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Development of the Turnip Aphid, *Lipaphis erysimi* Kaltenbach (Homoptera: Aphididae), and Test of Insecticidal Efficacy of Some Commercial Natural Products

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The turnip aphid is a worldwide pest, damaging mainly to crucifers. In order to understand the life parameters of *Lipaphis erysimi* for the eventual goal of control, the developmental periods, survival rates, lifespan, and fecundity of the species were investigated under five temperature regimes (15°C - 35°C). Furthermore, the efficacy of several environment-friendly agricultural materials (EFAMs) that are on the market was subjected to test in order to obtain further accurate information. The developmental period of the turnip aphid nymph was longest at 15°C as 16.9 days, shortened as temperature goes up to 25°C (5.4 days), and then somewhat increased at 30°C (5.9 days), suggesting that the most efficient temperature for nymphal development could be around 25°C. Mortality of the nymphal turnip aphid was obvious at 35°C, whereas it was minimal at other temperature schemes. The longevity of adults shortened as temperature goes up to 30°C. In particular, the maximum lifespan for adults continued for 55 days at 15°C, but shortened to 21 days at 30°C. The total fecundity was 35.7 at 15°C, 81 at 20°C, 64.2 at 25°C, and 6.6 individuals at 30°C, showing the highest fecundity at 20°C. After the turnip aphids were successfully stabilized in indoor environment the insecticidal activity was tested and mortality was determined 12, 24, 36, and 48 hrs after EFAMs are treated. Several on-the-market EFAMs showed more than 90% of insecticidal activity within 24 hrs or 48 hrs, but a few showed less than 90% activity, signifying importance of selection of proper EFAMs.

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Introduction

The turnip aphid (*Lipaphis erysimi* Kaltenbach), belonging to a homopeteran family Aphididae is distributed world-widely (Blackman and Eastop, 1984). This aphid attacks several vegetable crops, particularly crucifers including broccoli, cabbage, Chinese broccoli, Chinese cabbage, radish, tomato, and zucchini. In Korea, the aphid mainly attack cabbage and radish. Large colonies of the species feed by sucking sap from theirs host, resulting in deformation and leaves curled, shriveled, and yellowed (Metcalf, 1962; Singh, *et al.*, 1965; Jagan Mohan *et al.*, 1981). Along with the damage caused by direct feeding on host plant, the aphid produces honeydew, which serves as a medium on which a sooty fungus grows. The turnip aphid is a vector of about 10 plant viruses, such as cabbage black ring spot and mosaic diseases of cauliflower, radish and turnip (Ahlawat and Chenulu, 1982; Blackman and Eastop, 1984; Castle *et al.*, 1992). The losses caused by the viruses may be greater than caused by direct feeding injury.

The biology of the species had been studied in several regions of the world (Kawada and Murai, 1979). In Korea, the aphids are known to over-winter in the form of eggs on the winter host, cruciferous plants and weeds, hatch from the last third of April to first third of May, become live female nymphs, produce winged adults, disperse to summer host, such as cabbage and radish, and cycle for over ten generations (website, http://insect.niast.go.kr). At the end of October, they disperse to winter host and over-winter as eggs again (website, http://insect.niast.go.kr).

For the eventual control of the aphids, possibly in the case of all insect pests, it would be important to have a closer examination of the life cycle of the target pest, and one such way could be artificial indoor rearing, because it allows us to observe many undetectable scenes that may not be possible in the field situation. Although a diverse studies on other aphids from domestic and foreign regions are available (Barlow, 1962; Komazaki, 1982; Liu and Perng, 1987; Kocourek and Beraniova, 1989; Kim *et al.*, 2004; Kim and Kim, 2004a; Kim and Kim, 2004b; Kim *et al.*, 2005), no such information was obtainable for the Korean population, although studies on the population of foreign region (Liu and Yue, 2001) and control of the species are present (Jeon *et al.*, 2005). Furthermore, the study by Liu and Yue (2001) did not investigate the life cycle at 35°C, although there is possibility for the species being exposure to such a high temperature in the field. Therefore, in this study, we investigated the developmental periods, survival rates, lifespan, and fecundity of the species under five temperature schemes (15°C - 35°C) using the Chinese cabbage as a host. Furthermore, we tested several on-the-market environment-friendly agricultural materials (EFAM) that state insecticidal efficacy against aphids. After the turnip aphid was successfully stabilized by rearing for over several generations in the laboratory condition a total of 18 EFAMs was purchased from local markets in Jeollanamdo Province and tested for insecticidal activity against the turnip aphid.

Materials and Methods

The turnip aphid and host plant

Nymphs of the turnip aphid (*Lipaphis erysimi*) were collected from the cabbage field of Chonnam National University in Gwangju, Korea. The aphids were maintained on the Chinese cabbage in a plastic cage of $35 \times 35 \times 40$ cm. The laboratory condition for the aphid rearing was as follows: 25 ± 1°C, relative humidity (RH) of 60 ± 5%, and a photoperiod of 16L : 8D.

To provide the turnip aphid with the cabbage the Elgari Chinese cabbage seeds were purchased from a market, sowed in a plastic cage ($6 \times 6 \times 10$ cm), and provided to the turnip aphids 25 days after growing in a growth cage ($165 \times 83 \times 124$ cm) with a photoperiod of 18L : 6D.

Development, survivorship, longevity, and fecundity

In order to investigate the developmental periods, survival rates, lifespan, and fecundity, individual healthy female aphids were inoculated in a round-shaped plastic cage ($\Phi 10 \times 6$ cm), containing tissues saturated with water on the bottom, filter paper on the middle, and one cabbage leaf disk (Φ10 cm in size) with the adaxial surface facing up on the top. New-born nymphs were collected for 12 hrs and were individually located to the plastic cages using a small hair brush. Thirty new-born nymphs were used for each temperature scheme. Development, survival rates, lifespan, and fecundity were examined for every 24 hrs. For the investigation of number of new-born nymph per day the counted nymphs were removed from the cage. Decision for the death was made when the movement of the aphids was not detectable for a while by touching with the brush. The RH and photoperiod were fixed to 60 ± 5% and 14L : 10D, whereas temperature scheme was set to 15 ± 1°C, 20 ± 1°C, 25 ± 1°C, 30 ± 1°C, and 35 ± 1°C.

Screening bioassay

For the test of insecticidal efficacy 18 environment-friendly agricultural materials (EFAM) were purchased from local markets located in Jellanamdo Province in 2007 (Table 1). To avoid unnecessary advertisement of the products used in this study, product names and companies were initialized and the applicable range of EFAMs and source of the products are listed in Table 1. Briefly, most products were originated plant extract, but the product H was mixture of *Bacillus subtilis* and plant extract, the product R contained fatty acid as the major ingredient, and the products N provided no information at all. Detailed components were not obtainable. According to the product description, they were all targeted at least for the control of the aphid. These products were diluted as recommended for the test of insecticidal efficacy (Table 1).

A spraying method was used to evaluate the activity of the test samples. The aphids were provided with a plain cabbage leaf was cut into Φ10 cm in size, inoculated with 20 mixed adults and nymphs, and sprayed with recommended concentration of EFAMs in a round plastic cage ($\Phi 10 \times 6$ cm). Every 12 hrs, the aphids were checked, dead aphids were removed, and eventually mortality was determined 48 hrs after EFAMs were treated. Nothing was treated for the control. The influence of water droplet was also tested with ddH_2O. Each set of experiment was carried out in triplicate. Using SAS program, Duncan's multiple range test ($p < 0.05$) was performed to test if any significant difference in the insecticidal effect exists among EFAMs.

Results and Discussion

Nymphal development

Sachan and Bansal (1975) reported that the turnip aphid undergoes four nymphal stages (instars) and takes about 8

Table 1. List of environment-friendly agricultural materials tested in the study

Product	Company	Insecticidal range	Major component	Recommended Dilution*
A	FM	Insect pests	Plant extracts	1000
B	PD	ML, A	〃	〃
C	F	A, other pests	〃	〃
D	NB	A	〃	〃
E	B	A, F, other pests	〃	〃
F	K	M, other insects	〃	〃
G	SL	Insect pests	〃	500
H	B	ML, M	〃	1000
I	H	A	Unknown	500
J	A	A, Insect pests	Plant extracts	〃
K	NB	ML	〃	1000
L	F	A, Insect pests	〃	〃
M	K	Insect pests	〃	〃
N	NB	A	〃	〃
O	KO	A	Plant extracts, Bacillus subtilis	〃
P	K	A, other pests	Plant extracts	〃
Q	L	A	〃	〃
R	A	A	Fatty acid	〃

*per 20 liter of water.
Abbreviations in insecticidal range represent A for aphid, AS for *Agrotis segetum*, F for flies, M for mite, and ML for moth larvae.

Table 2. Development periods of *Lipaphis erysimi* on Chinese cabbage under several temperature regimes in the laboratory

Temperature (°C)	Duration (mean ± SD)				Accumulated duration
	1st instar	2nd instar	3rd instar	4th instar	
15	118.4±0.74[a]	96.0±1.49[a]	88.8±2.15[a]	101.6±1.41[a]	404.8±4.43[a]
20	51.6±0.66[b]	46.4±0.45[b]	36.4±0.78[b]	54.6±0.65[b]	189.5±1.48[b]
25	30.0±0.45[c]	33.6±0.50[b]	26.4±0.37[b]	37.2±0.60[c]	128.4±0.49[c]
30	33.6±0.50[c]	36.0±0.51[b]	33.6±0.50[b]	39.2±0.68[c]	140.4±0.81[c]

Mean values with the same alphabet are not significantly different ($P>0.05$, Duncan's Multiple Range Test).

-9 days, although minor variations can occur depending on the host plants (Sachan and Bansal, 1975). The developmental duration of the turnip aphid at different temperatures are presented in Table 2 and Figure 1. It was 16.9 days (404.8 hrs) at 15°C, 7.9 days (189.5 hrs) at 20°C, 5.4 days (128.4 hrs) at 25°C, and 5.9 days (140.4 hrs) at 30°C, showing statistically significant difference among temperature regimes (Table 2). Developmental duration shortened as temperature goes up to 25°C (5.4 days, 128.4 hrs) and shows that the duration decreased more than three folds as temperature goes up. On the other hand, developmental duration increased unexpectedly at 30°C compared with 25°C. At 35°C most nymphal turnip aphids were all died before/at 4th instar, although other temperature regimes showed a minimal death ratio during nymphal development (data not shown). Considering these results it seems that the most efficient temperature for nymphal development of the turnip aphid could be around 25°C.

Liu and Yue (2001) reported the developmental duration of the apterous nymphs of the turnip aphids was 13.8, 6.8, 6.1, and 5.0 days at 15, 20, 25, and 30°C. This result indicates somewhat shorter developmental duration (Liu and Yue, 2001) than our result, except for the duration at 25°C, wherein it was 5.4 days in this study, but was 6.1 days by them. Other different feature of our study was unexpectedly increased developmental duration at 30°C, although Liu and Yue (2001) did not observe such abnormality. Nevertheless, similar result was reported from other aphids. For example, Kim and Kim (2004a) reported the developmental duration decreased from 12.4 days to 4.9 days as temperature goes up from 15 to 27.5, but it again increased to 5.0 days at 30 and 6.3 days at 35 in the green peach aphid, *Myzus persicae*. Furthermore, Kim *et al.* (2004) reported it decreased from 11.5 days to 4.6 days as temperature goes up from 15 to 30, but it again increased

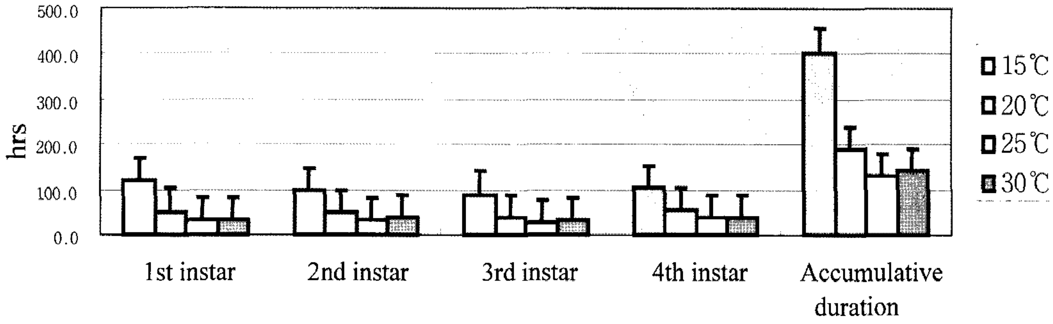

Fig. 1. Development periods of Lipaphis erysimi nymphs on Chinese cabbage under four different temperature schemes in the laboratory.

Table 3. Adult longevity and fecundity of *Lipaphis erysimi* at various temperatures (mean ± SD)

Temperature (°C)	Adult		
	Longevity (hrs)	Fecundity (hrs)	Nymphs/female/day
15	1148.0±7.62[a]	35.7±23.55[c]	1.2±0.82[c]
20	785.6±11.3[b]	80.6±20.52[a]	2.6±0.81[b]
25	579.6±6.92[c]	64.2±24.24[b]	3.4±1.33[a]
30	458.4±5.11[d]	6.60±4.12[d]	0.3±0.21[d]

Mean values with the same alphabet are not significantly different ($p > 0.05$, Duncan's Multiple Range Test).

to 5.5 days at 32.5 in the cotton aphid, *Aphis gossypii.* Thus, these results are totally in agreement with our result of the turnip aphid in that the developmental duration increases from certain higher temperature. Considering most nymphal turnip aphids were died at 35°C in this study, it seems that the temperature higher than 30°C may be lethal or at least sub-lethal for the survival of the turnip aphis, although more dense temperature regime may require for better speculation.

Fecundity and longevity of adults

The forth-molted adult turnip aphids started to produce nymphs one day after become adults. Sachan and Bansal (1975) also found it takes one - two days for the adult females start to produce young after emerging from the last molt.

Sachan and Bansal (1975) reported that wingless females produce 70 - 87 young in their lifetime, while winged females produce 31 - 40 young. In this study, a total of 35.7, 81, 64.2, and 6.6 individuals were produced at 15°C, 20°C, 25°C, and 30°C, respectively and these values were different statistically ($p < 0.05$) (Table 3). Thus, the largest number of nymph were produced at the temperature regime of 20°C, but the number of production decreased as temperature goes up (Fig. 2). At 30°C, a significant amount of decrease in nymphal production was observed (only 6.6 individuals per female). Furthermore, some of the nymphs produced were abnormal in the morphology, not fully developed and these abnormal nymphs were died after a few days (Fig. 3). Thus, this temperature seems to be damaging that hampers normal physiological development of the turnip aphids. On the other hand, Liu and Yue (2001) reported the number of nymphs was 52.5, 90.8, 83.2, and 29.7 individuals at 15°C, 20°C, 25°C, and 30°C. Thus, somewhat higher number of young was produced from all temperature regimes than this study (Liu and Yue, 2001). Nevertheless, the nymphal production pattern between the two studies is similar in that the highest number of nymph was observed at 20°C, number of nymphs decreased as temperature increases, and there were somewhat large increase between temperature regimes 15°C and 20°C.

It has been reported that the turnip aphids produces young for 13 - 20 days (Sachan and Bansal, 1975). In this study, the nymph production was continued for 21.9, 19, 17, and 5.1 days at 15°C, 20°C, 25°C, and 30°C, respectively. Nymphal production reached to the highest peak at 7 days (9 nymphs) and second highest peak at 12 days (7 nymphs), indicating that most progeny are borne at early stage of adulthood. On the other hand, Liu and Yue (2001) reported the nymphal production for 34, 24, 25, and 11 days at 15°C, 20°C, 25°C, and 30°C, respectively. Thus, longer production duration was reported by Liu and Yue (2001). Nevertheless, both studies show similar pattern in that the temperature regime at 15°C is longest for nymphal production, but dramatically dropped down at 30°C, suggesting that the temperature regime 30°C is obviously unfavorable condition for nymphal production in the turnip aphids.

The longevity of adult turnip aphids is also presented in Figure 2. The longevity was 31, 24.9, 18.8, and 13.2 days at 15°C, 20°C, 25°C, and 30°C, respectively, and these val-

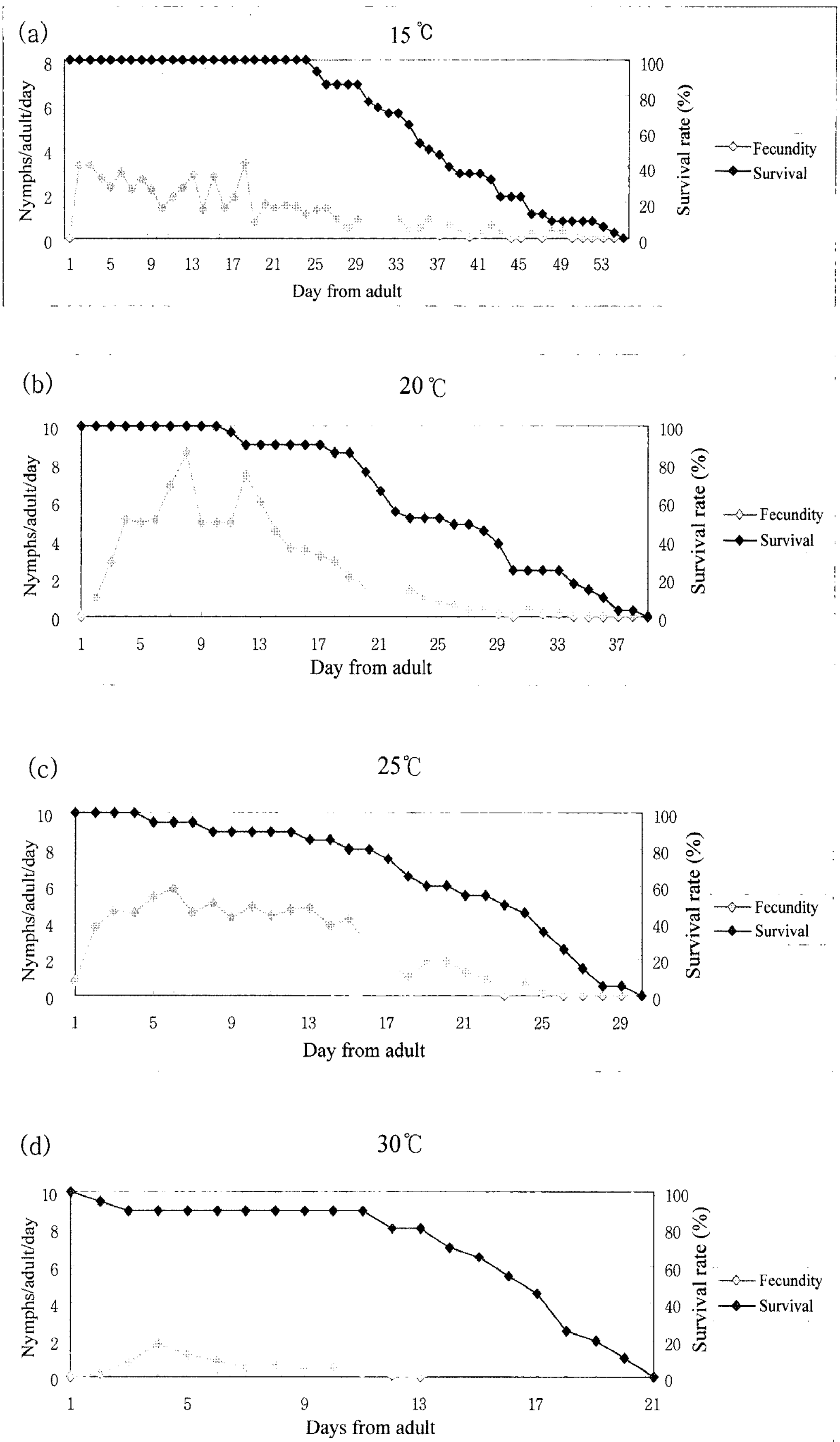

Fig. 2. Survival rates and fecundity of *Lipaphis erysimi* on Chinese cabbage under five temperature schemes in the laboratory. Adult survival rates and fecundity at (a) 15°C, (b) 20°C, (c) 25°C, and (d) 30°C. (e) Nymph survival rate at 35°C.

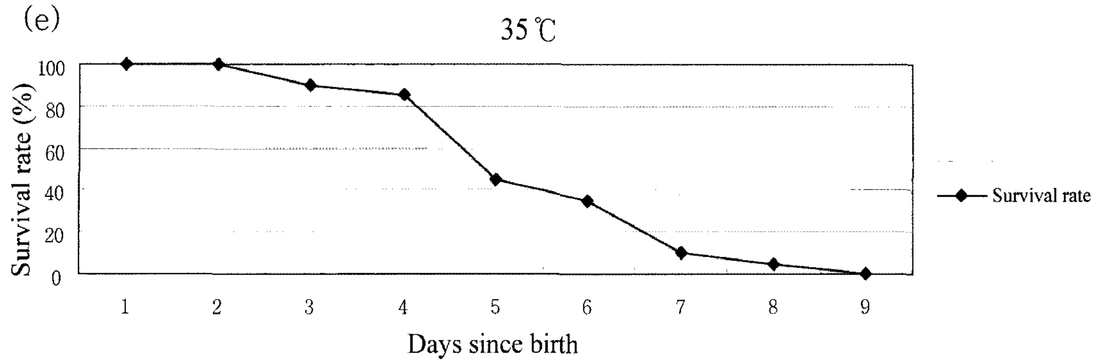

Fig. 2. Continued.

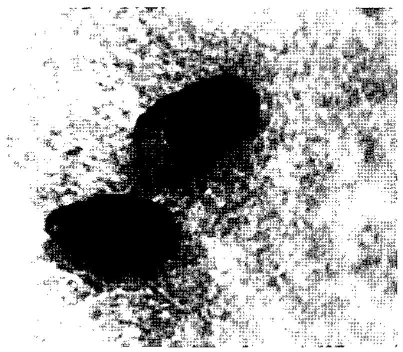

Fig. 3. Malformed 1st instar nymph of *Lipaphis erysimi* reared on 30°C.

ues were different statistically ($p<0.05$) (Table 3). At 35 about 50% of the nymphs were dead before 4^{th} instar and all but one nymph (4.7 days for mean survival duration) (Fig. 2e). Only a single nymph stayed as nymph up to 9^{th} days, without metamorphosis as adult (Fig. 2e). This result suggests that the lifespan of the turnip aphids were longest at 15°C and shortest at 30°C. On the other hand, Liu and Yue (2001) reported the longevity of the turnip aphis was 25.3, 21.3, 17.5, and 11.7 at 15, 20, 25, and 30, respectively, indicating somewhat shorter lifespan in the study by Liu and Yue (2001). Nevertheless, both studies show the adult lifespan decreases as temperature goes up.

Table 4. Insecticidal activity of eighteen environment-friendly agricultural materials against to *Lipaphis erysimi*

Products	% mortality (±SD) after			
	12 hrs	24 hrs	36 hrs	48 hrs
A	36.7 ± 7.6^{c}	98.3 ± 2.9^{a}	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}
B	95.0 ± 5.0^{a}	98.3 ± 2.9^{a}	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}
C	73.3 ± 5.8^{b}	98.3 ± 2.9^{a}	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}
D	13.3 ± 5.8^{def}	55.0 ± 21.8^{b}	98.3 ± 2.9^{a}	100.0 ± 0.0^{a}
E	36.7 ± 7.6^{c}	98.3 ± 2.9^{a}	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}
F	3.3 ± 5.8^{efg}	56.7 ± 40.7^{b}	96.7 ± 2.9^{ab}	98.3 ± 2.9^{a}
G	11.7 ± 7.6^{efg}	56.7 ± 16.1^{b}	93.3 ± 5.8^{ab}	98.3 ± 2.9^{a}
H	0.0 ± 0.0^{g}	26.7 ± 12.6^{cd}	65.0 ± 5.0^{ef}	96.7 ± 2.9^{ab}
I	76.7 ± 2.9^{b}	91.7 ± 2.9^{a}	93.3 ± 5.8^{ab}	93.3 ± 5.8^{abc}
J	15.0 ± 5.0^{de}	40.0 ± 5.0^{bc}	83.3 ± 7.6^{bcd}	91.7 ± 2.9^{abc}
K	21.7 ± 15.3^{d}	56.7 ± 11.5^{b}	91.7 ± 7.6^{abc}	91.7 ± 7.6^{abc}
L	1.7 ± 2.9^{gh}	25.0 ± 0.0^{cd}	68.3 ± 2.9^{ef}	91.7 ± 10.4^{abc}
M	5.0 ± 8.7^{efg}	56.7 ± 23.1^{b}	75.0 ± 21.8^{de}	91.7 ± 2.9^{abc}
N	70.0 ± 5.0^{b}	83.3 ± 2.9^{a}	86.7 ± 2.9^{abcd}	86.7 ± 2.9^{bcd}
O	8.3 ± 7.6^{efg}	40.0 ± 13.2^{bc}	83.3 ± 2.9^{bcd}	86.7 ± 2.9^{bcd}
P	1.7 ± 2.9^{gh}	38.3 ± 2.9^{bc}	78.3 ± 2.9^{cde}	83.3 ± 2.9^{cd}
Q	6.7 ± 2.9^{efg}	35.0 ± 8.7^{bc}	76.7 ± 7.6^{de}	80.0 ± 5.0^{d}
R	6.7 ± 7.6^{efg}	21.7 ± 5.8^{cde}	56.7 ± 17.6^{f}	60.0 ± 20.0^{e}
ddH_2O	1.7 ± 2.9^{gh}	3.3 ± 2.9^{de}	3.3 ± 2.9^{g}	3.3 ± 2.9^{f}
Control	0.0 ± 0.0^{g}	0.0 ± 0.0^{e}	0.0 ± 0.0^{g}	0.0 ± 0.0^{f}

Mean values with the same alphabet are not significantly different ($p>0.05$, Duncan's Multiple Range Test).

In fact, Sidhu and Singh (1964) reported that high temperatures shorten the life span and cooler temperatures increase longevity in India.

Insecticidal efficacy

Among 18 EFAMs, several showed more than 90% of insecticidal activity against *Lipaphis erysimi* within 24 hrs (Table 4). These are A, B, C, E, and I. Along with these, the product N showed ~80% insecticidal efficacy. Thus, many commercialized EFAMs truly have insecticidal efficacy. Considering the observation that the turnip aphids produce several nymphs per day during life cycle of adult female, prompt insecticidal efficacy of the EFAMs would be very critical. In this regard, these products may be very useful, although field experiment should confirm this result. When test duration increased to 48 hrs most EFAMs showed strong insecticidal efficacy against *L. erysimi* and these also can be the possible candidates for the control of the turnip aphids. Nevertheless, the products N, O, P, Q, and R never reached to 90% even within 48 hrs. Thus, these products are questionable for the field efficacy for insecticidal effect, because the field situation might be much coarse for the EFAMs to exert efficacy.

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