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# Efficient Harvesting of Safe Edible Grasshoppers: Evaluation of Modified Drums and Light-Emitting Diode Bulbs for Harvesting *Ruspolia differens* (Orthoptera: Tettigoniidae) in Uganda

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## Abstract

*Ruspolia differens* (Serville) (Orthoptera: Tettigoniidae) is a delicacy in many African countries. It is commonly mass-harvested from the wild using light traps consisting of energy-intensive mercury bulbs which pollute the environment when poorly disposed. The catch is collected using open-ended drums which are inefficient in retaining the insects. The drums also collect nontarget insects including those that produce toxic chemicals (such as pederin) that cause severe burns to human skin. To prevent escape of trapped *R. differens*, trappers apply potentially hazardous substances like waste cooking oil on the walls of drums. Here, we modified the collection drum by fitting a funnel to retain *R. differens*; and partitioned it into three compartments with wire meshes of variable sizes to filter nontarget insects. Additionally, we replaced mercury bulbs with light-emitting diode (LED) bulbs which are energy-efficient. We evaluated the performance of the modified *R. differens* trap (modified drums and LED bulbs) compared to the current collection drums and mercury bulbs. The catch of *R. differens* in the modified drums was comparable to that of current drums. Nontarget insects were significantly filtered from the catch collected in modified drums compared to the current drums. Further, LED bulbs of 400 W trapped a comparable quantity of *R. differens* as 400 W mercury bulbs, but with less than half the consumption of electricity compared to the mercury bulbs. We concluded that modified *R. differens* light traps have better energy-use efficiency and ensure safety to collectors, processors, and consumers.

**Key words:** light-emitting diode bulbs, mercury bulbs, collection drum, nontarget insects

Approximately 2,000 species of insects are consumed by more than 2 billion people globally (Van-Huis 2015), with about 524, 349, 679, 152, and 41 species eaten in Africa, Asia, America (mainly Central and South America), Australia, and Europe, respectively (Jongema 2015, Kelemu et al. 2015). In many countries, a number of native edible insects are traditionally harvested from the wild using different methods depending on the behavior of the target species (Van-Huis et al. 2013). In Uganda, *Ruspolia differens* (Serville) (Orthoptera: Tettigoniidae) is the most harvested and widely consumed insect species (Okia et al. 2017). *Ruspolia differens* swarms twice a year (March–May and November–December) (Agea et al. 2008, Ssepuuya et al. 2016). According to the Old Masaka Basenene Association of Uganda Limited which is registered by Uganda Registration Services Bureau (Registration No. 80010003846165), approximately 800 people in Masaka district, central Uganda are employed in the value chain of *R. differens*, undertaking trapping, transporting, whole selling, processing, and retailing. According to Agea et al. (2008), each *R. differens* trader in Uganda generated over US$220 per swarming season in 2007.

*Ruspolia differens* is currently harvested using light traps that consist of high wattage mercury bulbs (400 W), metallic drums for collecting the insects, and slanting iron sheets to slide the insects into the drums (Okia et al. 2017). Sadly, when mercury bulbs are poorly disposed, they release mercury into the ecosystems causing biomagnification along the food chains (SCHER 2010, Lim et al. 2012). According to Bibha and Ranjana (2015), mercury in the atmosphere can enter the human body through the lungs, skin, and the digestive system and acts as a neurotoxin, interfering with the brain and nervous system, hence leading to health complications. In addition, mercury from the bulbs causes irritation of the skin and eyes due to its corrosiveness (Okia et al. 2017). This puts commercial harvesters of *R. differens* and the people around the trapping sites at high health risk. Given that the mercury bulbs are costly, energy-intensive, and short-lived (Benson et al. 2013), they can significantly increase the costs of trapping *R. differens*.

In recent years, light-emitting diode (LED) bulbs have become increasingly popular as safer and energy-efficient alternatives to mercury bulbs. They are reportedly cheaper, produce less heat, durable, and are less hazardous to humans and the environment (Lim et al. 2012). These bulbs also produce much more focused lights with a narrow spectrum of about 5 nanometers (nm), allowing for specific lighting characteristics and specific purposes (Green et al. 2012). For instance, Lysakov et al. (2019) found blue LED lamps to be effective in trapping locusts. Liu and Zhou (2011) reported that locusts select LED bulbs of stronger illuminance gradient. However, the use of low-cost LED bulbs as an alternative to mercury bulbs has not yet been considered for trapping *R. differens*.

The traps currently used for harvesting wild *R. differens* also trap many nontarget insect species, some of which are poisonous to humans. For example, the Nairobi fly, *Paederus sabaeus* (Fabricius) (Coleoptera: Staphylinidae) commonly trapped along with *R. differens* (Mmari et al. 2017), secretes pederin, a substance which causes temporary blindness and dermatitis in humans (Iserson and Walton 2012). The harmful nontarget insects are usually sorted out manually before *R. differens* are prepared for consumption, which not only predisposes handlers to toxic substances such as pederin but is also labor-intensive.

Because of high rates of escape of *R. differens* from collection drums, commercial harvesters commonly sprinkle waste cooking oil, cassava flour, and water into the drums to prevent the catches from escaping (Okia et al. 2017). These materials contaminate the harvest and render processing for markets difficult. Waste cooking oil is also linked to the presence of heavy metals in foods, hence increasing the risk of carcinogenic diseases on consumers (Ganesan et al. 2017).

To address challenges associated with current *R. differens* light traps, we modified the trap by 1) fitting a funnel to retain *R. differens* catch; 2) partitioning the collection drum into three compartments by fitting a 6 × 6 mm wire mesh to retain nontarget insects that are bigger than *R. differens* in the upper compartment and a 3 × 3 mm mesh to retain *R. differens* in the middle compartment while filtering smaller nontarget insects to the lower compartment; and 3) replacing the mercury bulbs with LED bulbs. The modified drums and LED bulbs were evaluated for trapping *R. differens* compared to the current drums and mercury lamps. We tested the hypotheses that; 1) catches of *R. differens* and nontarget insects were not affected by drum design and light type, 2) the wire meshes fitted to the collection drum were inefficient in filtering nontarget insects from *R. differens* harvest, and 3) the consumption of electricity by LED and mercury bulbs was not different.

## Materials and Methods

### Study Site

The study was carried out in Nyendo town, Masaka district, central Uganda, which is one of the popular *R. differens* trapping sites in Uganda (Agea et al. 2008, Ssepuuya et al. 2016). Trapping experiments were set up at four randomly selected sites of commercial harvesters in Nyendo town. The coordinates of each trapping site were recorded using a geographical positioning system (GPS) (GARMIN eTrex 20X, Garmin Ltd, Olathe, KS) and plotted on Arc Map using the Arc GIS software version 10.3 (Esri Eastern Africa Ltd, Naiobi, Kenya) (Fig. 1).

### Modification of *R. differens* Collection Drum

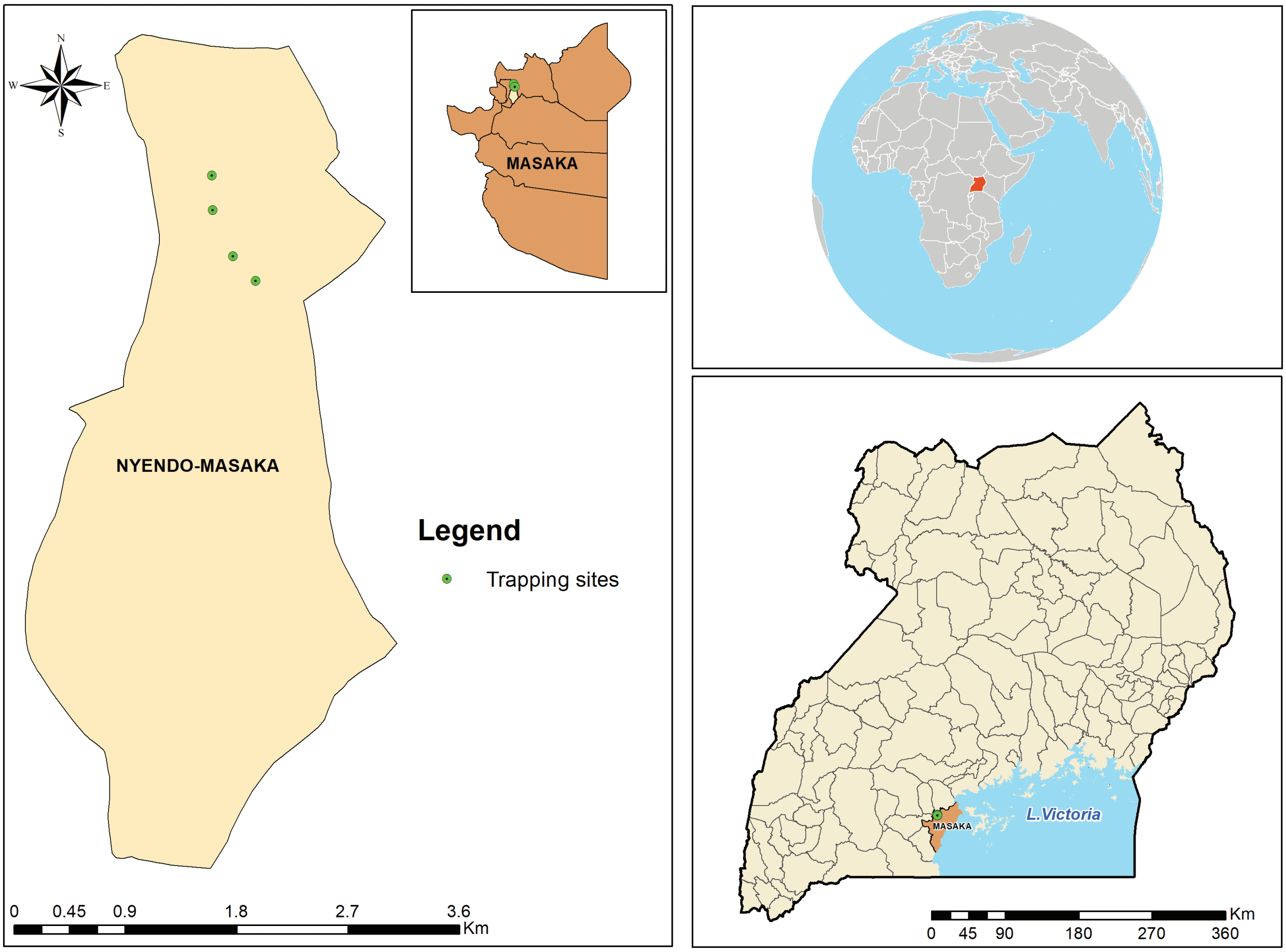
Clean empty metallic drums (TRWY container LTD, Shandong, China) of 200 liters capacity with a 0.57-m diameter were fitted with funnels made from plain iron sheets to minimize escape of the catches (Fig. 2). The drums were vertically partitioned into three compartments; upper (0.35 m height), middle (0.35 m height), and lower (0.15 m height) using wire meshes. A 6 × 6 mm wire mesh was designed to retain nontarget insects that are bigger than *R. differens* in the upper compartment and a 3 × 3 mm mesh was fitted to retain *R. differens* in the middle compartment while filtering smaller nontarget insects to the lower compartment. Doors of 0.1 m × 0.2 m were fitted on each compartment in the same vertical line along the drums to facilitate collection of the catch from each compartment.

### Preliminary Experimental Design

A preliminary trial was carried out during the swarming season from April to May 2019. In this trial, two wattages of LED bulbs (100 and 200 W) (Cob, GS light, YAYE Lighting Company, Zhongshan, China) were compared with 400 W mercury bulb (GE lighting, Ningbo Sunfine, Lanxi Qiming Illumination Company, Zhejiang, China) using current and modified drums at three commercial trapping sites. The trapping sites were set at 200–300 m apart to ensure similar environmental conditions (Silva et al. 2016) but minimizing light spillover effects across sites. Three bulbs were equally spaced from each other to provide uniform light for all the drums at the trapping site. The type of bulb used per site was rotated every night to avoid locational effect. Each type of bulb was used twice at a site, totaling to six effective trapping nights during the season, depending on occurrence of swarming.

The experiments were overlaid with existing setups of commercial harvesters which consisted of 16–20 drums. The drums were arranged in a 'U' shape to allow entry from the open end. The drums were suspended on raised wooden frames made of Eucalyptus poles, 0.6 m from the ground. Each drum had an equal chance of selection as the six experimental drums. The treatments (current or modified drums), were then randomly assigned to the selected experimental drums (Supp Fig. 1 [online only]). Each treatment was replicated thrice in each site. One iron sheet was placed in each drum at about 75° to the inner vertical plane and tied to the eucalyptus pole to prevent it from falling. At least three quarters of the length of the iron sheet was outside the drum/funnel. Three bulbs connected to the power source per site were fitted above the experimental drums and the other drums in the setup on Eucalyptus poles (6 m high). The bulbs were placed approximately equal distances apart to provide uniform light for all the drums at the site. Trapping was done for 9 h each night from 2000 to 0500 h, East African Time. After each trapping night, catches of *R. differens* from control and modified drums were collected and weighed. The catches of *R. differens* in modified *R. differens* collection drums were recorded per compartment.

The catches of nontarget insects per current drum or compartment of modified drum were collected, sorted by morphospecies, and counted. Individuals of each species were placed in labeled 250-ml plastic bottles containing ethyl acetate in cotton wool to



*The boundaries and names shown, and the designations used on the maps do not imply official endorsement or acceptance by icipe*

**Fig. 1.** Location of *Ruspolia differens* trapping sites in Nyendo, Masaka, Uganda in 2019.

kill them (Silva et al. 2015). For each lepidopteran morphospecies of nontarget insects, five individuals were put in paper envelopes and later mounted; whereas nonlepidopterans were wet preserved in 95% ethanol (Duehl et al. 2011). The voucher specimens were deposited in the museum at the Department of Zoology, Entomology and Fisheries Sciences, Makerere University. The nontarget samples were morphologically identified with certainty to genera using the identification keys described by Klimaszewski and Watt (1997), Jagbir and Mudasir (2013), and Timm et al. (2007).

## Experimental Design

The trial was carried out during the swarming season from November to December 2019. Owing to observations that catches of *R. differens* were influenced by wattage of LED lights with both 100 and 200 W bulbs catching significantly fewer *R. differens* than 400 W mercury bulbs in the preliminary trial, two modifications were made to this experimental design. The first modification was addition of 400 W LED bulbs (Cob, GS light, YAYE Lighting Company), increasing the number of types of bulbs from three to four (LED: 100, 200, and 400 W; and mercury: 400 W) thereby extending the trapping duration from six to eight effective days to allow each bulb the chance to be used twice per site. The second modification was measurement of energy consumption per bulb type. The amount of electricity consumed by LED (100, 200, and 400 W) and 400 W mercury bulbs was measured using Actaris electricity meters of 2,000 kWh capacity (Actaris, Itron, London, United Kingdom), which were connected to the bulbs at each trapping site. Electricity consumption in a night was determined by taking the readings before lights were turned on and just after switching them off, then subtracting the former reading from the latter. Electricity consumption per bulb per night was determined by dividing the electric consumption per night per site by the number of bulbs served by the meter. Other procedures in the second season were like those in the first season.

## Data Analyses

Weights of *R. differens* were subjected to two-way analysis of variance (ANOVA) to determine effect of drum type and light source on the catch. Mean kilowatts of electricity consumed by the LED and mercury bulbs were compared using one-way ANOVA. Mean weights of *R. differens* in the upper and middle compartments of the modified drums were compared using independent two-sample *t*-test.

Total counts of nontarget species caught with *R. differens* were subjected to generalized linear models (GLMs) with Poisson distribution error and logit link, to determine effect of drum type, compartment, and light source on the catches (Zuur et al. 2009). Counts of each morphospecies caught with *R. differens* were also individually subjected to GLMs with Poisson distribution error and logit link, to

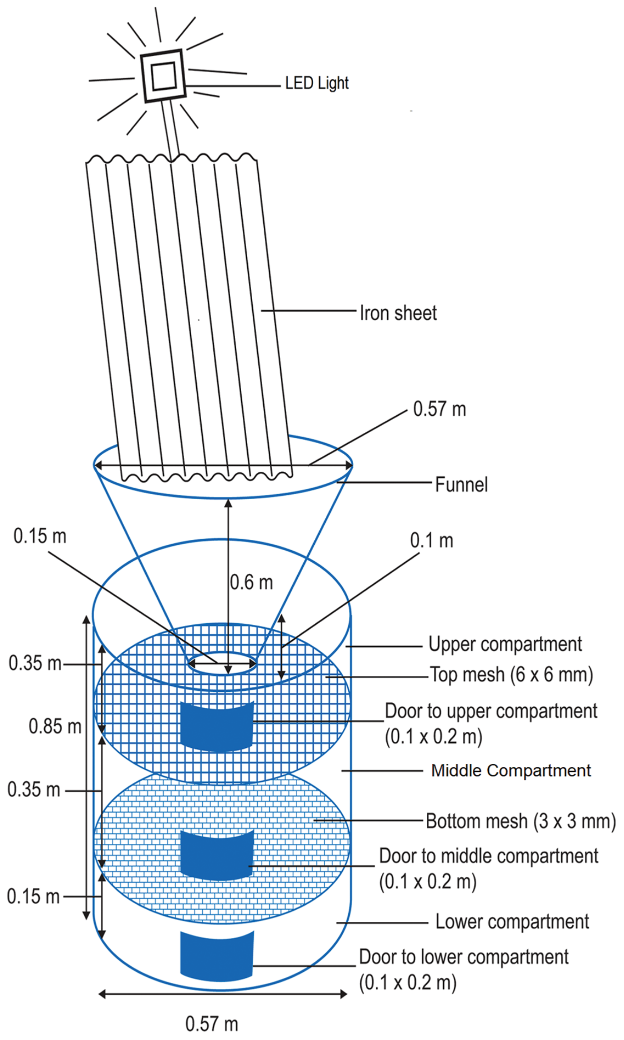


**Fig. 2.** Schematic design of the modified *Ruspolia differens* collection drum. Drawing by: Brian Mwashi.

determine the effect of drum type and light source on the catches. All the GLMs had dispersion parameters (ratios of residual deviances to degrees of freedom) which were approximately 1, which confirmed their suitability for the analyses.

For nontarget morphospecies which were recorded in only two compartments of the modified drums, mean counts were compared using chi-square ($\chi^2$) tests. Counts of nontarget insects which were recorded only in one compartment of the modified drum were not subjected to statistical analysis, but their means and standard errors were computed.

Where necessary, Turkey's multiple comparisons were used for mean separation. All analyses were carried out in R-statistical computer software version 3.5.1 (R Development Core Team 2018) at $\alpha = 0.05$.

## Results

### Effect of Collection Drum Design and Light Source on Catches of *R. differens*

The mean weight of *R. differens* collected in modified drums per night (165.2 ± 8.4 g) was not significantly different from the mean catch in the current drums (172.4 ± 8.7 g) ($F = 43.1$; df = 1, 104.3; $P = 0.44$). On the other hand, the type of bulb had a significant effect on catches of *R. differens* ($F = 42.2$; df = 3, 104.3; $P < 0.001$; Fig. 3). Whereas the mean catch of *R. differens* collected using LED 400 W lit drums per night was not significantly different from catches by 400 W mercury bulbs; these catches were significantly higher than the catches of *R. differens* collected using 200 and 100 W LED bulbs. The mean catch of *R. differens* collected using LED 200 W was significantly higher than that collected using LED 100 W.

### Electricity Consumption of LED and Mercury Bulbs During *R. differens* Trapping

There were significant differences in the electricity consumption by different light sources ($F = 28755$; df = 3, 48.7; $P < 0.001$; Fig. 4). The consumption of electricity by 400 W mercury bulbs was significantly higher than the consumption by LED bulbs of the same wattage.

### Efficiency of Wire Meshes in Filtering *R. differens* to the Middle Compartment

The mean catch of *R. differens* collected in the upper compartment per night (128.8 ± 7.3 g) was significantly higher than the catch in the middle compartment (37.6 ± 2.2 g) ($t = 11.9$; df = 194; $P < 0.001$). No *R. differens* were caught in the lower compartment.

### Effect of Drum Design and Light Source on the Number of Nontarget Insect Species

In total, nine nontarget species were trapped (Supp Fig. 2 [online only]). These included five lepidopterans: *Acherontia* sp. Linnaeus (Lepidoptera: Sphingidae), *Achaea* sp. (Walker) (Lepidoptera: Erebidae), *Amerila* sp. (Hauser and Boppre) (Lepidoptera: Erebidae), *Haritalodes* sp. Fabricius (Lepidoptera: Crambidae), and *Mythimna* sp. (Walker) (Lepidoptera: Noctuidae). Three of the species were coleopterans: *Paederus* sp., *Cybister* sp. (Olivier) (Coleoptera: Dytiscidae), and *Heteronychus* sp. Fabricius (Coleoptera: Scarabaeidae). One species was a hemipteran; *Lethocerus* sp. Linnaeus (Hemiptera: Belostomatidae). The mean total number of nontarget insects collected with *R. differens* from the modified drums was significantly lower than the total counts of nontarget species in *R. differens* from current drums (Fig. 5; Table 1). The number of *Achaea* sp., *Acherontia* sp., *Amerila* sp., *Cybister* sp., *Haritalodes* sp., *Mythimna* sp., and *Paederus* sp. collected with *R. differens* from modified drums was significantly lower than those collected with *R. differens* from current drums. There were no detectable differences in the number of *Lethocerus* sp. and *Heteronychus* sp. caught with *R. differens* in the two types

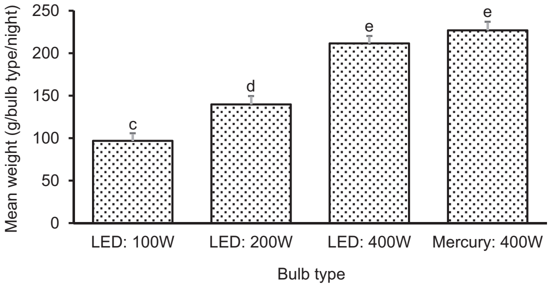


**Fig. 3.** Mean weights of *Ruspolia differens* collected using different types of bulbs in 2019. Bars with the same letters were not significantly different ($\alpha = 0.05$). Error bars represent standard errors of the mean.

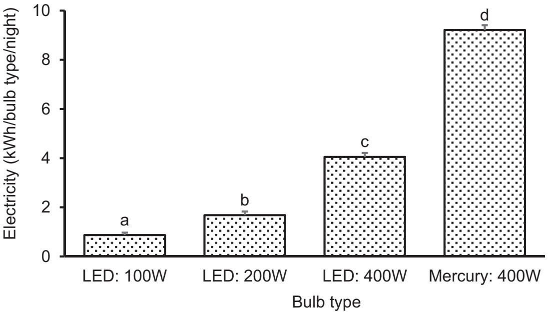


**Fig. 4.** Mean kilowatts of electricity consumed per night by the different types of bulbs during *Ruspolia differens* trapping. Bars with different letters are significantly different (α = 0.05). Error bars represent standard errors of the mean.

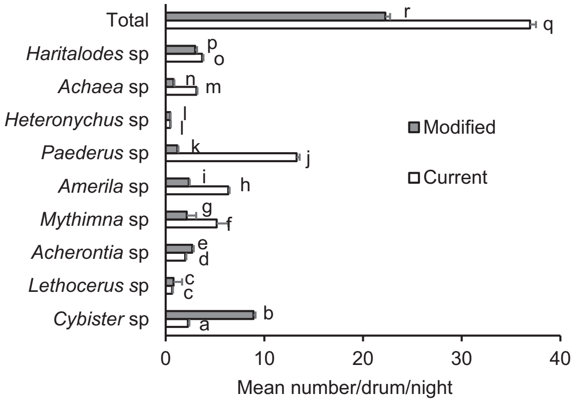


**Fig. 5.** Mean number of nontarget species collected with *Ruspolia differens* caught in modified and current drums in 2019. Bars with the same letters are not significanly different (α = 0.05). Error bars represent standard errors of the mean.

of drums. There were no significant effects of light source on both the total number of nontarget species and counts of individual species collected with *R. differens* (Fig. 6).

### Efficiency of Wire Meshes in Filtering Off Nontarget Insect Species From *R. differens*

The total mean numbers of nontarget insects caught in the upper, middle, and lower compartments per night were significantly different ($\chi^2$ = 1,038.4; df = 2; $P < 0.001$; Fig. 7). The mean number of *Cybister* sp. caught in the middle compartment was significantly higher than its catch in the upper compartment ($\chi^2$ = 136.9; df = 1; $P < 0.001$). Similarly, the mean numbers of *Achaea* sp., *Haritalodes* sp., and *Paederus* sp. caught in the lower compartment were significantly higher than their catches in the middle compartment ($\chi^2$ = 143.9; df = 1; $P < 0.001$, $\chi^2$ = 145.9; df = 1; $P = 0.001$, and $\chi^2$ = 142.3; df = 1; $P < 0.001$, respectively). *Acherontia* sp. and *Lethocerus* sp. were caught only in the upper compartment; whereas *Amerila* sp. and *Mythimna* sp. were obtained in the middle compartment only.

## Discussion

Our data show that the catch of *R. differens* in the modified drums and current drums was comparable. This suggests that the funnel in the modified drum was effective in retaining *R. differens* catches without applying materials like water, cassava flour, and waste cooking oil (Okia et al. 2017). Therefore, adoption of the modified drum in trapping *R. differens* would help to improve on the quality of *R. differens* harvest and reduce the risk of carcinogenic diseases associated with waste cooking oil to consumers (Ganesan et al. 2017).

*Ruspolia differens* was not found in the lower compartments of the modified drums, suggesting that a 3 × 3 mm wire mesh effectively prevented the grasshoppers from going through. On the other hand, the catch of *R. differens* in the upper compartment was significantly higher than the catch of the insect in the middle compartment, contrary to the intention to retain only nontarget insects bigger than *R. differens* in the upper compartment. This may be a result of adhesive action of numerous hairs located on pulvilli found on the tarsi of *R. differens* (Matojo 2017) that could have allowed a majority of them to hold onto the mesh. It is also possible that *R. differens* that crossed to the middle compartment could have reverted to the upper compartment in an attempt to escape from the drum, only to be intercepted by the funnel. The retention of *R. differens* to the upper compartment predisposes them to escape through the funnel opening, should the compartment fill up. Therefore, the top mesh was found inessential.

The upper and middle compartments contained less nontarget insects compared to the lower compartment. This is because most of the nontarget insects were smaller than *R. differens*, so they were filtered out by the wire meshes. Since *R. differens* was only collected from the upper and middle compartments which had less nontargets than the lower compartment, *R. differens* collected from modified drums were less contaminated with nontarget insects compared to those collected from current drums. Interestingly, about 85% of *Paederus* sp. which secretes pederin that causes irritation of eyes and skins for both harvesters and processors of *R. differens* (Iseroson and Walton 2012) was collected in the lower compartment. This was a significant improvement in the safety to commercial harvesters, processors, and consumers of *R. differens* from this hazardous insect. However, nontarget species that were relatively bigger than (*Lethocerus* sp., *Acherontia* sp., and *Cybister* sp.) or the same size as (*Amerila* sp. and *Mythimna* sp.) *R. differens* were not filtered out of the catch as desired. The existence of insects of the same species in two compartments was probably due to variation in the sizes of these insects and their ability to move back-and-forth between the different compartments. For example, *Achaea* sp., *Haritalodes* sp., and *Paederus* sp. that were filtered into the lower compartment could have been able to move back into the middle compartment to contaminate *R. differens*. Therefore, there is need for further improvement of the collection drum to separate nontarget insects that are of the same size or bigger than *R. differens* and to prevent nontargets filtered into the lower compartment from moving into the middle compartment.

Five out of nine nontarget species trapped with *R. differens* were lepidopterans. This is consistent with previous reports that most nocturnal insects belong to the order Lepidoptera (Nowinszky 2014, Price and Baker 2016). This result concurs with the report by Ramamurthy et al. (2010) that lepidopterans account for most insects caught in different types of light traps. Most of the lepidopterans trapped were *Achaea* sp. and *Haritalodes* sp. and these were found in the lower compartments because they were smaller than *R. differens*. This explains why *R. differens* caught in modified drums contained fewer nontargets compared to those from current drums. The health effects of some of these nontarget insects to humans are not known. However, if they are not eliminated from *R. differens*, the processors spend a lot of time and more energy to sort them

**Table 1.** Summary of statistical parameters from GLMs for the effect of drum design and light source on the number of nontarget species collected with *Ruspolia differens*

| | $\chi^2$ | df | *P* |
|---|---|---|---|
| Drum design | | | |
| Total nontargets | 747.6 | 1 | 0.001 |
| *Achaea* sp. | 141.8 | 1 | <0.001 |
| *Acherontia* sp. | 10.4 | 1 | 0.001 |
| *Amerila* sp. | 183.7 | 1 | <0.001 |
| *Cybister* sp. | 8.6 | 1 | 0.003 |
| *Haritalodes* sp. | 7.2 | 1 | 0.007 |
| *Heteronychus* sp. | 0.9 | 1 | 0.340 |
| *Lethocerus* sp. | 0.3 | 1 | 0.612 |
| *Mythimna* sp. | 124.5 | 1 | <0.001 |
| *Paederus* sp. | 186.7 | 1 | <0.001 |
| Light source | | | |
| Total nontargets | 3.4 | 3 | 0.339 |
| *Achaea* sp. | 0.7 | 3 | 0.884 |
| *Acherontia* sp. | 0.9 | 3 | 0.819 |
| *Amerila* sp. | 2.3 | 3 | 0.518 |
| *Cybister* sp. | 3.3 | 3 | 0.349 |
| *Haritalodes* sp. | 0.5 | 3 | 0.923 |
| *Heteronychus* sp. | 1.3 | 3 | 0.733 |
| *Lethocerus* sp. | 1.2 | 3 | 0.749 |
| *Mythimna* sp. | 0.1 | 3 | 0.994 |
| *Paederus* sp. | 1.1 | 3 | 0.781 |

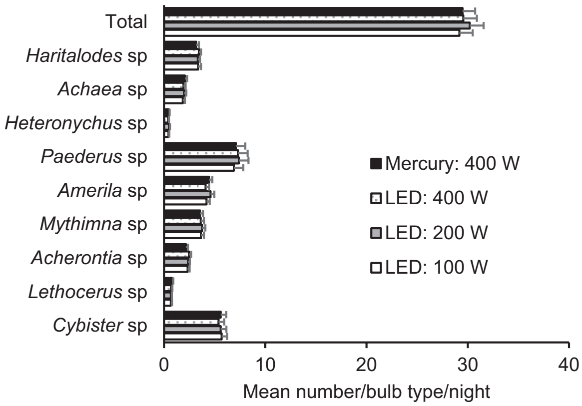


**Fig. 6.** Mean number of nontarget species collected with *Ruspolia differens* using different types of bulbs in 2019. Error bars represent standard errors of the mean.

out. The scales from lepidopterans contaminate *R. differens*, hence requiring thorough washing which takes a lot of water and time. Most of the nontarget insects that were trapped are known prey for birds and insects; whereas lepidopterans, especially noctuids, are crop pollinators (Goldstein 2017). Therefore, filtering some of these nontarget insects to the lower compartments of modified drums where they were not mixed with *R. differens* could allow harvesters to easily release them back to the wild by opening the door of the lower compartment. This would contribute to conservation of these species, unlike in the current drums where they end up being packed in sacks together with *R. differens*.

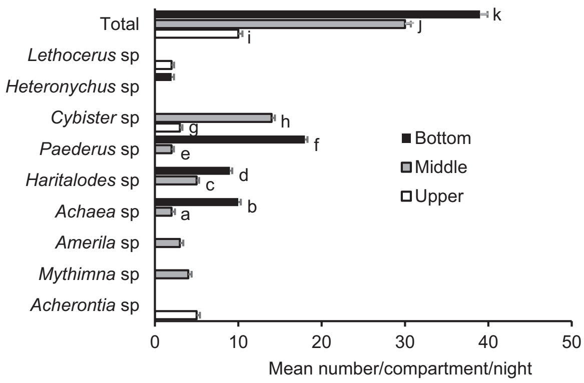


**Fig. 7.** Mean number of nontarget species caught in the different compartments of the modified drum in 2019. Bars within a species with the same letters are not significantly different between compartments (α = 0.05). Error bars represent standard errors of the mean.

The mean catch of *R. differens* collected using LED bulbs increased with the increase in the wattage of the bulbs. This indicates that *R. differens* responds proportionately to light intensity. Insects exhibit two major phototactic behaviors which include attraction (positive phototaxis) and repulsion (negative phototaxis). However, these two responses are affected by the intensity and wavelength of the light and this varies among insect species (Shimonda and Honda 2013). Lysakov et al. (2019) found blue LEDs of wavelength within 440–470 nm effective at trapping locusts. Therefore, the optimum intensity, wavelength, and color of light for *R. differens* need to be investigated. Importantly, the LED 400 W bulbs attracted the same quantity of *R. differens* as 400 W mercury bulbs. This first report of the effectiveness of LED bulbs in trapping *R. differens* corroborates the proposition by Silva et al. (2016) that LED bulbs could be useful for trapping other insect orders apart from mosquitoes. Price and Baker (2016) also reported that LED bulbs can effectively attract nine insect orders which included Ephemeroptera, Plecoptera, Trichoptera, Diptera, Coleoptera, Hemiptera, Hymenoptera, Orthoptera, and Lepidoptera.

Electricity consumption approximately doubled with doubling of the wattage of LED bulbs, but the 400 W LED bulbs consumed less than half of the electricity consumed by 400 W mercury bulbs. This implies that lamps with LED bulbs can save over 50% of the money spent on electricity used for trapping *R. differens*. Lyatuu (2019) reported that Umeme Limited (the largest electricity distributor in Uganda) charges US$94.97 per 400 W mercury bulb per season from harvesters of *R. differens*; therefore, reducing this cost by over 50% would be a great relief to hundreds of harvesters who use over three bulbs per site. The electricity energy conserved would be made available for other household needs. Cohnstaedt et al. (2008) underscored power saving as the primary advantage of LED bulbs over mercury bulbs. However, saving slightly over 50% of electricity compared to mercury bulbs is still far from the report by Lim et al. (2012) that LED bulbs consume about 85% less energy than mercury bulbs. Therefore, investigations are required to further optimize power efficiency of LED bulbs in trapping *R. differens*. Besides energy efficiency, LED bulbs do not release mercury to the environment (Lim et al. 2012) unlike mercury bulbs when poorly disposed, which further supports the need to replace mercury bulbs with LED bulbs in trapping *R. differens*.

The total numbers of nontarget species caught with *R. differens* using LED and mercury bulbs were not significantly different, indicating that the numbers of these nontarget insects were not influenced by the intensity and type of light. This finding is consistent with the report by Duehl et al. (2011) that most nocturnal insects are attracted to light irrespective of its intensity and type. This suggests that improvements in the collection drums, rather than light source, are critical in reducing contamination of *R. differens* with nontarget insects.

## Conclusions and Recommendations

Our results indicate that the modified drums are comparable to the current drums in collecting *R. differens*; therefore, the fitted funnel is an alternative way of retaining catches instead of using contaminants like waste oil. LED bulbs of 400 W were as effective as 400 W mercury bulbs in attracting *R. differens*, while saving over 50% of electricity, and without releasing mercury to the environment. The lower wire mesh in the modified drums markedly filtered out insects smaller than *R. differens* especially the poisonous *Paederus* sp., reducing contamination of the harvest with potentially poisonous nontarget insects. This makes the harvest safer for human consumption. However nontarget insects that were of the same size or bigger than *R. differens* were not filtered out of the harvest. Therefore, we recommend adoption of the modified drums (without the upper mesh) and 400 W LED bulbs as a replacement of current drums and 400 W mercury bulbs, respectively, in order to improve quality and energy efficiency in trapping *R. differens*. The upper wire mesh in the modified drum was inessential in filtering insects bigger than *R. differens* from the harvest; therefore, further studies are required to achieve this objective. There is also a need to further investigate the optimum wattage of LED bulbs above 400 W for trapping *R. differens*.

## Supplementary Data

Supplementary data are available at *Journal of Economic Entomology* online.

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