Supplementary Material

Influence of Temperature on Age-Stage, Two-Sex Life Tables for a Minnesota-Acclimated Population of the Brown Marmorated Stink Bug, (*Halyomorpha halys*)

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The supplementary material tables (**Table S1**, **S2** and **S3)** and one figure **(Figure S1)** are provided to summarize additional information to support our findings from the research on "Influence of Temperature on Age-Stage, Two-Sex Life Tables for a Minnesota-Acclimated Population of the Brown Marmorated Stink Bug, (*Halyomorpha halys*). **Table S1** presents information on stage specific survival (%) and egg-adult survival (%); the egg-adult survival peaks to 96% at 27 °C and declined towards both lower and upper temperature extremes of 15 °C and 36 °C, respectively. **Table S2** presents estimated parameters from non-linear models fit to data on intrinsic rate of increase for *H. Halys* using the *devRate* [1] and *OPTIMSSI* [2] package for R. The Ratkowsky model [3] with the lowest AIC (-59.52) among all models best fitted the data. **Table S3** is a compilation of mean developmental time (days) and egg-adult survival (%) for the MN and the PA acclimated *H. halys* at constant temperatures. Mean development times for the two populations are compared ($\alpha = 0.05$) using independent two-sample Student's t-test or Welch's t-test, depending on whether sample variances are equal or unequal, respectively. **Figure S1** presents Sharpe-Schoolfield-Ikemoto (SSI) model fit to data on intrinsic rate of increase for *H. Halys*, and it was the best among all models (AIC= -56.24) when biological significance of parameters is also accounted as a model selection criteria [4].

Supplementary Tables

Table S1. Stage-specific apparent survival (%) and the cohort-specific total survival (%)

Table S2. Estimated parameters from models fit to assess temperature-dependency of intrinsic rate of increase for *Halyomorpha halys* using the *devRate* and *OPTIMSSI* package for R, and the corresponding AIC values for each model

Table S3. Mean developmental time (days ± standard error) and egg-adult survival (%) for the MN and the PA acclimated *H. halys* at constant temperatures. For the PA population, data is adapted from Nielsen *et al.* (2008)

Supplementary Figure

Figure S1. Effect of temperature on intrinsic rate of increase of *H. halys*, as described by the Sharpe-Schoolfield-Ikemoto (SSI) model, where maximum rate of increase is estimated to occur at 28.03 °C

Table S1. Stage-specific apparent survival (%) and the cohort-specific total survival (%)

Temperature (°C)	n	Egg	First Instar	Second Instar	Third Instar	Fourth Instar	Fifth Instar	Cohort-specific Survival
15	59	69.41	96.61	2.00	0.00	-	-	0.00
17	50	100.00	66.00	87.88	75.86	63.64	64.29	18.00
20	35	100.00	96.55	100.00	96.43	88.89	100.00	68.00
23	51	100.00	100.00	100.00	82.76	82.76	82.76	82.00
25	51	100.00	100.00	96.08	98.00	95.83	95.65	86.00
27	50	100.00	100.00	96.00	100.00	100.00	97.92	96.00
30	50	100.00	100.00	96.00	93.75	95.56	93.02	80.00
33	56	91.07	100.00	96.08	71.43	82.86	17.24	10.00
36	133	62.41	55.42	63.04	41.38	41.67	50.00	2.00

Table S2. Estimated parameters from models fit to assess temperature-dependency of intrinsic rate of increase for *Halyomorpha halys* using the *devRate* and *OPTIMSSI* package for R, and the corresponding AIC values for each model

Sl. No.	Model	Parameters	AIC
devRate Package in R:			
1	Taylor_81: rT ~ Rm * exp(-1/2 * ((T - Tm)/To)^2)	Rm = 0.0934 Tm = 26.9894 To = 4.2276	-44.41
2	Lactin_95: rT ~ exp(aa * T) - exp(aa * Tmax - (Tmax - T)/deltaT)	aa =0.1643 Tmax = 35.7889 deltaT = 6.0816	-29.20
3	Logan6_76: rT ~ phi * (exp(bb * T) - exp(bb * Tmax - (Tmax - T)/deltaT))	phi = 0.0484 bb = 0.1665 Tmax = 35.7791 deltaT = 5.9433	-27.21
4	**Ratkowsky_83:** **rT ~ (cc * (T - T1) * (1 - exp(k * (T - T2))))^2**	**cc = 0.0540** **T1 = 15.6621** **T2 = 35.9606** **k = 0.0749**	**-59.52**
5	Beta_16: rT ~ rm * (T2 - T)/(T2 - Tm) * ((T - T1)/(Tm - T1))^((Tm - T1)/(T2 - Tm))	rm = 0.0824 T1 = 17.0000 T2 =35.8232 Tm = 27.8516	-40.45
6	Beta_95: rT ~ exp(mu) * (T - Tb)^aa * (Tc - T)^bb	mu = -13.663 Tb =14.424 Tc = 36.00 aa = 2.833 bb = 1.858	-54.04
7	Performance-2: rT ~ cc * (T - T1) * (1 - exp(k * (T - T2)))	cc = 0.0271 T1 = 17.2861 k = 0.0413 T2 = 35.7893	-39.70
8	Root square: rT ~ (bb * (T - Tb))^2	bb = 7.938e-04 Tb = -2.299e+02	-21.96
9	Wangengel_98: rT ~ (2 * (T - Tmin)^aa * (Topt - Tmin)^aa - (T - Tmin)^(2 * aa))/((Topt - Tmin)^(2 * aa))	aa = 3.965e-01 Tmin = 1.700e+01 Topt = 1.356e+05	-20.50
10	Regniere_12:	Tb = 16.4650 Tm = 35.9889 phi = -0.4248	-50.91

	rT ~ phi * (exp(bb * (T - Tb)) - ((Tm - T)/(Tm - Tb)) * exp(-bb * (T - Tb)/deltab) - ((T - Tb)/(Tm - Tb)) * exp(bb * (Tm - Tb) - (Tm - T)/deltam))	bb = 0.1149 deltab = -0.6501 deltam = 4.1917	
11	Stinner_74: eqn. 1: rT ~ C/(1 + exp(k1 + k2 * T)) eqn. 2: rT ~ C/(1 + exp(k1 + k2 * (2 * Topt - T)))	Did not converge	NA
12	Logan10_76: rT ~ alpha * (1/(1 + cc * exp(-bb * T)) - exp(-((Tmax - T)/deltaT)))	alpha = 0.1981 bb = 0.3488 cc = 1865.9861 Tmax = 35.8791 deltaT = 10.6802	-43.68
13	SharpeDeMichele_77: rT ~ ((T + 273.16) * exp((aa - bb/(T + 273.16))/1.987))/(1 + exp((cc - dd/(T + 273.16))/1.987) + exp((ff - gg/(T + 273.16))/1.987))	aa = 37.27 bb = 16022.62 cc = -855.38 dd = -250493.15 ff = 436.03 gg = 132644.05	-49.12
14	Analytis_77: rT ~ aa * (T - Tmin)^bb * (Tmax - T)^cc	Tmin = 1.073e+01 Tmax = 3.600e+01 aa = 1.244e-04 bb = 1.819e+00 cc = 5.584e-01	-27.94
15	Schoolfield_81: rT ~ (p25 * (T + 273.16)/298 * exp(aa/1.987 * (1/298 - 1/(T + 273.16))))/(1 + exp(bb/1.987 * (1/cc - 1/(T + 273.16))) + exp(dd/1.987 * (1/ee - 1/(T + 273.16))))	p25 = 7.391e-02 aa = 1.602e+04 bb = -2.505e+05 cc = 2.928e+02 dd = 1.326e+05 ee = 3.042e+02	-49.12
16	SchoolfieldHigh_81: rT ~ (p25 * (T + 273.16)/298 * exp(aa/1.987 * (1/298 - 1/(T + 273.16))))/(1 + exp(dd/1.987 * (1/ee - 1/(T + 273.16))))	p25 = 7.501e-02 aa = 3.564e+04 dd = 1.159e+05 ee = 3.023e+02	-37.88
17	SchoolfieldLow_81: rT ~ (p25 * (T + 273.16)/298 * exp(aa/1.987 * (1/298 - 1/(T + 273.16))))/(1 + exp(bb/1.987 * (1/cc - 1/(T + 273.16))))	p25 = 1.208e+00 aa = -8.026e+04 bb = -1.159e+05 cc = 3.023e+02	-37.88
18	Poly2: rT ~ a0 + a1 * T + a2 * T^2	a0 = -0.5850 a1 = 0.04983 a2 = -0.0009	-40.05
19	HarcourtYee_82: rT ~ a0 + a1 * T + a2 * T^2 + a3 * T^3	a0 = -2.054e-01 a1 = 3.799e-03 a2 = 8.588e-04 a3 = -2.249e-05	-40.16

20	Poly4: rT ~ a0 + a1 * T + a2 * T^2 + a3 * T^3 + a4 * T^4	a0 = 2.973e+00 a1 = -5.137e-01 a2 = 3.165e-02 a3 = -8.167e-04 a4 = 7.505e-06	-49.97
21	HilbertLogan_83: rT ~ phi * (((T - Tb)^2/((T - Tb)^2 + aa^2)) - exp(-(Tmax - (T - Tb))/deltaT))	phi = 0.275 aa = 10.902 Tb = 13.604 Tmax = 24.128 deltaT = 9.025	-39.33
22	Lamb_92[[1]]: rT ~ Rm * exp(-1/2 * ((T - Tmax)/To)^2)	Rm = 0.0934 Tmax = 26.9894 T0 = -4.2276	-44.41
23	Lamb_92[[2]]: rT ~ Rm * exp(-1/2 * ((T - Tmax)/To)^2)	Rm = 0.0934 Tmax = 26.9894 T0 = -4.2276	-44.41
24	Lactin1_95: rT ~ exp(aa * T) - exp(aa * Tmax - (Tmax - T)/deltaT)	aa =0.1643 Tmax = 35.7889 deltaT = 6.0816	-29.20
25	Lactin2_95: rT ~ exp(aa * T) - exp(aa * Tmax - (Tmax - T)/deltaT) + bb	aa = 0.0288 bb = -1.0623 Tmax = 51.3935 deltaT = 16.8618	-39.35
26	Briere1_99: rT ~ aa * T * (T - Tmin) * (Tmax - T)^(1/2)	aa = 6.991e-05 Tmax = 3.600e+01 Tmin = 1.544e+01	-29.12
27	Briere2_99: rT ~ aa * T * (T - Tmin) * (Tmax - T)^(1/bb)	aa = 1.892e-05 bb = 7.748e-01 Tmax = 3.600e+01 Tmin = 1.743e+01	-42.66
28	Kontodimas_04: rT ~ aa * (T - Tmin)^2 * (Tmax - T)	aa = 5.208e-05 Tmax = 3.568e+01 Tmin = 1. 382e+01	-37.85
29	Damos_08: rT ~ aa * (bb - T/10) * (T/10)^cc	aa = -2.351 bb = 1.721 cc = -3.707	-24.83
30	Damos_11: rT ~ aa/(1 + bb * T + cc * T^2)	aa = 0.0025 bb = -0.0716 cc = 0.0013	-34.86
31	Wang_82: rT ~ (K/(1 + exp(-r * (T - T0)))) * (1 - exp(-(T - TL)/aa)) * (1 - exp(-(TH - T)/aa))	K =55.1509 r = 0.4752 aa = 447.4390 TL = -20.5821 T0 = 23.6922 TH = 35.8769	-41.40
32	Bayoh and Lindsay (bayoh_03):	aa = 2.927e-02	-26.11

	rT ~ aa + bb * T + cc * exp(T) + dd * exp(-T)	bb = 1.147e-03 cc = -1.670e-17 dd = -1.203e+06	
33	Wagner_88 rT ~ 1/((1 + exp((cc/1.987) * ((1/dd) - (1/(T + 273.16)))))/(aa * (T + 273.16)/298.15 * exp((bb/1.987) * ((1/298.15) - 1/(T + 273.16)))))	aa = 7.736e-02 bb = 3.564e+04 cc = 1.159e+05 dd = 3.023e+02	-37.88
34	Bieri1_83: rT ~ aa * (T - Tmin) - (bb * exp(T - Tm))	Did not converge	NA
OPTIMSSI Package in R:			
35.	Sharpe-Schoolfield-Ikemoto model: $r(T) = \frac{\rho_{\Phi} \frac{T}{T_{\Phi}} \exp\left[\frac{\triangle H_A}{R}\left[\frac{1}{T_{\Phi}} - \frac{1}{T}\right]\right]}{1 + \exp\left[\frac{\triangle H_L}{R}\left[\frac{1}{T_L} - \frac{1}{T}\right]\right] + \exp\left[\frac{\triangle H_H}{R}\left[\frac{1}{T_H} - \frac{1}{T}\right]\right]}$	T_{Φ}= 2.959408e+02 ρ_{Φ} = 5.436652e-02 $\triangle H_A$ = 2.841494e+04 $\triangle H_L$= -2.846197e+05 $\triangle H_H$ = 1.241860e+05 T_L = 2.925017e+02 T_H = 3.029137e+02	-56.24

Note 1: The Ratkowsky non-linear empirical model [3], with the lowest AIC (-59.52) among all models considered [1], best described the relation between temperature and intrinsic rate of increase for *H. halys*. The r_m was maximized (0.0899 day^{-1}) at 27.49˚C.

Note 2: The Sharpe-Schoolfield-Ikemoto (SSI) non-linear biophysical model [2] based on enzyme kinetics approach provided the next best fit (AIC = -56.24). If the ability to estimate parameters of biological significance is also accounted as a model selection criteria [4], the best fit model was SSI model (**Figure S1**). The r_m was maximized (0.0983 day^{-1}) at 28.03˚C.

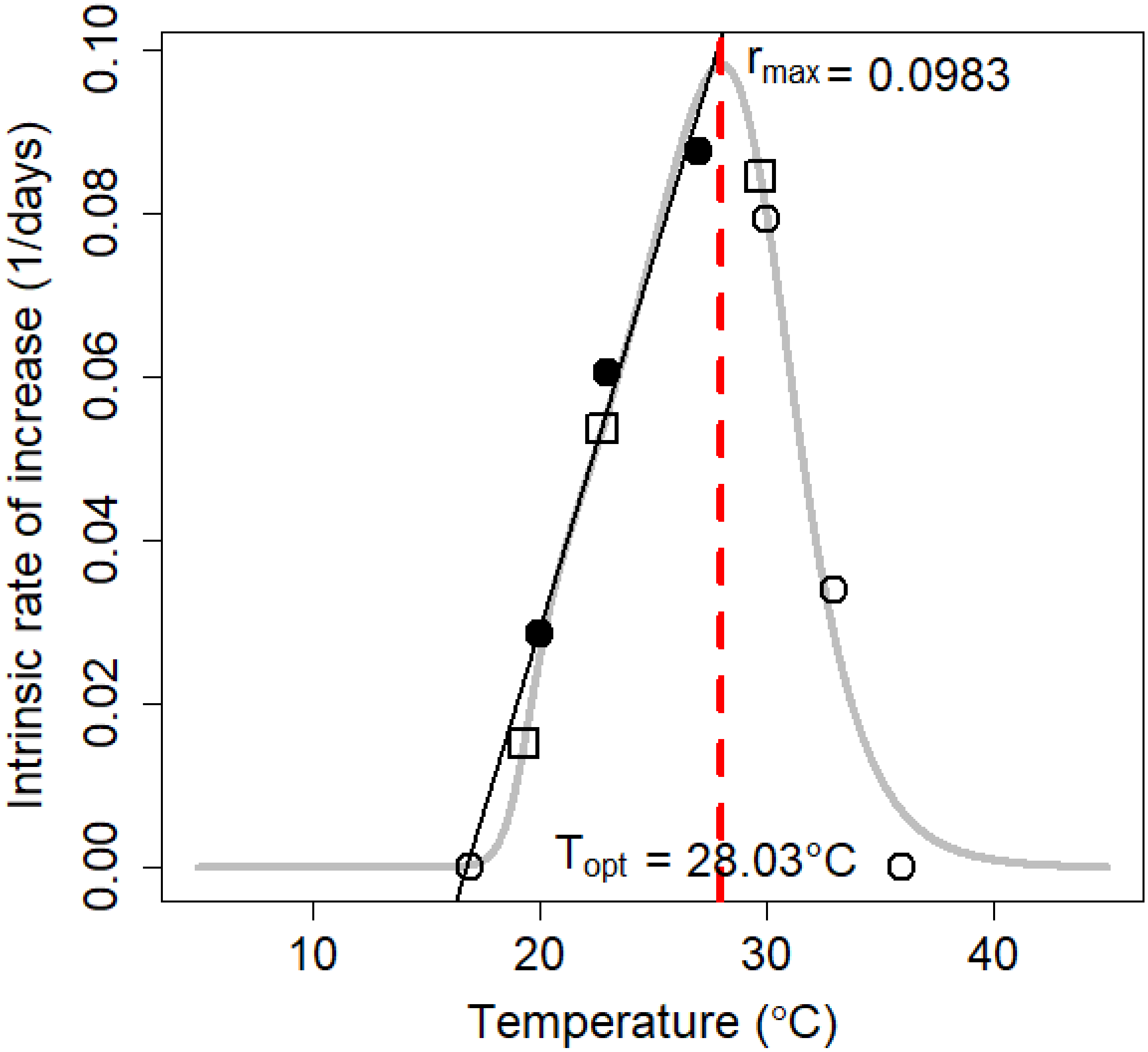

Figure S1. Effect of temperature on intrinsic rate of increase of *H. halys*, as described by the Sharpe-Schoolfield-Ikemoto (SSI) model, where maximum rate of increase is estimated to occur at 28.03 °C

Table S3. Mean developmental time (days ± standard error) and egg-adult survival (%) for the MN and the PA acclimated *H. halys* at constant temperatures. For the PA population, data is adapted from Nielsen *et al.* (2008) [5]

Temperature	n	Egg	First Instar	Second Instar	Third Instar	Fourth Instar	Fifth Instar	Pre-adult	Survival (%)
15°C: MN	59	21.01± 0.07[a]	26.57 ± 0.18	38.25 ± 1.37	32.59 ± 1.04	28.59 ± 1.23	43.73 ± 1.72	186.23± 0.78	0.00
15°C: PA	50	22.00 ±0.00[b]	—	—	—	—	—	—	0.00
		(t_{98} = -7.44, $P = 3.87 \times 10^{-11}$)							
17°C: MN	50	13.23 ± 0.04[a]	13.20 ± 0.14[a]	24.95 ± 0.80[a]	22.16 ± 1.55	21.43 ± 2.18	17.90 ± 1.63[a]	103.89 ± 4.69[a]	18.00
17°C: PA	100	17.20 ± 0.08[b]	17.01 ± 0.16[b]	30.36 ± 1.53[b]	22.40 ± 4.02	23.00 ± 1.08	28.00 ± 0.00[b]	121.50 ± 0.50[b]	2.00
		(t_{148} = -44.39, $P = 2.54 \times 10^{-83}$)	(t_{95} = -17.92, $P = 1.25 \times 10^{-31}$)	(t_{38} = -3.73, P = 0.006)			(t_{7} = -6.20, P = 0.0002)	(t_{9} = -3.73, P = 0.006)	
20°C: MN	35	12.71 ± 0.11[a]	10.90 ± 0.10[a]	18.77 ± 0.37[a]	12.56 ± 0.90	11.15 ± 0.49[a]	16.46 ± 0.45[a]	80.67 ± 1.04	68.00
20°C: PA	100	11.50 ± 0.05[b]	9.34 ± 0.08[b]	16.25 ± 0.23[b]	11.78 ± 0.29	13.66 ± 0.31[b]	20.16 ± 0.36[b]	81.16 ± 0.80	62.00
		(t_{149} = -7.79, $P = 3.83 \times 10^{-9}$)	(t_{118} = 12.03, $P = 2.27 \times 10^{-18}$)	(t_{102} = 5.78, $P = 4.95 \times 10^{-7}$)		(t_{95} = -4.33, $P = 8.82 \times 10^{-5}$)	(t_{83} = -6.42, $P = 4.29 \times 10^{-8}$)		
25°C: MN	51	5.60 ± 0.07[a]	5.06 ± 0.10	9.58 ± 0.18	7.07 ± 0.17	6.52 ± 0.11[a]	9.06 ± 0.08[a]	42.62 ± 0.38[a]	86.00
25°C: PA	100	6.10 ± 0.03[b]	4.82 ± 0.10	9.62 ± 0.21	7.08 ± 0.22	7.38 ± 0.28[b]	10.44 ± 0.28[b]	44.92 ± 0.80[b]	61.00
		(t_{149} = -6.57, $P = 1.08 \times 10^{-9}$)				(t_{107} = -2.86, P = 0.005)	(t_{103} = -4.74, $P = 1.10 \times 10^{-5}$)	(t_{103} = -2.60, P = 0.01)	
27°C: MN	50	3.25 ± 0.04[a]	3.80 ± 0.04[a]	7.98 ± 0.15	5.41 ± 0.11	5.38 ± 0.11[a]	7.46 ± 0.12	33.21 ± 0.36[a]	94.00
27°C: PA	80	4.87 ± 0.10[b]	4.25 ± 0.05[b]	7.64 ± 0.19	5.49 ± 0.21	5.90 ± 0.18[b]	7.81 ± 0.28	35.81 ± 0.52[b]	52.50
		(t_{128} = -15.04, $P = 1.20 \times 10^{-27}$)	(t_{128} = -7.03, $P = 1.11 \times 10^{-10}$)			(t_{97} = -2.47, P = 0.02)		(t_{87} = -4.11, P = 0.0001)	
30°C: MN	50	3.00 ± 0.00	3.02 ± 0.07[a]	6.60 ± 0.19[a]	5.41 ± 0.14[a]	5.31 ± 0.13[a]	8.01 ± 0.25	30.95 ± 0.45[a]	80.00
30°C: PA	100	3.00 ± 0.00	3.70 ± 0.05[b]	7.05 ± 0.13[b]	6.11 ± 0.28[b]	6.11 ± 0.23[b]	8.47 ± 0.28	33.39 ± 0.50[b]	51.00
			(t_{142} = -7.03, $P = 8.29 \times 10^{-11}$)	(t_{128} = -2.01, P = 0.05)	(t_{117} = -2.23, P = 0.03)	(t_{103} = -3.14, P = 0.002)		(t_{89} = -3.63, P = 0.0005)	
33°C: MN	56	3.76 ± 0.10[a]	3.25 ± 0.04[a]	5.43 ± 0.09[a]	6.04 ± 0.22[a]	6.74 ± 0.53	8.20 ± 0.25[a]	31.20 ± 0.56[a]	10.00
33°C: PA	95	4.00 ± 0.00[b]	3.01 ± 0.01[b]	7.47 ± 0.23[b]	7.45 ± 0.53[b]	7.20 ± 0.40	10.60 ± 0.81[b]	37.80 ± 0.86[b]	5.00
		(t_{149} = -2.40, P = 0.02)	(t_{106} = -5.10, $P = 4.51 \times 10^{-6}$)	(t_{76} = -8.26, $P = 6.77 \times 10^{-10}$)	(t_{53} = -2.46, P = 0.02)		(t_{8} = -2.83, P = 0.04)	(t_{8} = -6.43, P = 0.0004)	

Data are mean ± standard error. Estimates for the PA population of BMSB are from Nielsen *et al.* 2008). The 'n' denotes sample size (# of eggs) at the beginning of the experiment. For each instar (or phase) at a given temperature, the means in a column followed by a different letter suggest that estimates for the MN and for the PA population of *Halyomorpha halys* are significantly different (t test, $P < 0.05$). Comparisons were not possible for 23°C and 36°C, due to lack of estimates for the PA BMSB. An em dash [—] suggests lack of data owing to 100% mortality.

References:

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