate with the foliar insecticide sprays yield (Table 3).

Discussion

Our study demonstrated that an insect-proof net can effectively protect cabbage plants from aphids and caterpillars. This method of control reduced insect numbers more and produced greater cabbage yield and quality than standard foliar insecticide sprays. Protection from insects was achieved with the netting in place only at night, when the temperature is lower and the flight activity of adult moths is higher. This approach minimizes the negative effects of netting on

Table 3. Cabbage production with untreated netting compared with foliar insecticide sprays and unprotected controls

Treatment	Marketable cabbage[a] (no./100 m^2)	% marketable cabbage	Yield (kg/100 m^2)
Control	117 ± 39b	21.9 ± 9.2b	80 ± 32b
Foliar insecticide sprays	156 ± 69b	28.8 ± 12.8b	103 ± 46ab
Untreated net	383 ± 42a	67.9 ± 7.8a	198 ± 22a

Means ± SEM in the same column with the same letter are not significantly different ($P < 0.05$).
[a] Marketable cabbage is not damaged or slightly damaged.

the crop due to shading and overheating in hot climates similar to those of Benin where our experiments were conducted. In seedling nurseries, netting protected young plants from caterpillar infestations, evidently by preventing the females from laying eggs on the cabbage leaves at night. The physical barrier of the netting alone seems effective against *H. undalis*, *S. littoralis*, *P. xyllostella*, *T. ni*, and *Agrotis* spp. but not against small pests such as aphids, which can go through the commonly available mesh size we tested (25 per cm^2). Treating the netting with an insecticide (deltamethrin) provided 100% protection against aphids in our study. The treated nets also were more effective at reducing damage by all insects to cabbage plants. Plants protected with insecticide-impregnated netting were ≈3 times less damaged compared with those with untreated netting, and the rate of production of good-quality plants was significantly better from plots with treated netting. In contrast to the effectiveness of treated netting, the production of young plants from seedlings protected with foliar insecticide sprays was no different from the unprotected control, showing the ineffectiveness of two sprays of deltamethrin.

The use of netting at night also provided protection from caterpillar infestations in the cabbage crop after planting-out. There were 10-fold fewer caterpillars with the netting than on unprotected controls. The netting provided suppression of *H. undalis* equivalent to 10 sprays of deltamethrin. For *P. xylostella*, the netting reduced adult numbers three-fold more effectively than the insecticide treatments. The poor control of foliar insecticide sprays for *P. xylostella* could be due to the suspected pyrethroid resistance in this pest in Benin (Goudegnon et al. 1998). Genetic resistance in *P. xylostella* to chemical insecticides and biopesticides is a worldwide problem (Ferre and Van Rie 2002, Sayyed et al. 2004). The low-level caterpillar infestations that did occur on cabbages protected by netting in our study could be due to adult moths immigrating from nearby unprotected plots during the periods when the netting was removed in the daytime. This possibility seems likely for *P. xylostella*, which flies principally throughout the night (Goodwin and Danthanarayana 1984) but can be observed flying erratically when disturbed in the daytime. Despite this risk of occasional oviposition when the nets are removed, the practice has three advantages that offset this risk: 1) avoidance of overheating and shading the crop, which could decrease photosynthetic efficiency; 2) facilitation of watering and cultural practices; and 3) increasing longevity of the netting by limiting its exposure to UV.

Insect control using netting is cost-effective. The number of marketable cabbages produced under netting was twofold higher than the number produced using insecticide sprays. The current price of cabbages in local markets is approximately US$1/unit. The net returns per 100 m^2 were US$247 by using netting (US$383–US$76 cost of netting), US$149 by using insecticide (US$156–US$7 cost of insecticide), and US$117 for controls. These returns estimates for using netting are based on replacing the net at each crop cycle. But netting can be reused several times depending upon conditions, increasing the profit margin. Netting manufacturers have developed long-lasting nets for mosquito netting, which were still effective after 3.5–4 yr (Guillet 2001). They are wash-resistant and release insecticide over time, maintaining activity for at least 4 yr. They are commercially available in drugstore (≈US$7–15/unit) and could be used for the protection of seedling nurseries against aphids. The labor cost of removing the netting for a 100-m^2 plot is negligible (US$0.12/d).

The protection of growing vegetables with a net, insecticide treated or untreated, could prevent unsustainable insecticide practices in peri-urban areas of tropical countries. Advantages are protection of human health by reducing hazardous insecticide sprays, reducing environmental pollution from insecticide residues (important material for mosquito insecticide resistance issues), and increasing effectiveness of crop protection by improving yield and crop quality. This crop protection technique also might be useful in controlling insecticide-resistant pests highly selected in small-scale farming. The netting technique is well adapted to farmers cultivating intensively small plots in peri-urban areas of big African cities. The material is available in local markets and is cost-effective because it can be easily used many times. Africans are already familiar with protection from insects via bednets through the national malaria control programs, which should help adoption of netting for pest control in vegetables.

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