Food Utilization and Fecal Pellet Production by Drywood Termites (Isoptera: Kalotermitidae)

by

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ABSTRACT

Cryptotermes brevis (Walker) and *Incisitermes immigrans* (Light) nymphs were held either individually or in groups of ten for an eight-week period, and fed either filter paper, Douglas-fir, or Ponderosa pine. Total consumption was noted; and fecal pellet number, mass, and volume were recorded weekly. Solitary individuals defecated more and produced smaller fecal pellets than nymphs maintained in groups, although the total individual mass of feces produced was similar. Diet affected feeding, food utilization, and fecal pellet number and mass. Consumption and defecation reflected cellulose and lignin content of the substrate, with less ingestion of filter paper than wood on a weight basis, but greater utilization of the ingested paper (98%) and less fecal mass. The percentages of the ingested wood utilized (not excreted) were virtually equivalent for Douglas-fir and pine: 63% and 65%, respectively, with *C. brevis*, and 71% and 72% with *I. immigrans*. Each *I. immigrans* nymph consumed about 0.2 mg of wood each day, while each *C. brevis* nymph consumed slightly less than 0.15 mg of wood per day. On the average, nymphs of both termite species deposited from 0.7 to 1.0 fecal pellets per day, equivalent to a daily average fecal mass of 0.06 mg when fed Douglas-fir, and 0.05 mg when fed pine. Correlation of these data with population growth curves could permit estimation of the size and age of drywood termite colonies.

INTRODUCTION

Drywood termites (Family Kalotermitidae) are cryptic social insects occupying either a single piece of wood, or closely adjoining pieces (Woodrow *et al.* 2006). Biological investigations of these termites are complicated by their

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cryptic habitat, and by the fact that common pest species occur almost exclusively within structural lumber or man-made wooden objects. Although tools such as an acoustic emissions detector can be used to detect termites within the wood, such methods are only partially successful and provide more of a binary indication of presence/absence than any quantitative measure of termite numbers (Woodrow & Grace 2007, Woodrow *et al.* 2006).

Since drywood termite colonies grow slowly and never attain the large numbers characteristic of some subterranean temite colonies, the presence of small fecal pellets expelled from the wood through "kick-out" holes are often the only visible evidence of termite infestation. Haverty *et al*. (2005) demonstrated that these fecal pellets retain the cuticular hydrocarbon pattern characteristic of the defecating species, and can thus be used to identify a cryptic infestation to species.

The present study was designed to examine the efficiency of food utilization of two common drywood termite species in Hawaii: *Cryptotermes brevis* (Walker), a serious pest worldwide in wood products and the most common species infesting buildings in Hawaii; and *Incisitermes immigrans* (Light), a species generally found infesting dead wood on living trees, but also occasionally infesting structural lumber (Woodrow *et al*. 1999, Grace *et al*. 2002). To this end, we measured both feeding and fecal pellet production when termites were exposed to either wood or processed filter paper.

MATERIALS AND METHODS

Cryptotermes brevis (Walker) nymphs were collected by careful dissection of infested shipping pallets collected in the vicinity of Pearl Harbor, Hawaii. *Incisitermes immigrans* (Light) nymphs were collected from infested branches of *Leucaena leucocephala* (Lamk.) de Wit (Koa Haole, Family Fabaceae) on the Manoa campus of the University of Hawaii.

Individual nymphs (10 with each food source) were held in aerated 15-dram plastic vials with the food source for 8 weeks in an unlighted incubator (28° C). One to three drops of water were added weekly to the food source. Termites were observed daily for molting activity and mortality, and pellets were collected and weighed weekly. At the conclusion of the 8-week exposure, each food source was dried (90° C, 24 hrs) and weighed to determine consumption.

Groups of 10 nymphs were held under the same conditions as individuals, with three groups for each food source. Again, the total exposure period was 8 weeks, with pellet collections, observations, and food consumption determined as in the individual assays.

Table 1. Average daily number of fecal pellets produced by solitary individual drywood termites over an 8-week period.

Species	Substrate	Mean daily fecal pellets per termite[a] Wk 1	Wk 2	Wk 3	Wk 4	Wk 5	Wk 6	Wk 7	Wk 8	Overall individual daily mean	Average pellet mass (mg)[g]	Average daily fecal mass (mg)
C. brevis	Filter paper	0.2	0.3	0.2	0.3	0.7	0.1b	0.1c	0.3d	0.3	0.009	0.003
	Douglas-fir	1.8	1.6	1.6	1.1	0.8	1.0	1.0	1.1	1.3	0.022	0.029
	Pine	2.3	1.4	1.4	1.4[e]	1.2[e]	1.0[b]	1.4[b]	0.8[f]	1.4	0.023	0.032
I. immigrans	Filter paper	0.4	0.3	0.4	0.3	0.4	0.8	0.5	0.6	0.5	0.020	0.010
	Douglas-fir	2.9	2.3	2.5	2.4	1.6	1.6[c]	2.5[f]	2.7[f]	2.3	0.038	0.087
	Pine	2.9	2.4	1.8	2.9[e]	1.8[e]	1.4[e]	0.8[e]	1.0[b]	1.9	0.034	0.065

[a]Mean of 10 individual termites, each held seperately, unless otherwise noted.
[b]Mean of 8; [c]mean of 6; [d]mean of 4; [e]mean of 9; [f]mean of 7 individuals.
[g]Average mass of an individual fecal pellet, based upon total pellet mass and number produced over 8-week period.

Food sources in each vial were as follows: Whatman No. 2 filter paper (0.14g), Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) (0.5g), Ponderosa Pine (*Pinus ponderosa* C. Lawson) (0.5g).

Food utilization was calculated as (mass ingested) - (mass defecated); and percent food utilization as ([mass ingested] - [mass defecated]) / (mass ingested) * 100.

RESULTS AND DISCUSSION

When held in solitary containers (Table 1), nymphs of both drywood termite species defecated more and produced a greater number of small fecal pellets than nymphs maintained in groups of 10 (Table 2). However, the total mass of the fecal pellets produced by solitary individuals and by those in groups was roughly similar. The differences observed in defecation frequency and pellet size may result from the stress exhibited by a social insect held under solitary conditions. In a termite colony, digestion is not only an individual response but also a social activity (La Fage & Nutting 1978), and solitary individu-

als are afforded no opportunity for trophallactic behavior or other normal social interactions. Thus, measurements of food intake and digestion based upon group responses are more likely to reflect the normal condition.

With groups of both *C. brevis* and *I. immigrans*, fecal pellet number and total mass (Table 3) varied over this 2-month study depending upon termite mortality, and probably also upon the age and molting cycles of the individuals within the small groups. Our observations indicated that molting individuals did not defecate for 2-3 days. Overall, the larger species, *I. immigrans*, consumed and utilized more food than the smaller, *C. brevis* (Table 4, 5). Individual fecal pellets produced from feeding on wood were generally larger with *I. immigrans* than with *C. brevis* (again, reflecting larger body size), but the average daily fecal mass production was similar (Table 2).

Diet affected feeding, fecal pellet number and mass, and percent food utilization (Table 4) by both drywood termite species. Whatman No. 2 filter paper, with high cellulose content and virtually no lignin was utilized most efficiently, with 98% of the food consumed retained and utilized. As a result of this high degree of utilization of the paper, termites found it necessary to consume (and excrete) less paper than was

Table 2. Average daily individual fecal pellet production of drywood termites held in groups of 10 over an 8-week period.

Species	Substrate	Mean daily fecal pellets per termite[a] Wk 1	Wk 2	Wk 3	Wk 4	Wk 5	Wk 6	Wk 7	Wk 8	Overall individual daily mean	Average pellet mass (mg)[b]	Average daily fecal mass (mg)
C. brevis	Filter paper	0.06	0.03	0.02	0.08	0.09	0.05	0.11	0.02	0.06	0.031	0.002
	Douglas-fir	1.3	1.1	0.9	0.7	0.8	0.7	1.0	1.2	1.0	0.057	0.055
	Pine	0.8	0.6	0.8	0.7	0.7	0.6	0.6	0.6	0.7	0.069	0.046
I. immigrans	Filter paper	0.04	0.09	0.05	0	0.03	0.12	0.15	0.12	0.08	0.037	0.003
	Douglas-fir	1.0	1.4	1.0	0.6	0.4	0.6	0.7	0.7	0.8	0.071	0.057
	Pine	0.8	0.9	1.0	0.6	0.3	0.5	0.6	0.6	0.7	0.076	0.050

[a]Individual grand mean from 3 groups originally containing 10 termites each. No mortality occurred over the 8 week period in any groups fed Douglas-fir. No mortality occurred during the first 2 weeks with filter paper or Ponderosa pine. After the second week, mortality in groups fed paper ranged from 10-50% (weekly mean of 3-30%), and mortality in groups fed pine ranged from 0-20% (weekly mean of 3-7%). Means were calculated from actual group numbers.

[b]Average mass of an individual fecal pellet, based upon total pellet mass and number produced over 8-week period.

the case with either of the two solid wood species. Percent utilization values were virtually equivalent for Douglas-fir and pine: 63% and 65%, respectively, with *C. brevis*, and 71% and 72% with *I. immigrans* (Table 4). These results with both paper and solid wood correspond closely to the coeffecients of utilization reported for *Kalotermes flavicollis* by Seifert & Becker (1965, in Noirot & Noirot-Timothée [1969]). On an individual basis (Table 5), each *I. immigrans* nymph consumed approximately 0.2 mg of wood each day, while each *C. brevis* nymph consumed slightly less than 0.15 mg of wood per day.

On the average, nymphs of both termite species deposited from 0.7 to 1.0 fecal pellets per day, equivalent to a daily average fecal mass of 0.06 mg when fed on Douglas-fir, and 0.05 mg when fed on pine (Table 2, 5).

It is interesting to note that both termite food consumption and defecation appear to be directly

Table 3. Number, mass, and volume of fecal pellets produced by groups of 10 drywood termites during consecutive 4-week intervals.

		Number of termites[a]		Total pellet no.		Total pellet mass (mg)		Total pellet volume (ml)	
Species	Substrate	Wk 1-4	Wk 5-8	Wk 1-4	Wk 5-8	Wk 1-4	Wk 5-8	Wk 1-4	Wk 5-8
C. brevis	Paper	10	6.25±1.89	16	22	0.6	0.4	b	b
		10	9.00±0.82	10	14	0.4	0.6	b	b
		10	9.50±1.00	16	11	0.5	0.3	b	b
	Douglas-fir	10	10	368	226	21.2	12.6	0.025	0.020
		10	10	255	286	17.1	14.8	0.020	0.020
		10	10	223	262	12.0	14.3	0.015	0.020
	Pine	10	10	188	167	13.7	12.4	0.020	0.020
		9.50±0.58	9	178	148	12.4	12.9	0.020	0.020
		10	9.25±0.50	203	190	11.9	11.0	0.020	0.020
I. immigrans	Paper	9.00±1.15	8	12	30	0.4	1.3	b	0.005
		9.50±0.58	8	13	12	0.5	0.3	b	b
		9.00±1.15	7	12	27	0.5	0.9	b	b
	Douglas-fir	10	10	249	187	14.5	15.8	0.020	0.020
		10	10	270	119	19.4	11.3	0.025	0.015
		10	10	314	198	19.6	14.7	0.030	0.020
	Pine	9.75±0.50	9	175	131	14.2	11.3	0.020	0.015
		10	10	258	125	21.0	11.0	0.030	0.015
		9.50±0.58	8.50±0.58	219	137	12.2	10.2	0.020	0.020

[a]Mean (±SD) number of termites (initial N=10) over the 4-week period, based on weekly counts.
[b]Volume not measurable due to small number of pellets.

Table 4. Food utilization by two drywood termite species, exposed in groups of 10 nymphs to three different feeding substrates (3 replicate groups per substrate) for 8 weeks.

Species	Substrate	Replicate	Mass loss of substrate (mg)	Total mass of fecal pellets (mg)	Total mass utilized (mg)[a]	% food utilization[b]
C. brevis	Filter paper	1	64.0	1.0	63.0	98.4
		2	43.2	1.0	42.2	97.7
		3	40.7	0.8	39.9	98.0
		Mean±SD	49.3±12.8	0.9±0.1	48.4±12.7	98.0±0.35
	Douglas-fir	1	86.6	33.8	52.8	61.0
		2	78.8	31.9	46.9	59.5
		3	81.4	26.3	55.1	67.7
		Mean±SD	82.3±4.0	30.7±3.4	51.6±4.2	62.7±4.4
	Pine	1	78.9	26.1	52.8	66.9
		2	68.0	25.3	42.7	62.8
		3	66.0	22.9	43.1	65.3
		Mean±SD	71.0±6.9	24.8±1.7	46.2±5.7	65.0±2.1
I. immigrans	Filter paper	1	54.6	1.7	52.9	96.9
		2	49.3	0.8	48.5	98.4
		3	62.8	1.4	61.4	97.8
		Mean±SD	55.6±6.8	1.3±0.5	54.3±6.6	97.7±0.8
	Douglas-fir	1	114.0	30.3	86.7	73.4
		2	108.2	30.7	77.5	71.6
		3	103.7	34.3	69.4	66.9
		Mean±SD	108.6±5.2	31.8±2.2	77.9±8.7	70.6±3.4
	Pine	1	93.5	25.5	68.0	72.7
		2	109.3	32.0	77.3	70.7
		3	83.5	22.4	61.1	73.2
		Mean±SD	95.4±13.0	26.6±4.9	70.5±5.5	72.2±1.3

[a] Mass utilized = (mass ingested) - (mass defecated).
[b]% food utilization = [(mass ingested) - (mass defecated)] / (mass ingested) * 100.

correlated with nutritional quality of the substrate (i.e., cellulose and lignin content). One would expect such a correlation with defecation, reflecting greater utilization of an ingested substrate with higher cellulose and lower lignin content; but not necessarily with ingestion, where feeding might be expected to be modulated by the quantity of food ingested (e.g., abdominal distension) rather than by nutritional quality. Thus, it is likely that building materials of lower nutritional quality, such as composite materials, might suffer greater damage from termite attack than building products with a higher cellulose content exposed to termites for the same period of time.

Due to their cryptic nature, the size and age of drywood termite infestations in buildings are difficult to determine, but often of interest when it comes to assessing legal liability for termite damage or the cost of control efforts. Theoretically, one could couple the results of this study with the limited information

Table 5. Food ingestion and utilization by individual drywood termites, based upon exposure of groups of 10 nymphs to three different feeding substrates (3 replicate groups per substrate) for 8 weeks.

Species	Substrate	Rep.	Mean no. termites	Daily individual consumption (mg)	Daily individual fecal mass (mg)	Daily individual food utilized (mg)[a]
C. brevis	Filter paper	1	8.125	0.141	0.002	0.139
		2	9.500	0.081	0.002	0.079
		3	9.750	0.075	0.001	0.074
		Mean±SD		0.099±0.036	0.002±0.001	0.097±0.036
	Douglas-fir	1	10	0.155	0.060	0.095
		2	10	0.141	0.057	0.084
		3	10	0.145	0.047	0.098
		Mean±SD		0.147±0.007	0.055±0.007	0.092±0.007
	Pine	1	10	0.141	0.047	0.094
		2	9.250	0.131	0.049	0.082
		3	9.625	0.122	0.042	0.080
		Mean±SD		0.131±0.010	0.046±0.004	0.085±0.008
I. immigrans	Filter paper	1	8.500	0.115	0.004	0.111
		2	8.750	0.101	0.002	0.099
		3	8.000	0.140	0.003	0.137
		Mean±SD		0.119±0.020	0.003±0.001	0.116±0.019
	Douglas-fir	1	10	0.204	0.054	0.150
		2	10	0.193	0.055	0.138
		3	10	0.185	0.061	0.124
		Mean±SD		0.194±0.010	0.057±0.004	0.137±0.013
	Pine	1	9.375	0.178	0.049	0.129
		2	10	0.195	0.057	0.138
		3	9.000	0.166	0.044	0.122
		Mean±SD		0.180±0.015	0.050±0.007	0.130±0.008

[a] (mass ingested) - (mass defecated) = food utilized.

available on drywood termite colony growth to estimate the number of termites present in a given situation, and the age of the infestation. Caution is advised, since very little information is actually available on the development of these cryptic and long-lived insects; and this exercise rests on the assumption that one could recover virtually all fecal pellets produced over a given period by a drywood termite colony. However, in furniture, or even limited structural infestations, pellet collection could be accomplished by thorough removal of any visible pellets with a vacuum, placement of plastic sheets (or bags) around the infested wood, and subsequent careful removal of collected pellets over a period of time in order to estimate daily fecal production, and thus termite numbers.

Using regression plots of the data presented here for both consumption and pellet production of termites fed wood, and *Incisitermes minor* (Hagen) colony growth data from Harvey (1934), Grace (2009) derived the following set of equations:

Daily wood consumption in mg (y) as a function of population size (x):

$y = -0.000994 + 0.194x$

Population size (y) as a function of daily pellet mass in mg (x):

$y = -0.15 + 1.67x$

Population size (y) of an *I. minor* colony as a function of the age in years (x) of the colony (data from Harvey, 1934):

$y = -553 + 221x$

Daily wood consumption in mg (y) of a drywood termite colony as a function of the age in years (x) of the colony:

$y = -107 + 42.8x$

Age in years (y) of a drywood termite colony as a function of daily pellet mass in mg (x):

$y = 2.53 + 0.00751x$

Drywood termites are clearly efficient at utilization of ingested cellulose. As well as providing the identity of the termite species through cuticular hydrocarbon analysis (Haverty *et al*. 2005), fecal pellets also provide information on the nutritional value of the food source, and possibly also the size and age of the termite colony.

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