Trash to treasure: leaf-cutting ants repair nest-mound damage by recycling refuse dump materials

Alejandro G. Farji-Brener and Mariana Tadey
Laboratorio Ecotono, CRUB-Universidad del Comahue-INIBIOMA-CONICET (8400) Bariloche, Argentina

INTRODUCTION

Animal behavior is molded by natural selection to minimize costs and maximize benefits (Krebs and Davies 1997). However, behaviors occur in the context of ever changing environments, and so costs and benefits also change. Behaviors that are inappropriate under one circumstance may become the best choice under another (Robinson et al. 2008). The capacity to adequately respond to changing conditions is known as behavioral plasticity (Chesson 1986). Although the study of behavioral plasticity is an important topic in evolution and ecology (Mercy and Burns 2010), our knowledge regarding how much flexibility exists, how it works, and when it matters is still limited (Gordon 2011). In this study, we describe a potentially harmful ant behavior that was never documented before: recycling of refuse materials to repair nest damage, and we explore why this behavior fluctuates temporarily.

The implementation of an adequate waste disposal strategy is vital at all levels of biological organizations (Hart et al. 2002b). Discarded materials usually are a source of pathogens and their accumulation may enhance the spread of diseases. This is especially true for social organisms that form dense societies. As groups become larger, the manipulation and accumulation of waste and associated diseases pose an increasing threat to the group (Cremer et al. 2007). Leaf-cutting ants are an example of dense societies that discard a large quantity of organic material that represents a potential threat for the colony.

Leaf-cutting ants (Atta and Acromyrmex) use leaf fragments to cultivate a fungus in underground nest chambers. This symbiotic fungus is the main food source for the colony and has strict requirements for suitable growth: it depends nutritionally on the leaf fragments collected by the ants, it dies at high temperatures (Powell and Stradling 1986), and it is highly susceptible to parasitic fungi (Currie et al. 1999). Ant workers harvest large quantities of fresh vegetation (Wirth et al. 2003), build and maintain nest structures that keep the fungus gardens under favorable microclimatic conditions (Bollazzi et al. 2008), and remove infectious fungi and pathogenic waste to refuse dumps (Hart and Ratnieks 2001). Consequently, it might be expected that ant behaviors adjust to changes in food, weather, and hygienic conditions to maximize fungus growth and colony survival.

Leaf-cutting ants often exhibit adaptive flexible behaviors toward food and weather changes. For example, ants may concentrate their foraging on tree-fall gaps when the availability of palatable species in the surrounding matrix is low (Peñaloza and Farji-Brener 2003) and switch from...
diurnal to nocturnal foraging when soil temperatures are high (Rockwood 1975). Nevertheless, ants occasionally perform suboptimal behaviors under variable food and weather conditions without paying especially larger costs. Leaf-cutting ants sometimes gather novel plant resources potentially harmful for their fungus garden, but thereafter avoid their collection (“delayed rejection”; Herz et al. 2008). Ants sometimes forage under unsuitable weather conditions and are forced to drop the leaf fragments during heavy rain, but later they recover those fragments after the rain stops (Hart et al. 2002a). These behaviors imply the waste of a fraction of the foraging time, but they do not represent a high risk for colony survival. Conversely, suboptimal behaviors that potentially affect the survival of the fungus garden are potentially dangerous because the fungus is the only food source for the developing larvae (Powell and Stradling 1986).

The survival of the symbiotic fungus strongly depends on an adequate microclimate and on low levels of pathogens inside the nest. The fungus can suffer severe damage at humidity levels below 60% and above temperatures of 33 °C (Quinlan and Cherrett 1978; Powell and Stradling 1986). Accordingly, ants often relocate their fungus gardens to nest chambers where temperature and humidity are more suitable for their survival (Bollazzi and Roces 2002), and invest a considerable amount of energy in building, repairing, and maintaining nest structures that provide adequate microclimatic conditions (Kleineidam and Roces 2000; Bollazzi and Roces 2007, 2010). In addition, the fungus garden produces large quantities of waste such as degraded plant materials (hereafter, refuse), which is often contaminated with fungal competitors (i.e., Escenopysis) and other microorganisms potentially lethal to the fungus and to the ants themselves (Haeder et al. 2009 and references therein; Lacerda et al. 2010). Therefore, leaf-cutting ants allocate their waste in separate internal chambers or in external piles isolated from their fungus gardens, and also show hygienic behaviors that include a strict division of labor to reduce their contact with the garbage (Bot et al. 2001; Hart and Ramíekes 2001, 2002; Hart et al. 2002a, 2002b; Fernández-Marín et al. 2003; Ballari et al. 2007). Because the maintenance of an adequate microclimate and a relatively pathogen-free environment inside the fungus chamber are critical for colony survival, natural selection may favor the ability to detect changes in these conditions and to behave appropriately to reduce the risk of fungal mortality. Surprisingly, we observed that the leaf-cutting ants Acromyrmex lobicornis occasionally use their refuse instead of the usual building materials (e.g., dry twigs) to repair nest structures, a behavior that hypothetically implies a contamination threat for the fungus garden. Inspired by these observations, we conducted a series of field measurements and experiments to test the hypotheses that fluctuations in this behavior depend on 1) seasonal changes in pathogens levels in the refuse dump materials, and/or 2) seasonal foraging restrictions.

MATERIALS AND METHODS

Study area and species

The study area is located in Neuquén province in northwestern Patagonia (39°17’S, 68°55’W), Argentina. This is a xerophytic scrubland with considerable portions of bare ground. The leaf-cutting ant A. lobicornis Emery is widespread in temperate-semi-deserts of South America reaching 44°S (Farji-Brener and Ruggiero 1994). This ant deposits refuse in external dumps and builds mounds mostly made of dry twigs covering a single central fungus chamber, which they maintain at proper temperatures (Farji-Brener 2000; Bollazzi et al. 2008). Mounds are often damaged by mammals and sometimes partially collapse because of natural erosion. Mound damages have been associated with increased colony mortality in this ant species (Farji-Brener 2000), probably because they affect the microclimatic conditions inside the nest, and allow the entrance of pathogens to the fungus garden. Accordingly, ants regularly collect dry twigs and desiccated plant parts (hereafter, building materials) to repair damage and to expand the nest-mound (Farji-Brener 2000).

Methodology

All the measurements described below were performed in a total of 50 mature nests of A. lobicornis 10 nests per season in summer, autumn, winter, and spring 2007, and summer 2008 (a total sampling period of 15 months). We analyzed whether foraging activity, ant diet composition, mound condition, and the temperatures of the internal fungus chamber and the soil surface explained the use of refuse materials for mound repairing, using a classification tree, a powerful recursive partitioning method (Breiman et al. 1984). Additionally, we measured 1) the occurrence of worker rejection toward experimental piles of refuse (a proxy for waste pathogen levels; see Farji-Brener and Sasal 2003; Ballari and Farji-Brener 2006; Lacerda et al. 2010; Waddington and Hedges 2010), and 2) the growth rate in a random sample of 30 nests with different status of mound repair (see below for methodological details).

Foraging activity, diet composition, and foraging rate

We monitored daily foraging activity of each nest every 2 h during 24 h. Nests were classified as active or inactive according to the presence of foragers. This procedure was repeated on 3 different days in each sampling season. To determine the foraging composition (food for the fungus vs. building materials), we counted all items transported by workers during a 5-min interval. This measure was performed on the 2 main foraging trails of each colony, every 2 h in 3 days during the period of foraging activity (nocturnal during the summer and diurnal during the rest of the seasons). Our sample effort was ~1800 min per nest (10 min × 12 sampling periods × 5 days × 5 seasons). The ant loads were classified as fresh plant material (for the fungus gardens) or building material (dry twigs for the mound). The relative importance of fresh plant and building materials during foraging was expressed as a proportion of each type of item over the total number of items. We used the number of laden workers (i.e., number of all fragments transported per 10 min per nest) and the period of daily activity (number of hours foraging per day) to extrapolate in each season the number of laden workers per trail per daily period of activity per nest. This measure was taken as the foraging rate of each colony (i.e., an estimation of the overall harvesting activity, which includes the collection of dry and green plant materials).

Nest-mounds, temperatures and the use of refuse dump materials to repair mound damage

During the visits to each nest we 1) measured 3 mound radius (long, wide, and height, in centimeter) and used the volume formula of the sphere to estimate the mound volume (MV) considering a mound as a hemisphere (MV = [4/3 × π × r^3]/2), 2) monitored whether the mound was intact or damaged, 3) estimated the relative area of mound damaged (in percentage) using digital photos and the software imageJ®,
and 4) documented whether damaged mounds were repaired with building materials (i.e., dry twigs) or refuse materials. The use of refuse was easy to identify because of its texture and color (see Figure 1). Mound dimensions were used as a proxy for colony size (see Fowler et al. 1986), and the change in MV between 2007 and 2009 (in percentage) was used as an estimate of colony growth. We simultaneously measured the temperatures of the internal mound in the fungus garden (see Farji-Brener 2000; Bollazzi et al. 2008 for a detailed description of fungus gardens’ location) and on the adjacent soil surface in 3 intact and 3 damaged nest-mounds (20–40% of damage) using HOBO® internal/external data loggers (Onset Computer Corporation, MA). Temperatures inside mounds were obtained using a thin cable for HOBO® external data loggers (Ø 3 mm). Cables were carefully inserted inside mounds in a non-destructive way. Preliminary sampling and a previous study (Farji-Brener 2000) showed that sensor insertion into the nest does not influence the accuracy of the information. Temperatures were measured every 15 min during 4 continuous days per season. Sampling days represented the typical weather conditions for the respective sampling seasons.

Field experiment: indirect evaluation of pathogens changes in refuse among seasons

Leaf-cutting ants are capable of detecting pathogens and of avoiding contact with contaminated substrates (Bot et al. 2001; Hart and Ratnieks 2001, 2002). It was possible that the levels of pathogens in external refuse piles might vary with weather changes (Ballari and Farji-Brener 2006), so we used the fluctuations in the rejection of refuse material by foraging ants as an indirect estimation of temporal changes in the amount of pathogens on this substrate. This measure has been employed in other studies to estimate the threat level of waste (Farji-Brener and Sasal 2003; Ballari and Farji-Brener 2006; Lacerda et al. 2010; Waddington and Hudges 2010). In the 2 seasons with the most contrasting climates and ant foraging activity (autumn and summer), we blocked the ant traffic of 2 trails per nest placing experimental piles of refuse or soil (as a control for pile effect). Refuse samples were collected from 10 cm depth to the surface of the refuse dump of each nest to include all refuse microclimatic conditions that may affect their pathogenicity (Ballari and Farji-Brener 2006). Experimental piles were ~5 cm high and 15 cm wide. We counted the number of foragers that walked over the pile (i.e., a non-rejection behavior), returned through the same way before reaching the pile, and surrounded the pile (i.e., rejection behaviors) during a 10-min interval. In autumn and summer we performed a total of 28 trials (14 per treatment) using 5 randomly selected nests.

Statistical analyses

A classification tree was used to explore the fluctuations in the behavior of using refuse materials to repair mound damage.
This is a binary recursive partitioning method that explains the variation of a single categorical response variable by 1 or more explanatory categorical or continuous variables; it is free of distributional assumptions and represents information intuitively (Breiman et al. 1984). The tree is constructed by repeatedly splitting the data, defined by a simple rule based on a single explanatory variable. At each split the data is partitioned into 2 mutually exclusive groups, each of which is as homogeneous as possible with respect to the response variable. The splitting procedure is then applied to each group separately. The objective is to partition the response into homogeneous groups, although keeping the tree reasonably small. Each group is typically characterized by the distribution of the categorical response. Trees are represented graphically, with a root node at the top, which represents the undivided data, and the branches and leaves beneath it (each leaf representing one of the final groups). Our categorical response variable was the use of refuse materials to repair mound damage or not. The explanatory variables were season, mound damage (in percentage), foraging rate, and the proportion of building material from the foraged items.

A blocked, repeated measures analysis of variance (ANOVA) was used to determine whether the rejection level of worker ants toward the experimental refuse piles depended on the season. Pile substrate (refuse or soil) was considered a main, fixed effect; nest a random effect, and season as the repeated measure factor. The response variable was the proportion of ants that returned and surrounded the experimental pile from the total number of ants during a 10-min sampling period. A 1-way analysis of covariance (ANCOVA) was conducted to determine whether the status of the nest-mound influenced colony size. The difference (in percentage) between 2007 and 2009 MVs was the response variable; mound condition (repaired with building materials, \( n = 12 \); repaired with refuse dump, \( n = 8 \); or un repaired, \( n = 10 \)) was considered a main, fixed effect and the initial MV was the covariable. Prior to ANOVA analyses, the response variables were tested to meet the assumptions and arcsine square root transformations were used when necessary. Duncan post hoc comparisons of means were applied when the model was statistically significant (\( P < 0.05 \)). All analyses were performed using the Software Statistica 7.0®

RESULTS

Foraging patterns of the leaf-cutting ants changed through the sampling period. No foraging activity occurred during winter, whereas the summer was the only season in which foraging was entirely nocturnal. Ants moved more slowly at night because of low soil temperatures (\( 4 \pm 0.30 \) s to walk along 10 cm of a trunk-trail at night vs. \( 1 \pm 0.04 \) s at day, \( n = 64 \) ants, mean \( \pm \) SE), and summer showed the lowest overall foraging rate. Annual foraging rates (number of foraging ants per trail per day) varied between 3360 (summer) and 4608 (spring). The number of laden ants carrying building materials was strongly correlated with the number of laden ants carrying green or fresh plant material (\( r = 0.88, P < 0.001, n = 180 \))

Figure 2

Seasonal and daily variation of temperatures on the soil surface (black circles) and inside damaged (grey triangles), and intact (white triangles) nest-mounds of the leaf-cutting ant Acromyrmex lobicornis. One daily cycle (24h) is shown. Values are means from 4 sampling days and 3 nests per category per season. The measures of dispersion around each value are not show to improve figure clarity. The line represents the thermal limit for the symbiotic fungus that inhabits in the mound chamber; the fungus can suffer severe damage above temperatures of 33 °C. Note that damaged nest-mounds reached lethal daily temperatures only during summer. None of the sampled nests (\( n = 10 \) per season) showed damage during winter. Fungus chambers inside mounds repaired with building materials (e.g., dry twigs) showed similar temperatures as those repaired with reused material (data not shown).
sampling periods). Soil surface temperatures varied annually between –6 ºC (winter) and 69 ºC (summer) whereas temperatures inside intact nest-mounds only varied between 5 ºC (winter) and 32 ºC (summer). Temperatures inside damaged mounds ranged between 13 ºC (autumn) and 42 ºC (summer) (Figure 2). Temperatures inside mounds in each season showed very little variation across nests in the same category (i.e., intact and damaged, in both cases with coefficients of variation of 0.04 ± 0.004, mean ± SE). No damaged mounds were found during the winter.

The use of refuse material for mound repairs depended on the season and the foraging rate of the ants. The classification tree concerning using refuse or not showed 2 splits, 3 terminal boxes (“leaves”) and a misclassification rate of zero (i.e., boxes containing no misclassified nests, Figure 3). The first split established that the use of refuse dump materials was only present in summer, when soil temperatures reached up to 70 ºC, foraging was fully nocturnal, and damaged nest-mounds reached lethal temperatures for the symbiotic fungus every day (Figure 3). During the summer, the second split established that only nests with the lowest foraging rate (i.e., with the lowest collection of building materials, see correlative results) used their refuse to repair mounds. The other explanatory variables were not selected by the model (Figure 3). On the other hand, foraging ants rejected more refuse than soil piles (0.93 ± 0.016 vs. 0.17 ± 0.016, mean rejection rate ± SE, respectively, \( P < 0.001 \)), and showed a slightly higher rejection rate in summer than in autumn (0.56 ± 0.012 vs. 0.54 ± 0.012, mean rejection rate ± SE, respectively, \( P < 0.04 \)). Nests also showed some variation in their rejection rates to soil and refuse piles (0.09–0.34 and 0.89–0.97, respectively, \( P < 0.01 \)). However, rejection rates of refuse piles were similar between seasons (substrate × season \( F_{1,22} = 0.001, P = 0.97 \)). In other words, refuse piles were equally highly rejected by foraging ants in summer and autumn (Table 1). All nests increased in size during the 3-year period. This increment was similar between nest-mounds repaired with building materials or refuse (~35%), but higher than non-repaired mounds (~10%) \( (F_{2,26}, P < 0.001, \text{Table } 2) \).

![Figure 3](https://academic.oup.com/beheco/article-abstract/23/6/1195/189949/128)
Table 1
Rejection rates of the leaf-cutting ant *Acromyrmex lobicornis* toward experimental piles of refuse and soil (control) in 2 seasons, and the statistical results associated

<table>
<thead>
<tr>
<th>Season</th>
<th>Soil pile</th>
<th>Refuse pile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autumn</td>
<td>0.16±0.02</td>
<td>0.92±0.02 (*)</td>
</tr>
<tr>
<td>Summer</td>
<td>0.18±0.02</td>
<td>0.94±0.02 (*)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Df</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate</td>
<td>1</td>
<td>4.7</td>
<td>0.04</td>
</tr>
<tr>
<td>Nest</td>
<td>4</td>
<td>4.1</td>
<td>0.01</td>
</tr>
<tr>
<td>Error</td>
<td>22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Season (repeated measure)</td>
<td>1</td>
<td>2.9</td>
<td>0.04</td>
</tr>
<tr>
<td>Season x Substrate</td>
<td>1</td>
<td>0.001</td>
<td>0.97</td>
</tr>
<tr>
<td>Season x Nest</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>22</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Rejection rates were calculated as the proportion of foragers that either returned through the same way or surrounded the experimental pile that we located blocking the main trail during a 10-min period (see MATERIALS AND METHODS). Values are mean ± SE. A blocked, repeated measures ANOVA were conducted to determine whether the rejection level of worker ants to their organic waste depended on the season. (*) = P < 0.05, Duncan post hoc test.

Table 2
Mound growth in nests of the leaf-cutting ant *Acromyrmex lobicornis* repaired with non-food materials, refuse, and non-repaired and the statistical results associated

<table>
<thead>
<tr>
<th>Mound status</th>
<th>Repaired with non-food material (n = 12)</th>
<th>Repaired with refuse (n = 8)</th>
<th>Non-repaired (n = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>34.5±2.1a</td>
<td>32.8±2.3b</td>
<td>10.6±1.8b</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Df</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial MV</td>
<td>1</td>
<td>137.8</td>
<td>0.25</td>
</tr>
<tr>
<td>Mound status</td>
<td>2</td>
<td>1.4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Error</td>
<td>26</td>
<td></td>
<td>2023.1</td>
</tr>
</tbody>
</table>

Values are the difference between MV between the years 2007 and 2009 (mean ± SE, in percentage). One-way ANCOVA was conducted to determine whether mound growth depended on mound status. Initial MV was considered as a covariable. a,b Denote significant statistical differences (Duncan post hoc test).

**DISCUSSION**

Recycling of discarded materials might be an adaptive and flexible response to limit the waste accumulation generated by dense societies and to confront restrictions in the availability of resources. This behavior is rare in social insects presumably because the use of potentially pathogenic materials for new functions results in significant health risks and behavioral problems (Cremer et al. 2007). In this study, we documented that ants, under certain environmental conditions, can “recycle” their own refuse material to repair nest-mound damages.

Our results suggest that the use of refuse material for mound repair is determined by a hierarchical set of decisions dependent on the risk of fungal damage by heat and on foraging restrictions, rather than the other alternatives that we evaluated. Although we did not directly measure the pathogenic level of refuse, it has been assumed that the rejection rate of forager ants to refuse material is a good estimation of its pathogenicity (Ballari and Farji-Brener 2006; Lacerda et al. 2010; Waddington and Hedges 2010). Therefore, the similar rejection levels toward refuse materials between seasons partially discard the hypothesis that ants use refuse only in summer as a result of a seasonal decrease in its pathogenic level. However, seasonal changes in pathogenicity might still play a role. It has been shown that refuse from superficial layers is less rejected than those from inside the refuse dumps (Ballari and Farji-Brener 2006). Because our experimental refuse piles were a mixture of superficial and deep materials, the effect of a reduced pathogen activity in summer may be underestimated by our experiment. A decrease in the availability of building materials to repair forage mounds during the summer is another alternative explanation for this behavior. Although not formally tested, this hypothesis seems also improbable at first glance, because dry twigs are available year-round in the study area (personal observations). It may also be possible that refuse showed better physical properties than dry twigs to repair mounds. However, this does not explain the use of refuse only in the summer.

The high temperatures during summer could be responsible for the hierarchical set of decisions that determine the use of refuse to repair mounds. First, damaged mounds reached lethal temperatures for the symbiotic fungus only during summer, forcing ants to repair the mounds and bring down internal temperatures. The symbiotic fungus of *A. lobicornis* ants is probably more sensitive to higher than to lower temperatures normally encountered in its environment. Recent studies in species of northern temperate leaf-cutting ants demonstrated that cold-tolerance of the symbiotic fungus increased with winter harshness, indicating a selection for cold-tolerant fungi variants along a temperature cline at the northern distribution limit (Mueller et al. 2011). This selection for cold-tolerant cultivars may also occur in species at the southern limit of the leaf-cutting ants’ distribution (Mueller et al. 2011). Therefore, mound damage during summer may jeopardize fungus survival in temperate populations of *A. lobicornis*. Second, extremely hot soil temperatures limit ant foraging activity (Whitford and Ettershank 1975; Mintzer 1979). High temperature increases oxygen consumption, water loss, and transport costs all reduce the foraging period of ants (Lighton and Feener 1989). High temperatures also increase the desiccation rate of leaf-fragments, reducing the quality of fresh plant material for fungal growth (Bowers and Porter 1981). Therefore, the high diurnal temperatures observed in the summer (almost 70 °C all mum) force leaf-cutting ants to forage at night. However, nocturnal foraging entails costs such as a decrease walking speed because of low temperatures, which ultimately reduces the overall foraging rate of the colony. The collection of building materials for mound repair may decreases during the summer either because ants show a low overall foraging rate or because under climatic restrictions ants give foraging priority to substrates on which to grow their fungus.

In sum, repairing the mounds is essential during summer because this is the only season when temperatures inside damaged mounds are potentially lethal to the fungus. However,
the high summer temperatures also restrict the ants' foraging activity, reducing the amount of building materials they can collect for mound repair. Faced with this dilemma, colonies reduce the amount of building materials they can use in repairing damaged mounds because this substrate is structurally similar to the usual building materials (see Figure 1), but demands less searching and carrying time. The workers know the location of their refuse dump, and the distance between the refuse dump and the nest-mound is short (e.g., <1 m, see Figure 1). The potential hygienic cost of reusing refuse is ameliorated by the weather of arid environments, which often decreases the toxicity of refuse (Ballari and Farji-Brener 2006; Ribeiro and Navas 2007). The cost of colony contamination is also reduced because the manipulation of refuse is exclusively performed by specific workers (Ballari et al. 2007). In accord with this idea, we observed only waste-manage workers manipulating refuse material to repair mounds. The similar growth rates of nests repaired with building materials and refuse suggests that, at least in the summer, the potential sanitary costs of the use of refuse materials to repair mounds did not exceed their benefits as building resources. It is possible that the use of refuse to repair nests in other seasons implies some costs that were not measured in this work. When temperatures inside damaged mounds do not represent a lethal risk for the fungus culture and foraging is not limited, ants commonly used dry twigs instead of refuse. This intriguing, context-dependent trade off could be further explored in the future.

Nest structures can be considered as functionally versatile extensions of the animals’ phenotypes (Hansell 2005). Building behavior and material selection for mound building are indicators of how ants cope with variations of their external environment (Alexiev et al. 2007). It is known that ants can use leaf-fragments or vegetable debris to plug the circulation of dry air flows in nest-mounds (Bollazzi and Roces 2007, 2010a). collect leaves as building material for thatched nests (Bollazzi and Roces 2010b), use different soil particle sizes to improve the resilience of nest walls (Alexiev et al. 2007), and deposit charcoal litter around nest entrances to modify soil temperature (Smith and Schinkel 2007). Some termites include feces in their nest architecture (Emerson 1938): however, this is the first record of ants using the waste from their fungus gardens for building purposes and to regulate the internal environment of the nest. This behavior appears only in circumstances when the cost of collecting usual building materials for that purpose exceeds the potential cost of reusing degraded plant materials. These results reveal how ants integrate information about food, hygienic and nest conditions through a novel and plastic behavior: the recycling of discarded materials. Moreover, they emphasize how the relative costs and benefits of behaviors vary as circumstances change, supporting the importance of behavioral plasticity to deal with changing environmental conditions.

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