Phenology Model for Diaphorina citri (Homoptera: Psyllidae), Asian citrus psyllid

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1. Immature Development

Main Source:

Liu, Y.H., and J.H. Tsai. 2000. Effects of temperature on biology and life table parameters of the Asian citrus psyllid, Diaphorina citri Kuwayama (Homoptera: Psyllidae). Ann. Appl. Biol 137:20

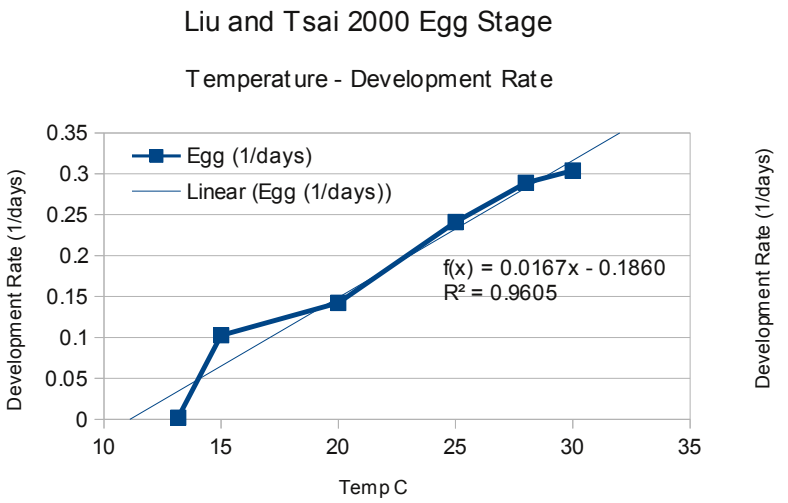
From Table 1 (work done in Florida)

Culture obtained from orange jessamine (Murraya paniculata) in Broward County, Florida, maintained on potted orange jessamine in walk-in insect room at 28C, 75-80% RH, 13:11 L:D.

Temp C	Egg (days)	Temp C	Egg (1/days)	Nymph (days)	Temp C	Nymph (1/days)
	500	13.17	0.0020	500	11.7	0.0020 '← a
15	9.74	15	0.1027	39.6	15	0.0253
20	7.03	20	0.1422	21.76	20	0.0460
25	4.15	25	0.2410	12.82	25	0.0780
28	3.46	28	0.2890	10.6	28	0.0943
30	3.29	30	0.3040	13		0.0769

Regressions forced through a common threshold of 11.11 C (52 F):

	Egg Stage	Nymphal Stage
Intercept	-0.18602	-0.06174
Slope	0.01675	0.00556
R-sq	0.96047	0.99514
-a/b	11.11	11.11
1/b	59.7	179.9



Summary of results: Use Tlow = 11.11 C (52 F), Thi = 32 C (90 F)

Dds for egg stage = 60

Dds for nymphal stage = 180

Source 2: The goal of using other (non-USA) regressions are to compare differences from Florida results

Nava 2007 (Sao Paulo Brazil)

Table 1 Duration at 24 +/- 2C RH 70%, 14:10 L:D

	Egg	Nymph
Rangpur lime	3.61	14
Orange jessamine	3.63	14.11
Sunki mandarin	3.57	13.46
Mean	3.6	13.9

Interpretation: development is not highly variable due to host plant differences

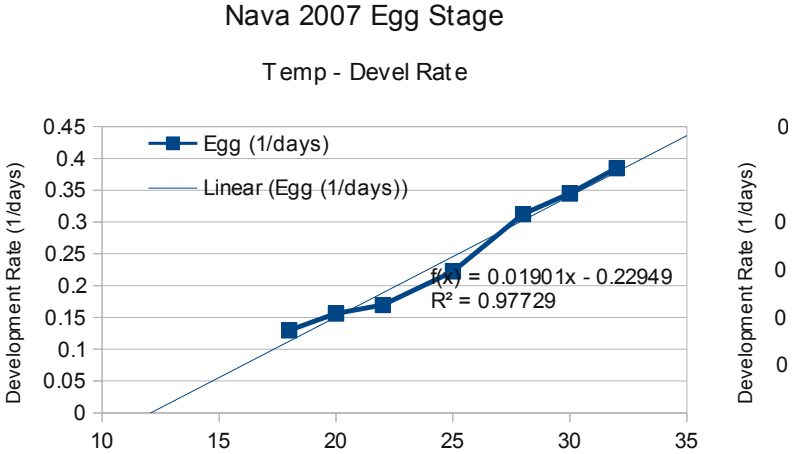
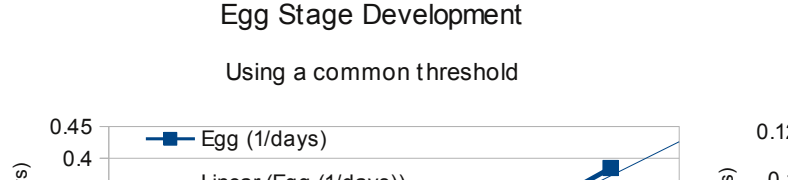


Table 5 Duration on Rangpur lime at different temps

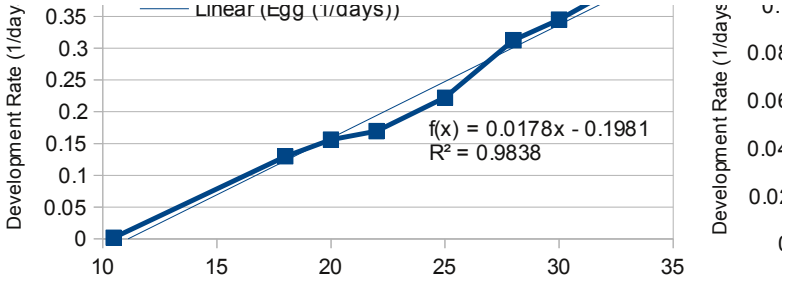
Temp C	Egg (days)	Temp C	Egg (1/days)	Nymph (days)	Temp C	Nymph (1/days)
18	7.7	18	0.1299	35.8	18	0.0279
20	6.4	20	0.1563	24.5	20	0.0408
22	5.9	22	0.1695	23.8	22	0.0420
25	4.5	25	0.2222	12.6	25	0.0794
28	3.2	28	0.3125	12.2	28	0.0820
30	2.9	30	0.3448	9.4	30	0.1064
32	2.6	32	0.3846	9.4	32	0.1064
Intercept		-0.22949			-0.08086	
Slope		0.01901			0.00601	
R-sq		0.97729			0.95334	



-a/b		12.1			13.5	
1/b		52.6			166.5	

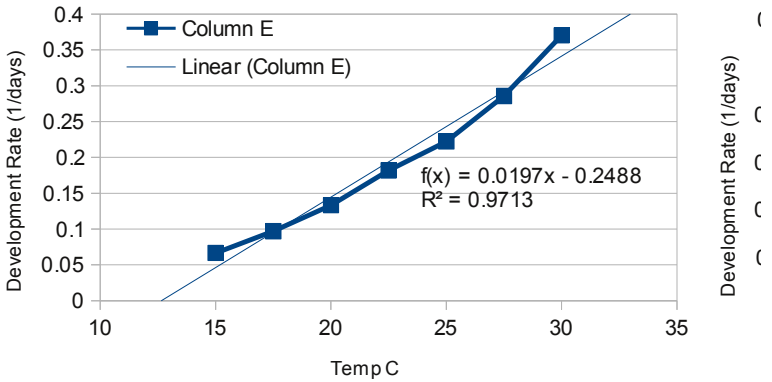
Revised – force a common Tlow

Temp C	Egg (days)	Temp C	Egg (1/days)	Nymph (days)	Temp C	Nymph (1/days)	
12.95	500	10.47	0.0020	500	9.56	0.0020	← a
18	7.7	18	0.1299	35.8	18	0.0279	
20	6.4	20	0.1563	24.5	20	0.0408	
22	5.9	22	0.1695	23.8	22	0.0420	
25	4.5	25	0.2222	12.6	25	0.0794	
28	3.2	28	0.3125	12.2	28	0.0820	
30	2.9	30	0.3448	9.4	30	0.1064	
32	2.6	32	0.3846	9.4	32	0.1064	
Intercept		-0.19813			-0.05650		
Slope		0.01783			0.00509		
R-sq		0.98384			0.94685		
-a/b		11.11			11.11		
1/b		56.1			196.6		



Nakata 2006 Egg Stage

Temperature - Development Rate



Interpretation: Regressions for Brazil population forced through 11.11 C appear good; supporting the use of this threshold
Egg Dds are very similar; Nymph Dds greater by 16 Dds (ca. 5%)

2. Upper Threshold Temperature:

Nava 2007 Table 6. Nymphal viability dropped sharply from 74% to 7% at 32C; egg stage held up well (82% at 32C)

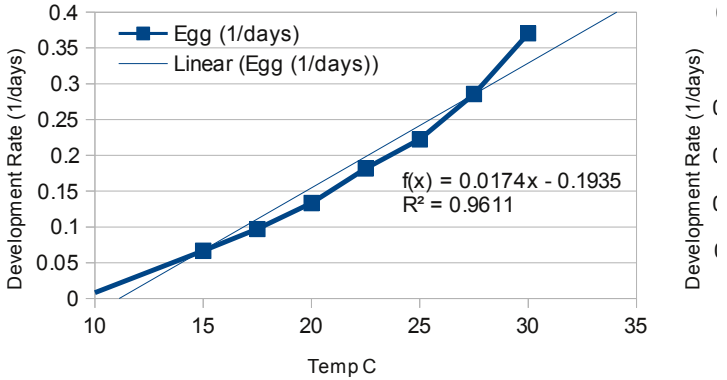
Interpretation: Upper threshold should be near 31-32 C

Source 3:
Nakata 2006 Work done in Japan
From Table 2. 16:8 L:D

Temp C	Egg (days)	Temp C	Egg (1/days)	Nymph (days)	Temp C	Nymph (1/days)	
12.95	500	9.48	0.0020	500	14.66	0.0020	← artificial
15	15	15	0.0667	36.3	15	0.0275	
17.5	10.3	17.5	0.0971	21.9	17.5	0.0457	
20	7.5	20	0.1333	16.8	20	0.0595	
22.5	5.5	22.5	0.1818	13	22.5	0.0769	
25	4.5	25	0.2222	11.9	25	0.0840	
27.5	3.5	27.5	0.2857	10.7	27.5	0.0935	
30	2.7	30	0.3704	9.4	30	0.1064	
Intercept		-0.19349			-0.06612		
Slope		0.01741			0.00595		
R-sq		0.96114			0.92830		
-a/b		11.11			11.11		
1/b		57.4			168.0		

Egg Stage Development (Nakata 2006)

Using a common threshold



Interpretation: Regressions for Brazil population forced through 11.11 C appear good; supporting the use of this threshold although forcing for Nymphal stage is a bit difficult, results are opposite Brazilian data (natural fitting of regression would result in a much lower Nymphal developmental threshold of 8 C which is not in accordance with most other studies reviewed).
Japan results when forced through 11.11 C: Egg Dds same as Florida, Nymphal Dds same as Florida

3. Mating and Pre-oviposition period

Wenninger and Hall 2007. Daily timing of mating and age at reproductive maturity in Diaphorina citri (Hemiptera: Psyllidae)
Mate & lay eggs mainly during daytime, most any temperatures espec. 25-35C
2 day old females had no diminishing of production of fertile eggs, with a pre-ov period of around 3 days.

Hollis (2004) – in general may mate within a few hours of emergence (males usually wait a few days),

Nava 2007 (Sao Paulo Brazil)
Pre-OV (days) at 24C, 70% RH, 14:10 L:D

Rangpur lime	9.53
Orange jessamine	10.93
Sunki mandarin	9.91
Mean	10.1

Estimated Dds for Pre-OV Period = 24C – Tlow (11.11C) x avg no. Days:
130.5 '= 130 Dds

Tsai and Liu 2000: Adults on caged plants at 25 C, 756-80% RH, 13:11 L:D
Results from Fig. 1A-d.
First signif. OV after approx. 12, 9, 9, and 6 days (reported at 3 day intervals so fairly coarse time scale used)
Mean Pre-OV = 9 days
Estimated Dds for Pre-OV Period = 25C – Tlow (11.11C) x avg no. Days:
125.0 '= 125 Dds
Extra factor for mating of 2 days in field at ca 24 DD/day 48 DD

4. Oviposition schedule

Tsai and Liu 2000: Adults on caged plants at 25 C, 756-80% RH, 13:11 L:D
Approx. 33% OV at: 21, 18, 24, and 21 days
Mean 33% OV = 21 days
Estimated Dds for 33%-OV Period = 25C – Tlow (11.11C) x avg no. Days:
292 '= 292 Dds (including Pre-OV period)
167 (excluding Pre-OV period)

Nava 2007 (Sao Paulo Brazil)

	Approx. % OV at #days at 24 +/- 2C RH 70%, 14:10 L:D (from Fig. 3.)											
	5%	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**95%**	**98%**
Mean Days	**1.0**	**1.8**	**3**	**3.9**	**4.9**	**5.95**	**7.1**	**8.2**	**9.95**	**13.7**	**17**	**19**
Dds (11.11 Tlow)	**12.9**	**23.2**	**38.7**	**50.3**	**63.2**	**76.7**	**91.5**	**105.7**	**128.3**	**176.6**	**219.1**	**244.9**

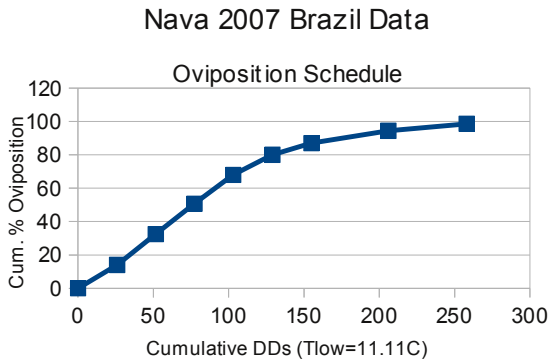
Assessment: at the named conditions, 50% OV at about 6.0 days/77 Dds. In the field we use a lesser percentage for mean generation time, so 4.0 days/52 Dds would be about right for ca. 33%
Note: this number for 33% is used to best approximate peak to peak generation times from field data; e.g. analysis of Tsai et al. 2002 work done in S. Florida

Details for above:

	No. Eggs (From Fig. 3) Days											
	1	2	4	6	8	10	12	14	16	18	20	22	24
Rangpur lime	0	615	950	1100	810	610	475	220	140	45	0	0	0
Orange jessar	0	730	820	640	805	545	480	380	390	400	230	110	100
Sunki mandari	0	240	320	305	310	190	35	30	10	5	0	0	0
	Cum. Eggs												
	0	615	1565	2665	3475	4085	4560	4780	4920	4965	4965	4965	4965
	0	730	1550	2190	2995	3540	4020	4400	4790	5190	5420	5530	5630
	0	240	560	865	1175	1365	1400	1430	1440	1445	1445	1445	1445
	Degree-Days (Tlow = 11.11 C):												
	Cum. %	**25.78**	**51.56**	**77.34**	**103.12**	**128.9**	**154.68**	**180.46**	**206.24**	**232.02**	**257.8**	**283.58**	**309.36**
	0	12.4	31.5	53.7	70.0	82.3	91.8	96.3	99.1	100.0	100.0	100.0	100.0
	0	12.9	27.4	38.7	52.9	62.5	71.0	77.7	84.6	91.6	95.7	97.6	99.4
	0	16.6	38.8	59.9	81.3	94.5	96.9	99.0	99.7	100.0	100.0	100.0	100.0
Mean	**0.0**	**14.0**	**32.5**	**50.7**	**68.1**	**79.7**	**86.6**	**91.0**	**94.4**	**97.2**	**98.6**	**99.2**	**99.8**

Check – Dds for OV schedule

Dds for OV	% OV
0	0
26	14
51.6	32.5
77.3	50.7
103	68
129	80
155	87
206	94.4
258	98.6



Comparison with Tsai and Liu 2000 results: these results indicate more rapid oviposition than the Florida data suggest. We will use the Florida result for the time being, and await other studie
It is somewhat likely that experimental conditions limited adult longevity and oviposition in the Brazil studies (that being more likely than finding a way to extend life!)

5. Adult Longevity (and Max OV period)

Tsai and Liu 2000: Adults on caged plants at 25 C, 756-80% RH, 13:11 L:D

	Duration at 25 C, 75-80% RH, 13:11 L:D
	Female
Grapefruit	39.7
Orange jessamine	39.7
Rough lemon	47.6
Sour orange	43.7
Mean	42.7

Results: Females lived 40-48 days depending on host, 42.7 days on average.
Using 95% of 42.7 to estimate maximum OV under field conditions,

Max OV period = 0.95 x 42.7 = 40.5 days
562.8 '= 563 Dds (including Pre-OV period)
563 (excluding Pre-OV period)

Nava 2007 (Sao Paulo Brazil)

	Duration at 24 +/- 2C RH 70%, 14:10 L:D	
	Male	Female
Rangpur lime	24.57	30.96
Orange jessamine	23.17	32.42
Sunki mandarin	21.19	31.16
Mean	23.0	31.5

Interpretation: Females lived 31.5 days at 24 C; this result is shorter than Florida results (but longer than the max 26 days from Nava's OV studies)

6. Estimated first and peak spring oviposition

Tsai and Liu 2002. Note: S. Florida is rather tropical/subtropical rather than temperate, so no evidence of “overwintering” behaviors can be found
Events extracted from Fig. 1 and historical weather data:

		Hollywood, FL		pomplanobeachairpar_fl.txt			
Event (Pampano Beach FL)	Date	HLWDFL98.tx	Gen diff estim.	Dds 30yr avg	Gen diff estim.		
First peak adults (assume peak OW OV)	02/25/99	991	1093	881	1111	836	1050
First peak adults (assume peak F1)	04/20/99	2084	1204	1992	1199	1886	1184
Second peak adults (assume peak F2)	06/05/99	3288	1296	3191	1354	3070	1350
Second peak adults (assume peak F2)	07/20/99	4584	1032	4545	1033	4420	1023

Forth peak adults (assume peak F3)	08/22/99	5616		5578		5443
1998 Data (Davie FL)						
	09/22/98	6770	961	6385	895	
	10/24/98	7731	744	7280	696	
	11/24/98	8475		7976		
	Mean generation time		1048			

7. Summary of Phenology Model Results:

Asian citrus psyllid, Diaphorina citri

	Celsius	Fahrenheit
Tlow	11.11	52
Tupper	32	90
Stage	Dds C	Dds F
Egg	60	108
Nymph	180	324
Mating+PreOV	173	311
50% OV in the field	167	300
95% OV in the field	563	1013
Total Gen Time	580	1043

6. Model Events Table

Estimated first spring OV	350	630
Estimated peak spring OV	550	990
Peak F1 nymphs	700	1260
Peak F1 adults 50% OV	1130	2033
Peak F2 nymphs	1280	2303
Peak F2 adults 50% OV	1709	3077
Peak F3 nymphs	1859	3347
Peak F3 adults 50% OV	2289	4120
Peak F4 nymphs	2439	4390
Peak F4 adults 50% OV	2869	5164
Peak F5 nymphs	3019	5434
Peak F5 adults 50% OV	3448	6207
Peak F6 nymphs	3598	6477
Peak F6 adults 50% OV	4028	7251
Peak F7 nymphs	4178	7521
Peak F7 adults 50% OV	4608	8294

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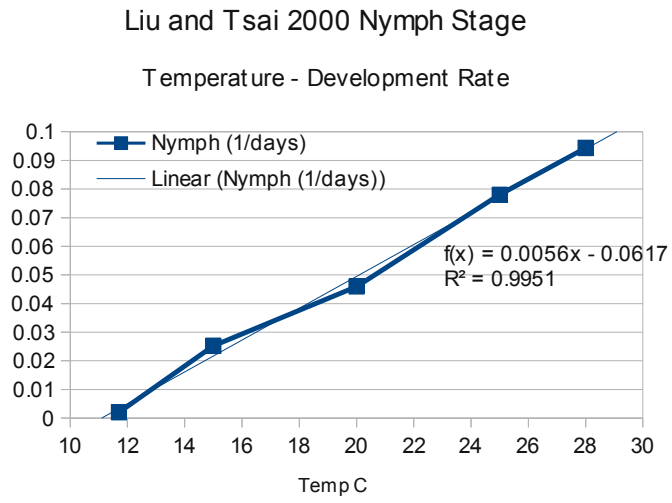
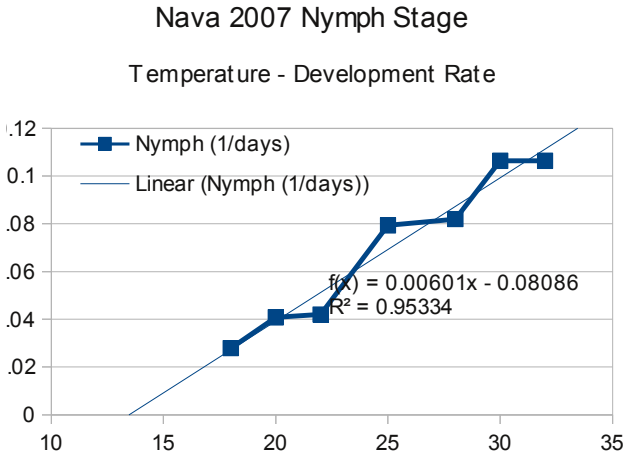
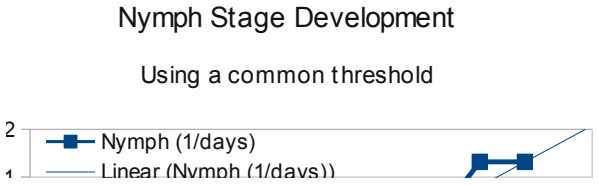
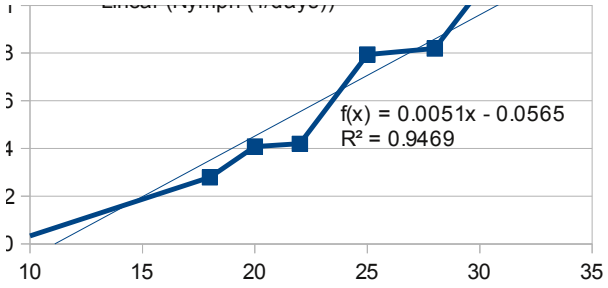

Liu and Tsai 2000 Nymph Stage
Temperature - Development Rate
Nymph (1/days)
Linear (Nymph (1/days))
f(x) = 0.0056x - 0.0617
R² = 0.9951
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
10
12
14
16
18
20
22
24
26
28
30
Temp C

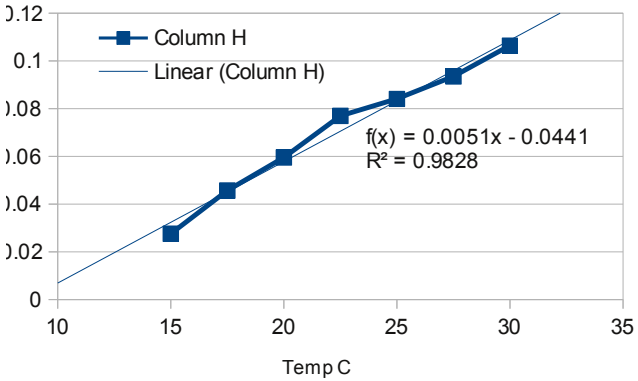

Nava 2007 Nymph Stage
Temperature - Development Rate
Nymph (1/days)
Linear (Nymph (1/days))
f(x) = 0.00601x - 0.08086
R² = 0.95334
.12
0.1
.08
.06
.04
.02
0
10
15
20
25
30
35


Nymph Stage Development
Using a common threshold
Nymph (1/days)
2
1



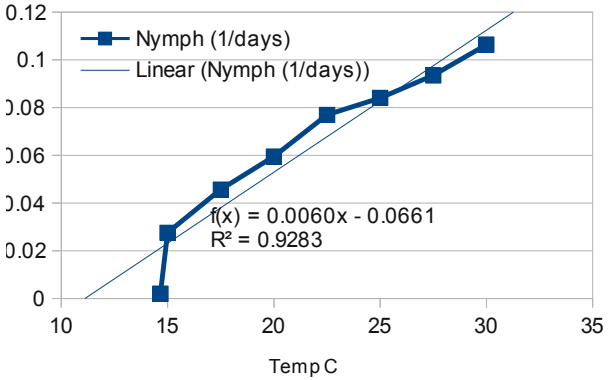
Nakata 2006 Nymph Stage

Temperature - Development Rate



Nymph Stage Development (Nakata 2006)

Using a common threshold



	99.8%	**100.00%**
	24	**26**
	309.4	**335.1**
% OV		
	26	28
	0	0
	35	0
	0	0
	4965	4965
	5665	5665
	1445	1445
	335.14	**360.92**
	100.0	100.0
	100.0	100.0
	100.0	100.0
	100.0	**100.0**

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