Comparative Repellency of Common Essentials Oils and Commercially Available Repellents Against the German Cockroach (*Blattella germanica*)

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Editor: Jacob Cruz

Abstract: *Blattella germanica* (Blattodea: Ectobiidae), the German cockroach, has been known to be attracted to various bacteria-laden surfaces such as feces and garbage, as well as food. The tendency for these cockroaches to transfer bacteria onto the food humans eat present a method of entry for bacteria into the human system, and therefore contribute to overall mechanical disease transmission. *B. germanica* does not only contribute to disease transmission, but also to a large amount of asthmatic reactions in humans. These negative effects, combined with this species tendency to live inside human dwellings, heightens the need for an effective repellent against them. Since repellents require application within homes, it is essential that it is non-toxic and safe. A current option other than manufactured repellents may be the use of essential oils. In this study, a combination of various commercially-available insect repellents as well as essential oils were assessed in terms of repellency against *B. germanica*. This assessment was completed through the observation of the amount of time necessary for a *B. germanica* cockroach to cross over a substance-treated filter paper when attracted by white bread. It was found that, while certain commercially-available repellents proved more effective than some essential oils, essential oils still demonstrated significant repellency and were more repellent than DEET, a commercial repellent with known adverse effects. This provides implications for further development of safer and potentially less expensive repellents, particular in future usage in Integrated Vector Management programs.

Keywords: Blattella germanica, repellency, essential oils, DEET, Permethrin

Many varieties of cockroach species have been proven to be vectors of disease, as supported through the presence of a wide range of pathogens associated with cockroaches such as bacteria, viruses, fungi, protozoa, and helminths; these cockroaches are also shown to be a major contributor to human asthmatic reactions (Baumholtz et al. 1997).

The cockroach in question throughout this study, *Blattella germanica*, has been shown to adopt human homes as their natural habitats more so than any other species of cockroach. Thus, management of these pests is essential in order to avoid asthmatic reactions and mechanically-spread diseases (Haines and Palmer 1952-53).

According to recent studies, *B. germanica* has been proven to show the most attraction to feces, peanut butter, and bread products (Nalyanya and Schal 2001, Ibrahim et al. 2017). Consequently, bacteria found on feces, the most attractive of the bunch, is bound to find its way into food products that humans consume daily, contributing to the mechanical transmission of diseases by *B. germanica*. High levels of infestations in homes can lead to some of these cockroaches venturing outdoors within the Central Texas region, exposing the species to a larger variety of pathogens, which increases the potential for disease transmission by the insect (Appel and Tucker 1986).

In order to provide potential protection against the risk associated with this species, recommendations for management of this pest include sanitation and insecticide treatment (Schal 1988). However, with organophosphorus, pyrethroid, and potentially more unresearched insecticides comes prenatal negative effects associated with impact on neurodevelopment, DNA damage, and reproductive hormone disorders (Tsakalof et al. 2012). In addition, continual usage of insecticide is bound to lead to insecticide resistance among strains of the series, such as reported 100% resistances in some strains against pyrethroid insecticides Permethrin and Allethrin (Cochran 1989).

Since *B. germanica* is often around humans while indoors, care must be taken to not utilize an insecticide that may induce detrimental health effects to humans, such as the insecticide derivatives previously mentioned. It is especially difficult to avoid the adverse effects of insecticides considering not all have been studied thoroughly. In addition, continual usage of insecticides may lead to resistance and, therefore, may make prevention of mechanically-transmitted disease and allergic or asthmatic reactions more difficult.

A reasonable and safe prevention method against cockroaches other than insecticide treatment involves repellency or deterrent methods. One of the best known insect repellents, DEET, holds no apparent serious adverse effects, yet it has been found that DEET may be associated with neurotoxicity in some individuals (Grothaus and Osimitz 1995). A safer alternative to chemical repellents such as DEET may be found in natural essential oils such as Psidium guajava, kaffir lime, citronella, eucalyptus and many more (Thavara et al. 2007, Chooluck et al. 2019). All of these oils have been shown to demonstrate a high degree of repellency towards *B. germanica*, some even showing more repellency than commercially-manufactured naphthalene repellent (Thavara et al. 2007).

The purpose of this study is to compare the repellent effects of natural essential oils Psidium guajava, kaffir lime, and citronella to commercially available repellents containing major ingredients Permethrin, DEET, and Picaridin. We hypothesize that the repellency of the essential oils will be equal to or greater than those of the commercially bought solutions.

Materials and Methods

Cockroach Collection and Preservation

Ten *B. germanica* cockroaches were collected from Dr. Vargo at the Texas A&M University, Rollins Urban and Structural Entomology Facility. The cockroaches were preserved in laboratory conditions until initial experimentation with insect repellants and essential oils.

Essential Oil Collection

The three decided essential oils tested in the experiment were Psidium guajava (100%), kaffir lime (100%), and citronella (100%). The particular essential oils were selected for the study based on their prior effectiveness as a repellent to cockroaches (Thavara et al. 2007). Each of the essential oils were individually, privately purchased and maintained at 20℃ - 23℃. Furthermore, the essential oils were upheld in sealed condition prior to experimental trials.

Commercial Repellent Collection

To study the effectiveness of natural essential oil as a repellent, commercially available insect repellants were individually, privately purchased for the experiment. The commercial repellants were selected based on their primary active ingredient. The three chosen commercial repellants for the experiment consisted of Permethrin (10%), DEET (10%), and Picaridin (10%). Each of the commercial repellants were preserved at 20℃ - 23℃ and in sealed condition prior to experimentation.

Laboratory Test

For the environment of the experiment's procedures, a clear storage bin (88.9 X 40.6 X 15.24 cm) was collected with the lid removed. The storage bin was sanitized using isopropyl alcohol (99%) and set to dry twenty-four hours prior to testing.

Beginning the experimental trial period of the study, Vaseline was applied to the walls of the storage bin to eliminate the ability of the cockroaches escaping the experiment's parameters. The three natural essential oils were uncapped and diluted in a solvent of carrier oil. This dilution process aimed at ensuring a standard concentration of 10% for each natural essential oil so that all insect repellent and essential oil concentrations were consistent. In this process, three 250.0 milliliter beakers were collected, each containing 45.0 milliliters of carrier oil. To each beaker of carrier oil, 5.0 milliliters of each unique essential oil was added. The three beaker solutions of essential oil and carrier oil were then thoroughly mixed for five minutes via a stir plate and stir rod. Additionally, three beakers were collected and inserted with 50.0 milliliters of each commercial insect repellant.

In each of the six set-up beakers, a 50 x 50 cm filter paper was set inside to soak for five minutes. The soaked filter papers were then removed using a spatula to dry for an additional five minutes. This soaking procedure was repeated in each beaker two more times with new filter paper each time. For each individual trial, the soaked filter paper was placed 10.0 cm from the long end of the storage bin.

A slice of white bread weighing 5.0 grams was then placed behind the filter paper, 5.0 cm from the long end of the storage bin. White bread was selected as the food source of choice for the experiment because *B. germanica* cockroaches display a particular attraction to bread products (Nalyanya and Schal 2001, Ibrahim et al. 2017).

A line was drawn across the width of the storage bin, in pen, 50.0 cm away from the center of the filter paper and 55.0 cm away from the bread. 1 cockroach was inserted with forceps behind this line to begin each trial of the experiment.

To measure the effectiveness of each essential oil or commercial repellant, the time was recorded for how long it took the cockroach to reach the bread on the treated filter paper.

At the conclusion of each trial, the cockroach used was extracted using forceps and placed in a separate container from the unused cockroaches. This measure was taken to avoid the repetition of using the same cockroach subject twice in each treatment. The trial was repeated with each remaining cockroach for a total of 10 trials for each treatment.

The used filter papers were discarded and replaced with the next trial's filter paper following sanitation of the bin with isopropyl alcohol and removal of any displacement markings. The previously described procedures were repeated until data for all treatments was obtained.

Results

According to the data obtained for the amount of time taken by *Blattella germanica* to cross a substance-treated filter paper in attraction to slices of white bread, there were no incidences of crossing when the filter paper was treated with Permethrin within 10 trials (Table 1; Table 2). Furthermore, Picardin treatment prevented 6 crossings, Kaffir lime oil prevented 5, Psidium guajava prevented 2, citronella prevented 1, and DEET failed to inhibit crossing within any trial (Table 1).

Out of the mean crossing times for each trial, excluding Permethrin in which there was no crossing, Picaridin exhibited a mean crossing time of 97.5 seconds, Kaffir lime followed with 77.0 seconds, DEET with 35.4 seconds, Citronella with 23 seconds, and Psidium guajava with 21.5 seconds (Table 2).

The raw data from which these mean times were derived exhibit ranges of over 40 seconds (Table 1). When outliers of data are not considered, Kaffir lime demonstrates a significantly smaller range of data as compared to the rest of the set, contributing to its validity.

A large standard deviation of 66.5 and margin of error of ±66.86% exist for the data on Picaridin, likely due to the large range of values reported (Table 2), and so this must be considered in the discussion of results.

Citronella and Psidium guajava oils demonstrated relatively high margins of errors at 95% confidence as well, ±50.09% and ±56.93% respectively, and deviations of 17.6 and 17.7 (Table 2). DEET exhibited a margin of error of ±43.28% and deviation of 24.7, while Kaffir lime oil held a deviation of 25.4 and the lowest margin of error at ±28.91%, again not considering Permethrin (Table 2).

Table 1. Cross times in seconds for *Blattella germanica* against substance-treated filter papers in attraction to bread slices[t]

Treatment Trials	Psidium guajava	Kaffir Lime	Citronella	Permethrin	DEET	Picaridin
Trial 1 times (s)	7	0	5	0	55	0
Trial 2 times (s)	10	120	0	0	11	0
Trial 3 times (s)	8	0	22	0	44	120
Trial 4 times (s)	12	80	61	0	59	180
Trial 5 times (s)	30	60	35	0	47	0
Trial 6 times (s)	45	0	34	0	82	60
Trial 7 times (s)	0	0	10	0	36	0

Treatment Trials	*Psidium guajava*	Kaffir Lime	Citronella	Permethrin	DEET	Picaridin
Trial 8 times (s)	0	60	15	0	7	0
Trial 9 times (s)	50	65	13	0	10	30
Trial 10 times (s)	10	0	12	0	13	0

[t] where a lack of crossing is indicated by t = 0

Table 2. Mean cross times in seconds, standard deviations, and margins of errors at a 95% confidence level for *Blattella germanica* against substance-treated filter papers in attraction to bread slices[n]

Treatment Trials	*Psidium guajava*	Kaffir Lime	Citronella	Permethrin	DEET	Picaridin
Mean time $\bar{x}$ (s)	21.5	77	23	N/A: did not cross	35.4	97.5
Standard deviation s[s]	17.7	25.4	17.6	N/A: did not cross	24.7	66.5
Margin of Error $s_{\bar{x}}$,	21.5 ±12.24	77 ±22.261 (±28.91%)	23 ±11.522 (±50.09%)	N/A: did not cross	35.4 ±15.32	97.5 ±65.19

95% confidence[c]	(±56.93%)				(±43.28%)	(±66.86%)

[n] where trials contributing to a lack of crossing are not considered

[s] Calculated by the equation $s^2 = [\Sigma(x_i - \bar{x})^2]/(N - 1)$, where x_i = the i^{th} value of the variable and N = sample size

[c] Calculated by $1.960s_{\bar{x}} = s/\sqrt{N}$, represented by $\bar{x} \pm$ determined $s_{\bar{x}}$(±percent difference), where percent difference is calculated by $(s_{\bar{x}}/ \bar{x}) *1$

Discussion

In this experiment, the treatment that increased crossing times the most or inhibited it completely was deemed to be the most repellent against *B. germanica*. Based on the data collected, the repellency was quite variable for every treatment besides Permethrin (Table 2). All cockroaches exposed to the Permethrin treatment did not cross the filter paper, demonstrating repellency of the Permethrin treatment from the food source. Thus, Permethrin may be considered the most repellent treatment in this experiment.

In the consideration of the number of crossings for each treatment, DEET demonstrated no ability to prevent crossing in any of the trials, while other treatments were able to exhibit full repellency in at least one of the 10 trials (Table 1). Therefore, DEET may be considered the least effective treatment, and thus, the least repellant out of all treatments considered.

Because there was large variability within the other trials, conclusions as to which of the intermediates were most effective were made by assessing which substance prevented the most number of crossings. Upon consideration of solely ability to prevent crossings as a whole, the most repellent treatments in descending order would be Permethrin, Picaridin, Kaffir lime essential oil, Psidium guajava essential oil, Citronella essential oil, and DEET.

However, due to the large deviations previously mentioned, the amount of seconds for crossing must also be considered in treatments that weren't definite in data as opposed to the defined data present in the Permethrin and DEET trial.

The amount of crossings for the Picaridin and Kaffir lime oil treatment were rather similar, with Picaridin preventing crossing in just one trial more than the Kaffir oil. However, the Picaridin treatment had an extremely large variance in its data, while the Kaffir oil treatment had the smallest range and smallest margin of error as compared to all treatments performed. Thus, it may be assumed that the Kaffir oil treatment is more repellent than the Picaridin treatment due to the increased validity of Kaffir oil data acting to compensate for highly similar data sets between the two.

Picaridin is still visibly more repellent than the Citronella and Psidium guajava treatments despite such a large range in data, considering these two treatments demonstrated similar large ranges except with much shorter mean crossing times and a greater inability to inhibit as much crossing as the Picaridin treatment. Both the Citronella and Psidium guajava have relatively similar mean times, standard deviations, and margins of errors. Therefore, the data suggests that these two treatments have similar or the same degrees of repellency.

Upon consideration of these results and factors, the descending order of repellency for the treatments is Permethrin, Kaffir oil, Picaridin, Citronella and Psidium guajava, and DEET. These results also suggest a greater repellency in commercial repellents as opposed to the essential oils, with two of the top 3 repellents being commercial repellents.

According to other research observing the repellency effects of essential oils, kaffir lime tends to be the most efficient repellent against *B. germanica*, with all other essential oils falling slightly under kaffir oil and exhibiting the same relative repellency to one another (Chooluck, et. al 2019, Thavara et. al 2007). While kaffir oil exhibits excellent repellency to *B. germanica* across the literature, Psidium guajava oil is said to have the same degree of repellency as kaffir oil, which is not evident in this particular study (Thavara et. al 2007). Variations may exist on the degrees of repellency of certain essential oils, but most of the literature suggests heightened repellency for kaffir oil as well as mostly similar degrees of high repellency for other essential oils, which is overall consistent with the data present. One paper was found in which kaffir lime oil demonstrated significantly diminished repellency effects as compared to other oils and DEET, but this does not align with the study presented nor with other literature (Tawatsin et. al 2001).

There is not much research pertaining to the comparison of repellency effects between various essential oils and commercially available repellents. One study investigated the effects of catnip essential oil, nepetalactone, and DEET to determine that nepetalactone, a component derived from catnip, was significantly more efficient at repellency than the other repellents considered (Peterson et. al 2002). No studies are evident on the effects of picaridin on *B. germanica*. Literature that includes DEET and Permethrin indicate that essential oils tended to have greater repellency than these two commercial repellents, although Permethrin was on the higher end of repellency (Peterson et. al 2002, Thavara et. al 2007). This study supports the assertion that essential oils demonstrate a greater repellency than DEET, but not Permethrin.

Although literature supports increased repellency of essential oils over Permethrin, the present study found that Permethrin was the most effective repellent amongst all treatment groups (Thavara et. al 2007). This variable result may be due to the contribution of insecticide resistance in some strains of *B. germanica*, as some have exhibited up to 100% resistance in Permethrin, specifically (Cochran 1989).

Although the issues of resistance exist with commercially based insecticides, discussion of the best way to administer essential oils as a repellent still continues to be reviewed. Typically, essential oil repellent would have to be applied every few hours, and thus may not be practical for a widespread Integrated Vector Management program. The best way to assure a diminishment in resistance may be to provide variation in insecticide treatment.

Despite this caveat, this study provides implications for safer methods of repellency overall, since essential oils have been shown to be at least more effective than widely-used

DEET. Many potential harmful effects of commercially-available repellents may not have been reviewed yet, while essential oils are known to have no detrimental health concerns, and thus integration of a safer method is recommended in this way.

Limitations of the current study surrounds lack of knowledge regarding the resistance developments in each individual cockroach utilized in the study. There is also no consideration of how the usage of the same cockroach for different repellency trials may affect results. In addition, the sample size was relatively low, leading to a large standard deviation and margin of error. A large sample size would provide more robu results. Furthermore, no control trial was conducted in this study, so relative repellency to a substance that is known to not be repellent must still be determined.

Future research may be aimed at assessing the repellency of a greater range of oils, as well as the repellency of these oils relative to other commercially available repellents. Development of methods to utilize essential oil repellency in large-scale programs may be an essential factor of future research. Effects of combining certain essential oils as based on the main chemical components shown to provide the greatest repellency in current literature may also be another path to consider.

In conclusion, this study presented provides evidence that Permethrin, a commercial repellent, provides the greatest repellency against commercial repellents DEET and Picaridin, as well as against essential oils kaffir lime, Psidium guajava, and Citronella. DEET proved to be the least repellent of this group. The data suggests that commercial repellents provide greater repellency than essential oils overall, as commercial repellents made up 2 of the top 3 repellent substances, but also that that essential oils are more repellent than certain commercially-available repellents such as DEET. Overall, though, more research must be done to solidify these results due to a diminished sample size as well as conflicting reports across the literature.

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