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ORIGINAL ARTICLE

Susceptibility of five cabbage varieties to attack by aphids (Hemiptera: Aphididae) in the Accra plains of Ghana

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Abstract We investigated the susceptibility of five cabbage varieties ('Oxylus', 'Super Cross', 'Vantar F1 Hybrid', 'Santa'F1 and 'Fortune') to aphids. Trials were set up in the Accra plains for two rainy seasons in 2017. The first trial examined aphid infestation and the second included weekly blanket spray of neem oil at 0.48 L/ha (60 ml/15 L water) during the second rainy season. Five systematically sampled cabbage leaves per plot were examined for the numbers of aphids and associated natural enemies (predators). Symptoms of aphid attack (incidence and severity of infestation) were also recorded. *Lipaphis erysimi pseudobrassicae* (Davis) and *Myzus persicae* (Sulzer) (Hemiptera: Aphididae) were the two aphid species observed and their numbers differed significantly between varieties in both seasons during the first but not the second trial. Few aphids settled on 'Oxylus', while more occurred on 'Fortune'. *L. e. pseudobrassicae* was the most abundant aphid on all the varieties. Aphid numbers were significantly decreased by neem application. Occurrence of natural enemies did not differ significantly between varieties, except for spiders during the major rainy season. There was no significant difference in aphid infestation between varieties during the first season as all of them completely succumbed to the infestation, while in the second season aphid incidence and severity of infestation was highest on 'Fortune', with 'Oxylus' being the least attacked by aphids. The crop yield was zero during the first season without protection for all the varieties. However, in the second season, lower yields (0.19–3.66 t/ha) was obtained with cabbage without protection, and much higher yields (14.8–21.1 t/ha) were obtained on neem-treated plots.

Keywords Natural enemies · Neem oil · Mustard aphid · Green peach aphid · Cabbage · Cultivars

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Introduction

In Ghana, cabbage (*Brassica oleracea* var. *capitata* L.) is an important vegetable that is cultivated extensively in nearly all regions of the country, except the Upper East and Western Regions (Timbilla and Nyarko 2004). Its cultivation not only provides food but also offers income to farmers and marketers (Abbey and Manso 2004; Asare-Bediako et al. 2010; Mochiah et al.

2011a, b). Cabbage is an important source of trace minerals, vitamins (A, B_1, B_2, B_6, K and C), dietary fibre, and protein needed for healthy development (USDA 2009). To satisfy the continuously increasing demand for this vegetable, farmers have resorted to monoculture and intensive cultivation of the plant, which has led to increased insect pest diversity and infestation, which is hindering cabbage production (Ninsin 1997).

Insect pests of cabbage in Ghana include: the aphids *Lipaphis erysimi pseudobrassicae* (Davis) and *Myzus persicae* (Sulzer) (Hemiptera: Aphididae); the diamondback moth (DBM), *Plutella xylostella* L. (Lepidoptera: Plutellidae); the cabbage webworm, *Hellula undalis* F. (Lepidoptera: Crambidae); the cabbage looper, *Trichoplusia ni* (Hübner) (Lepidoptera: Noctuidae); the whitefly, *Bemisia tabaci* (Genn.) (Homoptera: Aleyrodidae); the flea beetle, *Phyllotreta* spp. (Coleoptera: Chrysomelidae), and the variegated grasshopper, *Zonocerus variegatus* (L.) (Orthoptera: Pyrgomorphidae) (Baidoo et al. 2012; Fening et al. 2011; Forchibe et al. 2017; Mochiah et al. 2011a, b).

Aphids are important pests of cabbages that not only cause direct feeding damage to the crop but also transmit viruses that can result in total yield loss (Chivasa et al. 2002; Fening et al. 2016; Munthali 2009). They feed mainly from the abaxial side of leaves where their piercing and sucking of sap damages the leaves (Hughes 1963; Mochiah et al. 2011a, b). Symptoms of aphid feeding damage include yellowing and folding of leaves, slow and unhealthy growth, as well as distortion of infested plants (McKinley 1992). Aphids secrete honeydew as they feed, which promotes sooty mould growth on the leaves that renders the plants unsightly and of low market value (Amoabeng et al. 2013; Blackman and Eastop 1984; McKinley 1992).

In mitigation, farmers seek out control measures against aphids so as to protect their yields. Amoabeng et al. (2017) found that nearly 45% of cabbage farmers in Ghana resort to synthetic insecticides in managing pests. However, up to 44% of growers do not follow through with the application of the required rates of insecticides due to farmers' inability to read and understand pesticide labels. Chemical pesticides have their inherent shortcomings. They have been shown to affect non-target organisms, including beneficial insects such as bees and natural predators of aphids (Ntow et al. 2006; Obeng-Ofori and Ankrah 2002). Evolution of pesticide resistance by pests due to misuse and continued use is of concern (O'Connor-Marer 2000; Ware and Whitacre 2004). Also, due to the persistent nature of pesticide residues, a longer time is required after spraying before the crop can be safely sold for consumption (Nel et al. 2002). Therefore, viable alternatives to chemical-based pesticide are urgently needed for aphid control. Alternatives must be accessible to farmers, effective against the aphids, affordable, and environmentally friendly.

One effective new strategy is to investigate and explore natural host plant resistance to aphids. It has been demonstrated that naturally resistant crop varieties are effective against pest damage and by extension can reduce yield losses and protect the environment from insecticide use (Bosque-Perez and Buddenhagen 1992; Dar et al. 2006).

Another exciting possibility is to use plant natural products (botanicals) to protect crops from insects and, indirectly, from the pathogens they transmit (Isman 2015). The neem tree, *Azadirachta indica*, with the active ingredient Azadirachtin, has been widely used to control insect pests on various crops (Boopathi and Pathak 2011; Muhammad et al. 2013; Aline and Mauricio 2015; Djomaha et al. 2016; Forchibe et al. 2017). Crude extract from neem as well as commercial oil formulations have been effective in controlling pests on cabbage including aphids (Baidoo and Adam 2012; Ezena et al. 2016; Fening et al. 2017; Forchibe et al. 2017). Using neem as a plant-based insecticide will lead to the production of quality vegetables produced organically without the use of synthetic insecticides, thus minimising the risk of insecticide residues accumulating in harvested produce (Fening et al. 2017). Neem as a botanical insecticide exhibits several modes of action (anti-feedant, causes abnormal and delayed moults, growth arrestant, increased mortality, sterility effect, etc.), thus making it a candidate to manage insecticide resistance and its compatibility with other management strategies such as host plant resistance, utilised in IPM (Fening et al. 2017).

Several cabbage varieties are cultivated in Ghana. However, their ability to withstand aphid infestation has not been tested. In this study, we report on the susceptibility of five cabbage varieties to attack by aphids and on the efficacy of neem oil as a sustainable pest management agent for controlling these important brassica pests.

Materials and methods

Study site

The experiment for assessing the susceptibility of the five varieties of cabbage to aphids attack was conducted under open field conditions at the University of Ghana's Soil and Irrigation Research Centre, Kpong (0° 4′ 28.47″ E, 6° 7′ 58.72" N) in the Eastern region of Ghana. Kpong is part of the Accra plains of Ghana and belongs to the Coastal Savanna agro-ecological zone. The area has a low annual rainfall (approximately 700 to 1100 mm per annum). The average annual temperature is 28 °C with a relative humidity between 59% and 93%. The experiment was conducted from July to October 2017 and from November 2017 to January 2018.

Study design and crop management

The experimental field was arrayed in a randomized complete block design. There were five varieties or treatments and was replicated three times for all the experiments. Each block or replication consisted of 5 plots, giving a total of 15 plots. Each plot area was 3 m × 2.5 m, with all plots having twenty plants. The inter-row and intra-row plant spacing was 0.50 × 0.50 m. The distance between two plots was 1.5 m whilst between two blocks was 2 m. Seeds were sown in a nursery bed on the 6th of July and 22nd of September 2017 for the later part of the major and minor rainy seasons, respectively. All through the nursery period, agronomic practices such as hand weeding and watering were carried out. Four-week-old cabbage seedlings were transplanted into a well-irrigated experimental field. Healthy seedlings with five to six true leaves were selected for transplanting to make sure of good survival and uniform crop establishment. Seedlings were planted 2 cm deep into the soil, with four rows per plot, with five cabbage plants per row, giving a total of 20 plants per plot. Seedlings from different varieties of cabbage were randomly assigned to the various plots, and the plots labelled accordingly. After transplanting, fertilizer (NPK 15–15-15 and ammonium sulphate) was applied to the soil at rates of 5 g/plot and 3 g/plot 10 and 42 days, respectively, around each plant in a ring form for both seasons and regular weeding was done.

Plant material (cabbage varieties) and experimental set-up

Five commonly grown cabbage varieties, namely 'Super cross F1', 'Oxylus', 'Fortune F1', 'Santa F1' and 'Vantar F1 Hybrid' were evaluated for their susceptibility to aphids' attack for the major and minor rainy seasons. The cabbage varieties 'Super cross F1', 'Fortune F1' and 'Santa F1' were obtained from AGRISEED Limited at Adabraka, while 'Vantar F1' and Oxylus were bought at AGRIMAT at Madina, both located in Accra, Ghana. Two trials were set up during the experimental period for the major and minor rainy seasons.

Aphid abundance for the different experiments and seasons

The first trial was carried out during the late major and minor rainy seasons. In this trial, the response (susceptibility) of the different varieties to aphid infestation was evaluated without insecticide application to establish the natural infestation levels.

In the second experiment, the response of the different varieties to aphid infestation was evaluated with and without insecticide application. The insecticide application consisted of a weekly blanket spray of a commercial neem oil (Ozoneem®) (Ozone Biotech, India) (10,000 ppm EC) at 60 ml/15 L of water. Application of the neem oil started two weeks after transplanting of cabbage seedlings. However, the other experimental plots of the five varieties were not sprayed with insecticide to establish the natural response (susceptibility) of the varieties to the aphids, like what was done in the major rainy season.

Sampling of aphids on five cabbage varieties

The sampling method used for the aphids was modified from the method of Hughes (1963) and that of Forchibe et al. (2017). Five leaves per cabbage plot, systematically selected from the lower, middle and upper portions of cabbage plants, were harvested weekly (destructive sampling) and placed into 70% ethanol to collect the aphids from the leaves. The mixture obtained was poured into Petri dishes for insect counting using a hand lens. Aphids were separated from the natural enemies, and further segregated into winged (alate) and wingless forms, and the wingless into green and pink forms before counting.

Monitoring winged aphids (alates) population using yellow bowl water traps

Circular yellow bowls (20 cm diameter and 6 cm deep) were used for trapping winged aphids within the different plots of cabbage. The traps were placed on a wooden stand at the centre of each plot at the same height as the cabbage canopy. Water containing a few drops of liquid detergent was poured into each bowl and filled to 2/3. The detergent was used to remove the surface tension on water so that the insects sink to the bottom of the bowls (Wamonje et al. 2017). Aphids were trapped weekly, with traps placed in the morning from 7:00 am to 12:00 noon and again in the afternoon from 1:00 pm to 6:00 pm.

Assessment of the incidence and severity of aphids' infestation

The incidence and severity of aphid infestation was recorded in the field during each season, and the total number of cabbage plants per plot showing apparent symptoms (yellowing leaf curl, stunting and necrosis) were counted and recorded. Four plants were also randomly selected per plot and scored for severity of the symptoms of aphids' infestation. Severity of the symptoms or level of aphids infestation per plant was evaluated using a modification of the scoring method described by Munthali (2009) and Forchibe (2016) with a 0 to 5 scale depending on the symptoms' intensity, where 0 = no symptom, 1 = 1–20% leaves yellowing, leaf curl and stunting 2 = 21–40% leaves yellowing, leaf curl and stunting 3 = 41–60% leaves yellowing, leaf curl, stunting and mild necrosis 4 = 61–80% leaves yellowing, leaf curl, stunting and necrosis 5 = 81–100% leaves showing severe symptoms of aphid attack; defined as extreme yellowing leading to complete necrosis or drying of leaves and death of plant tissue. The number of aphids on the crop, incidence and severity of symptoms of aphid infestation were used to evaluate the susceptibility of the six varieties.

Abundance of natural enemies

Predators of aphids (hoverflies and ladybird beetle larvae and pupae) were also counted from the five leaves sampled from five cabbage plants in the inner rows from each treatment plot into 70% ethanol in vials. Additionally, the natural enemies (hoverflies, ladybird beetles, and spiders) observed directly on the leaves of the five plants were also counted.

Yield assessment

The cabbage heads were harvested from 3 to 4 months, depending on the maturity days (from germination of seeds, transplanting to harvesting), which varied from one variety to the other. Six cabbage heads from the inner rows (central) were harvested, and weights were taken and recorded. The yield per unit area was extrapolated into tons per hectare (t/ha).

Identification of insects

Aphids and their associated natural enemies collected from cabbage leaves and winged aphids trapped in yellow bowls were kept in separate vials and labelled. The vials were filled to 2/3 with 70% ethanol for preservation of the insects. Aphid species were identified under a microscope using taxonomic keys by Blackman and Eastop (1984) at the Entomology Laboratory of African Regional Postgraduate Programme in Insect Science, University of Ghana, Legon. Ladybird beetles and hoverflies larvae were collected directly on cabbage leaves and reared in the laboratory to the adult life stage, to allow identification. These ladybirds and hoverflies were sent to the entomology laboratory of the Department of Crop Science, University of Ghana, Legon, for identification using appropriate taxonomic keys and confirmation using reference specimens.

Data analysis

Count data was normalised (after confirming with Shapiro-Wilk test for normality) by square root transformation before ANOVA analyses. Least Significant Difference analysis was used to determine the significance of the differences between the means of the measured parameters. Student's *t* test was used to compare insect populations and yield between the two seasons (for the untreated plots), and between the neem treated and untreated plots during the minor rainy season. All analyses were carried out using Genstat 12th edition (Statistical package version 12.1).

Results

Aphid species encountered in the study

The two important aphid species known to attack cabbage plants in Ghana include the brassica specialist, *Lipaphis erysimi pseudobrassicae* (Davis) (Hemiptera: Aphididae) and the generalist aphid, *Myzus persicae* (Sulzer) (Hemiptera: Aphididae) (Fening et al. 2020). These two species of aphids were the ones recorded in the current study.

Aphid abundance on plants without and with application of insecticides

The mean number of aphids significantly differed among the varieties for both seasons (Figs. 1, 2, 3 and 4). *M. persicae* populations started building up from the first week of sampling (3 weeks after transplanting) and the peak was reached five weeks into the major rainy season (Fig. 3). Populations started increasing from the second week of sampling (4 weeks after transplanting) to reach their peak in the sixth week during the minor rainy season for the untreated plot. *L. e. pseudobrassicae* infestation started in the first week of sampling, which was about 3 weeks after transplanting of cabbage seedlings, for both seasons for the untreated plot (Figs. 1 and 2). However, infestation was first observed in the second week of sampling (about 4 weeks after transplanting) for the neem-treated plot during the minor rainy season (Fig. 2). *L. e. pseudobrassicae*

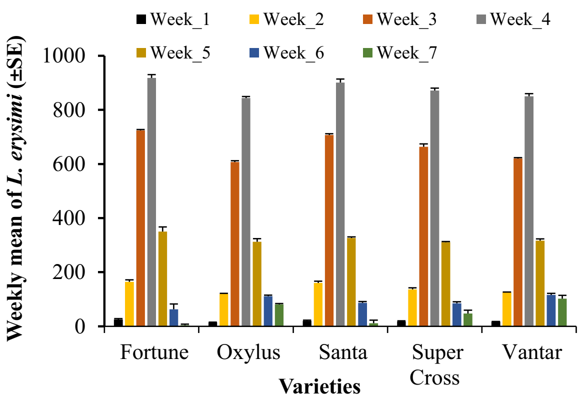

Fig. 1 Mean (± SE) number of *Lipaphis erysimi pseudobrassicae* on untreated cabbage per week in the major rainy season, 2017 in Kpong. There was a significant difference between the aphid populations on the different varieties of cabbage ($F_{4, 104} = 6.89$; $P = 0.0110$). The lowest mean number of aphids was recorded on 'Oxylus' while the highest number occurred on 'Fortune'

reached the peak infestation at weeks four and six for both seasons for the untreated plots (Figs. 1 and 2). For the neem-treated plot, infestation reached its peak in the seventh week of sampling (Fig. 2). A *t*-test between *L. e. pseudobrassicae* counts for the untreated and neem treated plots revealed a significant difference ($t = 2.10$; $P = 0.0490$ and $t = 51.46$; $P < 0.0010$). Aphid infestation of unsprayed plants of all varieties was significantly higher compared with sprayed plants (Figs. 2 and 4). *M. persicae* infestation was generally low throughout the sampling period for the neem-treated plot during the minor rainy season (Fig. 4). A comparison between *M. persicae* counts, for the unsprayed plots during both seasons revealed a non-significant difference ($t = 1.61$; $P = 0.1230$), while between the unsprayed and sprayed plot during the minor rainy season, revealed a significant difference ($t = 15.93$; $P < 0.0010$).

Winged aphid (alate) populations on cabbage

The numbers of winged aphids (alates) sampled from the cabbage leaves among the different varieties was significantly different for the major rainy season ($F_{4, 14} = 14.36$; $P < 0.0010$) (Table 1). Plots planted with Fortune followed by Oxylus recorded the highest mean number of alates compared to the remaining three varieties (Table 1). However, the number of alates among the different varieties during the second planting season (minor rainy season) for the sprayed and the unsprayed plots was not significant.

Monitoring winged aphid populations using yellow bowl water traps

The mean numbers of alates recorded in the yellow bowl traps were not significantly different among the varieties, for both seasons (unsprayed and sprayed plots) ($F_{4, 74} = 0.55$; $P = 0.7070$; $F_{4, 119} = 0.69$; $P = 0.6190$ and $F_{4, 119} = 0.1$; $P = 0.9780$, respectively) (Figs. 5 and 6). Catches of winged aphids recorded in the morning (7 am to 12 pm) and the afternoon (1 pm to 6 pm) were not significantly different for the major rainy season ($P =$ 0.8770). However, mean number of alates counted for the minor rainy season was higher in the morning than the afternoon, on both sprayed and unsprayed plots ($P =$ 0.0150 and $P < 0.0010$, respectively). A comparison between alates counts on unsprayed plots for the major and minor rainy seasons revealed a significant difference ($P < 0.0010$). There was also a significant

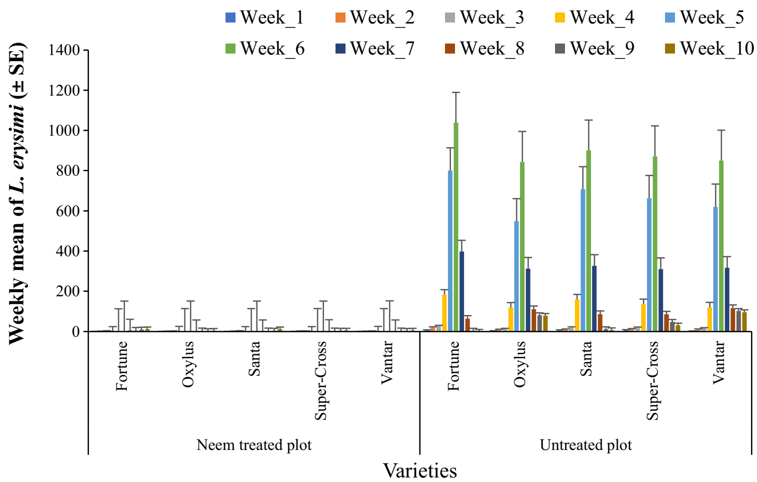

Fig. 2 Mean (± SE) number of *Lipaphis erysimi pseudobrassicae* counted on untreated and neem-treated cabbage each week in the minor rainy season, 2017 in Kpong. *L. e. pseudobrassicae* numbers did not significantly differ among the varieties of cabbage treated with neem ($F_{4,\ 149} = 0.83$; $P = 0.5410$). The mean number significantly varied between the different varieties of cabbage without protection ($F_{4,\ 149} = 4.4$; $P = 0.0360$). The fewest aphids occurred on the variety 'Oxylus' and the highest levels found on the variety 'Fortune'

difference between alates counts on unsprayed and sprayed plots for the minor rainy season ($P < 0.0010$).

Assessment of the incidence and severity of the symptoms of aphid infestation

The incidence of the symptoms of aphid infestation was higher during the major rainy season compared with the minor rainy season (Table 2). For the major rainy season, the different varieties recorded the same incidence levels in the fifth week of sampling. Plants in all the unsprayed plots showed symptoms of aphid attack, except in the neem-treated plots for the minor rainy season, although the incidence was not significantly different for the various varieties in the untreated plots. Regarding the neem-treated plots, aphid infestation symptoms were not observed at all.

The severity of aphid attack was significantly different among the varieties during the major and minor rainy seasons ($F_{4,\ 14} = 6.18$; $P = 0.0140$ and $F_{4,\ 14} = 6.20$; $P = 0.0140$, respectively) (Table 2). The greatest severity was observed on Fortune, Super-cross and Santa with the least severity on Oxylus and Vantar for the major rainy season. During the minor rainy season, plot planted with Fortune, Super-cross and Santa recorded the highest severity of the symptoms of aphids' infestation, with the least being Oxylus, although similar the performance of Santa and Vantar. In neem-treated plots we did not observe any aphid-infested plants.

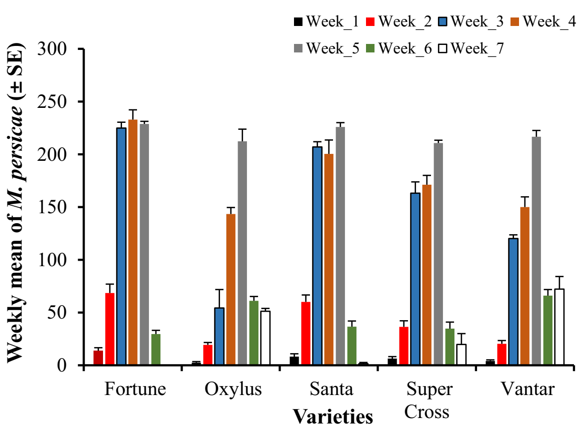

Fig. 3 Mean (± SE) number of *Myzus persicae* on untreated cabbage per week in the major rainy season, 2017 in Kpong. The average number significantly differ between the varieties of cabbage ($F_{4,\ 104} = 14.24$; $P = 0.0010$). The variety Fortune supported the highest *M. persicae* numbers, while the fewest were recorded in plots planted with Oxylus

Abundance of natural enemies on the different cabbage varieties

Ladybird beetle, *Cheilomenes lunata* (Fabricius) (Coleoptera: Coccinelidae), incidence was very low throughout the sampling period during the major rainy season (Fig. 7). During the minor rainy season ladybird beetles were recorded only on plants in the unsprayed plot of

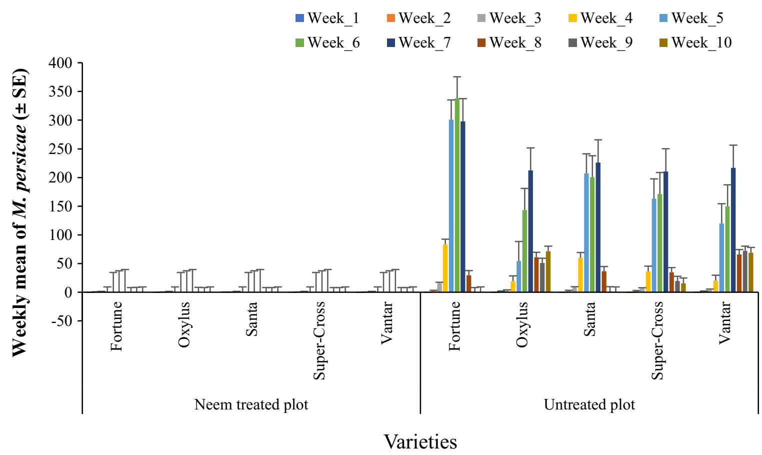

Fig. 4 Mean (± SE) number of *Myzus persicae* on neem-treated and untreated cabbage plant per week during the minor rainy season, 2017 in Kpong. The mean number of *M. persicae* did not significantly vary among the varieties treated with neem ($F_{4, 149} = 1.88$; $P = 0.2080$). However, the mean number significantly differ between the different untreated varieties ($F_{4, 149} = 6.95$; $P = 0.0100$). The fewest aphids were found on 'Oxylus' while the highest number occurred on 'Fortune'

the variety Fortune. The hoverfly, *Paragus borbonicus* Macq. (Diptera: Syrphidae) population started to increase in the second and first week of sampling for the major and minor rainy seasons (Figs. 8 and 9), respectively and increased progressively throughout the sampling period for the unsprayed plots. However, the hoverfly population was markedly lower on neem-treated plants during the minor rainy season (Fig. 9). Comparison between counts of hoverfly for the neem-treated and untreated plots during the minor rainy season were significantly different ($t = 16.96$; $P < 0.001$) (Fig. 9). The number of spiders started increasing from the first week of sampling and attained its peak between the fourth and fifth weeks for the major rainy season (Fig. 10), and the sixth week for the minor rainy season (Fig. 11), both on the plants in neem-treated and untreated plots. A comparison between spider counts for both seasons (unsprayed plot) revealed no significant differences ($t = 1.37$; $P = 0.1810$). However, the spider population was significantly higher on the untreated plants than on neem-treated plants ($P < 0.0010$) (Fig. 11).

Yield assessment

All the varieties resulted in a 100% yield loss for the major rainy season when no protection was offered. However, during the minor rainy season, yield obtained

Table 1 Mean number of aphids (± SE) per cabbage plant for the first (major) and second (minor) planting seasons

Varieties	Mean number of aphids		
	Major season	Minor season	
		Untreated plot	Neem-treated plot
Oxylus	3009 ± 41.1 a (375.7)	2915 ± 53.76 a (180)	14 ± 6.52 (3.2)
Super-Cross	3059 ± 69.82 a (284.1)	3124 ± 106.8 ab (281)	22.9 ± 3.83 (7.7)
Santa	3200 ± 96.38 b (248.7)	3215 ± 79.24 ab (236)	25.9 ± 6.352 (6.2)
Vantar	3060 ± 89.28 a (264)	3369 ± 90.2 b (400)	19.8 ± 2.205 (6)
Fortune	3475 ± 51.47 c (426.9)	3894 ± 175.8 c (282)	43.4 ± 13.16 (12.2)
F	22.81	15.51	1.99
P	< 0.001	<.001	0.189

Means with the same letter (s) are not significantly different ($P < 0.05$) within columns

() Values in bracket are the mean number of alates per cabbage plant

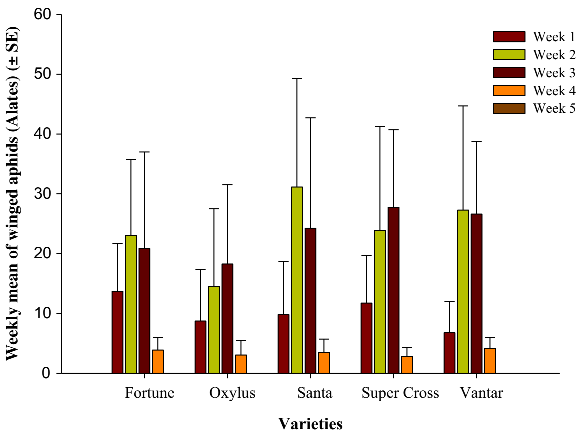

Fig. 5 Mean (± SE) number of winged aphids (alates) caught in yellow bowl traps in untreated plot of cabbage per week in the major season, 2017 at Kpong

on the unsprayed plots was relatively low (Table 3). The yield obtained on the plots sprayed with neem during the minor rainy season was higher compared to the unsprayed plots ($P < 0.0010$).

Discussion

Symptoms and severity of aphid infestation

In this study two aphid species, *L. e. pseudobrassicae* and *M. persicae*, were encountered in cabbage fields. These species were also observed by Fening et al. (2016, 2020) and Forchibe et al. (2017) on cabbage (Oxylus var.) in the same area, which was the first time *L. e. pseudobrassicae* had been reported in Ghana. Aphid populations varied significantly among the five cabbage varieties assessed. Ellis and Farrell (1995) reported from their study that it was possible to determine in the field the extent to which the aphids settled on plants providing a measure of the resistance present in plants. Based on that, the variation in aphid population observed in this study could be attributed to a difference in the level of susceptibility of the five varieties tested. On the unsprayed plants, the abundance of aphids (*L. e. pseudobrassicae* and *M. persicae*) on the variety Fortune was significantly higher than that on the other varieties, the lowest being on the Oxylus variety. The difference in aphid population abundance can be attributed to the high reproductive rate of these aphids on the variety Fortune compare to the other varieties. Munthali and Tshegofatso (2014) showed that the breeding behaviour of the cabbage aphid depends on the brassica cultivar infested. This indicates that cabbage variety affects the population abundance of aphids, and that a particular variety might affect aphid population more than other varieties.

Russel (1978) and Dent (2000) explained that a cabbage variety that affects the biology of the pest through reduction of its reproductive capacity or by affecting the development of the pest uses the antibiosis mechanism of resistance. The lowest mean abundance of these aphids found on the variety Oxylus showed that *L. e. pseudobrassicae* and *M. persicae* reproduction was lower on the Oxylus plant compared to the others. Hence, it is suggested that this variety to some extent may have affected the reproductive capacity of *L. e. pseudobrassicae* and *M. persicae*. According to Munthali and Tshegofatso (2014), the difference in the population of aphids observed in four leafy brassica vegetables were attributed to factors such as levels of

Fig. 6 Mean (± SE) number of winged aphids (alates) caught in yellow bowl traps in untreated and neem-treated plots of cabbage per week in the minor season, 2017 at Kpong

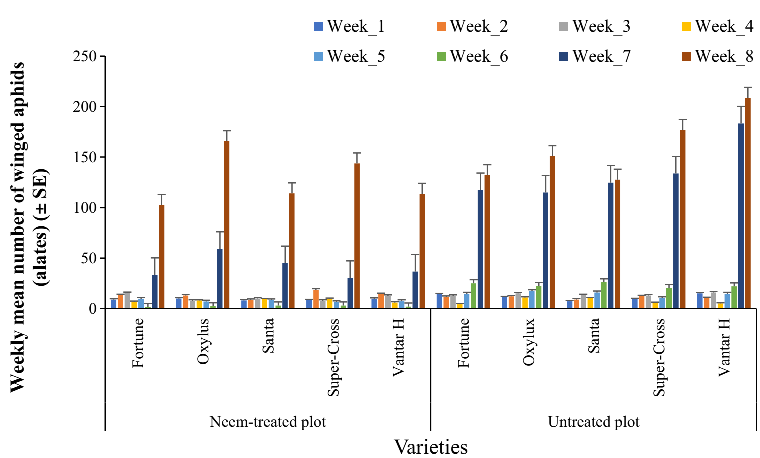

Table 2 Mean (±SE) number of plants showing symptoms of aphid infestation (incidence) and the extent of spread of symptoms (severity) on different varieties of cabbage in the first and second seasons of 2017 at Kpong

Variety	Major season		Minor season			
			Untreated plot		Neem-treated plot	
	Incidence	Severity	Incidence	Severity	Incidence	Severity
Oxylus	100.0 ± 0.0	3.0 ± 0.6 a	61.6 ± 10.8	3.0 ± 0.6 a	0.0 ± 0.0	0.0 ± 0.0
Super-Cross	100.0 ± 0.0	4.3 ± 0.3 c	79.7 ± 8.7	4.3 ± 0.3 bc	0.0 ± 0.0	0.0 ± 0.0
Santa	100.0 ± 0.0	4.0 ± 0.0 bc	84.8 ± 8.0	4.0 ± 0.0 abc	0.0 ± 0.0	0.0 ± 0.0
Vantar	100.0 ± 0.0	3.4 ± 0.3ab	77.5 ± 7.1	3.4 ± 0.3 ab	0.0 ± 0.0	0.0 ± 0.0
Fortune	100.0 ± 0.0	4.5 ± 0.0 c	96.1 ± 3.9	4.7 ± 0.2 c	0.0 ± 0.0	0.0 ± 0.0
F	–	6.18	2.87	6.2	–	–
P	–	0.014	0.096	0.014	–	–

Means with the same letter (s) are not significantly different ($P < 0.05$) within columns. (Aphids' infestation severity score = 0–5)

chlorophyll, water and protein content, and leaf thickness. Varieties with high chlorophyll, high water content and the thickest leaves were reported to be infested with fewer cabbage aphids than those with lower chlorophyll and water content and thinner leaves (Munthali and Tshegofatso 2014). Even though these factors were not tested, we could speculate they may have accounted for the difference in aphid populations observed in this study. However, Collier and Finch (2007) reported in a similar study that the level of resistance to aphids was not sufficient to ensure that varieties remained aphids free. This was the case in our current study, whereby all the varieties of cabbage succumbed to the attack by aphids resulting in their high numbers, 100% symptoms manifestation and zero yield during the major rainy season.

The symptoms observed as a result of the aphid infestation seems to be the major cause for the complete loss and low yield of cabbage in this current study. Also, the symptoms of aphid infestation were observed only on plants in the unsprayed cabbage experiment for both seasons. The incidence of the symptoms was not significantly different among the varieties, for both seasons. However, the severity of aphid infestation was significant among the varieties for both seasons. The symptoms were most severe on the variety Fortune and less severe on the Oxylus variety. During the major rainy season, all varieties succumbed to aphid infestation. However, in the minor season, the neem plot recorded no infestation of aphids. This indicates that the neem oil was able to protect the cabbage plant from attack by the aphids.

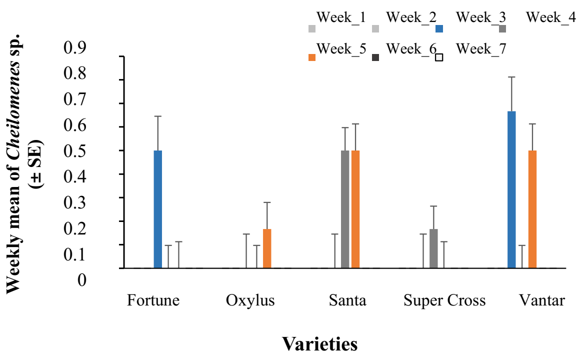

Fig. 7 Mean (± SE) number of *Cheilomenes lunata* ladybird larvae counted on untreated cabbage per week in the major rainy season, 2017 in Kpong. The difference in the ladybird abundance among the different varieties tested was not significant ($F_{4,\ 104}$ = 0.86; $P = 0.5260$)

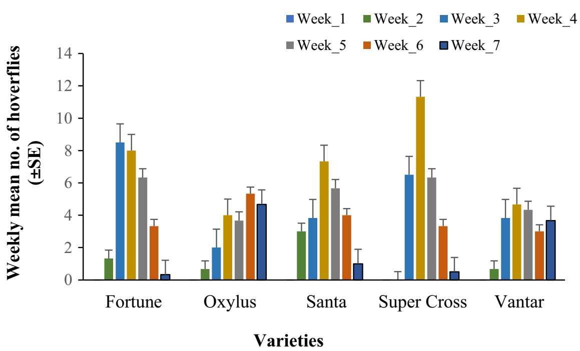

Fig. 8 Mean (± SE) number of hoverfly larvae on untreated cabbage per week in the major rainy season, 2017 at Kpong. The mean number of hoverflies was not significantly different among the varieties tested ($F_{4,\ 104} = 0.54$; $P = 0.7120$). However, the highest numbers were recorded in plots planted with Super Cross

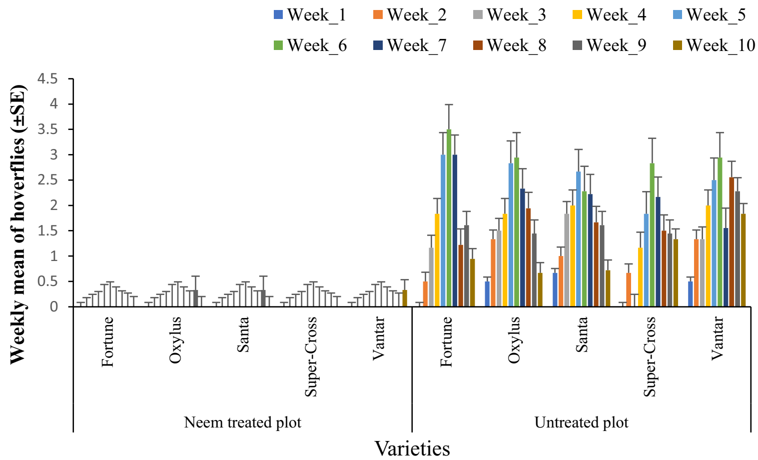

Fig. 9 Mean (± SE) number of hoverfly larvae counted per week on neem-treated and untreated cabbage in the minor rainy season in 2017 at Kpong. The average number of hoverfly larvae was not significantly different among the varieties of cabbage treated with neem ($F_{4,\ 149} = 1$; $P = 0.4610$). There was also no significant difference between the hoverfly larvae populations on the different untreated varieties of cabbage ($F_{4,\ 149} = 1.09$; $P = 0.4220$). Nevertheless, the highest numbers were recorded in plots planted with the variety Fortune

Neem-treated plots

The number of aphids (*L. e. pseudobrassicae* and *M. persicae*) on plants were significantly decreased by neem oil treatment and they were controlled to a similar degree by the treatment. Thus, neem oil reduces the aphid population to a very low level on all cabbage varieties tested, and supports earlier studies which found neem to be effective in controlling aphids on cabbage (Boopathi and Pathak 2011; Muhammad et al. 2013; Aline and Mauricio 2015; Djomaha et al. 2016; Ezena et al. 2016; Forchibe 2016; Forchibe et al. 2017).

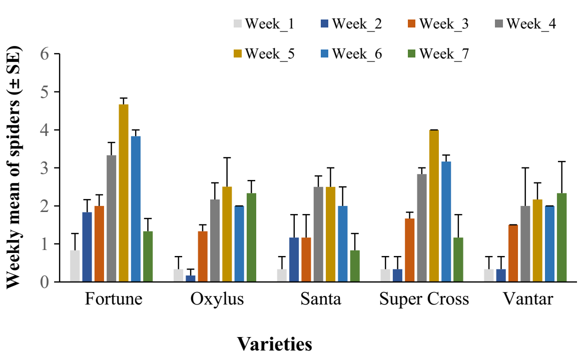

Fig. 10 Mean (± SE) number of spiders on untreated cabbage measured each week in the major rainy season in 2017 at Kpong. The difference in spider abundance among the varieties tested was significant ($F_{4,\ 104} = 8.53$; $P = 0.0060$). The most spiders were recorded in plots planted with the variety Fortune

Monitoring winged aphid populations using yellow water bowl traps

The results from the minor rainy season indicates that more winged aphids were caught during the morning than the afternoon, suggesting higher aphid activity during the morning. A similar study by Campbell and Muir (2005) suggested variations in aphid activity during the morning and afternoon. They observed a bimodal daily flight curves with 69% and 38% of emigrant aphids caught in the morning peak near Myrobalan and among hops, respectively. The fact that there were significantly higher number of winged aphids caught in the traps during the minor rainy season than the major rainy suggests that aphid populations increase during periods of limited and erratic rainfall. The minor rainy season in the study area is characterised by limited and erratic rainfall, unlike the major rainy season with more rainfall that is reliable (Forchibe et al. 2017; Fening et al. 2020).

Assessment of natural enemies (predators) of aphids and effects of neem oil on them

The natural enemies of aphids encountered during this study were ladybird beetle, *Cheilomenes lunata* (Fabricius) (Coleoptera: Coccinellidae), hoverfly, *Paragus borbonicus* Macq. (Diptera: Syrphidae) and spiders (Araneae). The populations of ladybird beetles and hoverflies were not significantly different between

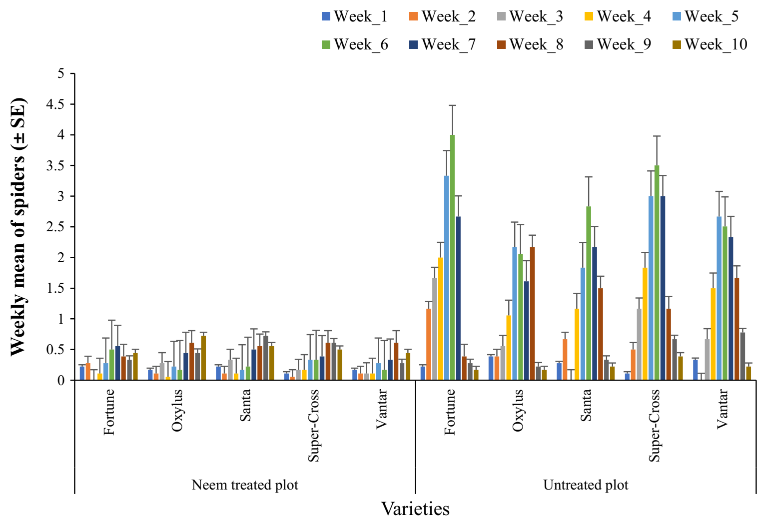

Fig. 11 Mean (± SE) number of spiders on neem-treated and untreated cabbage per week in the minor rainy season of 2017 in Kpong. There were no significant differences in spider abundance among the various treated cabbage varieties ($F_{4,\ 149} = 0.55$; $P = 0.7030$). There was also no significant difference between spider populations on the different untreated cabbage varieties ($F_{4,\ 149} = 3.18$; $P = 0.0770$)

the different varieties for the major and minor rainy seasons. This result can be explained by the fact that their prey (aphids) were available on the different varieties and that ladybird beetles and hoverflies were not directly attracted by the cabbage variety itself but by the aphids present on them. However, for the minor rainy season, the ladybird beetle was recorded only on the variety Fortune, possibly because of the high population of aphids observed on this variety. Conversely, the population of spiders on the different varieties of cabbage was significantly different for the major rainy season. The highest population was recorded on the variety Fortune, while the least was counted on the variety Vantar followed by Oxylus. This could be attributed to the higher population of aphids recorded on the variety Fortune compared to those recorded on Oxylus and Vantar and possibly the plant leaf architecture. Inversely, it was not significantly different for the minor rainy season, both on the unsprayed and the neem-sprayed plot. The neem treated plots had lower number of predators than the untreated plots. This low population of the natural enemies (ladybird beetles, hoverflies and spiders) recorded on varieties treated with neem oil, compared to the high numbers on the unsprayed plot, could be partly due to the equally low population of aphids which serve as their prey or food source, despite the fact that the neem seem to be reducing the population of the predators (Boopathi and Pathak 2011; Fening et al. 2013; Muhammad et al. 2013; Forchibe et al. 2017).

Table 3 Mean yield (± SE) for different varieties of cabbage in the second (minor) season of 2017 at Kpong

Varieties	Mean yield (tonnes/ha)		*t*-value	*P*
	sprayed	Unsprayed		
Fortune	14.80 ± 5.19	1.98 ± 1.67	10.15	< 0.001
Oxylus	21.10 ± 2.69	3.66 ± 1.66	5.51	0.005
Santa	17.50 ± 1.63	0.53 ± 0.53	9.86	< 0.001
Super-cross	20.40 ± 3.56	0.57 ± 0.57	5.49	0.028
Vantar	18.90 ± 2.73	0.19 ± 0.19	6.84	0.020
F	0.44	1.44		
P	0.775	0.304		

Means with the same letter (s) are not significantly different ($P < 0.05$) within columns. Means between treatments for the sprayed and unsprayed plots was compared using *t* test ($P < 0.05$) within rows

However, botanical insecticides, especially those derived from the neem tree, have been shown to be less toxic to spiders than synthetic insecticides (Stark 2013). Mansour et al. (1986) showed a relatively low toxicity of neem seed kernel extract when applied topically to the spider, *Chiracanthium mildei*. The results of a study undertaken by Punzo (1997) indicated that azadirachtin can cause significant mortality in wolf spider, *Lycosa pseudoannulata*. However, he reiterated that available information suggests that there is a wide range of tolerance among spiders toward neem extracts (Punzo 1997). The wolf spider, an important predator of rice pests, exhibited no mortality when exposed to 100 µg neem oil extract/spider. Punzo (1997) recommended that additional studies should be conducted on various species of spiders so that we may better understand the potential impact of neem extracts on these arthropods. A similar study by Mansour et al. (1986) on the toxicity of neem seed kernel extracts prepared with different solvents against the predatory spider, *Chiracanthium mildei* L. Koch revealed all neem extracts, irrespective of the solvent, were non-toxic at 2.5% and only caused some mortality from 4 to 8% concentrations for other solvents, but the aqueous crude extract was non-toxic.

Other studies have also demonstrated that neem negatively affected the population of natural enemies including ladybird beetles and hoverflies under laboratory conditions (Lowery and Isman 1994, 1995) but did not affect the field population. It is known that the desirable traits of neem that contribute to the preservation of natural enemies include limited oral toxicity, limited persistence, limited antifeedant and repellent activities and a general lack of toxicity to adult insects (Schmutterer 1990). These studies therefore concluded that in comparison to synthetic insecticides, neem-based botanicals appear to be relatively benign to beneficial insects and are suitable for inclusion in integrated pest management programmes (Schmutterer 1990; Lowery and Isman 1994, 1995).

Cabbage yield

From this study, the different varieties recorded a complete yield loss during the major rainy season. This result confirmed earlier work done by Palmer (1956) and Mc Cullum et al. (1992), who reported a complete yield loss on leafy brassica vegetables, owing to attack by the cabbage aphid, *B. brassicae*. However, the mean yield was not significantly different among the different varieties during the minor rainy season, for both unsprayed and sprayed plots. The yield obtained from the unsprayed plots was very low with further low quality in harvested heads (low marketability) compared to the neem-sprayed plots with high yield and high-quality heads (high marketability). From these findings, we suggest that cabbage cannot be cultivated in the study area without any protection measure if high yields and high-quality heads are expected.

Conclusion

In conclusion, the five cabbage varieties evaluated in the current study appeared in the following order of decreasing susceptibility: 'Fortune F1', 'Santa F1', 'Vantar F1', 'Super cross F1', and 'Oxylus'. However, all the varieties are suitable for cultivation in Ghana. These varieties should be used in combination with a low dose of botanicals such as neem oil or aqueous neem kernel extract to increase yield and quality of cabbage heads. Botanicals such as neem should be used as an alternative to synthetic insecticides for effective management of insect pests, and to preserve human health and the environment. Preferably neem should be applied during late afternoon to evening for enhanced action and that is the period most of the natural enemies may not be active on the crop. Since neem readily breaks down with sunlight, the natural enemies can recolonise the plant shortly afterwards to augment the control, after they were repelled way from the plant earlier on.

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Author contribution • Author 2 author 3, author 4 and author 5 conceived research.

• Author 1, 2 and 3 conducted experiments.
• Author 4 and author 5 contributed materials.
• Author 1 analysed data and conducted statistical analyses.
• All authors wrote the manuscript.
• Author 2 and author 5 secured funding.
• All authors read and approved the manuscript.Data availabilityAll raw data is provided in Supplementary File 1. We the authors confirm that, the data supporting the results have been

archived in an appropriate public repository. The raw data for this manuscript has been deposited in Figshare, https://figshare.com/s/09e8383904c7dd683d32.

Compliance with ethical standards

Conflict of interest There is no conflict of interest.

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