Phenology/Degree-Day Model Analysis – Vers. 1, Dec. 9, 2019

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Honeydew Moth/Christmas Berry Webworm ***Cryptoblabes gnidiella*** **(Millière)** **[Lepidoptera: Pyralidae]**

Native to Mediterranean Basin; established in many countries with similar climates including in Brazil and Uruguay

Hosts: Citrus, grape, avocado, pomegranate, banana, stone fruits, pome fruits, coffee, corn, cotton, sorghum

Goal: Develop a phenology model and temperature-based climate suitability model using available literature and weather data analysis

- We propose a compromise lower temperature threshold of 12.22C or 54.0F
- Ringenberg et al. 2005 (below) suggested a low threshold of 11.97C for eggs, 13.4C for larvae, 10.36C for pupae, and 12.26C for adults
- The larvae has the longest deveopment of the stage
- The species may overwinter as either larva (instars 1-5) or pupa or a combination of both

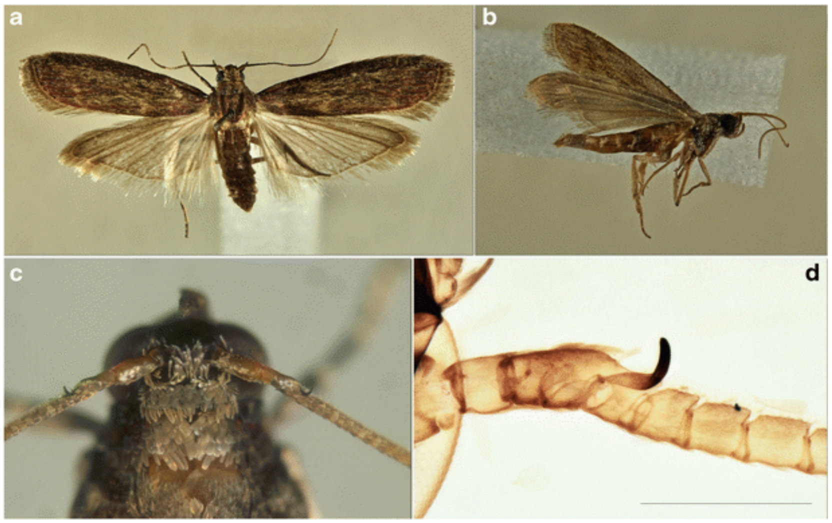


Figure from Lucchi et al. 2019 (Source 12, below)

Thresholds, degree-days and events used in Honeydew Moth model:

Parameter abbr.	Description	degF	degC	DDF	DDC
eggLDT	egg lower dev threshold	54.0	12.2	-	-
eggUDT	egg upper dev threshold	95.0	35.0	-	-
larvaeLDT	larvae lower dev threshold	54.0	12.2	-	-
larvaeUDT	larvae upper dev threshold	95.0	35.0	-	-
pupaeLDT	pupae lower dev threshold	54.0	12.2	-	-
pupaeUDT	pupae upper dev threshold	95.0	35.0	-	-
adultLDT	adult lower develpmental threshold	54.0	12.2	-	-
adultUDT	adult upper dev threshold	95.0	35.0	-	-
eggDD	duration of egg stage in DDs	-	-	91	50
larvaeDD	duration of larvae stage in DDs	-	-	523	290
pupaeDD	duration of pupae stage in DDs	-	-	262	145
adultDD	duration of adult stage in DDs	-	-	81	45
Gen TimeDD	duration of generations in Dds	-	-	956	531
OWpupaeDD	DDs until OWpupae emerge	-	-	221	123
eggEventDD	DDs into egg stage when hatching begins	-	-	81	45
larvaeEventDD	DDs into larvae stage when mid-larval occurs	-	-	261	145
pupaeEventDD	DDs until 1st adult emergence	-	-	261	145
adultEventDD	DDs into adult stage when 1st oviposition occurs	-	-	69	38

Parameter abbr.	**Description**	**degF**	**degC**	**DDF**	**DDC**
chillstress_threshold	chill stress threshold	46.4	8.0	-	-
chillstress_units_max1	chill degree day limit when most individuals die	-	-	1980	1100
chillstress_units_max2	chill degree day limit when all individuals die	-	-	3510	1950
heatstress_threshold	heat stress threshold	95.0	35.0	-	-
heatstress_units_max1	heat stress degree day limit when most individuals die	-	-	360	200
heatstress_units_max2	heat stress degree day limit when all individuals die	-	-	1080	600
distro_mean	average DDs to emergence	-	-	344	191
distro_var	variation in DDs to emergence	-	-	1080	600
xdist1	minimum DDs (°C) to emergence	-	-	221	123
xdist2	maximum DDs (°C) to emergence	-	-	466	259
distro_shape	shape of the distribution	-	-	normal	normal

Model for uspest.org (site model parameters):

1[st] adult emergence in Spring	-	-	221	123
Spring gen. peak adult emergence	-	-	344	191
Spring gen. peak larvae	-	-	696	387
Gen 1 peak adult emergence	-	-	1300	722
Gen 2 peak adult emergence	-	-	2255	1253
Gen 3 peak adult emergence	-	-	3211	1784
Gen 4 peak adult emergence	-	-	4167	2315
Gen 5 peak adult emergence	-	-	5123	2846
			6078.4825	

Notes about DDRP model

Thresholds
- Using durations of stages in this model yields a generation length of 531 DDCs
- A LDT of 12.22C was used based on x-intercept method analysis of Source 2 (Salama et al. 2008)
- UDT of 35.0C for all stages: at 35C, there is high mortality (~70%) of eggs and low adult emergence (only ~37% normal) (Source 3)
- Chill and heat stress thresholds and limits mainly derived from Source 2 and the CLIMEX model deveoped for this study

Durations
- Duration of egg stage and adult stage were compiled from other sources besides Source 2 (Salama 2008) (see next table)
- EggDD estimated using data of Salama 2008 was problematic (see analysis), so relied on other sources
- The duration of adult stage was the most problemetic to estimate. If we assume that sources 3 and 7 incorporate only part of OV, then adultDD (preOV + part of OV) is ~40 to 60 DDCs
- Thus, an adultDD of 45 was applied based on this range of values

Data synthesis across sources: stage durations in degree-days

Source 1 (Avidov & Gothilf 1960) LDT: 13.7C
Source 2 (Salama 2008) LDT: 12.2C (estimated using x-intercept method)
Source 3 (Ringenberg et al. 2005) LDT: 12.26; data frrom 26C raised on diet 2
Source 5 (Vidart et al 2013): LDT = 12.6C
Source 6 (Swailem et al. 1972) LDT: 12.22; data collected at avg. of 25C or 27C (very low sample size at 25C)
Source 7 (Ozturk 2018) LDT: 12C
Source 8 (Abdel Kareim et al. 2018): LDT of 12.26; data collected at 26C

Stage	Source 1	Source 2	Source 3	Source 5	Source 6	Source 7	Source 8	Notes
Immature stgs								
Egg	46.3	88.7	49.6	-	-	-	56.6	Source 2's estimate for egg DD is problemetic
Pre-pupa	-	39.8	-	-	-	-		
Larva	-	250.6	352.8	-	338.8	-	199.8	
1st instar	-	-	-	-	41.8	-	37.2	
2nd instar	-	-	-	-	41.8	-	31.7	
3rd instar	-	-	-	-	41.8	-	45.5	
4th instar	-	-	-	-	68.8	-	51.0	
5th instar	-	-	-	-	95.8	-	34.5	
Pupa	-	145.3	99.2	-	164.6	-	147.4	

Larva + pup	454.5	435.7	463.0	-	503.3	-	347.3	
Egg + L + P	500.8	525.0	512.6	-	-	-	406.5	
Adult stage^								
PreOV + OV	80.8	-	57.3	-	86.9	61.8	89.2	Sources 3 and 7: assume probably only part of OV
PreOV	22.2	-	-	-	29.4	-	-	Duration - see below
OV	58.7	-	-	-	57.5	-	-	
30% OV	17.6	-	-	-	17.3	-	-	
PreOV + 30% OV	39.8	-	-	-	46.6	-	-	
Full gen.	500.0	-	569.9	543.3	-	536.6	495.7	Source 1 does not appear to consider the adult pre-OV period in the generation time, but this is not clear

Data synthesis across sources: # of generations (to check against CLIMEX model developed for this study)

Gens - Literature	Gens - CLIMEX	Lat	Long	Site	Data source
5 to 6	5.4	31.89	34.81	Rehovot, Israel	Source 1 (Avidov & Gothilf 1960)
3.25	4.3	-29.16	-51.53	Caxias do Sul, Brazil	Source 3 (Ringenberg et al. 2005)
9.19	8.6	-9.37	-40.50	Petrolina, Brazil	Source 3 (Ringenberg et al. 2005)
5 to 7	5.5	32.70	35.27	Yizre'el Valley, Israel	Source 4 (Yehuda et al. 1991)
3	3.5	-34.59	-56.26	Dept of Canelones, Uruguay	Source 5 (Vidart et al. 2013)
5	5.1	36.92	34.89	Tarsus, Turkey	Source 7 (Ozturk 2018)
2 to 3	5.6	31.20	31.52	Shirbin, Dakahlia Province, Egypt	Source 8 (Abdel Kareim et al. 2018)
4	2.8	43.47	11.43	Tuscany, Italy	Source 11 (Bagnoli & Lucchi 2001)
4	3.2	41.15	16.04	Tomaresca, Apulia, Italy	Source 12 (Lucchi et al. 2019)

Data synthesis across sources: population density by DDC data

Event	Source 7	Source 12	Source 8	Source 5
1st pupae/larvae emergence			134	376
1st pupae/larvae peak density			669	
2nd pupae/larvae peak density			1550	
3rd pupae/larvae peak density			2424	
1st adult emergence	127	118		
1st adult peak density	233	149		
1st adult emerg - peak	106	31		
2nd adult emergence	696	538		
2nd adult peak density	767	635		
2nd adult emerg - peak	71	97		

- Sources 8 and 5 data are inconsistent with Sources 7 and 12 (which have very similar results)
- The methods of Source 8 were very different (they only sampled 5 trees and counted immature stages on a weekly basis), so perhaps are data aren't as robust?
- Source 5 documented adults as the stage present in Dec/Jan/however, this is in Uruguay where seasons are different, so not comparable to other studies?
- Used Sources 7 and 12 as source for emergence distro params - assumed that last adults emerged 100 DDs after peak emergence

Source 1. Avidov, Z. and S. Gothilf. 1960. Observations on the honeydew moth (*Cryptoblabes gnidiella* Milliere) in Israel. I. Biology, phenology and economic importance. Ktavim. 10:109-124.

- Investigated development on citrus and grapes in the coastal plain of Israel in 1957 and 1957
- For eggs (raised 1385 eggs), estimated a lower threshold of 13.7C and a thermal constant of 46.3 DDs
- For larvae and pupae (150 individuals), estimated a lower threshold of **12.7C** and a thermal constant of 454.5 DDCs, but development of larvae was 6-8 days shorter on grapes than grapefruit
- Overwintering passed in larval and pupal stages; adult emergence in Jan/Feb very rare; most emerged in early March
- Lifespan of adults in cold seaon is at least 1 month; warm seasons is 8-10 days
- Required 500 DDs to complete 1 generation
- Developed through 5 larval instars
- In summer, a generation takes 5 weeks on citrus and 4 weeks on grapes

- The overwintering generation may take up to 5 months
- May complete 5-6 generations a year on citrus in Israel (compared to 3 in Sicily)
- All those which hatched after Oct spent winter in the larval and pupal stages, and adults emerge from pupa in March
- Availability of 2 types of hosts likely allowed it to achieve additional generations
- ~50% of eggs were unable to hatch when temps in December dropped below the threshold of development (mean min: 9.9C)
- Hot and dry conditions can also reduce hatching
- Females can mate the night of their emergence, and oviposition usually begins the day after mating
- OV period varies from 4 days in summer to 15 days in winter

Pupal stage (results from text, p. 113)

Temp C	Days	N
14-15	34-42	5
16-17	19-29	10
27-28	6-8	21

Fig. 1. The authors raised 1385 eggs in test tubes in the shade during various months outdoors, and estimated a LDT = 13.7C and a thermal constant = 46.3 DDCs

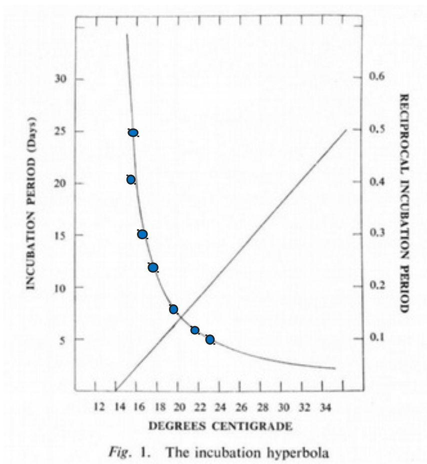
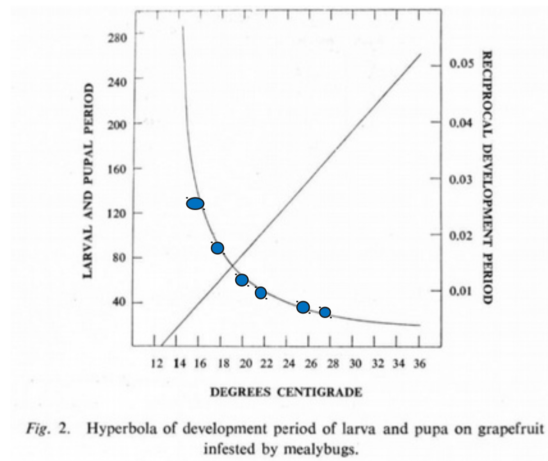


Fig. 2. The authors kept 150 grapefruit-fed larvae outdoors in shade and and estimated a LTD = 12.7C and thermal constant of 454.5 DDCs for larva + pupa stage



Estimated data based on these figures

Temp	Egg days	Egg DDCs	Larva + Pupa days	
16	25	94.5	130	491.4
18	11.5	66.47	90	520.2
20	7	54.46	65	505.7
22	5	48.9	50	489
24	4	47.12	35	412.3
26	4	55.12	30	413.4

Table 2: Development period of larva and pupa on grapes

Temp C	Avg (days)	N
26	28.5	13
27	24.5	47
28	24.6	24
29	20.5	102

Table 3: Longevity of male and female adults (days)

Month of emergence	Monthly avg temp (degC)	Avg. Longevity	Max. Longevity	Min. Longevity	N
July	26.5	11.5	19	5	21
August	27.6	7.8	18	2	97
September	26.5	11.6	24	6	53
October	23.5	16.2	36	9	88
November	19.4	35.1	40	24	8
December	14.8	35.1	44	26	6
January	14.3	19.3	23	17	3
March	17.6	24.8	34	15	20
April	21.5	16.3	19	13	6

Analyses based on these data
(Using average values - DDs in degC)

PreOV assuming OV = 4 d	DD Total LDT = 12.2C	DD PreOV LDT = 12.2C	DD OV LDT = 12.2C	DD 30% OV LDT = 12.2C
7.5	164.45	107.25	57.2	17.16
3.8	120.12	58.52	61.6	18.48
7.6	165.88	108.68	57.2	17.16
Avg.	150.2	91.5	58.7	17.6

This PreOV seems much too high - in text, the authors state that PreOV begins the night
after emergence and lay eggs the following night, so assume ~1.5 days

Adult estimates based on text on pg. 114 ("Preoviposition, oviposition and senescence")

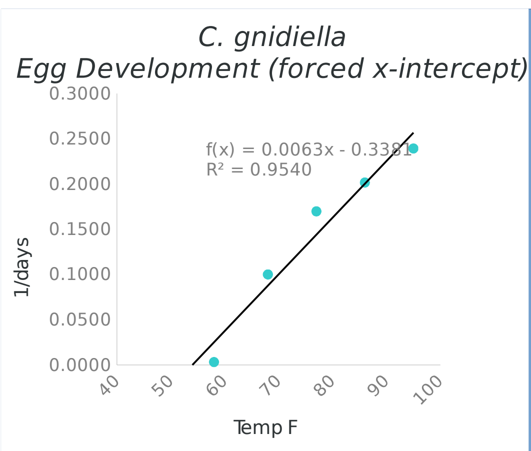
Event	Duration (days)	DDCs LDT = 12.22C
PreOV	1.5	22.2
OV	4	59.1
PreOV + OV	5.5	81.3
Senescence	1.5	22.2

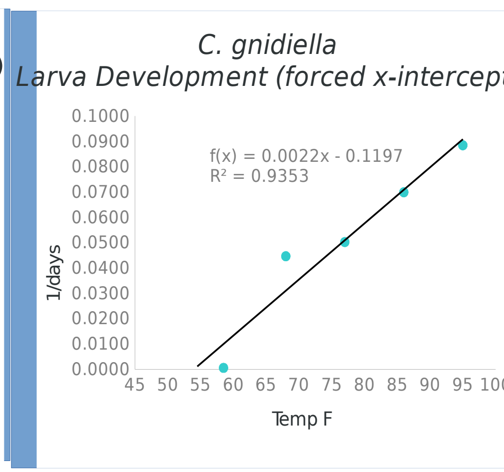
Source 2. Salama, S. (2008) Biological studies on *Cryptoblabes gnidiella* (Lepidoptera: Pyralidae) infesting stored garlic. Annals of Agricultural Science. 53:397-402.
- Recorded incubation period of egg, percent hatchability, larval and pupal durations, and % adult emergence
- Studies were conducted under 5, 10, 15, 20, 25, 30, 35, and 40C at 60.5% RH
- As previously noted, the egg data are problematic. The values had to be edited to make the x-intercept work, and even then the duration is quite a bit higher than Sources 1 and 3
- The egg data in Table 1 are strange anyway - there is no variation in the min duration of the egg stage as temp increases, which doesn't make sense

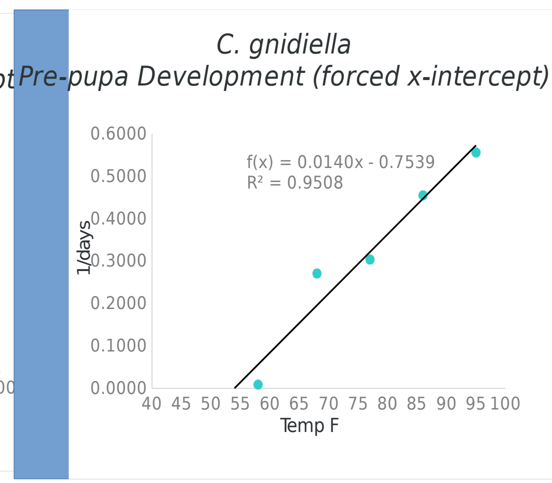
From Tables 1 & 3: based on rearing of 100 larvae in each treatment
Blue background: points added to force x-intercept to a common threshold of 54F
Changed from 7.23 to 10
Salmon background: most relevant results
Red background: removed data; does not appear to be linear (towards lower limit)

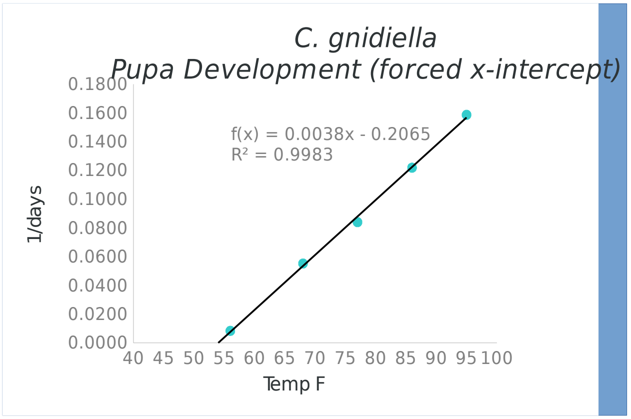
	Days Development				
Temp C	Egg (mean)	Larva	Pre-pupa	Pupa	Egg to adult emerg.
5	-	-	-	-	-
10	-	-	-	-	-
	310	1850	123	119	1675
15	12.82	25.1	5.9	21.3	65.12
20	10	22.4	3.7	18.1	54.2
25	5.89	19.9	3.3	11.9	40.99
30	4.96	14.3	2.2	8.2	29.66
35	4.18	11.3	1.8	6.3	23.58
40	-	-	-	-	-

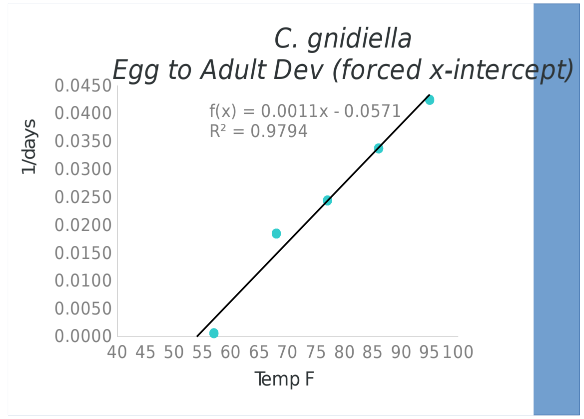
				Devel. Rate (1/days)						
Temp C	Temp F	Egg (mean)	Temp F	Larva	Temp F	Pre-pupa	Temp F	Pupa	Temp F	Egg to adult emerg.
5	41	-		-		-		-		-
10	50	-		-		-		-		-
	58	0.0032	58.5	0.0005	58	0.0081	56	0.0084	57	0.0006
15	59		59		59		59		59	
20	68	0.1000	68	0.0446	68	0.2703	68	0.0552	68	0.0185
25	77	0.1698	77	0.0503	77	0.3030	77	0.0840	77	0.0244
30	86	0.2016	86	0.0699	86	0.4545	86	0.1220	86	0.0337
35	95	0.2392	95	0.0885	95	0.5556	95	0.1587	95	0.0424
40	104	-		-		-		-		-
	slope:	0.0063	slope:	0.0022	slope:	0.0140	slope:	0.0038	slope:	0.0011
	intercept:	-0.3381	intercept:	-0.1197	intercept:	-0.7539	intercept:	-0.2065	intercept:	-0.0571
	R-sq:	0.9540	R-sq:	0.9353	R-sq:	0.9508	R-sq:	0.9983	R-sq:	0.9794
Tlow (F) =	-a/b	54.00		54.00		54.00		54.00		54.00
Tlow(C) =	-a/b	12.22		12.22		12.22		12.22		12.22
DDFs dev =	1/slope	159.7		451.1		71.6		261.5		945.1
DDCs dev =	1/slope	88.7		250.6		39.8		145.3		525.0







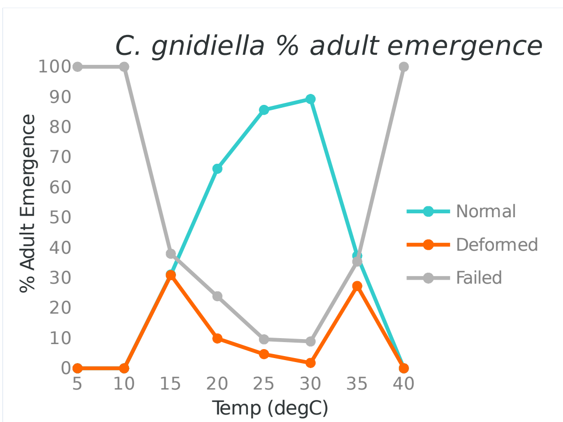


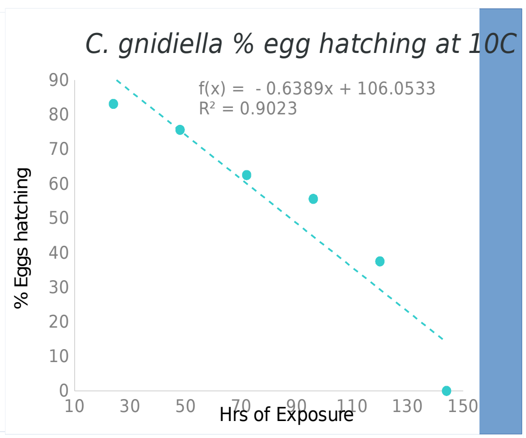


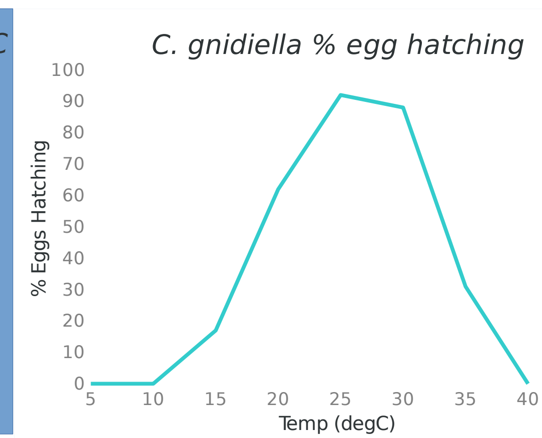
<u>Chill and heat stress</u>

- Below data suggest that stress begins accumulating between 15-20C (chill) and between 30-35C (heat)
- 40C is lethal to egg and adult stages
- Below 25 is not optimal for egg development and the formation of healthy (normal) adults

From Table 1		From Table 3		
	% egg	Adult emergence (%)		
Temp C	hatching	Normal	Deformed	Failed
5	0	0	0	100
10	0	0	0	100
15	17	31.1	30.9	38
20	62	66.2	9.9	23.9
25	92	85.7	4.7	9.6
30	88	89.3	1.8	8.9
35	31	37.3	27.3	35.4
40	0	0	0	100

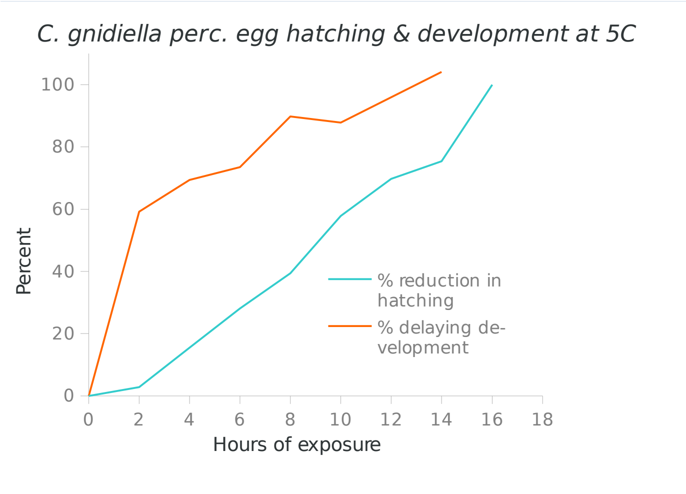


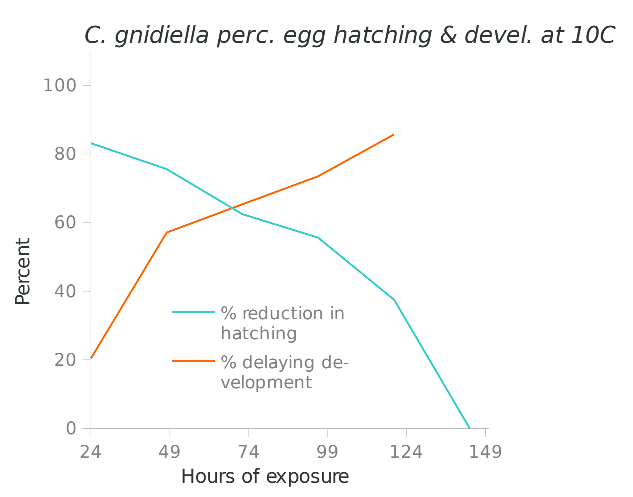




From Table 2

Temp C	Hrs of exposure	% of egg hatching	Avg. days of incubu-bation	% reduction of egg hatching	% delaying embryonic development
5	0	89.8	4.9	0	0
5	2	86.3	7.8	2.8	59.18
5	4	75	8.3	15.5	69.39
5	6	63.8	8.5	28.1	73.47
5	8	53.8	9.3	39.4	89.8
5	10	37.5	9.2	57.8	87.76
5	12	26.9	9.6	69.7	95.92
5	14	21.9	10	75.4	104.08
5	16	0	-	100	-
10	24	83.1	5.9	6.4	20.41
10	48	75.6	7.7	14.9	57.14
10	72	62.5	8.1	26.6	65.31
10	96	55.6	8.5	37.4	73.47
10	120	37.5	9.1	57.8	85.71
10	144	0	-	-	-





Source 3. Ringenberg, R., M. Botton, M.S. Garcia, and A. Nondillo. 2005. Biologia comparada e exigencias de *Cryptoblables ginediella* em diet artificial. Pesq. Agropec. Bras., Brasilia. 40:1059-1065.

- Evaluated development from egg to adult at 18, 22, 26 and 30degC (RH=60%) under different artificial diets
- Estimated of a lower threshold of **12.26C** for entire life cycle
- Estimated a duration of egg-to-adult (total cycle) = **569.91 DDC**
- Completes 3.25 generations in Caxias do Sul (Brazil) and 9.19 generations in Petrolina (Brazil)
- Their lower threshold for eggs (11.97C) is quite a bit lower than Avidov & Githolf's (1960) estimate (13.7C)
- Found variation in development times on 3 different artificial diets

Table 1: Duration (days) of the stages of larva, pupa, egg, and larva-to-adult
emergence on different aritificial diets at 26C

Diet	Egg	Larva	Pupa	Larva-adult emergence	Temp C
1	3.7	30.8	8.2	38.8	26
2	3.6	25.6	7.2	33.6	26
3	-	28.9	6.28	36.2	26

Analysis based on these data
DDCs based on 12.2C threshold (derived in this spreadsheet)
- Calc last column only for Diet 2 because gen length was est. from individuals fed diet 2

	Egg	Larva	Pupa	Larva + Pupa	Larva - adult emrg.	Egg-adult emrg	PreOV (total cycle - egg-to-adult)
	51.0	424.4	113.0	537.4	534.7	585.7	-
	49.6	352.8	99.2	452.0	463.0	512.6	57.3
		398.2	86.5	484.8	498.8	498.8	-
Avg.	50.3	391.8	99.6	491.4	498.8	532.4	

Table 4: Thermal requirements of HDM stages on artificial diet
- Evaluation was based on 150 newly hatched caterpillars fed diet 2 at 18, 22, 26, and 30C
- The authors do not report the original data - only this table - so can not est. DDs of each stage!
- Tb=lower base temp; R-squared=coefficient of determination of development period

Stage	Tb (degC)	Tb (degF)	R-squared
Egg	11.97	53.55	98.34
Larvae	13.4	56.12	98.85
Pupae	10.36	50.65	98.92
Egg-to-adult	12.26	54.07	99.21

Analysis based on these data

Avg larva/pupa		Rnd. up F	Rnd. down F
Temp C	11.88	12.2	11.7
Temp F	53.38	54.0	53

* A value of 54F = 12.2C is 0.06C lower than Ringenberg et al. (2005) [12.26C]
and 0.5C lower than Avidov & Gothilf (1960) [12.7C]
* A value of 53F would be quite a bit lower (0.8 to 1C) than these two studies

Source 4. Yehuda, S.B., M. Wysoki, and D. Rosen. 1991. Phenology of the honeydew moth, *Cryptoblabes gnidiella* (Milliere)(Lepidoptera: Pyralidae), on avocado in Israel. XXV:149-160.
- Conducted a 3-yr monitoring study between April 1986 to December 1988 in the Yizre'el Valley of Israel
- No moths were captured during Jan, Feb, and first half of March
- Overwintered as larvae, and pupation was observed in February
- Emergence of the OW generation began in late March/early April and continued through April
- 1st generation adults emerged in June
- 3 additional generations develop by September
- 5 generations may develop in avocado groves per year; up to 7 generations possible if continuous hosts available
- No diapause was observed in OW larvae (see also Gurevitz et al. 1969)
- Evidence for two or three overlapping generations (all developmental stages observed together during summer and fall)
* Could calculate DDs of peak adult flight if can find temperature data

Source 5. Vidart, M.V., M.V. Mujica, M.V. Calvo, et al. 2013. Relationship between male moths of Cryptoblabes gnidiella (Millière) (Lepidoptera: Pyralidae) caught in sex pheromone traps and cumulative degree-days in vineyards in southern Uruguay. SpringerPlus. 2:258.
- Monitored population dyanmics from 2003-2007 at 2 sites in southern Uruguay
- Used logistic models w/ 2 LTTs to model the proportion of cumulative male moths caught in traps at each grapevine cultivar to the accumulated DD in each year
- Estimated the mean generation time using cumulative sum of effective temps (DD) between the start of 1 gen's flight and the next
- They used Dec 1st as a biofix because males were caught on consecutive days in early December (= OW flight)

- OW adults lasted until late January to early Feburary
- The first generation developed during Feb/Mar; first larvae found on grape clusters in mid-January
- Used thresholds and life cycle DD of both Avidov & Gothilf (1960) and slightly lower one of Ringenberg et al. (2005)
- Identified 3 generations (similar to Ringerberg et al. 2005 for southern Brazil) w/ both threshold values
- Larvae and pupae overwinter under the rhytidome or in clusters and dry leaves that persist on plant
- They did not find significant differences among the grapevile cultivars
- The 1st generation ended at 500 (LTT=13C) or 570 DDs (LTT=12.6C)
- The species did not have a winter diapause, and completed its entire lifecycle in the vineyard (no alternative host was needed)
- Documented overlapping generations towards end of season
- Model was not validated

Table 2 - Accumulated degree-days by generation in Uruguay using two different lower thresholds

Year	Start date 1st gen	Gen1 LTT=13C	Gen1 LTT = 12.6C	Gen2 LTT=13C	Gen2 LTT=12.6
2004	29-Jan	482	527	999	1090
2005	27-Jan	527	570	1009	1098
2006	2-Feb	489	536	989	1089
2007	22-Jan	500	540	1011	1092
Avg. gen DDs	27-Jan	499.5	543.3	1002.0	1092.3

Analysis: average cumulative DDs of Gen 1 start dates (1st larvae) for last 3 years
Data source: degreedays.net
Station: Florida, FA, UY (56.24W,34.07S)
Station ID: 86545

Year	Cum_DDF on 27-Jan	Cum_DDC on 27-Jan
2017	677.1	376.2
2018	725.1	402.8
2019	630.2	350.1
Avg. cum. DDs	677.5	376.4

Source 6. Swailem, S.M. and I.I. Ismail. 1972. On the biology of the honey dew moth *Cryptoblabes gnidiella*, Milliere. Bulletin de la Societe entomologique d'Egypte. 56:127-134.
- Collected data on lab reared moths at 25C
- Preoviposition period ranged from 2-3 days
- Oviposition period ranged from 2-9 days (avg. = 4.5 days)
- When fed a 5% honey solution: males and females lived ca. 4 and 4.5 days in Sept, and 6 and 6.5 days in October
- Measured durations of immature stages at 2 conditions: (1) avg. temp of 27C (rng. 25-30) and 60% RH (rng. 52-68); and (2) avg. of 25C (rng. 22-27) and 62% RH (rng. 55-72)
- Duration of stages is shown in table below (taken from text) - note that a few are average values, as authors only reported a range
- Data on adults were from only 10 females reared at 25C and 62% RH (low sample size)
- According to data below, preOV = 31%, OV = 63%, and postOV = 5.5% of adult stage
- These data are not robust, as they were not collected at single temps, and had a very low sample size at 25C

Stage	Avg. temp (degC)	Avg. RH	Duration (days)	DDC	DDF
Larval instar 1	27	60	2.0	41.8	75.2
Larval instar 2	27	60	2.0	41.8	75.2
Larval instar 3	27	60	2.0	41.8	75.2
Larval instar 4	27	60	3.0	68.8	123.8
Larval instar 5	27	60	4.0	95.8	172.4
Total larval stage	27	60	13.0	338.8	609.8
Pre-pupal stage	27	60	1.0	14.8	26.6
Pupal stage	27	60	6.0	149.8	269.6
Total larval stage	25	62	15.0	362.8	653.0

Pupal stage	25	62	9.0	212.8	383.0	Duration in line w/ estimates from Avidox & Gothilf (1960) min values
Pre-oviposition stage	25	62	2.3	29.4	52.9	at similar temps
Oviposition stage	25	62	4.5	57.5	103.5	57.5DDC corroborates Avidov & Gothilf's (1960) estimate for OV (=58.7 DDC)
Post-oviposition stage	25	62	0.4	5.1	9.2	at similar temps
Total adult stage	25		7.2	92.0	165.6	

Source 7. Öztürk, N. (2018) Creating a degree-day model of honeydew moth [Cryptoblabes gnidiella (Mill., 1867) (Lepidoptera: Pyralidae)] in pomegranate orchards. Turkish Journal of Entomology. 42:53-62.

- Conducted a field study over 5 years (2008-2010 and 2012-2013) in an infested pomegranate orchard in Tarsus, Mersin Province, Turkey
- Found that their DD model was successful for scheduling control of HDM
- Calculated Effective Temperature Sum (ETS) values to determine appropriate spraying times and trapping times
- In the calculation of ETS values, they used a LDT of 12C, generation time of 564.6DD, and egg hatching period from adulthood of 120DD (Ringenberg et al. 2005; Ozturk, 2010)
- Moth was not negatively affected by temps > 30C and biological activity continued throughout the study
- Based on these results, they concluded that suitable temps for development was 25-30C and upper threshold for development was 40C
- First adults could be trapped when avg. temp was 17.4C (15-20C)
- Authors state that adults likely lays eggs withing 1-3 days of catching the first adult (consistent with Source 6)
- The authors do not state what the overwintering stage was - assuming it's late stage larvae or pupae based on first adult emergence timing
- The date when the first adult was trapped is similar (April 4) as their earlier study (Ozturk and Ulusoy 2012)

<u>Average DDCs of pest events across - from Table 1 (see raw data below)</u>

Instead of using these data, a set of corrected degree-days were used to calculate averages from the raw data

Event	DDC
1st adult caught in trap	126.8
1st adult peak	233.1
1st egg-hatching of 1st gen	245.4
1st adult emergence of 2nd gen	695.9
2nd adult peak	767.4
1st egg-hatching of 2nd gen	807.7
1st adult emergence of 3rd gen	1253.4
1st egg-hatching of 3rd gen	1377.2
1st adult emergence of 4th gen	1821.1
1st egg-hatching of 4th gen	1934.8
1st adult emergence of 5th gen	2386.3
1st egg-hatching of 5th gen	2506.6

Appears to be a typo in paper ("egg-laying"), because all other data are reported as adult emergence to egg hatching and Table 1 says "egg-hatching".

<u>Pest events (data from Table 2 and in text, pgs. 56-58)</u>

Last column of data (approx. adult density was estimated by extracting data from Fig. 1 via https://apps.automeris.io/wpd/)

Date	Event	DDC	DDC - corrected	Adult density	
4/4/2008	1st adult caught in trap	138.7	131.8	1	
4/9/2009	1st adult caught in trap	121.5	115.4	1	
3/31/2010	1st adult caught in trap	134.7	128.0	1	
4/18/2012	1st adult caught in trap	121.9	115.8	3.8	
4/1/2013	1st adult caught in trap	117	111.2	1	
4/21/2008	1st egg-hatching of 1st gen	253.8	241.1	6	adult density peak1 (Fig. 1)
5/1/2009	1st egg-hatching of 1st gen	238.9	227.0	11.1	adult density peak1 (Fig. 1)
4/24/2010	1st egg-hatching of 1st gen	253.5	240.8	3.4	adult density peak1 (Fig. 1)
5/1/2012	1st egg-hatching of 1st gen	243.8	231.6	2	adult density peak1 (Fig. 1)
4/23/2013	1st egg-hatching of 1st gen	237.1	225.2	6.6	adult density peak1 (Fig. 1)
6/9/2008	1st adult emergence of 2nd gen	708.2	672.8	4.1	
6/14/2009	1st adult emergence of 2nd gen	685.4	651.1	5.1	
6/11/2010	1st adult emergence of 2nd gen	699.5	664.5	1	

6/14/2012	1st adult emergence of 2nd gen	699.7	664.7	43.2	
6/6/2013	1st adult emergence of 2nd gen	686.8	652.5	5.6	
6/18/2008	1st egg-hatching of 2nd gen	820.2	779.2	17	adult density peak 2 (Fig. 1)
6/22/2009	1st egg-hatching of 2nd gen	796.1	756.3	18.9	adult density peak 2 (Fig. 1)
6/19/2010	1st egg-hatching of 2nd gen	809.8	769.3	8.5	adult density peak 2 (Fig. 1)
6/21/2012	1st egg-hatching of 2nd gen	807.4	767.0	66.3	adult density peak 2 (Fig. 1)
6/17/2013	1st egg-hatching of 2nd gen	805.2	764.9	13.1	adult density peak 2 (Fig. 1)
7/17/2008	1st adult emergence of 3rd gen	1269.3	1205.8	4.9	
7/21/2009	1st adult emergence of 3rd gen	1241.8	1179.7	178.3	
7/22/2010	1st adult emergence of 3rd gen	1260.9	1197.9	24	
7/19/2012	1st adult emergence of 3rd gen	1248	1185.6	264.6	
7/18/2013	1st adult emergence of 3rd gen	1247	1184.7	166.1	
7/22/2008	1st egg-hatching of 3rd gen	1389.7	1320.2	18	
7/28/2009	1st egg-hatching of 3rd gen	1361.9	1293.8	271.7	
7/30/2010	1st egg-hatching of 3rd gen	1391.5	1321.9	28.5	
7/26/2012	1st egg-hatching of 3rd gen	1374.9	1306.2	279.5	
7/26/2013	1st egg-hatching of 3rd gen	1368.1	1299.7	190.3	
8/20/2008	1st adult emergence of 4th gen	1834.9	1743.2	203.4	
8/25/2009	1st adult emergence of 4th gen	1807	1716.7	275.1	
9/24/2010	1st adult emergence of 4th gen	1825.9	1734.6	297.3	
9/19/2012	1st adult emergence of 4th gen	1822.9	1731.8	291	
9/24/2013	1st adult emergence of 4th gen	1814.6	1723.9	153	
8/27/2008	1st egg-hatching of 4th gen	1952.2	1854.6	209.5	
9/2/2009	1st egg-hatching of 4th gen	1930.6	1834.1	305.1	
9/27/2012	1st egg-hatching of 4th gen	1929.4	1832.9	169.8	
9/31/2010	1st egg-hatching of 4th gen	1941.8	1844.7	297	
9/31/2013	1st egg-hatching of 4th gen	1919.8	1823.8	11.3	
9/27/2008	1st adult emergence of 5th gen	2398.4	2278.5	223	
10/8/2009	1st adult emergence of 5th gen	2378.4	2259.5	366.9	
9/30/2010	1st adult emergence of 5th gen	2393.8	2274.1	300	
9/26/2012	1st adult emergence of 5th gen	2390.2	2270.7	169.8	
10/11/2013	1st adult emergence of 5th gen	2370.7	2252.2	143.2	
10/7/2008	1st egg-hatching of 5th gen	2514.6	2388.9	230.4	
10/18/2009	1st egg-hatching of 5th gen	2497.3	2372.4	337.7	
10/12/2010	1st egg-hatching of 5th gen	2516.3	2390.5	231	
10/4/2012	1st egg-hatching of 5th gen	2509.5	2384.0	110	
10/27/2013	1st egg-hatching of 5th gen	2495.4	2370.6	113	

Summary of adult emergence and 1st egg-laying (Table 2)
- Calculate average durations across 4 years (2008-2012)
- Estimated duration (DDC) of PreOV by assuming that eggDD = 50DDC

Gen	Avg. DDC adult emrg.	Full gen	Avg. DDC egg-hatch	1st adult emg. to egg-hatch	1st egg-laying	1st adult emrg. to 1st egg-laying (PreOV)
1	120.4	-	233.1	112.7	183.1	62.7
2	661.1	540.7	767.4	106.2	717.4	56.2
3	1190.7	529.6	1308.4	117.6	1258.4	67.6
4	1730.0	539.3	1838.0	108.0	1788.0	58.0
5	2267.0	537.0	2381.3	114.3	2331.3	64.3
	Avg. DDC	536.6		111.8		61.8
	Avg. DDF	966.0		201.2		111.2

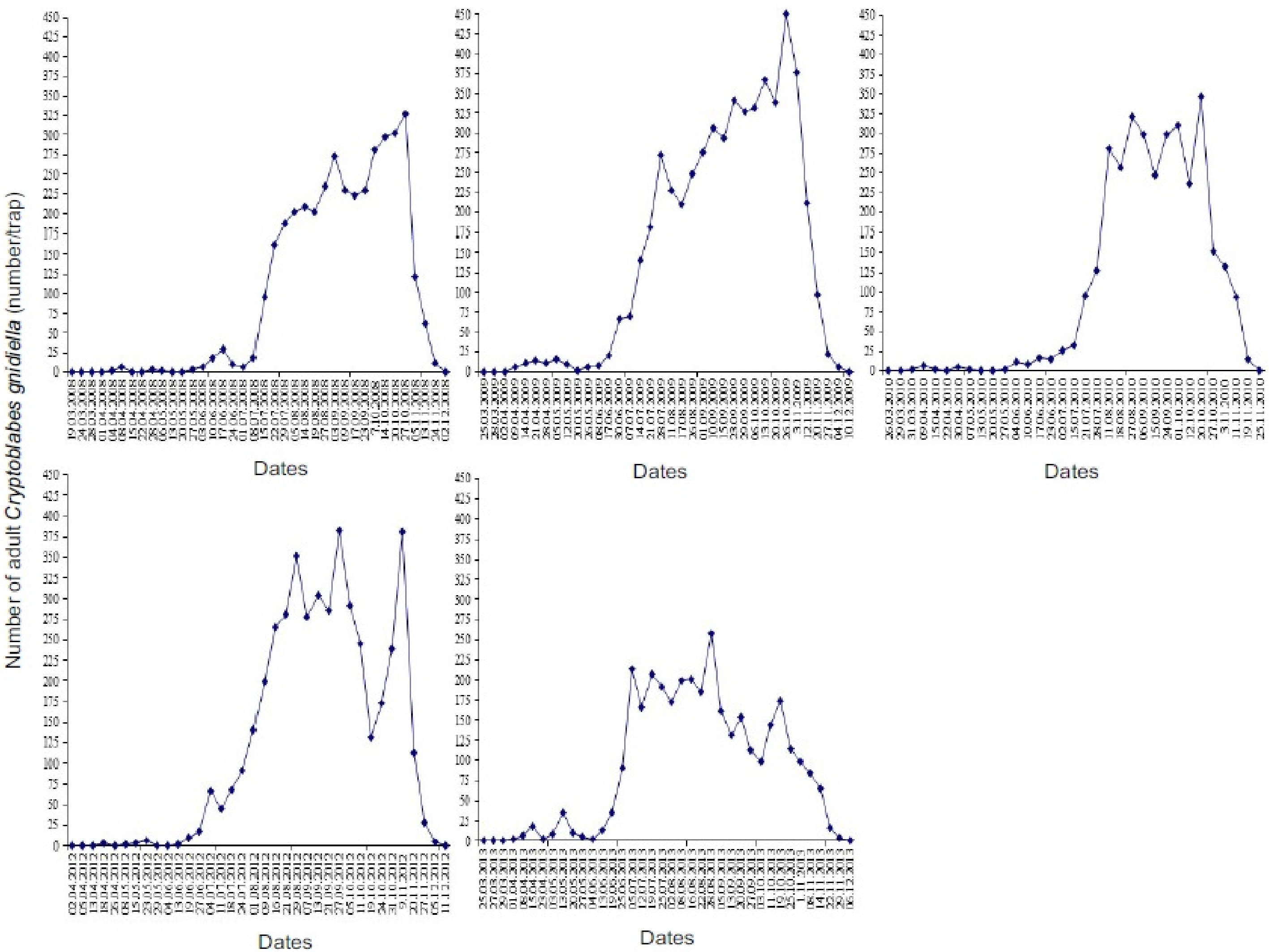


Figure 1. Adult population variation of *Cryptoblabes gnidiella* between 2008-2010 and 2012-2013 at the pomegranate orchard in the village of Akarsu, Tarsus, Mersin Province, Turkey.

Source 8. Abdel Kareim, AI, Ragab, ME, Ghanmn, NM, and SAA El-Salama. 2018. Seasonal activity, natural enemies and life table parameters of *Cryptoblabes gnidiella* Mill. on mango inflorescences. J. Plant Prot. and Path., Mansoura Univ., 9: 393–397

- Measured population density and observed natural enemies in an Egyptian mango orchard

-They sampled 20 inflorescenses from 5 mango trees each week and then counted immature stages in the lab to measure population density

- They also generated life and fertility tables of individuals reared on mango inflorescens in lab conditions
- Documented 3 peaks in larvae/pupae abundance annually (across 2 years)
- Peaks in 2017 = 5/17/2017; 7/19/2017; 9/13/17
- Generation time was 35.97 days (see Table 2 data below for specific stages)

- It appears their densities are based only on larvae and pupae in both Fig 1 and 2; no adult data are reported
- Assuming that both larvae and pupae were the overwintering stages, but not 100% sure

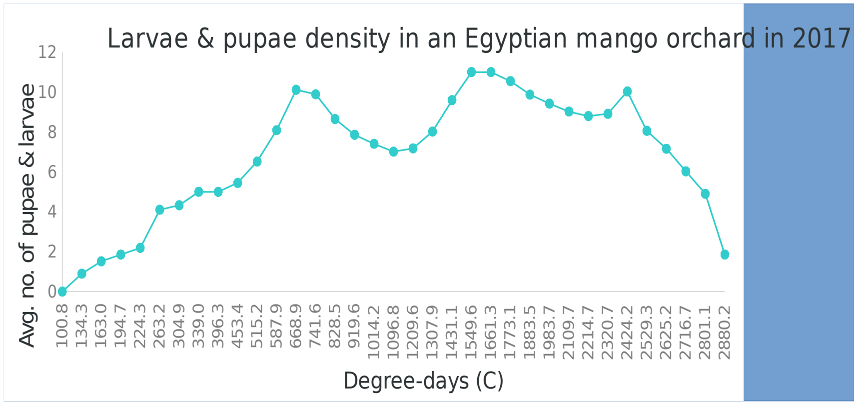
Table 2. Duration (days) of immature stages under lab conditions (26+-3.5C and 66+-5.5RH)
Analysis based on these data: calculated durations in DDC using a 12.22C threshold

Stage	Duration	DDC	
Egg	4.1	56.6	
Larva			
1st instar	2.7	37.2	
2nd instar	2.3	31.7	
3rd instar	3.3	45.5	
4th instar	3.7	51.0	
5th instar	2.5	34.5	
Pupa	10.7	147.4	
Total immature	29.5	406.5	
Generation	35.97	495.7	
Adult emrg. to OV	6.47	89.2	Duration very similar to est. by Swailem et al. 1972 of preOV + OV (= 6.8 days) at 25C

Analysis based on Figure 2: population density of larvae and pupae infesting mango inflorescenses in 2017
1) Generated degree-day data (base = 54F) using weather data from Alexandria airport. Weather data only went back 24 months at stations closer to the study site.
2) Used https://apps.automeris.io/wpd/ to extract data from the 35 points in Figure 2 (the hollow boxes)
* Note that Figure 1 is showing the same data, except the dates don't go back as far

Downloaded degree-day data (chilling units) at 54F base temp to calculate DDs for 2017 (data are incomplete for 2016 b/c can only go 36 months back)
Station: Alexandria / Nouzha, EG (29.95E,31.18N)
Station ID: HEAX

Date	Avg. number of larvae/pupae	Cum. DDFs	Cum. DDCs	
2/22/2017	0	181.5	100.8	
3/2/2017	0.9	241.8	134.3	first emergence
3/8/2017	1.5	293.4	163.0	
3/15/2017	1.9	350.5	194.7	
3/22/2017	2.2	403.8	224.3	
3/29/2017	4.1	473.7	263.2	
4/5/2017	4.3	548.8	304.9	
4/11/2017	5.0	610.2	339.0	
4/19/2017	5.0	713.4	396.3	
4/26/2017	5.4	816.2	453.4	
5/3/2017	6.5	927.3	515.2	
5/10/2017	8.1	1058.2	587.9	
5/17/2017	10.1	1204	668.9	peak 1
5/24/2017	9.9	1334.9	741.6	
5/31/2017	8.7	1491.3	828.5	
6/7/2017	7.9	1655.3	919.6	
6/14/2017	7.4	1825.5	1014.2	
6/20/2017	7.0	1974.2	1096.8	
6/28/2017	7.2	2177.2	1209.6	
7/4/2017	8.0	2354.2	1307.9	
7/12/2017	9.6	2575.9	1431.1	
7/19/2017	11.0	2789.3	1549.6	peak 2
7/26/2017	11.0	2990.4	1661.3	
8/2/2017	10.6	3191.6	1773.1	
8/9/2017	9.9	3390.3	1883.5	
8/15/2017	9.4	3570.6	1983.7	
8/23/2017	9.0	3797.5	2109.7	



8/30/2017	8.8	3986.4	2214.7	
9/6/2017	8.9	4177.3	2320.7	
9/13/2017	10.0	4363.5	2424.2	peak 3
9/20/2017	8.1	4552.8	2529.3	
9/27/2017	7.2	4725.3	2625.2	
10/4/2017	6.0	4890.1	2716.7	
10/11/2017	4.9	5042	2801.1	
10/18/2017	1.9	5184.4	2880.2	

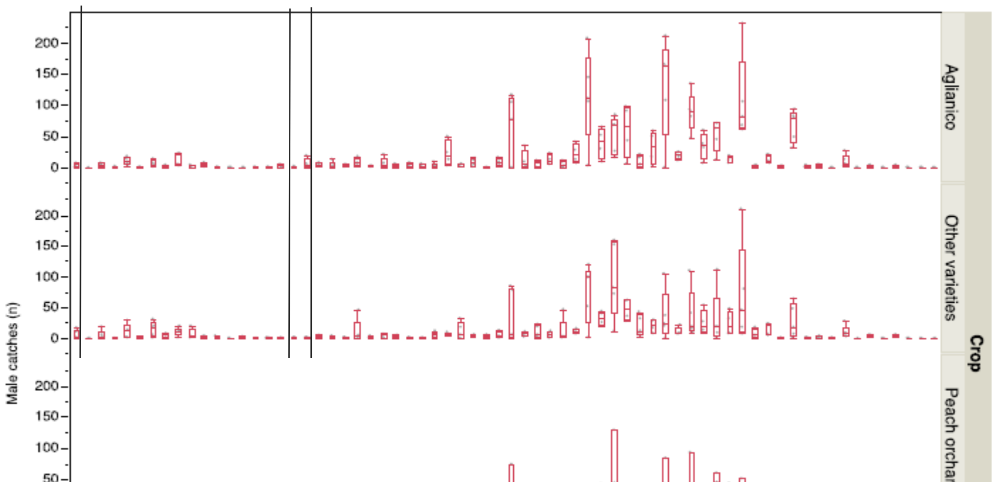
Source 9. Oztürk and Ulusoy. 2012. Determination of adult population dynamics and generation number of Honeydew moth [*Cryptoblabes gnidellia* Milliere., 1867 (Lepidoptera: Pyralidae)]. Turk. Entomol. Derg. 36:101-112.
- Studied populations in pomegranate fields in Adana, Mersin and Osmaniye provinces of Turkey in 2008-2009
- Adults from OW generation began emerging in April
- Peak flight was in April-June; documented activity for 8 months of the year, had a total of 4 to 5 generations for entire season
- Monitoring data not usable because lack DD data for this early of dates

Source 10. Dawidowicz, Ł. and R. Rozwałka. 2016. Honeydew Moth *Cryptoblabes gnidiella* (MILLIÈRE, 1867) (Lepidoptera: Pyralidae): an adventive species frequently imported with fruit to Poland. Polish Journal of Entomology. 85:181-189.
- Moth is native to the Mediterranean Basin. In Europe is mainly found in Portugal, Spain, Italy, Ukraine, and Austria (see Fig. 3)
- Outside Europe is native to northern African and SE Asia
- These authors document the records of the species presence on imported fruit in Poland
- They state there are no threats to fruit crops in Central Europe owing the region's cool climate and the species' quite high temp requirements

Source 11. Bagnoli, B. and Lucchi, A. 2001. Bionomics of *Cryptoblabes gnidiella* (Milliere)(Pyralidae Phycitinae) in Tuscan vineyards. Integrated Control in Viticulture. 24(7): 79-83.
- Monitored populations in 1996, 1998, 2000 in a La Parrina vineyard in Central Italy
- In Italian and French vineyards, has 4 gens per year w/ a first flight in May-June, a 2nd in July, a 3rd in Aug-Sep, and 4th from late Sept-Nov
[4 gens were also recorded for this region by Coscolla-Ramon (2004)]
- Possible overlapping generations on late harvest grape varieties
- Peaks in adult abundance very similar to those reported by Lucchi et al. 2019 (Source 12)

Source 12. Lucchi, A., R. Ricciardi, G. Benelli, and B. Bagnoli. 2019. What do we really know on the harmfulness of *Cryptoblabes gnidiella* (Milliere) to grapevine? From ecology to pest management. Phytoparasitica. 47:1-15.
- Monitored populations over 3 years (2015-2017) in Apulian vineyards of Southern Italy
- There were four main flight periods per year
- The first two peaks were distinct (April-May and June-July) but last two overlapped (August-November)
- Overwintered as larvae (1st-5th instar) in the vineyard, hidden in dried grape cluster leftover from the plant or fallen on ground
- In 2007 adult abundance was low … unfortunately the only year for which DD data are available

<u>Analysis to deduce peak flight of males to estimate first flight of each gen. based on Figs. 9 and 10</u>



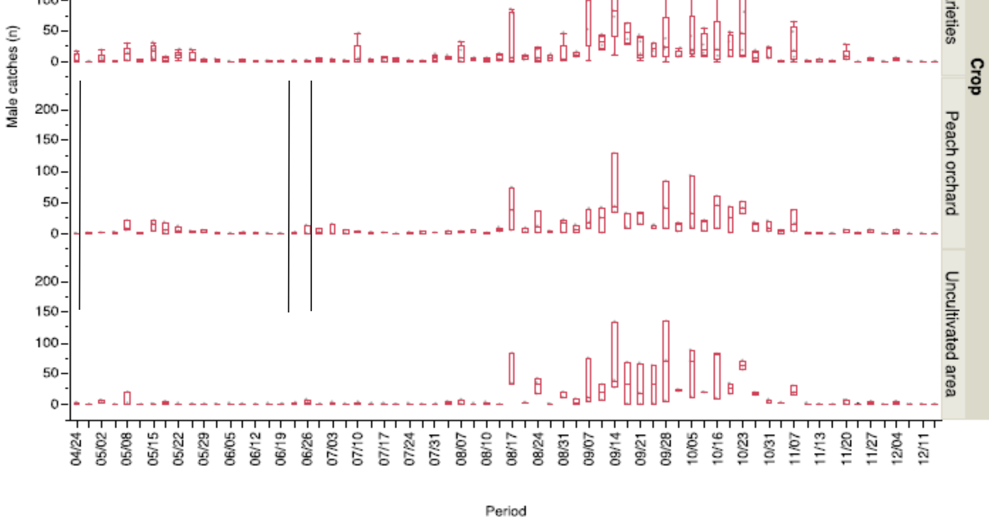


Fig. 9 *Cryptoblabes gnidiella* male catches recorded in Apulian vineyards ("Aglianico" and other grapevine varieties) and close-related agricultural settings during 2016 and 2017. Red box plots indicate the median (solid line) within each box and the range of dispersion (lower and upper quartiles and outliers) of weekly male catches in pheromone-baited traps

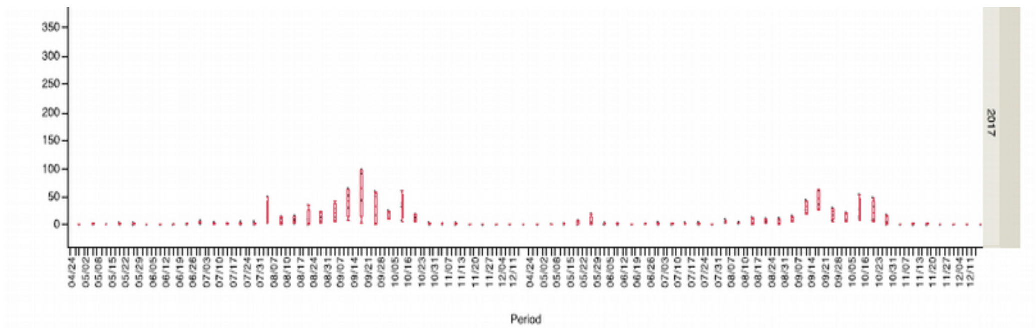


Fig. 10 Overall view of *Cryptoblabes gnidiella* male catches in Apulian vineyards ("Aglianico" and other grapevine varieties) over three study years (2015, 2016 and 2017). Red box plots indicate the median (solid line) within each box and the range of dispersion (lower and upper quartiles and outliers) of weekly male catches in pheromone-baited traps

Downloaded degree-day data (chilling units) at 54F base temp to calculate DDs for 2017 (data are incomplete for 2016 b/c can only go 36 months back)

Station: Bari / Palese Macchie, IT (16.77E,41.14N)

Station ID: LIBD

Date	Cum_DDFs	Cum_DDCs	Notes
4/24/2017	211.5	117.5	OW gen 1st adult emergence (?)
5/2/2017	267.3	148.5	peak abundance for OW gen adults (?)
6/19/2017	969.2	538.4	1st gen 1st adult emergence (?)
6/26/2017	1142.9	634.9	1st peak abundance for 2nd gen adults (?)

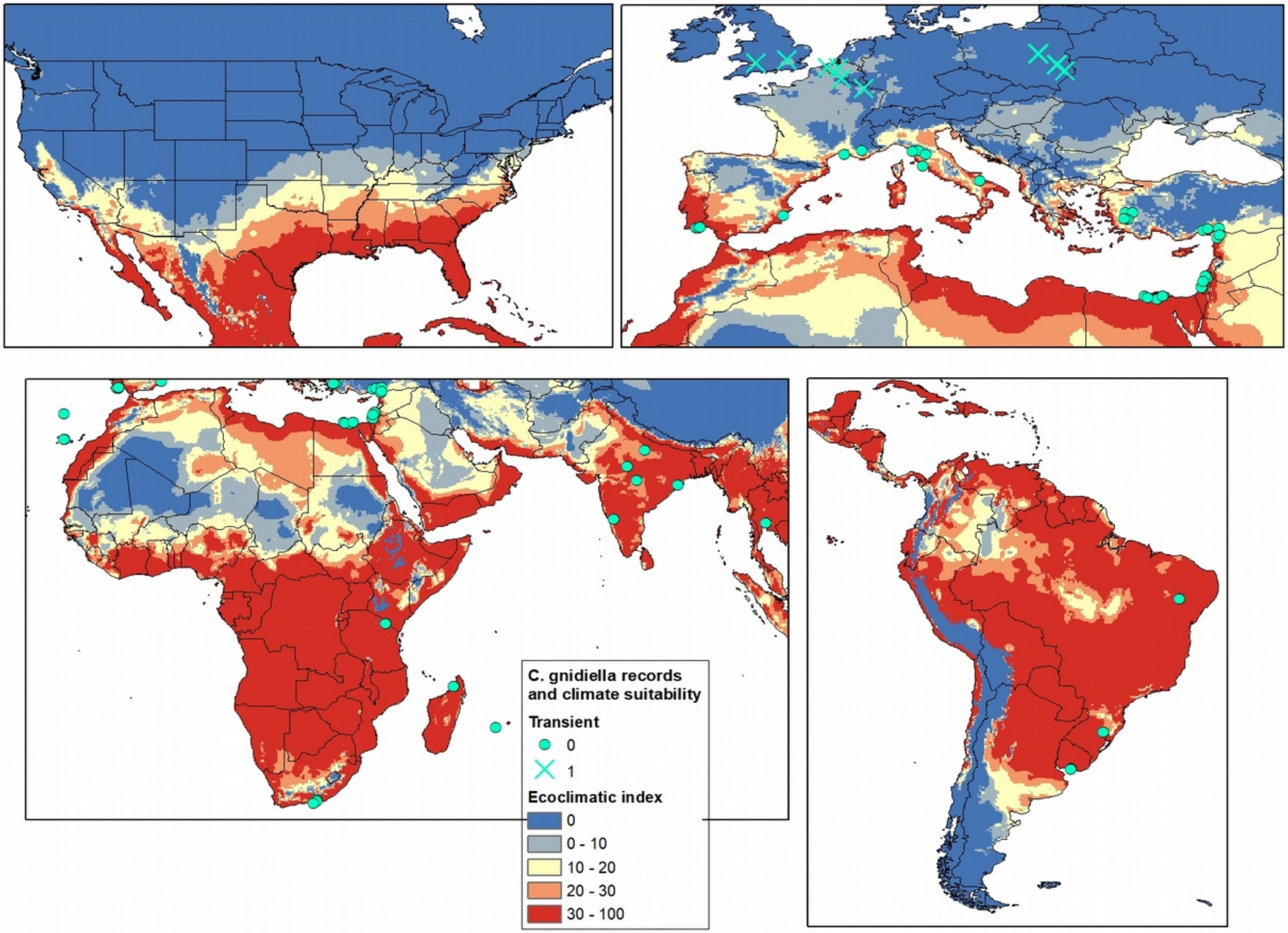
Source 13. Singh, Y.P. and D.K. Singh. 1996. Host plants, extent of damage and seasonal abundance of earhead caterpillar, Cryptoblabes gnidiella Miller Advances in Agriculture Research in India. 5:1-4

- Studied damage of CGN on sorghum in Kanpur, India
- Overwintering occurred as pupae
- Attacks on crop began in March and lasted until November; peak attacks were in Sept-Oct
- Study did not study stage durations at a constant temp - data are therefore not useful

Source 14. CABI, 2019. Distribution Map for *C. gnidiella*
Online at: https://www.cabi.org/isc/datasheet/16381#E4285FF2-5CE9-4F1B-ADFF-A9548DB01665

Source 15. CLIMEX model developed for this study (see white paper)

- As described in detail in the white paper for *C. gnidiella*, we developed a CLIMEX model for this species to aid with parameterizing the DDRP climate suitability model
- Locality data were downloaded from GBIF (accessed 12 August 2019) and gathered from the literature
- CLIMEX parameters were adjusted to ensure that the majority of these records fell withing areas with high climatic suitability (EI > 20)
- The cold stress threshold in DDRP was set to 8C, with a max1 limit of 1100 and max2 limit of 1950
- The heat stress threshold in DDRP was set to 35C, with a max1 limit of 200 and max2 limit of 600
- These thresholds and limits resulted in an "all stress exclusion" map that aligned well with climatic suitability according to CLIMEX



The CLIMEX model predicts EI > 20 for areas in all countries with records of the species

Continent	Country	Occ. Record	EI > 20	Source
Asia	India	yes	yes	Molet 2013
	Indonesia	no	yes	Molet 2013
	Israel	yes	yes	Molet 2013
	Lebanon	no	yes	Molet 2013
	Malaysia	no	yes	Molet 2013
	Pakistan	no	yes	Molet 2013
	Russia	no	yes	Molet 2013
	Thailand	yes	yes	Molet 2013
	Turkey	yes	yes	Molet 2013
Africa	Congo	no	yes	Molet 2013
	Egypt	yes	yes	Molet 2013
	Liberia	no	yes	Molet 2013
	Malawi	no	yes	Molet 2013
	Morocco	no	yes	Molet 2013
	Nigeria	no	yes	Molet 2013
	Sierra Leone	no	yes	Molet 2013
	South Africa	yes	yes	Molet 2013
	Zaire	no	yes	Molet 2013
Caribbean	Bermuda	no	n/a	Molet 2013
Europe	Austria	no	no	Molet 2013
	Cyprus	no	yes	Molet 2013
	France	yes	yes	Molet 2013
	Gibraltar	no	yes	Molet 2013
	Greece	no	yes	Molet 2013
	Italy	yes	yes	Molet 2013
	Malta	no	yes	Molet 2013
	Portugal	yes	yes	Molet 2013
	Spain	yes	yes	Molet 2013
	Ukraine	no	yes	Molet 2013
Oceania	Fiji	no	n/a	Molet 2013
	Hawaii	yes	yes	Molet 2013
	New Zealand	no	yes	Molet 2013
South America	Brazil	yes	yes	Molet 2013
	Uruguay	yes	yes	Molet 2013