

Temperature and Humidity Tolerances of the Ghost Ant, *Tapinoma melanocephalum* (Hymenoptera: Formicidae)

by

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ABSTRACT

Temperature and humidity tolerances of the ghost ant, *Tapinoma melanocephalum* (Fabricius) were examined in a series of laboratory experiments. LT₅₀ values for worker ants ranged from 2.0 h at 45°C and 97% RH to 43.7 h at 15°C and 55% RH. Mean 24 h mortality ranged from 5.7 to 100% for 15°C and 55% RH and 45°C and 75% RH, respectively. At 97% RH, ghost ants tolerated the greatest range of temperatures, with 24 h mortality of <30% between 15 and 35°C. The importance of temperature and humidity tolerance to ghost ants is compared with other urban insect pests of tropical origin.

Keywords: *Tapinoma melanocephalum*, temperature tolerance, humidity tolerance

INTRODUCTION

The ghost ant, *Tapinoma melanocephalum* (Fabricius) is one of the most important household ant species in the tropics (Lee & Robinson 2001) and is well established in parts of Asia, Europe, North and South America, Hawaii, and many Caribbean Islands (Hedges 1998). In Malaysia, *T. melanocephalum* is a common pest in residential premises (Lee 2002) and food outlets (Lee et al. 2002). This polygynous tramp species nests primarily outdoors in small, protected areas such as in and under potted plants, in dead tree limbs, under stones, in palm fronds, and in organic debris (Hedges 1998). Colonies can be polydomous, often nest in several locations, and form foraging trails among nests and between nests and food sources. Because of its small size (< 2 mm) and ability to nest in a variety of materials, *T. melanocephalum* can be easily transported in potted plants, cut flowers, and even luggage. This species forages on sugars such as honeydew, candy, and jellies as well as live and dead insects and their eggs. *Tapinoma melanocephalum* may

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tend honeydew producing homopterans but are a predator of the kissing bug, *Rhodnius prolixus* Stål, a primary vector of Chaga's disease in Venezuela (Gomez-Nunez 1971).

As a tropical species, *T. melanocephalum* may be sensitive to extreme abiotic conditions such as low relative humidities and temperatures. Tropical species in general are more sensitive to desiccation than temperate species (Edney 1977, Hadley 1994). For example, the average cuticular permeability of the tropical / subtropical red imported fire ant, *Solenopsis invicta* Buren, (Appel et al. 1991) is more than double than that of similar-sized desert species (Hadley 1994). In addition, rate of desiccation is affected by ant size; smaller ants have greater surface area to body volume ratios and desiccate more rapidly than larger ants (Francke & Cokendolpher 1986). At a constant relative humidity, *S. invicta* alates desiccate more rapidly at greater temperatures (Appel unpublished), a phenomena observed with numerous insects (e.g., Wigglesworth 1945), ticks (Lees 1947), and the black widow spider, *Latrodectus hesperus* Chamberlin and Ivie (Hadley & Quinlan 1989).

Temperature, relative humidity, and moisture can affect ant behavior and distribution. For example, mating flights of *S. invicta* generally occur between 20 and 32°C the morning and afternoon after a rain (Rhoades & Davis 1967, Markin et al. 1971). Foraging activity of the tropical leaf-cutting ant, *Acromyrmex octospinosus* Reich, is reduced during the dry season and during periods of low relative humidity and high vapor density deficits (Therrien et al. 1986). There are many other examples of ants selecting moist and warm areas to nest and foraging only when specific temperature and humidity conditions are reached. These conditions can clearly affect the movement and ultimately pest status of ant species.

Limited biological information is available on *T. melanocephalum*, particularly environmental parameters associated with its survivorship. The purpose of this study was to determine the temperature and humidity tolerances of *T. melanocephalum* and to compare these tolerances with other pest species of ants.

MATERIALS AND METHODS

Field populations of ghost ant workers were collected from the Minden campus of the Universiti Sains Malaysia, Penang, Malaysia using honey-baited index cards as described by Lee et al. (2002). Ants found on the cards were transferred to aluminum trays (38 x 24 x 8.5 cm) coated on the upper inside surface with a thin layer of fluon, before being brought back to the laboratory and maintained at $25 \pm 2^\circ\text{C}$, $60 \pm$

5% RH, and a photoperiod of 12:12 (L:D) h. Ants were provided a moistened harborage, water, and dead cockroaches [*Nauphoeta cinerea* (Olivier)] ad libitum.

Saturated solutions (Table 1) that provided specific relative humidities at different temperatures were prepared according to Winston & Bates (1960). Prior to the beginning of each experiment, a beaker containing 50 ml of a saturated solution was placed at the center of an air-tight 1.5-L polyethylene container and maintained overnight. Ten ghost ant workers were placed into each of 10 small polyethylene vials (without lids) [3.5 cm diam. x 5.0 cm height] coated on the upper inside surface with a thin layer of fluon and introduced into the main container. Main containers with vials and ants were kept in incubators (Incucell 55, MM Medcenter GmbH, Germany) at 30 ± 1 , 35 ± 1 and $45 \pm 2^\circ\text{C}$, while a low temperature incubator (Hotech 624, Hotech Instruments Co., USA) was used to produce temperatures of 12 ± 0.8 and $15 \pm 1^\circ\text{C}$. For $25 \pm 2^\circ\text{C}$, main containers were left in the laboratory with air-condition. Temperatures were checked periodically with digital thermometers. Mortality of the ants was recorded at selected time intervals of up to 48 h. Each temperature-RH combination was replicated three times for a total of 300 ants per combination. A three-parameter sigmoid function of the form:

$$\%mortality = \frac{a}{1 + e^{\frac{-(x-x_0)}{b}}},$$

where x is time, x_0 is the inflection point (in h), a is the asymptotic maximum mortality, and b is the slope at the inflection point was fit to each temperature-RH combination (SPSS 2002). Data were pooled and subjected to probit analysis according to the procedure described by Robertson & Preisler (1992). Percentage of mortality at 24 h was averaged over the vials and containers; arcsine-square root transformed, and analyzed by analysis of variance (ANOVA) and the LSD-multiple range test. Percentage of mortality at 4 h was further analyzed

Table 1. Relative humidity (%) at different temperature produced by saturated solutions.

Saturated Solution	Temperature				
	15.0°C	25°C	30°C	35°C	45°C
Glucose	57 (at 12°)	55.0		55.0	
NaCl	76.0	75.5	75.5	75.5	75.0
K2S04	99.0	97.5	96.5	96.0	96.0

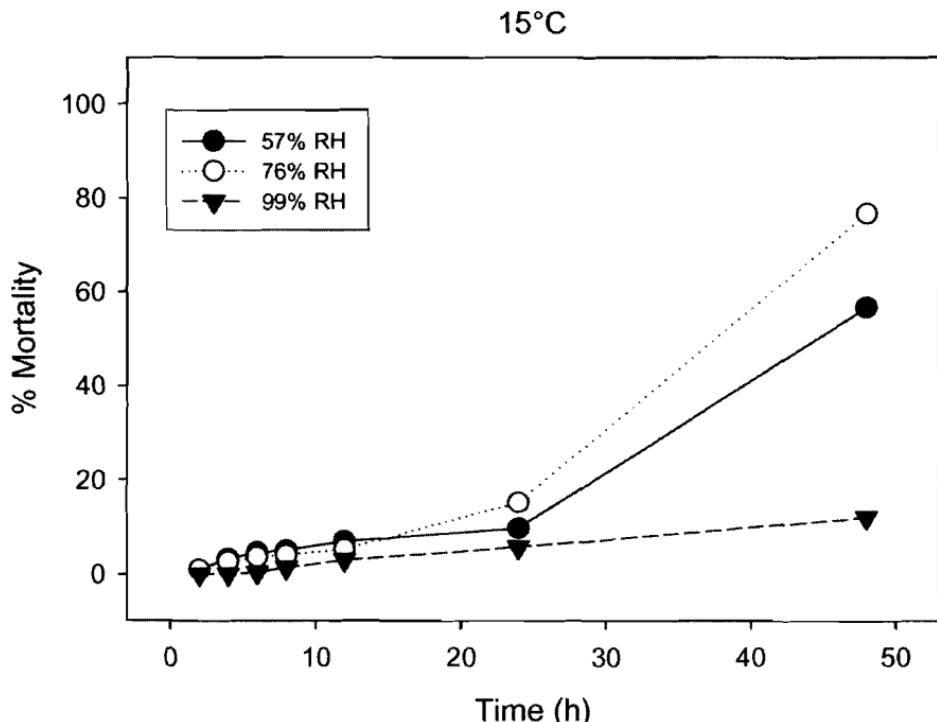


Fig. 1. Percentage mortality of worker *T. melanocephalum* when exposed to different humidity conditions at 15°C.

because mortality data were recorded at this time period for all but one temperature-RH combination. A three-dimensional plot of temperature, RH, and percentage mortality was generated using SigmaPlot (SPSS 2002) software. Raw data were smoothed and fit to a parabolic function of the form: % mortality = $y_0 + axx + bxy + cxx^2 + dxy^2$, where x is temperature and y is RH, to allow estimation of 4 hour mortality at any temperature-RH combination. Pearson product moment correlations were used to relate environmental conditions and mortality variables (SPSS 2003). A significance level of $P = 0.05$ is used throughout.

RESULTS AND DISCUSSION

As a primarily tropical species, *T. melanocephalum* generally experiences warm, humid, and consistent environmental conditions. It is also subject to a wide diversity of parasites, parasitoids, and predators that are also adapted to tropical conditions. If introduced without native biological control agents or competitors, a polygynous polydomous ant species with a generalized diet could become a pest. It is likely that this

Table 2. Regression statistics for percentage of worker *Tapinoma melanocephalum* mortality over exposure time at each temperatureRH combination.

RH (±2%)	Temperature (±1.5C)	n	Regression coefficients			F	P
			a	b	x_0		
55.0	15.0	7	2,245.57 ± 6.6 × 10 ⁴	14.92 ± 4.78	102.53 ± 74.76	0.992	<0.0001
	25.0	7	95.19 ± 3.11	5.02 ± 0.43	17.28 ± 0.78	0.993	<0.0001
	35.0	8	94.99 ± 3.78	3.09 ± 0.44	10.03 ± 0.58	0.982	<0.0001
75.0	15.0	7	143.81 ± 28.83	10.63 ± 0.83	46.58 ± 4.44	0.999	5,093.81
	25.0	7	98.92 ± 3.05	5.08 ± 0.39	18.00 ± 0.72	0.994	<0.0001
	30.0	9	98.06 ± 3.02	3.22 ± 0.37	10.67 ± 0.45	0.989	<0.0001
	35.0	8	97.49 ± 4.81	2.44 ± 0.44	7.78 ± 0.57	0.970	<0.0001
	45.0	13	101.20 ± 1.46	0.57 ± 0.03	2.38 ± 0.04	0.995	<0.0001
	97.0	7	12.45 ± 1.04	7.28 ± 1.60	24.65 ± 2.55	0.968	91.49
	25.0	7	21.38 ± 1.04	4.36 ± 0.60	16.92 ± 1.15	0.986	208.57
	30.0	9	41.65 ± 4.14	5.45 ± 1.30	19.15 ± 2.37	0.933	56.87
	35.0	8	23.45 ± 2.31	2.88 ± 1.09	10.65 ± 1.43	0.905	34.27
	45.0	11	97.62 ± 0.95	0.40 ± 0.02	2.07 ± 0.03	0.997	1,954.71
							<0.0001

is what has occurred with *T. melanocephalum*. This species is now found world-wide in tropical and subtropical areas in which it has been introduced. In addition, like many other insect pests of tropical origin, it is also found in green houses and other warm humid environments.

There is limited biological information available on *T. melanocephalum*, particularly the tolerances of this species to temperature and humidity

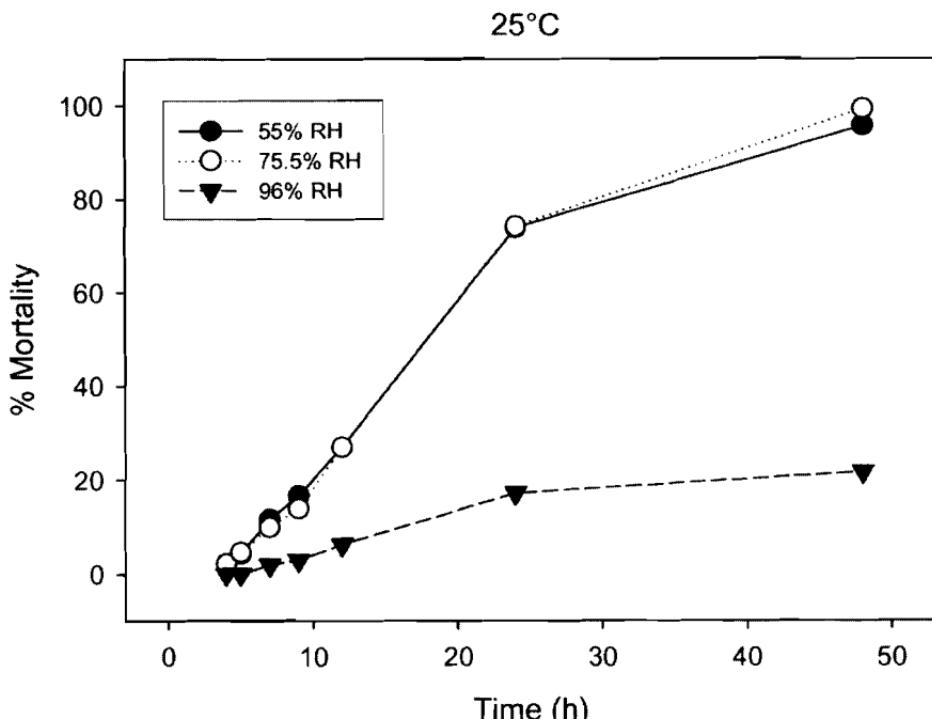


Fig. 2. Percentage mortality of worker *T. melanocephalum* when exposed to different humidity conditions at 25°C.

extremes. We exposed groups of worker caste *T. melanocephalum* to combinations of temperature and relative humidity that they might reasonably encounter in their native tropical and many subtropical areas. Worker mortality increased as a sigmoid function of exposure time for all combinations of temperature and RH (Figs. 1-5; Table 2). All temperature-RH combinations with humidities of <75% had estimated asymptotic maximum mortalities (the *a* regression coefficient) of more than »95%. Therefore, exposure to these conditions would result in »100% mortality of worker *T. melanocephalum*. At humidities of >96%, however, maximum mortality ranged between 12.5 and 41.6% for 15 and 30°C, respectively (Table 2). Lethal desiccation (see below) was likely prevented at >96% RH because of the low saturation deficit. Estimated maximal mortality at 96% RH and 45°C was »100% and was probably a result of overheating rather than desiccation. The *b* regression coefficient reflects the slope or degree of curvature at the inflection point of the sigmoid function. Slopes ranged from 0.4 at 97% RH and 45°C to 14.9 at 55% RH and 15°C (Table 2). Within a given RH, slope values generally decreased with increasing temperature except at 96% RH and 45°C. Smaller slope values actually result in steeper curves

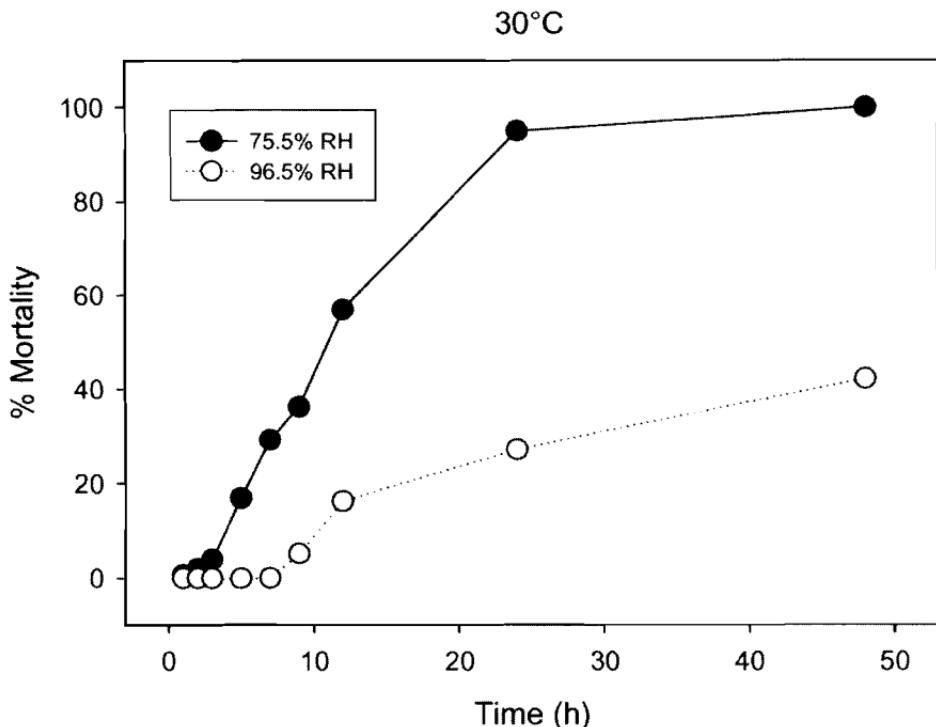


Fig. 3. Percentage mortality of worker *T. melanocephalum* when exposed to different humidity conditions at 30°C.

because the inverse of b is the exponent of the function. The inflection point, x_0 , also declined with increasing temperature within a given RH.

LT_{50} values ranged from »2 h at 45°C and 97% RH to »44 h at 15°C and 55% RH (Table 3). For a given relative humidity, LT_{50} values declined with increasing temperatures (Table 3). There was relatively little (<30%) mortality of worker *T. melanocephalum* held at 97% RH and 15–35°C for 24 h. The mortality that did occur was only at the end of the exposure period which did not fit the assumptions of probit analysis (Robertson & Preisler 1992).

Percentage of mortality at 4 h of exposure was modeled using a parabolic function to estimate the effects of temperature and RH combinations not tested in this study. The equation relating percentage mortality to temperature (°C) and humidity (% RH) is as follows: % mortality = $30.96 \pm 10.57 - 8.11 \pm 0.23 \times \text{Temperature} + 1.62 \pm 0.27 \times \text{RH} + 0.18 \pm 0.01 \times \text{Temperature}^2 - 0.01 \pm 0.01 \times \text{RH}^2$; $r^2 = 0.977$; Standard Error of Estimate = 4.50; $F = 2,593.64$; $P < 0.0001$ (Fig. 6). Mortality at 4 h is clearly more affected by temperature than RH, particularly above »35°C (Fig. 6).

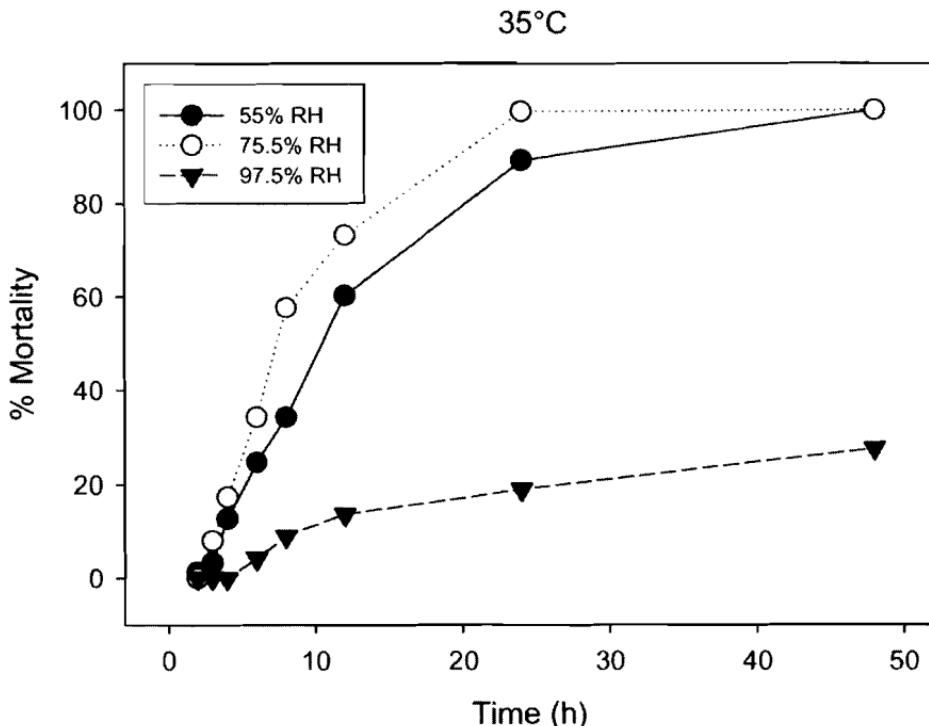


Fig. 4. Percentage mortality of worker *T. melanocephalum* when exposed to different humidity conditions at 35°C.

Although we did not measure water loss rates, it is likely that the mortality we observed between 15 and 35°C was due to desiccation. Because LT_{50} values increased with both increasing RH and temperature, we calculated the saturation deficit (see Edney 1977), or essentially the drying power of air. Water loss and therefore mortality rates generally increase with increasing saturation deficits (Edney 1977, Hadley 1994). Saturation deficits ranged from < 1 torr (mmHg) for 97% RH and 15–30°C, to »19 torr at 55% RH and 35°C. Mortality of worker *T. melanocephalum* at 24 h was significantly (Correlation coefficient = 0.812, N = 12, P = 0.0013) correlated with saturation deficit. Interestingly however, neither LT_{50} nor LT_{95} values were correlated with saturation deficit and probably reflects the non-sigmoidal time mortality relationship at many combinations of temperature and RH.

Compared with many other ant species, worker *T. melanocephalum* are exceedingly sensitive to low levels of environmental humidity. In fact, the high levels of 24 h mortality at 55% RH and moderate temperatures of 25 and 35°C (74.0 and 89.3%, respectively) demon-

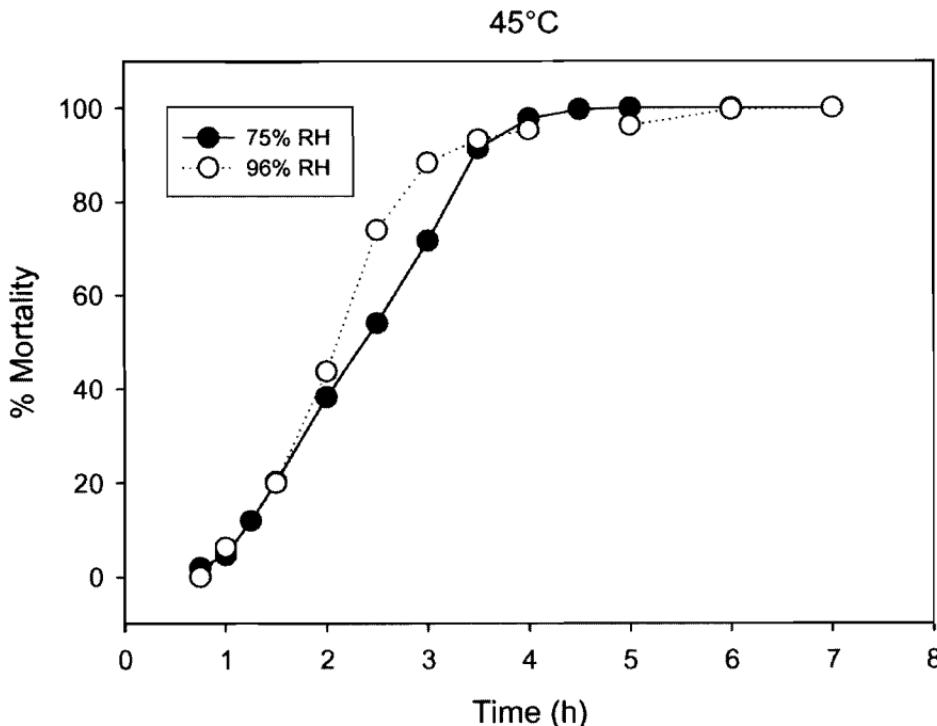


Fig. 5. Percentage mortality of worker *T. melanocephalum* when exposed to different humidity conditions at 45°C.

strate the sensitivity of this species to desiccation. Because *T. melanocephalum* is an important pest species and is clearly susceptible to desiccation, it is possible that an integrated pest management (IPM) program could be designed to manipulate environmental conditions. For example, a similarly desiccation-susceptible species, the garden millipede, *Oxidus gracilis* Koch, was successfully controlled by using methods that reduced moisture levels (Appel 1988). Sanitation including removal of water-retaining debris, large rocks, and elevating potted plants was one IPM tactic. The most important other tactic was lawn management: dethatching and moving to early morning irrigation. These tactics were successful in reducing infestations by >93% within 7 d, and without the use of insecticides. Similar alterations would also dry the environment of *T. melanocephalum*.

In conclusion, we have examined the temperature and humidity tolerances of worker *T. melanocephalum*, and found that this pest species is quite sensitive to desiccation. We suggest that a biologically-based IPM system can be designed to manage this pest by reducing the presence of moist and humid environments.

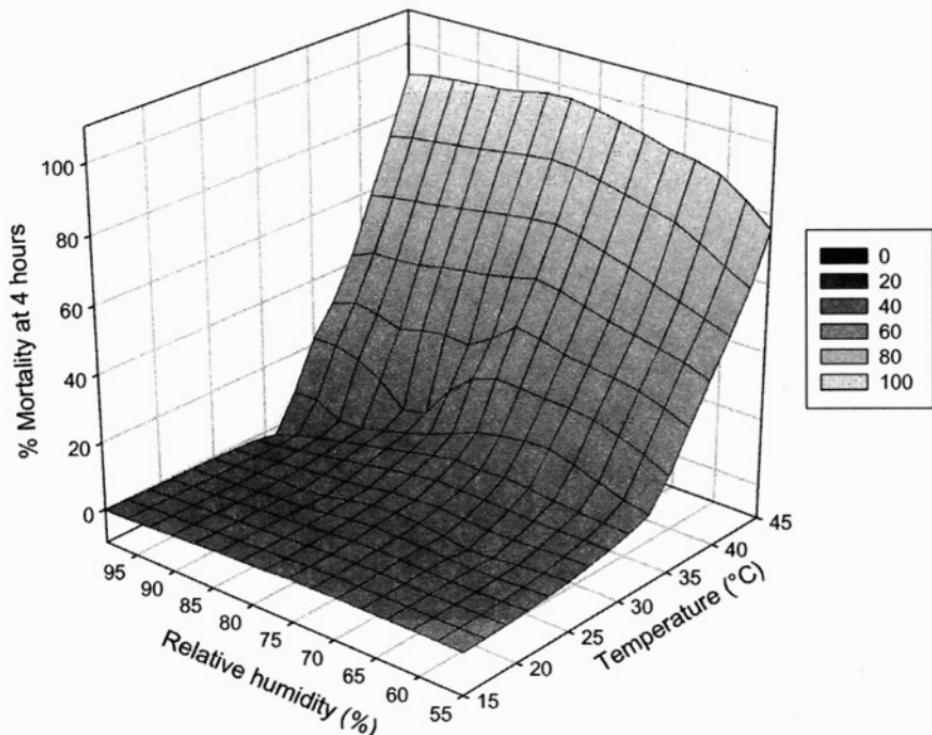


Fig. b. Surface plot of percentage mortality of worker *T. melanocephalum* when exposed to different combinations of temperature and RH.

Table 3. LT50 and LT95 values of *Tapinoma melanocephalum* exposed to various combinations of temperature and relative humidity. Percentage of mortality followed by different letters within the same column are significantly different ($P < 0.05$; LSD).

RH	Temperature (±2%)	n	LT50 (95%CI) h (±1.5°C)	LT95 (95%CI) h	% Mortality (±SE) at 24 h
55.0	15.0	300	43.7 (30.4-78.3)	274.3 (132.4-1,059.0)	9.7 ± 0.9 ab
	25.0	300	16.3 (15.1-17.7)	48.1 (41.3-58.1)	74.0 ± 3.5 c
	35.0	300	10.0 (9.4-10.8)	32.7 (28.2-39.0)	89.3 ± 5.5 g
75.0	15.0	300	29.8 (17.8-85.6)	117.4 (51.7-1,606.7)	15.3 ± 3.5 b
	25.0	300	15.9 (14.0-18.4)	42.7 (33.9-59.5)	74.3 ± 2.6 c
	30.0	300	10.1 (8.9-11.6)	30.5 (23.5-45.0)	95.0 ± 1.7 e
	35.0	300	7.4 (6.6-8.3)	20.2 (16.2-27.8)	99.7 ± 0.3 g
	45.0	300	2.2 (2.0-2.4)	4.7 (4.0-5.9)	100 i
97.0	15.0	300			5.7 ± 0.3 a
	25.0	300			17.3 ± 3.5 d
	30.0	300			27.3 ± 3.4 f
	35.0	300			19.0 ± 2.3 h
	45.0	300	2.0 (1.9-2.1)	3.8 (3.5-4.2)	96.3 ± 3.7 i

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REFERENCES

- Appel, A. G. 1988. Water relations and desiccation tolerance of migrating garden millipedes (Diplopoda: Paradoxosomatidae). *Environ. Entomol.* 17: 463 – 466.
- Appel, A. G., M. K. Miller & T. P. Mack. 1991. Cutaneous water loss of several stages of the red imported fire ant, *Solenopsis invicta* Buren. *Comp. Biochem. Physiol.* 98A: 281 – 283.
- Edney E. B. 1977. Water Balance in Land Arthropods. Springer-Verlag, Berlin.
- Cokendolpher J. C. & S. A. Jr. Phillips. 1990. Critical thermal limits and locomotor activity of the red imported fire ant (Hymenoptera: Formicidae). *Environ. Entomol.* 19: 878 – 881.
- Francke O. F. & J. C. Cokendolpher. 1986. Temperature tolerances of the red imported fire ant. pp. 104-113. In: Fire ants and leaf-cutting ants, biology and management. Lofgren, C. S. & R. K. Vander Meer, eds. Westview Press, Boulder.
- Gomez-Nunez J. C. 1971. *Tapinoma melanocephalum* as an inhibitor of *Rhodnius prolixus* populations. *J. Med. Entomol.* 8: 735 – 737.
- Hadley N. F. 1994. Water relations of terrestrial Arthropods. Academic Press Inc., San Diego.
- Hadley N. F. & M. C. Quinlan. 1989. Cuticular permeability of the black widow spider *Latrodectus hesperus*. *J. Comp. Physiol.* 159: 243 – 248.
- Lee C. Y. 2002. Tropical household ants – pest status, species diversity, foraging behavior and baiting studies. pp. 3–18. In: Proceedings of fourth international conference on urban pests. Jones, S. C., J. Zhai & W. H. Robinson, eds. Pocahontas Press, Blacksburg, VA.
- Lee C. Y. & W. H. Robinson. 2001. Handbook of Malaysian household and structural pests. Publisher: Pest Control Association of Malaysia. 96 pp.
- Lee C. Y., C. Y. Lim & I. Darah. 2002. Survey on structure-infesting ants (Hymenoptera: Formicidae) in food preparative outlets. *Trop. Biomed.* 19: 21 – 26.
- Lees A. D. 1947. Transpiration and the structure of the epicuticle in ticks. *J. Exp. Biol.* 23: 379 – 410.
- Markin G. P., J. H. Dillier, S. O. Hill, M. S. Blum & H. R. Hermann. 1971. Nuptial flight and flight ranges of the red imported fire ant, *Solenopsis saevissima richteri*. *J. Ga. Entomol. Soc.* 6: 145 – 156.
- Rhoades W. C. & D. R. Davis. 1967. Effects of meteorological factors on the biology and control of the imported fire ant. *J. Econ. Entomol.* 60: 554 – 558.

- Robertson J. L. & H. K. Preisler 1992. Pesticide bioassays with arthropods. CRC Press, Boca Raton, FL.
- Smith M. R. 1965. House-infesting ants of the eastern United States. USDA Tech. Bull. No. 1326.
- SPSS. 2003. SigmaStat, version 3.00. SPSS Inc., Chicago, IL.
- SPSS. 2002. SigmaPlot, version 8.02. SPSS Inc., Chicago, IL.
- Therrien P, J. N. McNeil, W. G. Wellington & G. Febvay. 1986. Ecological studies of the leaf-cutting ant, *Acromyrmex octospinosus*, in Guadeloupe. pp. 172-183. In: Fire ants and leaf-cutting ants, biology and management. Lofgren, C. S. & R. K. Vander Meer, eds. Westview Press, Boulder.
- Wigglesworth V. B. 1945. Transpiration through the cuticle of insects. *J. Exp. Biol.* 21: 97 - 114.
- Winston P. W. & D. H. Bates 1960. Saturated solutions for the control of humidity in biological research. *Ecology* 41: 232 - 237.

