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RESEARCH ARTICLE



The palatability of undyed carrot surface-coated with repellents, or dyed blue or green to a terrestrial macroinvertebrate

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ABSTRACT

Birds are at risk of being poisoned during pest control operations not only through eating toxic baits, but potentially by preying on invertebrates that have, themselves, consumed the toxic baits. Blue baits coated with anthraquinone and/or mint-scented repellents are avoided by some bird species compared with green baits coated with cinnamon oil; however, data on invertebrate avoidance patterns have not been explored. In our first experiment, we measured consumption rates in a large invertebrate, the Auckland tree wētā (*Hemideina thoracica*) for carrot that had been surface-coated with three repellent formulations: anthraquinone (0.8 g kg⁻¹) (a secondary repellent); anthraquinone (0.8 g kg⁻¹) and pennyroyal oil (a mint-scented product which acts as a primary repellent) (0.5 g kg⁻¹); and cinnamon oil (0.15 g kg⁻¹) (a primary repellent), over 4 days. In a second experiment, we tested whether tree wētā preferred carrot dyed either blue or green over 2 days. Tree wētā ate similar quantities of carrot from all three of the repellent formulations tested, but consumption of all three formulations was significantly lower than the control from the third day of the experiment. Tree wētā ate less blue-dyed carrot than green-dyed carrot on both days of the second experiment, but differences were not significant (day 1, $P=0.057$; day 2, $P=0.145$). Our findings complement the results of previous studies on some bird species. Together they show the potential of surface-coating baits with anthraquinone and/or mint oil and dyeing them blue in pest control operations to reduce non-target avian by-kill, while not increasing the risk of secondary poisoning of insectivorous species. Our results also indicate that cinnamon oil can be used not only as a toxin mask but also as a repellent to wētā.

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Introduction

Globally, introduced mammalian pests have reduced the viability of populations of native flora and fauna (Blackburn et al. 2004; Pimental 2007). In countries like New Zealand, this is especially true as the endemic wildlife have evolved in the absence of terrestrial

mammalian predators, and in many cases do not have appropriate phenotypic traits to cope with these threats (Holdaway 1989). Continued management or eradication of mammalian predators is needed to reduce the impact these species have on the native biota and to achieve the aim of a predator-free New Zealand by 2050 (O'Donnell & Hoare 2012; Russell et al. 2015).

In New Zealand baits containing toxins are deployed in the environment to reduce pest mammal populations, using both bait stations and large-scale aerial broadcasting (Innes & Barker 1999; Byrom et al. 2016). Regardless of delivery method, there is a risk that non-target species will interfere with toxic baits (Veltman & Westbrooke 2011). In some instances, non-target bird species have disappeared or been found dead after the deployment of toxic baits; for example, North Island robins *Petroica longipes* (Powlesland et al. 1999), North Island tomtit *P. macrocephala toitoi* (Powlesland et al. 2000) and kea *Nestor notabilis* (van Klink & Crowell 2015) (see Veltman & Westbrooke 2011 for a review).

Techniques to reduce non-target by-kill include removing small bait particles (Powlesland et al. 1999) and using visual and olfactory/gustatory repellents, such as colour dyeing of bait to reduce attractiveness to birds (Caithness & Williams 1971; Udy & Pracy 1981), or adding substances such as cinnamon to reduce palatability (Udy & Pracy 1981) (although cinnamon is primarily used to mask the flavour of certain toxins; Morgan 1990; Morgan et al. 1995). Despite the success of modern toxin delivery systems, resulting in positive outcomes for bird populations (Greene et al. 2013; Morriss et al. 2016), some sectors of the public still perceive high bird mortality to be an issue (Green & Rohan 2012).

In New Zealand toxic baits are dyed green as this colour was initially thought to be unattractive to non-target bird species (Caithness & Williams 1971), although more recent research is equivocal (Greig-Smith & Rowney 1987; Gionfriddo & Best 1996; Hartley et al. 1999; Clapperton et al. 2012; Oppel et al. 2016; but see Hartley et al. 2000; Weser & Ross 2013). In any case, colour avoidance effects may be relatively short-lived in birds; for example, in one trial, house sparrows (*Passer domesticus*) consumed significantly less blue and green coloured grain compared with uncoloured grain, but consumption increased over the 8 days of the experiment (Clapperton et al. 2012). Nonetheless, consumption of blue-dyed grain was consistently lower than that of green-dyed grain over the experiment, and significantly so on days 4 and 5. These findings led to a more sophisticated approach by Day et al. (2003) and Clapperton et al. (2014), who combined primary (offensive olfactory and/or visual cues) and secondary (illness inducing) repellents to maximise repellent effects. Such 'designer repellents' have been tested in crop protection management to reduce damage by pest birds (e.g. Avery et al. 1998; Clapperton et al. 2012; Werner et al. 2014), and applied to mammalian pest control practices to deter non-target bird species (Clapperton et al. 2015; Cowan et al. 2015; Crowell et al. 2016). Reduced bird by-kill results from the prefeeding stage of pest control operations (when non-toxic baits are deployed), as non-target species learn to associate the primary cues (coloured baits or an unpleasant smell) with a negative experience (feeling ill) (Clapperton et al. 2014; van Klink & Crowell 2015). In New Zealand, however, current best practice is to apply only a lure (e.g. cinnamon or orange) to prefeed baits (e.g. Warburton et al. 2009). Coloured dyes that could be used by non-target species as the salient cue for the establishment of a conditioned taste aversion are thus not included in these prefeed baits, but would need to be if repellents were used to reduce non-target consumption (e.g. Clapperton et al. 2014).

Direct feeding on toxins by non-target birds is, however, only one component of the potential by-kill. Many invertebrate taxa (including several Orthoptera species) have been observed feeding on toxic baits (Spurr & Drew 1999; Lloyd & McQueen 2000; Craddock 2003; Spurr & Berben 2004; Bowie & Ross 2006); however, there is some evidence that several invertebrate taxa avoid baits containing cinnamon (Spurr & Drew 1999; but see McGregor et al. 2004). Invertebrates appear to have a high tolerance for toxins used in pest control operations (Booth & Wickstrom 1999; Lloyd & McQueen 2000; Craddock 2003), and some insect species (including tree wētā *Hemideina* spp.) can accumulate and retain residual amounts of toxins in their systems at concentrations that may be dangerous to at least some insectivorous birds (Eason et al. 1993; Craddock 2003). The persistence of these toxins in invertebrate tissues is highly variable (Craddock 2003; Bowie & Ross 2006; Fisher et al. 2007); nonetheless, residual amounts of brodifacoum have been detected in free-ranging invertebrates (including tree wētā) for up to 4 weeks after the removal of toxic bait (Craddock 2003). Although the overall risk of invertebrate mortality from eating toxic bait for pest control thus appears to be low (Eason et al. 1993; Booth & Wickstrom 1999; Bowie & Ross 2006; Fisher et al. 2007), secondary poisoning of non-target species, through the consumption of invertebrate prey that have eaten toxic baits, remains a risk during pest control operations. Birds may receive a lethal dose of a secondary repellent after consuming invertebrate prey that have, themselves, eaten toxic baits (Bowie & Ross 2006; Fisher et al. 2007). Adult birds may also feed nestlings invertebrates containing toxins (Masuda et al. 2014).

The risk of secondary poisoning of birds may be more likely if large invertebrate prey are consumed, because the predator receives a higher amount of a toxin per kill. Thus, for example, consumption of tree wētā, a large (2.5–4.5 g) flightless invertebrate genus, may increase the risk of secondary poisoning to insectivorous birds (Lloyd & McQueen 2000; Craddock 2003; Bowie & Ross 2006; Fisher et al. 2007). Bowie & Ross (2006) estimated that consumption of as few as two Banks Peninsula tree wētā (*Hemideina ricta*) could lead to a lethal dose of brodifacoum in silvereyes (*Zosterops lateralis lateralis*). In contrast, those authors also estimated that silvereyes would need to consume 195 ground wētā (*Hemiandrus* spp.) or cave wētā (*Pleiopteron simplex*) over the same period before the LD₅₀ (the dose which will kill 50% of individuals) was achieved due to these species' smaller size. Therefore, while it is preferable to reduce all invertebrate consumption of toxic baits to reduce the risk of secondary poisoning of vertebrates, it is particularly important for large-bodied invertebrates.

The primary aim of the current study was to determine if baits surface-coated with repellents at concentrations shown to reduce bird consumption (but not affect rat [*Rattus* spp.] or possum [*Trichosurus vulpecula*] uptake; Clapperton et al. 2014, 2015) also reduced consumption by Auckland tree wētā (*Hemideina thoracica*, hereafter 'tree wētā'). Repellents tested were anthraquinone, in the form of the product AVEX[®], and/or a mint scent, pennyroyal oil; and cinnamon oil. Cinnamon oil and pennyroyal oil are both classed as primary repellents because of their strong smell. Although AVEX[®] has a subtle smell, it is generally classed as a secondary repellent because the active ingredient induces illness effects (Avery et al. 1998; Day et al. 2003; Clapperton et al. 2014). Our secondary aim was to determine if tree wētā consumption of baits was affected by colour in a similar way to non-target bird species during pest control operations. We therefore conducted a further experiment to test whether tree wētā consumed more baits dyed green

than dyed blue, as some evidence suggests that blue baits are less preferred by some non-target species (see above).

If tree wētā consumed baits either coated with anthraquinone and/or mint-scented repellent, or dyed blue, at rates less than or (at a minimum) equal to baits coated with standard substances (i.e. cinnamon or coloured green), it would justify a decision by managers to use these alternative repellents, because potential risks to non-target vertebrates through secondary poisoning would be further reduced.

Methods

Animal collection and husbandry

Adult tree wētā used in experiments 1 and 2 were collected on two occasions from free-ranging populations on Matakohe/Limestone Island, in Whangarei Harbour (35°47'3"S, 174°21'34"E) during December 2014 and January 2015. The tree wētā were transported in individual containers to a laboratory at NorthTec, Whangarei. On arrival, they were transferred into individual plastic enclosures (170 × 170 × 85 mm high) with a 75 × 85 mm mesh covered window in the lid to allow air exchange and viewing by observers. We weighed the tree wētā the day after arrival and observed their feeding, defecation and behaviour to assess acclimation. This minimal disturbance approach to wētā husbandry follows similar protocols used successfully in other studies (e.g. Fadzly & Burns 2010; Wehi et al. 2013). The acclimation periods before experiments commenced were 23 days and 6 days for the two collections, respectively. We initially implemented a long acclimation period as this was the first time we had kept tree wētā from a humid far north location in captivity, and we wanted to ensure husbandry conditions were optimal. However, we shortened the acclimation period for wētā from the second collection period, as it was apparent that the wētā were adjusting quickly to captivity, as observed in other studies (Wehi & Hicks 2010; Griffin et al. 2011; Wehi et al. 2013). We recorded food consumption within 1–2 days of removal from the wild for all individuals, as well as frass production, and defensive behaviour displays when we changed enclosure materials (see below). Nonetheless, as a precaution, tree wētā from each acclimation period were evenly distributed across groups (see below).

Each tree wētā enclosure was lined with a damp paper towel, and included several small branches and pieces of native foliage (e.g. *Piper excelsum* or *Coprosma* spp. leaves). Enclosures were checked every 1–2 days during the acclimation period, and the paper towel was sprayed with water to keep it moist. A single c. 5 mm slice of carrot was also placed in each enclosure. Currently, cereal baits are more commonly used in pest control operations than carrot (e.g. Crowell et al. 2016), but we used carrot in the current study because it is a food item known to be readily eaten by tree wētā in captivity (Barrett 1991). Although tree wētā have been observed feeding on cereal baits (e.g. Bowie & Ross 2006), their level of palatability is not well understood. Accordingly, we considered that using carrot bait would provide a more robust test of the repellents. During the experiments, we made observations during enclosure checks to confirm that tree wētā were consuming the carrot baits. Consumption was observed for all subjects. Consumption of carrot was also observed during the day, consistent with other observations of diurnal tree wētā behaviour in captivity (Wehi et al. 2015). Every 3–4 days, the paper towel was replaced, frass

removed, and vegetation and carrot replaced. Air conditioning in the laboratory maintained room temperature at < 22 °C.

Tree wētā were deprived of food for 24 h before the start of each experiment. At the end of both experiments, all remaining tree wētā were returned to Matakahe/Limestone Island.

Experimental protocol

Experiment 1: repellent palatability

Forty-five female and 20 male adult tree wētā were randomly allocated into either one of three treatment groups or the control group. The composition of each group and the formulations of the three treatments and the control are listed in Table 1. The repellents used in the experiment were anthraquinone in the form of AVEX[®] (a commercially available product containing 50% 9, 10 anthraquinone, CAS number: 84-65-1, imported by Etec Crop Solutions Limited); pennyroyal oil (Lotus Oils Limited); and cinnamon oil (Connovation Ltd.). Previous trials of bird repellents have used d-pulegone, the major monoterpene constituent of the pennyroyal plant (Díaz-Maroto et al. 2007) as the mint scent (Mason 1990; Day et al. 2003; Orr-Walker et al. 2012; Clapperton et al. 2014). Commercially available pennyroyal essential oil is a potentially effective, lower cost alternative (Avery et al. 1996; Clapperton et al. 2012).

Repellent concentrations were similar to those shown to repel North Island robins and tomtits (*Petroica macrocephala toitoi*) but not affect pest mammal control efficacy when surface coated on carrot (Clapperton et al. 2014, 2015) (Table 1). Cinnamon concentrations were similar to those used in New Zealand Department of Conservation pest control operations during prefeeding periods (Crowell et al. 2016).

We sliced carrot into c. 5 mm discs, patting the discs with a paper towel to remove excess water. In order to calculate the correct quantity of solution to produce (with appropriate repellent concentrations), the carrot was divided into four equivalent amounts and weighed. We prepared enough carrot for one piece per tree wētā plus several extras to measure natural desiccation rates (see below).

Quantities of the repellents (see Table 1) were mixed with tap water to give a 5% wt/wt (solution/carrot weight) for each treatment group. For groups that included anthraquinone, we doubled the required amount of AVEX[®] as this only included 50% active ingredient. The solution for the control group was entirely water. The repellent and control solutions were then thoroughly mixed with the carrot slices. At the end of the mixing period (c. 30 sec), the carrot pieces were visibly wetted with an even surface coating of the solution. Mixing was done in different plastic containers for each treatment type and the control to prevent cross contamination. After mixing, there was noticeably little

Table 1. Concentrations of repellents (treatment groups) mixed with water to give a 5% wt/wt (solution/carrot weight) applied to carrot in a surface coating, and fed to tree wētā.

Group	Concentration (g [repellent]/kg [carrot])	n ^a
Anthraquinone	0.8	11F, 6M
Anthraquinone (AQ) and pennyroyal oil (PR)	0.8 (AQ) and 0.5 (PR)	11F, 5M
Cinnamon oil	0.15	11F, 6M
Water only	N/A ^b	12F, 3M

^an: the number of female (F) and male (M) tree wētā in each group.

^bThe solution in the control group (water only) was entirely water at a 5% wt/wt (water/carrot).

solution left in the container as most was applied to the carrot; residues were not quantified. Solutions and carrot used during each day of the experiment were prepared immediately before being given to the subjects.

The palatability of the different treatments and the control was tested on the individually housed tree wētā over 4 consecutive days. We weighed all carrot slices immediately before delivery. From day 2 of the experiment, we removed and recorded the weight of carrot from all enclosures in order to determine consumption rates. We replaced these pieces with freshly prepared, weighed carrot pieces coated with the appropriate treatment and control solutions. Additional carrot pieces (four per group) coated with solutions from each treatment and the control were placed in empty enclosures to measure natural desiccation rates, which were on average $13.9\% \pm 0.8$; consumption rates by tree wētā were adjusted accordingly.

Experiment 2: colour preference

To determine if tree wētā had a preference for green- or blue-dyed carrot, we conducted a choice test on 33 female and 13 male tree wētā over 2 consecutive days. We used a shorter experimental duration as previous research has shown that colour preferences in tree wētā can be detected relatively quickly (Fadzly & Burns 2010). Tree wētā used in experiment 2 had previously been used in experiment 1 in order to reduce the number of subjects that needed to be removed from the wild. However, it was possible that previous exposure to a repellent may have affected later consumption. In order to control for this, we summed blue and green carrot consumption on the first day of the experiment and conducted a one-way ANOVA to investigate whether differences existed between the groups that tree wētā were assigned to during experiment 1. Because significant differences were detected ($F_{(3, 59)} = 7.34, P < 0.001$), Tukey post-hoc tests were conducted and data from the cinnamon group were excluded from the final analysis (see below) as consumption rates were significantly lower than the control (water only) group. Experiment 2 began 4 days after the completion of experiment 1. Between experiments, tree wētā husbandry was the same as described above, and all the tree wētā ate unmodified carrot during this period.

For experiment 2, we prepared carrot pieces (c. 600 g for each colour treatment) as described above and combined these with a treatment blue or green dye solution for 60 min, by first mixing 2 g of dye powder into 200 mL of warm (c. 45 °C) tap water. A mixing period of 60 min was observed so there was sufficient time for the carrot to be dyed (see below for electromagnetic wavelengths). The non-toxic dyes used in the experiment were navy blue (Rit, Phoenix Brands) and Exacol green V200A (product number R2136; Cathay Industries). The main ingredients of both these dyes were sodium salts. The green dye was a similar product to that commonly used in pest control operations in New Zealand (e.g. Clapperton et al. 2015); however, because baits are not generally dyed blue in New Zealand pest operations, we used a previously untested product. After dyeing, the carrot was drained and patted dry to remove excess liquid. Dyed carrot was prepared immediately before being placed in wētā enclosures on each day of the experiment.

We visually compared dry green and blue carrots to an electromagnetic wavelength chart with a wavelength range of 390–760 nm. Using this method, we estimated that the blue and green carrot had wavelengths of c. 425 and 550 nm, respectively. Inspection showed that colour penetration into the carrot after the dying process was minimal (< 0.5 mm).

During the experiment, a single disc from each colour treatment was weighed and placed c. 60–100 mm apart inside each enclosure daily. The side on which a given colour treatment was placed was kept constant over the 2 days of the experiment so that subjects would associate a given area with a particular colour. Previous experiments with captive tree wētā did not find any place preferences during feeding choice tests (Dewhurst 2012), but the enclosure was also small enough that wētā were able to visually assess both carrot baits simultaneously. On the second morning of the experiment all carrot discs were removed and weighed, and the protocol was then repeated with fresh carrot slices. The carrot consumption measurements were adjusted for desiccation as in experiment 1.

Data analysis

Experiment 1: repellent palatability

We used a general linear mixed-design model with the sphericity assumed correction factor (Mauchly's test of sphericity: $P > 0.05$) to compare the palatability of the treatments and the control during the experimental period. This analysis allows for unbalanced group sizes and, in addition, controls for within-subject variation (such as potential size differences, and thus consumption, between male and female wētā) because it incorporates a repeated-measures component into the model (Krueger & Tian 2004). A single tree wētā died in both the control group and the cinnamon group during experiment 1, and their data were removed from the analysis.

Data were normalised using a square root transformation. We conducted simple effects tests to examine differences among means for the control and treatment groups over the duration of the experiment, because a significant interaction effect ($P = 0.001$) was detected (Tabachnick & Fidell 1996). Data are presented as back-transformed means (\pm SE).

Experiment 2: colour preferences

Colour preference was determined by conducting a paired t -test for each day of the experiment. No tree wētā died during this experiment.

All data were analysed using IBM SPSS Statistics for Windows v22.0 (Armonk).

Results

Experiment 1: repellent palatability

Tree wētā always ate at least some carrot on each day of the experiment (range for all groups = 0.13–4.44 g). Carrot consumption differed significantly over the 4 days of the experiment ($F_{(3, 183)} = 12.07$, $P < 0.001$) and between groups ($F_{(3, 61)} = 8.12$, $P < 0.001$). A significant interaction effect was detected between group and time ($F_{(9, 183)} = 3.25$, $P = 0.001$), indicating that the changes we observed in carrot consumption over time were not equivalent across the control and treatment groups (Figure 1). The simple effects analysis indicated that there were no significant differences among groups in the amount of carrot consumed in the first 2 days of the experiment; however, from the third day, significantly less carrot was consumed in the treatment groups compared with the control group (Figure 1). There were no significant differences among the

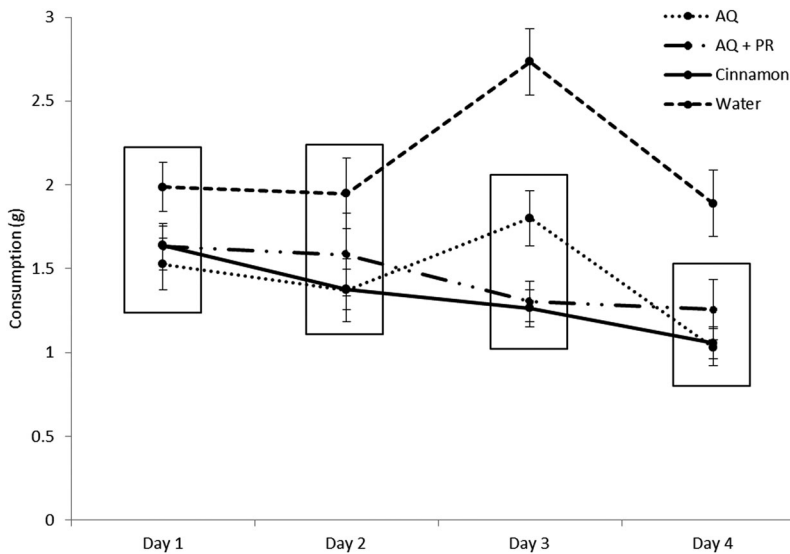


Figure 1. Mean (\pm SE) daily consumption of carrot surface-coated with different repellent formulations (AQ: anthraquinone; AQ + PR: anthraquinone and pennyroyal oil; Cinnamon: cinnamon oil) or water (control) over 4 consecutive days. Data points enclosed within a box indicates no significant difference between groups on that given day. See Table 1 for treatment and control specifications.

treatment groups on any day of the experiment (Figure 1). In addition, the simple effects analysis also indicated that consumption was generally lower on day 4 of the experiment cf. day 1 for the treatment groups (although, the AVEX[®] group showed a marked increase in consumption on day 3; Figure 1, Table 2). For the control group, consumption of carrot was not significantly different on day 4 cf. day 1; although consumption of carrot on day 3 was significantly higher than all other days ($P < 0.05$) (Figure 1, Table 2).

Experiment 2: colour preferences

The mean consumption of blue-dyed carrot was lower than that of green-dyed carrot across both days of this experiment (Figure 2); however, differences were not significant (day 1, $P = 0.057$; day 2, $P = 0.145$). In addition, tree wētā always consumed some of both types of carrot on each day of the experiment (range for all groups = 0.16–6.77 g).

Table 2. Results of a simple effects analysis which compared the within-treatment group consumption rates of carrot surface-coated with repellent formulations or water over the four days of the repellent palatability experiment.

Group	Day			
	1	2	3	4
Anthraquinone	A	AB	A	B
Anthraquinone and pennyroyal oil	A	AB	AB	B
Cinnamon oil	A	AB	AB	B
Water only	A	A	B	A

Days with the same letter indicate that no significant differences ($P > 0.05$) exist between those days within that given group. See Table 1 for the repellent concentrations. See Figure 1 for consumption rates across groups.

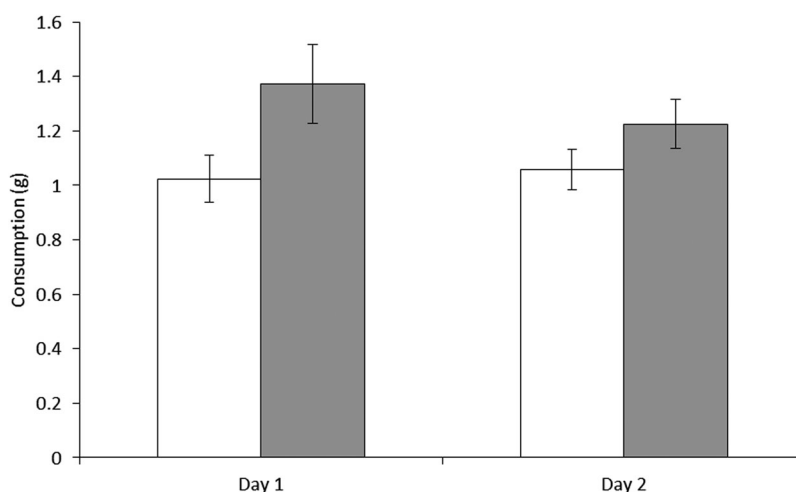


Figure 2. Mean (\pm SE) consumption of blue (open columns) and green (filled columns) dyed carrot offered to tree wētā ($n = 46$) in a choice experiment over 2 consecutive days.

Discussion

The results show that the addition of either anthraquinone, or anthraquinone and pennyroyal oil, had similar effects to cinnamon on carrot consumption by tree wētā, and that all the repellent treatments tested reduced the consumption of carrot by tree wētā compared with the control group from the third day of the experiment. This is encouraging, as it suggests that the risk of secondary poisoning to insectivorous birds is not likely to increase with these additions to bait in mammal pest operations.

Our results contrast with studies on birds, where baits coated with formulations containing anthraquinone and/or mint-scented repellent are generally consumed at lower rates than baits treated with cinnamon (Day et al. 2003; Clapperton et al. 2014). Consumption rates by North Island robins and house sparrows of food items coated only with cinnamon generally increased over time compared with food items coated with anthraquinone or anthraquinone and mint-scented oil (Clapperton et al. 2012, 2014). There may be a higher net benefit, therefore, of using anthraquinone and/or pennyroyal oil based repellents instead of cinnamon.

Tree wētā are covered with hair sensilla, some of which probably function as chemoreceptors to enable olfactory and taste perception (Field 2001). It seems likely that tree wētā were therefore able to differentiate between baits with repellents and control baits. The ability of anthraquinone to induce an illness effect on tree wētā has not been tested, but our results suggest that it does not have an effect greater than those produced through primary repellent mechanisms.

The general decline in repellent treated carrot consumption during the period of the experiment suggests that the efficacy of all repellents increased over time. If tree wētā had been simply responding to a novel odour/taste, then we would have expected to see an increase in consumption over time. This finding emphasises the importance of prefeeding during pest control operations as subjects appear to need a period of time to sample and subsequently avoid repellent-coated baits. There was, however, an increased

consumption of carrot in the anthraquinone treatment and control group on day 3 for reasons that are not clear. Nonetheless, differences between repellent treatments were not detected on any given day of the experiment.

The colour choice test in experiment 2 showed differing rates of consumption by colour in the two time periods and although tree wētā ate more green-dyed carrot than blue on both days, significant differences were not detected (see above) suggesting a high degree of variability between subjects. Few studies have investigated the photoreceptor sensitivities of Orthoptera; however, Wellington tree wētā (*Hemideina crassidens*) can distinguish between naturally coloured *Coprosma acerosa* berries (white streaked with blue) and berries dyed either red or blue (Fadzly & Burns 2010). In that study, Wellington tree wētā preferred blue-dyed berries over red. We did not include red-dyed carrot in our tests as previous studies have found that some birds have a preference for this colour (Hartley et al. 1999, 2000) making it an inappropriate colour for baits to be dyed in pest control operations. Furthermore, legislative changes would be required before toxic baits could be dyed red.

Our findings indicate that colour may not be a strong deterrent to these wētā; however, we suggest that further research is needed to explore colour preferences between differently coloured food items in tree wētā. Although our results did not conclusively determine if tree wētā will avoid blue- compared with green-dyed carrot, it was nevertheless encouraging that tree wētā did not have a marked preference for blue-dyed carrot. It suggests a net benefit may occur if managers dye toxic baits blue rather than green in pest control operations; if at risk bird species find blue baits less preferable than green baits, the non-target by-kill may reduce further.

In summary, previous research has shown that surface-coating baits with anthraquinone and/or mint-scented repellents, and dyeing them blue, reduces by-kill of some birds while not compromising pest mammal consumption at optimal concentrations (Clapperton et al. 2014, 2015). Other trials have shown that although cereal baits containing anthraquinone within the bait matrix (i.e. not surface-coated) were effective at reducing both possum and rat tracking rates, they were less palatable to rats than baits without this bird repellent (Cowan et al. 2015; Crowell et al. 2016). The results of the current study show that, at the tested concentrations, surface-coated anthraquinone, or anthraquinone and pennyroyal oil has no effect on the consumption of treated carrot by tree wētā compared with cinnamon, the bait additive currently used in New Zealand. While the acceptance of pennyroyal oil alone to tree wētā was not tested in this study, the reduced acceptance of the combination repellent compared with water indicates that this primary bird repellent is not acceptable to tree wētā. Furthermore, Clapperton et al. (2015) show that the addition of cinnamon to baits coated with anthraquinone and d-pulegone were acceptable to both Norway rats (*Rattus norvegicus*) and possums, which indicates that using alternative repellents in conjunction with cinnamon would not compromise the toxin masking effect of cinnamon. Accordingly, we suggest that anthraquinone, and/or pennyroyal oil based repellents be considered in possum control operations as a means of reducing non-target by-kill and not increasing the risk of secondary poisoning to insectivorous species.

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