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전남지역에서 꽃매미 부화시기 예측과 친환경 방제방법

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Environmentally-friendly Control Methods and Forecasting the Hatching Time *Lycorma delicatula* (Hemiptera: Fulgoridae) in Jeonnam Province

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ABSTRACT: This study was conducted to predict the hatching time of eggs of *Lycorma delicatula*, to select an effective environmentally-friendly agriculture material (EFAM) and to evaluate the attraction effect of brown sticky traps for controling of *Lycorma delicatula* nymph and adults. Eggs hatched 55.9, 26.8, 21.6 days after incubation at 15, 20, 25℃ with 14L:10D condition and the hatching rates of egg were 61.9, 57.8, 30.4%, respectively. At high temperature conditions, egg development periods were shorter and the hatching rate was lower. The relationship between temperature and developmental rate was expressed by the linear equation Y=0.0028X-0.0228, R^2=0.9561. The low temperature threshold of eggs was 8.14℃ and the thermal constant required to reach larva was 355.4 DD. According to this relationship, the mean estimated hatching date was 22nd May. The effective EFAM was natural plant extract, sophora extract, derris extract to nymph and natural plant extract, pyrethrum extract, sophora extract to adult. Among three colors of sticky trap : brown, blue and yellow, the brown sticky trap was the most attractive to nymphs and adults of *L. delicatula* over a 2 weeks trial period. It suggested that the brown sticky trap could be a very useful and environment-friendly control method for nymphs and adults of *L. delicatula*.

Key words: *Lycorma delicatula*, Low temperature threshold, Sticky trap

초 록: 본 시험은 온도 발육모델을 이용하여 꽃매미 알의 부화시기를 예측하고 약충과 성충 방제에 효과적인 친환경 자재선발 및 끈끈이트랩 색상별 유인효과를 찾기 위하여 수행하였다. 꽃매미 알은 15, 20, 25℃(14L:10D)에서 각각 55.9, 26.8, 21.6일 만에 부화하였고 부화율은 각각 61.9, 57.8, 30.4%로 온도가 높을수록 부화소요기간은 짧고 부화율은 낮았다. 알의 온도와 발육속도와의 관계식은 Y=0.0028X-0.0228 (R2=0.9561)이었으며, 발육영점온도는 8.14℃, 유효적산온도는 355.4일도였다. 위의 관계식에 의하여 전남지역 꽃매미 알의 부화시기는 5월 22일로 예측되었다. 꽃매미 약충방제에 효과적인 친환경자재는 제충국추출물, 고삼추출물, 데리스추출물이었고, 성충은 제충국추출물, 고삼추출물이었다. 황토색, 파랑색, 노랑색 끈끈이트랩 중에서 황토색끈끈이트랩의 유인량은 2주 동안에 약충 535마리, 성충 87.7마리였다. 황토색 끈끈이트랩은 꽃매미 약충과 성충의 유인포살효과가 우수하였다.

검색어: 꽃매미, 발육영점온도, 끈끈이트랩

우리나라에서 꽃매미(*Lycorma delicatula*)는 2006년부터 밀도가 증가하기 시작하여, 2007년에는 서울, 경기, 충북, 2008년에는 충남 천안, 공주, 연기, 전북 정읍, 경북 상주 등으로 확산되었고(KFRI, 2007; Han et al., 2008), 전남지역에는 2010년에 장성, 영광, 담양을 시작으로 2011년에는 나주, 화순, 구례 등 전남 중북부 지역까지 확대되었다. 꽃매미는 중국 및 동남아시아 등지에서 서식하는 아열대성 해충으로 중국에서 국내로 유입 정착한 것으로 보고되었다(Han et al., 2008). 꽃매미의 기주식물은 목본류 38종, 초본류 3종 등 총 41종이며, 피해가 심한 종은 가래나무, 유럽참죽나무, 참죽나무, 호주참죽나무, 쉬나무, 황벽나무, 소태나무, 가죽나무, 미국담쟁이덩굴, 머루, 포도로 알려져 있으며(Park et al., 2009), 특히 기주를 선택하고

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섭식하는데 영향을 미치는 것은 당 성분으로 가죽나무와 포도나무를 가장 선호한다(Lee et al., 2009). 지금까지 꽃매미 방제를 위한 농약으로 람다사이할로스린+티아메톡삼입상수용제 등 7종이 등록되었다(KCPA, 2010). 또한 신 등(2010)은 알과 1~2령 약충에 대하여 26약제의 약제감수성을 조사한 결과 Chlorpyrifos는 알에 대하여 100%의 높은 부화억제율을 나타내었으며 약충은 모든 약제에서 100% 살충효과가 있었다.

꽃매미의 친환경 방제에 관한 연구는 국내외적으로 거의 이루어지지 않았으며, Liu et al.(2006)은 꽃매미 장기로부터 *Bacillus polymyxa* 등 4종을 분리하였으며 의학적으로 중요한 해충자원이라고 한 바 있다. 꽃매미를 친환경적으로 방제하는 가장 확실하고 효과적인 방법은 산란된 알집을 부화하기 전에 제거하는 방법이지만 넓은 면적에 대발생한 경우 일일이 하나하나 제거하기는 매우 어려운 일이다. 따라서 본 시험은 꽃매미 알의 온도별 발육시험을 통하여 유효적산온도에 의한 알의 부화시기를 예측하여 방제적기를 산출하고, 약충과 성충 방제에 효과적인 친환경자재를 선발하고, 끈끈이트랩 색상별 꽃매미 약충과 성충의 유인효과를 검정하여 친환경적인 꽃매미 방제방법을 찾고자 수행하였다.

재료 및 방법

온도별 발육시험을 이용한 알의 부화시기 예측

2010년 가을에 꽃매미가 대량 발생하였던 광주 무등산 인근 산림속에 산란된 알덩어리를 2011년 2월 15일에 채집하여 항온기내에서 2월 16일부터 4월 17일까지 부화시험을 수행하였다. 또, 자연조건에서 부화시기와 부화율을 조사하기 위하여 알 채집지역에 있는 난괴 10개에 매직으로 표시하여 놓고 5월에 매일 부화한 충을 조사하였다.

망사뚜껑이 달린 직경 90 mm, 높이 40 mm의 플라스틱 페트리디쉬 바닥에 증류수로 적신 탈지면을 깔고 그 위에 파라필림과 채집한 난괴 1개씩 넣고 뚜껑을 닫아 온도별 15반복으로 15, 20, 25, 30 ℃(14L:10D) 항온기(EYELA MTI-201)에 넣어 매일 부화하는 약충을 조사하였다. 이 때 항온기 내에서 알의 건조를 막기 위하여 바닥에 증류수를 담은 스테인레스 밧드(28×22×5 cm)를 넣었고 3일 간격으로 증류수를 보충하여 주었다. 부화가 완결된 후 10호 붓을 이용하여 난괴를 덮고 있는 밀납물질을 털어내고 해부현미경하에서 탈출구멍을 확인하며 부화여부를 판단하였다. 발육영점온도는 알의 온도별 발육기간의 역수를 취하여 발육속도를 산출하였고, 발육속도가 0이 되는 온도를 발육영점온도로 하였으며, 유효적산온도는 발육시험하였던 각각의 온도에서 발육영점온도를 뺀 값에 발육기간을 곱하여 산출된 온도의 평균값을 취하였다. 온도와 발육속도와의 관계식은 Excel 2007 프로그램을 이용하여 계산하였다.

친환경 자재의 꽃매미 살충력 검정

친환경자재의 꽃매미 약충에 대한 살충력을 검정하기 위하여 꽃매미가 많이 발생한 광주 무등산 인근의 야산에서 포충망을 이용하여 어린약충을 채집하였으며, 가죽나무를 기주로 유리온실에서 사육하며 이용하였다. 친환경 자재의 살충율 시험은 실험실 조건에서 수행하였다. 겉에 가는 망사를 씌운 20×40 cm(직경×높이)의 원통형 케이스 내부에 300 ㎖ 삼각플라스크에 증류수를 담고 야외에서 채집한 가죽나무 가지를 꽂고 약충을 각각 10 마리씩 접종한 후 약충이 안정을 찾을 수 있도록 1일간 정치한 후 처리자재별 1,000배로 희석한 약제가 담긴 스프레이를 이용하여 망사케이지 밖에서 돌려가며 10회 분무하여 약제가 식물체에서 흘러내리도록 분무하였으며 살포량은 약 15 ㎖였다. 또한 최대한 자연조건에 맞추기 위하여 약제처리 직후부터 시험종료 시까지 회전식 선풍기를 약풍으로 돌려 야외조건에서 바람에 의한 건조 조건과 유사하게 맞추어 주었으며, 약제처리 1일, 3일, 5일 후 죽은 충수를 조사하여 살충율을 계산하였다. 모든 약제시험은 3반복으로 수행하였으며 성충에 대한 살충력 시험도 약충과 동일한 조건으로 수행하였다.

끈끈이트랩 색상별 꽃매미 유인 포살효과

꽃매미 약충과 성충의 친환경적이고 생력적인 방제방법을 찾고자 끈끈이트랩의 색상별 유인효과를 조사하였다. 2011년 6월 하순 꽃매미 약충이 3~4령인 시기에 꽃매미 발생량이 많은 숲 인근의 참나무 줄기에 지면에서 1 m 높이에서부터 폭 20 cm의 황토색, 파랑색, 노랑색 끈끈이트랩을 차례로 설치하였다. 트랩과 트랩의 간격은 10 cm로 하였으며, 색상 위치간의 차이를 줄이기 위하여 색깔별 상, 중, 하로 배치하여 3반복으로 설치하였고 2주 후 트랩에 부착하여 죽은 충수를 조사하였다. 성충에 대해서도 동일한 장소에서 동일한 방법으로 2011년 9월 1일에 설치하였고 2주후 포획된 성충을 조사하였다. 또한 성충에 대하여는 추가적으로 유인효과가 가장 높았던 황토색 끈끈이트랩을 이용 상, 중, 하에 모두 황토색을 붙여 위치에 따른 유인량을 조사하였다.

결과 및 고찰

온도별 발육시험을 이용한 알의 부화시기 예측

꽃매미 알은 갈색이며 길이 2.40 mm, 폭 1.49 mm, 높이 1.51 mm로 난괴당 36.8개를 4.4줄로 산란하는데 식물체 표면 또는 편평한 부위에 알을 낳고 밀납물질로 알의 형태가 보이지 않도록 덮어 씌운다. 꽃매미 알의 온도별 부화율은(Table 1), 15, 20, 25, 30℃에서 각각 61.9, 57.8, 30.4, 0 %였고, 부화하는데 소요기간은 15, 20, 25℃에서 각각 55.9일, 26.8일, 21.6일로 온도가 높을수록 부화율은 낮았고, 부화하는데 소요기간은 짧았다. 특히 30℃에서는 전혀 부화하지 못했는데, 이는 항온기 내부에 증류수를 공급하였음에도 불구하고 알이 건조하여 부화하지 못했거나, 자연조건에서 저온에 있던 알을 갑자기 높은 온도조건으로 이동에 따른 온도충격에 의한 것으로 판단된다. 신 등(2010)은 꽃매미 알 채집일자별 부화율을 조사한 결과 채집일이 늦을수록 부화율은 높고 알 기간은 짧아지는데, 2월 20일에 채집한 알의 알기간이 25℃에서 26.4±4.05일로 본 시험결과인 21.6일보다 다소 짧았다.

알의 온도별 발육기간의 역수를 취하여 발육속도를 산출하였고, 온도와 발육속도와의 관계식을 Excel 프로그램을 이용하여 산출한 결과 Y= 0.0028X-0.0228 (R^2=0.9561)의 관계식을 얻을 수 있었고, Y가 0이 되는 발육영점온도는 8.14℃였으며, 유효적산온도는 355.38일도였다(Table 1).

이상의 결과를 기초로 2011년 4월 30일을 기준으로 꽃매미 알 채집지역인 광주 기상대 자료를 이용하여 꽃매미 부화시기를 예측하였다(Table 2). 2월 1일부터 4월 30일까지는 2011년 기상자료를 이용하였고, 5월 1일 이후는 전년도인 2010년 기상자료를 이용하여 일평균기온이 발육영점온도인 8.14℃ 이상이 되었던 최초일은 2월 24일이었으며 유효적산온도인 355.4일도가 되는 날은 5월 22일로 계산되어 알의 부화시기는 2011년에는 5월 22일로 예측할 수 있었다. 한편, 부화시험용 난괴 채집지역의 실제 부화기간은 5월 15일부터 20일이였으며 부화율은 82.8%였다. 발육영점온도, 유효적산온도와 기상자료를 이용하여 예측한 부화시기보다 4일 빠르며 부화율도 82.8%로 항온기에서 시험하였던 부화율보다 높게 나타났다. 현지포장에서의 부화율이 항온기 시험보다 부화율이 높았던 것은 인위적으로 조성한 환경 즉 소음, 건조, 광조건 등이 알의 부화를 저해하는 스트레스로 작용하였을 수 있으며, 현지의 부화시기와 예측하였던 시기가 차이가 나는 것은 미세기상의 차이에 의한 것으로 판단된다.

현재까지 우리나라에서 지역별 꽃매미 부화시기를 직접 언급한 결과는 없지만 신 등(2010)에 의하면 충북 청주지역에서 5월 25일까지 부화하지 않은 알을 채집할 수 있었는데 본 연구에서는 5월 20일에 부화완료 되었는데, 2011년 2월부터 5월의 일평균기온이 청주는 9.38℃, 광주는 9.9℃로 광주지역이 청주보다 평균기온이 0.52℃ 높기 때문에 부화시기가 빨랐던 것으로 판단된다.

친환경 자재의 꽃매미 살충력 검정

농촌진흥청 유기농자재로 공시된 제충국추출물 등 9종의 꽃

Table 1. Hatching rate of *L. delicatula* at different temperatures (14L:10D), developmental zero point and effective cumulative temperature

Temp. (℃)	Sample size	Hatched egg	Hatching rate(%)	Time required for hatch(days)	Calculated temperature
15	574	355	61.85	55.9(54~59)	• linear equation : Y=0.0028X-0.0228 (R^2=0.9561)(Y=temp., X=dev. rate) • Lower threshold temp. : 8.14℃ • Degree day : 355.4
20	626	362	57.83	26.8(26~29)	
25	543	165	30.39	21.6(21~23)	
30	572	0	0		

Table 2. Prediction of the hatching time of *L. delicatula* eggs based on low developmental threshold and effective cumulative temperature (prediction day : 30 April, 2011)

Division	Date	Calculation source
Predicted hatching time	22 May (5/19~24)	- 2/1~4/30 : Used 2011 weather data[1] - 5/1~ : Used 2010 weather data
Real hatching time	18 May (5/15~5/20)	- Hatching rate : 82.8%

[1]Data were obtained from Gwangju regional meteorological administration.

Table 3. Cumulative mortality of *L. delicatula* nymphs treated with several environmentally-friendly agricultural materials (EFAM)

Materials	Dilution rate	No. of sample	Cumulative mortality (%)		
			1 DAT[1]	3 DAT	5 DAT
Pyrethrum extract Ⅰ	1,000	19	89.6 a*	100 a	100 a
Pyrethrum extract Ⅱ	1,000	23	65.2 b	69.5 bc	73.8 c
Sophora extract Ⅰ	1,000	29	23.9 c	58.8 cd	93.3 ab
Sophora extract Ⅱ	1,000	20	15.0 cd	55.0 cds	95.0 a
Derris extract	1,000	19	10.8 de	79.1 b	94.4 a
Neem extract Ⅰ	1,000	22	8.9 de	45.2 de	73.7 c
Neem extract Ⅱ	1,000	22	13.6 cd	40.5 e	77.6 bc
Sophora+cinnamon extract	1,000	20	19.5 cd	19.5 f	54.5 d
Sophora extract Ⅲ	1,000	19	15.4 cd	79.4 b	100 a
Untreated		20	0.0 e	9.6 f	14.9 e

* Means followed by different letters within the column are significantly different at the 5% level by DMRT.
[1]DAT : day after treatment.

Table 4. Cumulative mortality of *L. delicatula* adult treated with several environmentally-friendly agricultural materials (EFAM)

Materials	Dilution rate	No. of sample	Cumulative mortality (%)	
			1 DAT1	2 DAT
Pyrethrum extract Ⅰ	1,000	20	95.0 a*	100 a
Pyrethrum extract Ⅱ	1,000	20	95.0 a	100 a
Sophora extract Ⅰ	1,000	20	83.3 ab	93.3 ab
Sophora extract Ⅱ	1,000	20	71.6 bc	85.0 b
Derris extract	1,000	20	76.7 bc	90.0 ab
Neem extract Ⅰ	1,000	20	85.0 ab	100 a
Neem extract Ⅱ	1,000	20	83.3 ab	100 a
Sophora+cinnamon extract	1,000	20	65.0 c	85.0 b
Sophora extract Ⅲ	1,000	20	96.7 a	100 a
Untreated		20	10.0 d	15.0 c

* Means followed by different letters within the column are significantly different at the 5% level by DMRT.
[1]DAT : day after treatment.

매미 약충에 대한 살충효과를 조사한 결과(Table 3), 처리 1일 후 제충국추출물은 89%의 살충율을 보였고 나머지 자재는 비교적 낮은 살충율을 보였다. 처리 3일후 70% 이상의 살충율을 보였던 자재는 제충국추출물, 데리스추출물, 고삼추출물로 3종이었고, 5일 후에는 고삼+계피추출물을 제외한 모든 처리에서 70% 이상의 살충율을 보였다. 성충에 대한 살충효과도(Table 4), 제충국추출물 등 6종이 처리 1일후 80% 이상의 높은 살충율을 보였다. 박 등(2009)에 의하면 2~3령 약충은 일부 화학농약 처리 2시간 후 100%의 살충율을 보인 것으로 보아 약제에 약한 해충이었는데, 본 시험에서 꽃매미의 살충효과 검정시 무처리구에서 약충은 3일후 12.5%, 성충은 1일후 10%로 비교적 사망률이 높았던 것으로 보아 약충, 성충 모두 제한된 밀폐공간에 적응하지 못하는 약한 해충임을 알 수 있었다.

끈끈이트랩 색상별 꽃매미 유인 포살효과

황토색, 파랑색, 노랑색 끈끈이트랩을 이용하여 꽃매미 약충에 대한 유인 포살효과를 조사한 결과(Table 5, Fig. 1), 트랩 높이에 관계없이 황토색 끈끈이트랩에만 많은 약충이 유인 포살되었다. 참나무 줄기의 크기는 다르지만 황토색을 맨 위쪽에 설치했을 때 단위면적당 부착량이 5.5 마리/10 cm^2로 가장 많았으며 다음으로 하 3.6, 중앙 3.2순이었으며, 상부 설치 트랩에는

Table 5. Attraction effect of colored sticky traps to the nymphs (3~4th) of *L. delicatula*

Repeat	Trap size	Trap color	No. of attracted/trap	No. of attracted/10 cm^2
1	78×20 cm (1,560 cm^2)	Brown (top)	860	5.5
		Blue (middle)	5	0
		Yellow (under)	3	0
2	60×20 cm (1,200 cm^2)	Yellow (top)	1	0
		Brown (middle)	385	3.2
		Blue (under)	3	0
3	50×20 cm (1,000 cm^2)	Blue (top)	2	0
		Yellow (middle)	1	0
		Brown (under)	360	3.6
Mean	1,253 cm^2	Brown	535.0	4.3
		Blue	3.3	0
		Yellow	1.7	0

※ Trap installed periods (2011. 6. 30 ~ 7. 13).

Fig. 1. The attraction effect of colored sticky traps to the nymphs and adults of *L. delicatula* (A; installed colored sticky traps ; brown, blue and yellow, B; Nymphs attracted to brown, blue and yellow, C; Adults attracted to brown sticky traps, D; nymphs attraction to brown sticky traps, E; adult attraction to brown sticky traps).

더 이상 붙을 공간이 없을 정도로 약충이 많이 붙었다. 이러한 결과는 성충에 대하여도 동일한 경향으로(Table 6), 황토색 끈끈이트랩에서 단위면적당 부착량이 상, 중, 하 위치별 각각 0.8, 0.4, 0.7마리/10 cm^2였다.

Table 6. Attraction effect of colored sticky traps to the adults of *L. delicatula*

Repeat	Trap size	Trap color	No. of attracted/trap	No. of attracted/10 cm^2
1	85×20 cm (1,700 cm^2)	Brown (top)	132	0.8
		Blue (middle)	2	0
		Yellow (under)	2	0
2	65×20 cm (1,300 cm^2)	Yellow (top)	1	0
		Brown (middle)	58	0.4
		Blue (under)	0	0
3	55×20 cm (1,100 cm^2)	Blue (top)	1	0
		Yellow (middle)	2	0
		Brown (under)	73	0.7
Mean	1,366.7 cm^2	Brown	87.7	0.6
		Blue	1	0
		Yellow	1.7	0
	80×20 cm (1,600 cm^2)	Brown (top)	67	0.4
		Brown (middle)	39	0.2
		Brown (under)	49	0.3

※ Trap installed periods (2011. 9. 1 ~ 9. 14).

이상의 결과를 종합해 볼 때, 황토색 끈끈이트랩은 꽃매미 약충과 성충 유인효과가 높은 것으로 판단되어 2011년 9월 중순 꽃매미가 소량 발생한 전남 담양군 고서면의 산림과 인접한 포도밭 (3,000 m^2)의 가장자리 포도나무 70주에 격주로 줄기의 1m 높이에 황토색 끈끈이트랩을 설치한 결과 2주 후 3마리의 성충이 끈끈이트랩에 부착하여 죽은 것을 확인할 수 있었으며, 포도밭 전체에 서식하면서 끈끈이트랩에 부착되지 않은 성충은 없었다. 이상의 결과로 황토색 끈끈이트랩의 가장자리 설치는 꽃매미가 발생한 산림 인근의 포도밭으로 유입되는 꽃매미를 효율적이고 생력적으로 차단시킬 수 있을 것으로 판단되며, 도시 근교 공원지역에 발생하여 등산객에게 혐오감을 유발하는 지역에서도 적용할 수 있을 것으로 생각된다.

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Environmentally-friendly Control Methods and Forecasting the Hatching Time *Lycorma delicatula* (Hemiptera: Fulgoridae) in Jeonnam (South Jeolla) Province

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ABSTRACT: This study was conducted to predict hatching time of *Lycorma delicatula*, to select effective environmentally-friendly agricultural material (EFAM) and to evaluate the attraction effectiveness of sticky traps in different colours for controlling *L. delicatula* nymphs and adults. At temperatures 15, 20, and 25d°C (14L:10D), eggs of *L. delicatula* hatched after 55.9, 26.8 and 21.6 days, respectively, and the hatching rates were 61.9, 57.8 and 30.4%, respectively. The higher the temperature, the shorter the time it took the eggs to hatch, and the lower the hatching rate. The relation between the temperature and the development rate of eggs can be expressed as $Y=0.0028X-0.0228$ ($R^2=0.9561$), and the threshold temperature was 8.14°C and the effective thermal constant was 355.41 DD. Based on the relationship above, the hatching date of *L. delicatula* in the Jeonnam area was predicted to be May 22. The effective EFAMs were pyrethrum extract, sophora extract and derris extract against nymphs, and pyrethrum extract and sophora extract against adults. Of the three colours of sticky traps, brown, blue and yellow, the brown attracted 535 nymphs and 87.7 adults over two weeks, and found to be highly effective in attracting and killing nymphs and adults of *L. delicatula*.

Key words: *Lycorma delicatula*, threshold temperature, sticky trap

In South Korea, the densitity of *L. delicatula* started to increase in 2006, and their distribution expanded to Seoul, Gyeonggi Province and North Chungcheong Province in 2007, to Cheonan, Gongju and Yeongi in South Chungcheong Province, Jeongeup in North Jeolla Province and Sangju in North Gyeongsang Province in 2008 (KFRI, 2007, Han et al., 2008). In South Jeolla (Jeonnam) Province, they spread into Jangseong, Yeonggwang and Damyang in 2010 and in 2011 they spread to the central north area of the province including Naju, Hwasun and Gurye. It was reported that *L. delicatula* was a subtropical pest insect living in China and Southeast Asia, and that they entered to South Korea from China (Han et al., 2008). Thirty-eight species of trees and three species of grasses, a total of 41 species of trees and grasses are known as host plants of *L. delicatula*, and the plants known to have been most badly affected are Juglans mandshurica, European Toona sinensis, Toona sinensis, Australian Toona sinensis, Evodia daniellii, Phellodendron amurense, Picrasma quassioides, Ailanthus altissima, Parthenocissus quinquefolia, Vitis coignetiae and Vitis(Park et al., 2009). In particular, when selecting a host to feed on, they prefer Ailanthus altissima and Vitis most for their sugar content (Lee et al., 2009). So far, as insecticides to control *L. delicatula*, seven types have been registered including lambda-cyhalothrin and thiamethoxam water soluble granules (KCPA, 2010). Also, Shin et al (2010) investigated chemical sensitivity of *L. delicatula* eggs and first- and second-instar nymphs to 26 types of materials and found that Chlorpyrifos had 100% effectiveness as an egg-hatching inhibitor and that all the materials were 100% effective as insecticides against nymphs.

Few studies have been done either in Korea or elsewhere regarding environmentally-friendly methods of controlling *L. delicatula*, and Liu et al. (2006) collected 4 types [of bacteria?] including Bacillus polymyxa from organs of *L. delicatula* and stated they were medically important resources for insect control. The most reliable and effective method to control *L. delicatula* in an environmentally friendly way is to remove eggs before they hatch, but it is very hard to remove eggs one by one when they are laid in large numbers over large areas. Therefore this study was conducted to determine the appropriate time to control them by predicting the egg-hatching time based on the effective thermal constant through investigation into their development at different temperatures. The study also aimed at selecting environmentally friendly materials to control nymphs and adults of L. delicature and identifying environmentally friendly method of controlling them by determining effectiveness of sticky traps in different colours in attracting nymphs and adults of *L. delicatula*.

Materials and Methods

Predicting egg-hatching time through studying development at different temperatures

Egg masses laid in forests near Mt. Mudeun in Gwangju City, where a large outbreak of *L. delicatula* took place in the fall of 2010, were collected on February 15, 2011, and were incubated in incubators from February 16 to April 17. Also to observe hatching time and rate under natural conditions, 10 egg masses in the area where eggs were collected were marked with a permanent marker and hatched insects were studied every day in May.

In plastic Petri dishes 90 mm in diameter and 40 mm in height, absorbent cotton made wet with distilled water was placed at the bottom and on top of it parafilm and one egg mass per dish were placed. The dishes were closed with a mesh lid and kept in incubators (EYELA MTI-201) at the temperatures 15, 20, 25 and 30°C (14L:10D), and every day hatched nymphs were observed. This was repeated 15 times for each temperature. To prevent eggs from getting dry in incubators, a stainless pad (28x22x5 cm) soaked with distilled water was placed at the bottom of the dishes, and distilled water was added every three days. After hatching was complete, waxy substance covering the egg mass was swept off using a number 10 brush and eggs were examined to determine whether or not they had hatched by observing emergence holes with dissecting microscope. The development rate was calculated by taking the reciprocal of the incubating period of each temperature and the temperature where the development rate was 0 was identified as the threshold temperature. The effective thermal constant was determined as the mean value of the temperatures that were calculated by subtracting the threshold temperature from each temperature used in the development experiment and multiplying the resulting value by the development period. The relationship between the temperature and the development rate was calculated using Excel 2007 program.

Examination of effectiveness of environmentally friendly materials as insecticides for *L. delicatula*

To examine the effectiveness of environmentally friendly materials for nymphs of *L. delicatula*, young nymphs were collected using insect nets on fields and in forests near Mt. Mudeun in Gwangju City and Ailanthus altissima was grown in a glass greenhouse and used as a host. Environmentally friendly materials were tested for their effectiveness as insecticides under laboratory conditions. In cylinder shaped cases 20 cm in diameter and 40 cm in height, covered with fine mesh on surface, a 300ml Erlenmeyer flask with distilled water inside was placed. Branches of Ailanthus altissima collected outside were inserted, and 10 nymphs were inoculated in each case and let sit for one day to give the nymphs time to settle. Each material was diluted 1000 times and sprayed 10 times while circulating the sprayer around the mesh cage, in a way that the solution would drip from the plant matter. Approximately 15 ml was sprayed. To simulate natural conditions, from the application of materials till the end of the experiment, a rotating fan was operated at low speed, creating a drying condition similar to that by

natural wind outside. One, three and five days after the materials were applied, the numbers of dead insects were counted and mortality rates were calculated. Tests of all the materials were repeated three times, and effectiveness of materials for adults was tested in the same way.

Effectiveness of sticky traps in different colours in attracting and killing *L. delicatula*

For the purpose of finding environmentally friendly and efficient methods of controlling *L. delicatula* nymphs and adults, effectiveness of sticky traps in different colours in attracting them was studied. In late June 2011, when *L. delicatula* nymphs are in the third to fourth instar, brown, blue and yellow sticky traps 20 cm in width were affixed on the trunk of oak trees, at one metre from the ground near a forest where *L. delicatula*s appear in large numbers. The distance between two traps was set at 10 cm, and to diminish the differences due to the location of the colours, each colour was placed top, middle and bottom, and each pattern was repeated three times. After two weeks, the adults that had been captured were examined. Also, regarding adults, to study the effect of the locations, the brown sticky traps, which had shown the highest attraction effect, were placed at the top, middle and bottom and their attraction effect was examined.

Results and observations

Predicting egg-hatching time through examination of development at different temperatures

The egg of *L. delicatula* is brown and 2.40mm long, 1.49mm wide and 1.51mm high, and one egg mass contains 36.8 eggs in 4.4 rows. They are laid on the surface or flat part of a plant, and covered with waxy substance, which make them invisible from outside. Hatching rates of *L. delicatula* eggs by temperature are 61.9%, 57.8%, 30.4% and 0% at 15℃, 20℃, 25℃ and 30℃, respectively, and the numbers of days that the eggs took to hatch were 55.9 days, 26.8 days and 21.6 days at 15℃, 20℃ and 25℃, respectively (Table 1). The higher the temperature, the lower the hatching rate and the shorter the time required before hatching. The reason why no eggs hatched at 30℃ is thought to be either that the eggs got dry despite the supply of distilled water in the incubator, or that eggs were affected by the rapid change of conditions due to the transfer from natural low temperature to the high temperature. Shin et al. (2010) examined hatching rates by egg collection date and reported that the later the collection date, the higher the hatching rate. The egg period of eggs collected on February 20 was 26.4±4.05 days at 25℃ and was slightly shorter than the result of this study, which was 21.6 days.

By taking the reciprocals of the development periods of the eggs and calculating the development rates, the relation between the temperature and development rate was calculated by the Excel program as $Y=0.0028X-0.0228$ ($R^2=0.9561$). The threshold temperature, where Y becomes 0 was 8.14℃ and the effective thermal constant was 355.38 DD (Table 1).

Based on the results above, using data from the meteorological observatory in Gwangju City, where *L. delicatula* eggs were collected, hatching time of *L. delicatula* was predicted with April 30, 2011 as the base date (Table 2). For the period February 1 to April 30, meteorological data from 2011 were used and for May 1 and later, those in the previous year, 2010, were used. The first date when the daily mean temperature was 8.14℃, which is the threshold temperature, or higher was February 24, and the date when the effective thermal constant is reached was calculated to be May 22. Therefore for 2011, the hatching date was predicted to be May 22. The actual hatching period in the area where egg masses had been collected for the study was from May 15 to 20 at the hatching rate of 82.8%; four days earlier than the hatching date predicted based on the threshold temperature, thermal constant and meteorological data, and the hatching rate of 82.8% was higher than that in the study using incubators. The reason for

the higher hatching rate in the actual collection area is thought to be that in the study, artificial conditions such as noise, dryness and lighting affected the eggs as stress factors that inhibited hatching. The difference between the actual hatching time and the predicted time is attributed to subtle differences in meteorological conditions.

So far, there are no study results that directly discuss the hatching time of *L. delicatula* by region, but according to Shin et al. (2010), in Cheongju City in North Chungcheong Province, unhatched eggs could be collected until May 25, whereas in the present study in Gwangju City, hatching was complete by May 20. The mean daily temperature from February to May, 2011 was 9.38°C in Cheongju and 9.9°C in Gwangju, and Gwangju's mean temperature being 0.52°C highter than that of Cheongju is thought to be the cause of earlier hatching in Grangju.

Table 1. Hatching rate of *L. delicatula* at different temperatures (14L:10D), developmental zero point and effective cumulative temperature

Temp. (℃)	Sample size	Hatched egg	Hatching rate(%)	Time required for hatch(days)	Calculated temperature
15	574	355	61.85	55.9(54~59)	• linear equation : Y=0.0028X-0.0228 (R^2=0.9561)(Y=temp., X=dev. rate) • Lower threshold temp. : 8.14℃ • Degree day : 355.4
20	626	362	57.83	26.8(26~29)	
25	543	165	30.39	21.6(21~23)	
30	572	0	0		

Table 2. Prediction of the hatching time of *L. delicatula* eggs based on low developmental threshold and effective cumulative temperature (prediction day : 30 April, 2011)

Division	Date	Calculation source
Predicted hatching time	22 May (5/19~24)	- 2/1~4/30 : Used 2011 weather data[1] - 5/1~ : Used 2010 weather data
Real hatching time	18 May (5/15~5/20)	- Hatching rate : 82.8%

[1]Data were obtained from Gwangju regional meteorological administration.

Examination of insecticidal effectiveness of environmentally friendly materials for *L. delicatula*

The insecticidal effectiveness for *L. delicatula* nymphs of nine environmentally friendly materials publicly notified by the Rural Development Administration [of South Korea], including pyrethrum extract, was studied, and the results are shown in Table 3. One day after the application, pyrethrum extract recorded the insecticidal rate of 89% and other materials indicated relatively lower rates. Three days after the application, the number of materials that recorded an insecticidal rate of 70% or higher went up to three: pyrethrum extract, derris extract and sophora extract. Five days after the application, all the materials except sophora+cinnamon extract recorded a rate of 70% or higher. For *L. delicatula* adults, six materials including pyrethrum extract recorded a high insecticidal rate of 80% or higher one day after the application (Table 4). According to Park et al. (2009), nymphs in the second or third instar were 100% dead after application of chemical insecticides and therefore they are found to be weak against chemicals. In the present study, during the preparation period of examination of insecticidal effectiveness, 12.5% of *L. delicatula* nymphs were dead after three days and 10% of adults were dead after one day; these relatively high mortality rates indicate that both nymphs and adults of *L. delicatula* are weak and cannot adapt to restrictive closed space.

Table 3. Cumulative mortality of *L. delicatula* nymphs treated with several environmentally-friendly agricultural materials (EFAM)

Materials	Dilution rate	No. of sample	Cumulative mortality (%)		
			1 DAT[1]	3 DAT	5 DAT
Pyrethrum extract Ⅰ	1,000	19	89.6 a*	100 a	100 a
Pyrethrum extract Ⅱ	1,000	23	65.2 b	69.5 bc	73.8 c
Sophora extract Ⅰ	1,000	29	23.9 c	58.8 cd	93.3 ab
Sophora extract Ⅱ	1,000	20	15.0 cd	55.0 cds	95.0 a
Derris extract	1,000	19	10.8 de	79.1 b	94.4 a
Neem extract Ⅰ	1,000	22	8.9 de	45.2 de	73.7 c
Neem extract Ⅱ	1,000	22	13.6 cd	40.5 e	77.6 bc
Sophora+cinnamon extract	1,000	20	19.5 cd	19.5 f	54.5 d
Sophora extract Ⅲ	1,000	19	15.4 cd	79.4 b	100 a
Untreated		20	0.0 e	9.6 f	14.9 e

* Means followed by different letters within the column are significantly different at the 5% level by DMRT.
[1]DAT : day after treatment.

Table 4. Cumulative mortality of *L. delicatula* adult treated with several environmentally-friendly agricultural materials (EFAM)

Materials	Dilution rate	No. of sample	Cumulative mortality (%)	
			1 DAT1	2 DAT
Pyrethrum extract Ⅰ	1,000	20	95.0 a*	100 a
Pyrethrum extract Ⅱ	1,000	20	95.0 a	100 a
Sophora extract Ⅰ	1,000	20	83.3 ab	93.3 ab
Sophora extract Ⅱ	1,000	20	71.6 bc	85.0 b
Derris extract	1,000	20	76.7 bc	90.0 ab
Neem extract Ⅰ	1,000	20	85.0 ab	100 a
Neem extract Ⅱ	1,000	20	83.3 ab	100 a
Sophora+cinnamon extract	1,000	20	65.0 c	85.0 b
Sophora extract Ⅲ	1,000	20	96.7 a	100 a
Untreated		20	10.0 d	15.0 c

* Means followed by different letters within the column are significantly different at the 5% level by DMRT.
[1]DAT : day after treatment.

Effectiveness of sticky traps in different colours in attracting and killing *L. delicatula*

Brown, blue and yellow sticky traps were used to study their effectiveness in attracting and killing *L. delicatula* nymphs (Table 5, Fig.1). Regardless of the height of the traps placed, only the brown trap attracted and killed a large number of nymphs. While the oak trunks varied in size, in terms of the number of nymphs captured per area, the brown trap placed at the top recorded the highest number, which was 5.5 nymphs/10 cm^2, followed by the brown trap placed at the bottom at 3.6 nymphs/10 cm^2, and in the middle at 3.2 nymphs/10 cm^2. The trap at the top had so many nymphs attached that it looked like there was no space left for more. The results with adults showed the same tendency (Table 6), and the numbers of adults per area on the top, middle and bottom brown traps were 0.8/10 cm^2, 0.4/10 cm^2, and 0.7/10 cm^2, respectively.

Table 5. Attraction effect of colored sticky traps to the nymphs (3~4th) of *L. delicatula*

Repeat	Trap size	Trap color	No. of attracted/trap	No. of attracted/10 cm^2
1	78×20 cm (1,560 cm^2)	Brown (top)	860	5.5
		Blue (middle)	5	0
		Yellow (under)	3	0
2	60×20 cm (1,200 cm^2)	Yellow (top)	1	0
		Brown (middle)	385	3.2
		Blue (under)	3	0
3	50×20 cm (1,000 cm^2)	Blue (top)	2	0
		Yellow (middle)	1	0
		Brown (under)	360	3.6
Mean	1,253 cm^2	Brown	535.0	4.3
		Blue	3.3	0
		Yellow	1.7	0

※ Trap installed periods (2011. 6. 30 ~ 7. 13).

Fig. 1. The attraction effect of colored sticky traps to the nymphs and adults of *L. delicatula* (A; installed colored sticky traps ; brown, blue and yellow, B; Nymphs attracted to brown, blue and yellow, C; Adults attracted to brown sticky traps, D; nymphs attraction to brown sticky traps, E; adult attraction to brown sticky traps).

Table 6. Attraction effect of colored sticky traps to the adults of *L. delicatula*

Repeat	Trap size	Trap color	No. of attracted/trap	No. of attracted/10 cm^2
1	85×20 cm ($1,700\ cm^2$)	Brown (top)	132	0.8
		Blue (middle)	2	0
		Yellow (under)	2	0
2	65×20 cm ($1,300\ cm^2$)	Yellow (top)	1	0
		Brown (middle)	58	0.4
		Blue (under)	0	0
3	55×20 cm ($1,100\ cm^2$)	Blue (top)	1	0
		Yellow (middle)	2	0
		Brown (under)	73	0.7
Mean	$1,366.7\ cm^2$	Brown	87.7	0.6
		Blue	1	0
		Yellow	1.7	0
	80×20 cm ($1,600\ cm^2$)	Brown (top)	67	0.4
		Brown (middle)	39	0.2
		Brown (under)	49	0.3

※ Trap installed periods (2011. 9. 1 ~ 9. 14).

Considering all the results above, it is determined that the brown sticky trap is highly effective in attracting nymphs and adults of *L. delicatula*. In mid September 2011, in a vineyard (3,000m^2) near mountains and forests in Goseo-myeon, Damyang-gun, South Jeolla Province, where there had been an outbreak of *L. delicatula*, 70 grapevines at the edges were selected and a brown sticky trap was installed on every other grapevine at the height of one metre from the ground. After two weeks, three *L. delicatula* adults were found dead on traps, and in the entire vineyard, there were no adults who lived there and were not caught on a trap. Therefore, installation of brown sticky traps at the edges of vineyards near mountains and forests where *L. delicatula* emerged can be consider to be useful to block the inflow of *L. delicatula* into the vineyards efficiently and without too much effort. It is also thought that this method can also be used with parks near urban areas, where L. delicature can emerge and cause unpleasant feelings among hikers.

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