Australian Journal of
Crop Science
AJCS

AJCS 6(6):1110-1115 (2012) ISSN:1835-2707

# Effects of cultivar on rodent damage in Australian macadamia orchards

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## Abstract

The Black rat (*Rattus rattus)*, a serious pest of Australian macadamia orchards has been estimated to cause up to 30% crop damage in Australian orchards. In recent years an increase in the number of commercially available cultivars has seen a change in orchard characteristics in Australia, primarily effecting fruiting and flowering patterns. This has been suggested to affect the feeding behaviour of rodents and in turn altered the damage process. In this study we compare the extent of damage in orchards containing one of three prevalent cultivars (A4/A16, A268 and HAES 344/741) and investigate the influence of these cultivars, particularly their distinctive fruiting traits, on rodent damage within the orchard. We demonstrate that the temporal pattern and extent of damage differs between cultivar types. Newer Australian macadamia cultivars tested in this study were found to be far more susceptible to rodent damage than the older Hawaiian developed cultivars, most likely due to an extended fruiting period and thinner shells. This has resulted in a more sustained period of crop damage than the patterns of crop damage observed in previous Australian studies. Crop damage caused by *R. rattus* is significantly higher in orchards that maintain high levels of canopy resources through the fruiting season and we postulate that this is due to the extended fruiting periods of the new cultivars used. The maintenance of canopy resource load in turn corresponds to high crop damage, in this study resulting in crop losses of up to 25%.

**Keywords**: *Rattus rattus*; crop damage; macadamia; cultivar; rodent.

## Introduction

The Black Rat (*Rattus rattus*) is a significant pest in macadamia orchards globally (Tobin, 1992; White et al., 1997). This species causes significant crop damage resulting in major economic losses to orchards throughout the primary macadamia production regions of the world such as Hawaii and Australia (Tobin, 1992; White et al., 1998). Crop damage of 5-10% of the annual macadamia production has been recorded in Hawaiian systems, whilst estimates as high as 30% have been suggested in Australian orchards (Horskins et al., 1998). Rodents persisting in macadamia orchards typically feed on the macadamia nut once it has reached full maturation while on the tree thus rendering the eaten macadamia nut as unfit for consumer use. However, *Rattus rattus* also has the ability to feed on macadamia nuts during the entire nut maturation process (Tobin, 1992). As such crop damage caused by *R. rattus* in macadamia orchards has seen it recognised as one of the main pest species of the macadamia industry (White et al., 1997). Studies conducted in Hawaii and Australia have demonstrated that macadamia plantations in both these countries provide ideal habitat conditions for rodent populations to be maintained at relatively high densities (Elmouttie et al., 2009; Tobin et al., 1994). Rodent foraging behaviours differed between Hawaiian orchards and Australian orchards however, resulting in two distinct patterns of crop damage (Tobin et al., 1994; White et al., 1997). Within Hawaiian orchards damage occurred throughout the year and rodents fed primarily on macadamia nuts, (Tobin et al., 1994) whilst in Australia damage was more seasonal with rodents relying on alternate food sources during periods of scarce nut availability (Horskins et al., 1998; White et al., 1997). Alternate food sources are utilised during the warmer months in Australia when orchards are without nut. These alternate food sources are generally located in habitats adjacent to orchard blocks. Tobin et al (1994) suggested that rodent populations in Hawaiian orchards were able to be sustained throughout the year due to the relatively constant supply of resources in Hawaiian orchards, resulting in sustained crop damage throughout orchard blocks. The relatively consistent production of macadamia resources observed was found to be a result of a prolonged fruiting and flowering season in Hawaiian orchards (Tobin et al., 1994). Analysis of stomach contents of captured rodents within the orchard reinforced this idea, with an average of 85% of the rodent diet made up of macadamia kernel throughout the year (Tobin et al., 1994). This demonstrated that rodents were primarily reliant on macadamia nuts rather than alternative food sources. In contrast, early studies showed that damage patterns in Australian orchards were more seasonal (White et al., 1997). Horskins et al (1998) suggested this was a response to nut availability within these orchards. Unlike Hawaiian orchards, the Australian orchards studied undergo a distinct fruiting and flowering season and these distinct seasons typically lead to periods of low availability of mature nuts. Consequently, rodents persisted within complex non-crop habitats adjacent to orchards that offered a variety of alternative food resources during periods of low nut availability. Manipulation of the adjacent habitat was an effective management strategy with a reduction in damage of up to 65%, (White et al., 1998). This type of control strategy was aimed at removing the food resources and potential harbour sites from the habitats immediately adjacent to orchard blocks, thus reducing the potential for rodent populations to persist around orchard blocks. Previous research into the damage pattern occurring in Australian orchards was generally based on older cultivars which were first developed in Hawaii, in particularly cv. HAES 246 and HAES 508. Macadamia is a high value crop however, and the production region in Australia has expanded considerably since these studies were conducted. While farming practices are generally consistent among Australian orchards, newer orchards in the warmer, more northern regions of central Queensland have planted a variety of different cultivars. These cultivars, developed specifically for Australian conditions, have a number of different characteristics to the original cultivars planted in Australia including fruiting and nut abscission periods as well as physical nut properties such as size and shell thickness (Nagao et al., 1992; Stephenson et al., 1986a). There has been growing concern within the macadamia industry that management strategies developed for Australian farming systems are less effective in newer growing regions although the reasons for this are as yet unknown. The aims of the current study are therefore to establish damage levels within newer production regions as well as to investigate any influence that cultivar type may be having on rodent behaviours and subsequent damage levels and patterns. Understanding any influence of cultivar susceptibility to rodent damage is important knowledge to allow farmers to plan for effective management.

## Results

### *Damage*

Overall mean rodent damage (± S.E.) was highest in cv. A4/A16 with 19.7 ± 1.4%, followed by cv. A268 (8.44 ± 1.1%), and cv. 344/741 (5.6 ± 0.8%). An overall significant difference in damage was observed among cultivars ($\chi^2$ = 74.82, df = 2, $\rho < 0.001$) as well as among sampling periods ($\chi^2$ = 89.22, df = 4, $\rho < 0.001$) (Figure 2). Damage within cv. A4/A16 was significantly higher than either cv. A268 ($\rho < 0.001$) or cv. 344/741 ($\rho < 0.001$). No significant difference was identified between cv. A268 and cv. 344/741 ($\rho = 1.000$). Further pairwise comparisons highlighted significant differences in rodent damage between March and May ($\rho = 0.010$), July ($\rho = 0.005$), September ($\rho < 0.001$) and November ($\rho < 0.001$). No other significant differences in rodent damage were observed among sampling periods.

### *Floristics*

Overall mean rank of mature nut availability varied significantly among cultivars ($\chi^2$ = 163.08, df = 2, $\rho < 0.001$) with cv. A4/A16 providing the highest levels of mature nut (2.36) followed by cv. A268 (1.92) and cv. 344/741 (1.72). A significant difference in mature nut availability was also noticed among sampling periods ($\chi^2$ = 797.07, df = 4, $\rho < 0.001$) (Figure 3). According to mean ranks, March held the highest quantities of mature nut (4.90) followed by May (3.36), July (2.74), November (2.11) and lastly September (1.89) (Figure 3). There was no difference among abundance of mature nut within the orchard canopy during the March sampling period. However as the season progressed, mean mature nut abundance was consistently higher for cv. A4/A16, suggesting that this cultivar retains mature nuts longer than both cv. A268 and cv. 344/741. As expected, immature nut availability remained low and relatively constant among cultivars across sampling periods from March through till September (Figure 4). In November, cv. A268 produced the highest abundance of immature nuts followed by cv. A4/A16 and cv. 344/741 ($\chi^2$=6.27, df =2, $\rho$=0.043). Similarly to immature nuts, flowers were plentiful for one sampling period only, September. During all other sampling periods, only two scores of 3 were allocated in July and November, either side of peak flowering.

### *Shell thickness*

Macadamia shell thickness varied significantly among cultivars ($F$ =111.15, df =2, 267, $\rho < 0.001$). Mean shell thickness for cv. A4/A16 (±S.E.) was (1.86 ± 0.02mm) followed by cv. 344/741 (2.05 ± 0.04mm) with cv. A268 (2.69 ± 0.04mm) producing the thickest shelled macadamias.

## Discussion

In this study we have demonstrated for the first time the susceptibility of a particular cultivar to rodent damage within a macadamia orchard. Cv. A4/A16 showed significantly higher overall levels of damage than other cultivars, and consistent with this, damage for this cultivar was higher at every sampling period through the year, reaching almost 30% in November. The impact of cultivar on affecting crop damage caused by *R. rattus* in macadamia orchards has until now been overlooked, mainly because of the limited range of cultivars traditionally used in macadamia plantations. For example, many of the studies into Australian orchards were based solely on the predominant cultivars used at the time, including mainly cultivars HAES 246 and HAES 508 (Elmouttie and Wilson, 2005; Horskins et al., 1998; White et al., 1997). Cultivars HAES 246 and HAES 508 were sufficiently similar that in a series of studies they were not distinguished as different experimental units (Horskins et al., 1998; White et al., 1997). With the growth in the industry in Australia in the last 15-20 years and the expansion of plantations into different geographic regions, numerous different cultivars have been developed for various reasons such as increased yields, varied growth forms, increased tolerance to climatic and other environmental conditions, and improved nut quality and oil content to meet market requirements (Stephenson et al., 1986a; Stephenson et al., 1986b). As we have shown here however, different cultivars may exhibit different levels of susceptibility to rodent damage, potentially leading to high levels of damage in orchard compartments in which these cultivars predominate. While crop damage was present for all cultivars at all sampling periods, the level of damage was highly variable throughout the year. For cv. A268 and cv. 344/741, damage was at low to moderate levels throughout most of the year, rising substantially in November. Cv. A4/A16 also showed a marked increase during the November sampling period. This spike in damage levels across cultivars coincided with the availability of immature nuts in November and likely represents the beginning of the following season. Despite this similarity, cv. A4/A16 showed a different pattern of crop damage to other cultivars throughout the year. Contrary to the low to moderate damage levels observed in cv. A268 and cv. 344/741 from March through to September, cultivar A4/A16 experienced high levels of damage in March decreasing slowly throughout the season until a sharp rise to the November maximum. These differences in damage patterns throughout the year vary to the pattern of nut availability between cultivars. In March, mature nut availability was high and there was no difference in availability among different cultivars. As the season progressed, the availability of mature nuts of all cultivar types decreased. In all sampling periods subsequent to March the availability of mature A4/A16 nuts was significantly higher than for other cultivars, however. Taken together, these results show that there was no difference in productivity between cultivars but that cv. A4/16 retained mature nuts longer in the canopy. This is perhaps unsurprising given that one of the known characteristics of cv. A4/A16 is to retain higher quantities of mature nut for an extended period into the season. The level of nut retention could be further exacerbated by a condition known as ‘sticktight’ (Trueman, 2003) which results in adult macadamia trees retaining large quantities of mature nut late into the season and into the early part of the following season. It is not known why some macadamia trees display ‘sticktight’ characteristics and others do not, however it may be related to various factors influencing the development of the host tree including moisture stress, temperature and hormone imbalances (Akinsanmi et al., 2012). Cv. A4/A16 was developed to drop nut later in the season however it also suffers from the ‘sticktight’ condition, further extending the period of high nut availability. While the availability of mature and immature nuts shown in this study support known characteristics of the different cultivars, they do suggest a mechanism by which different cultivars are subject to different levels of damage. Elmouttie and Wilson (2005) demonstrated that in crop damage primarily occurred within the canopy component of the orchard system, and that when damaged, nuts tended to fall to the orchard floor. For cultivars in which abscission occurs early in the season, nuts will only be available to rodents in the canopy for a limited time and therefore high levels of damage throughout the year are unlikely. This explains damage patterns for cv. 344/741 and cv. A268 throughout the year, with damage being highest when mature and immature nuts were most abundant. Of note is the fact that cv.344/741, which was developed in Hawaii and is known to be the earliest abscising experimental cultivar, displays similar characteristics to the cultivars studied in early Australian orchards (Elmouttie and Wilson, 2005). These characteristics include seasonal nut production with subsequent crop damage highest early in the season followed by a period of limited nut production and therefore minimal crop damage (Elmouttie et al., 2009). It is therefore not surprising that of the three experimental cultivars (344/741, A4/A16 and A268) cv. 344/741 is the most similar to those examined in early Australian studies in its tendency to display distinct cyclic periods of high nut production followed by periods of lower production later in the cropping season (Elmouttie and Wilson, 2005; Horskins et al., 1998; White et al., 1997). In contrast, the availability of mature nuts at significantly higher levels in the canopy throughout orchard blocks containing cv. A4/A16 would allow this resource to be available to rodents for a longer period through the season, in turn allowing for more damage as the season progressed. It is possible that this pattern could also be carrying through to the following season, with mature nut remaining available up until the onset of the following season’s crop. An extended study spanning two or more cropping seasons would be required to test this hypothesis.

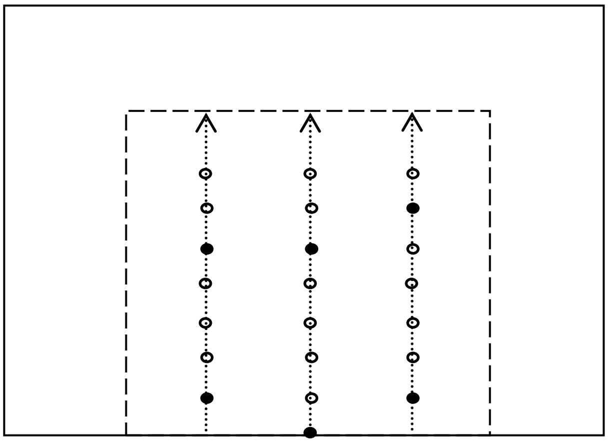

**Fig 1.** Diagrammatical representation of the layout of study sites within a single orchard block used in the experiment. Each orchard block is surrounded by roads, headlands or windbreaks. Circles represent macadamia trees and filled circles represent sampling positions, located at every fourth tree on each transect. There are 10 sampling points on each transect. Transect, sampling position and experimental areas are not to scale.

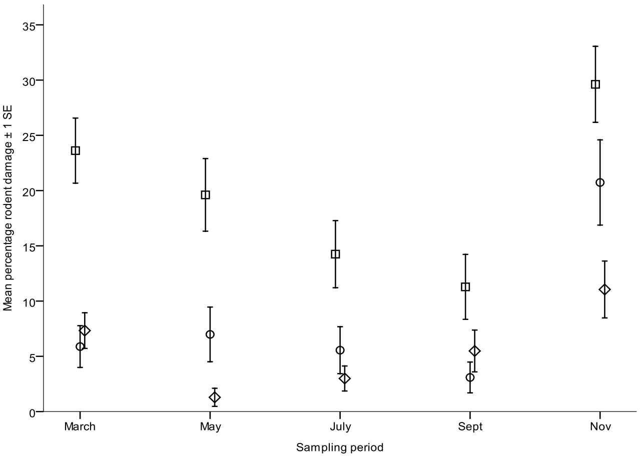

**Fig 2.** Mean percent damage levels between cultivars for each sampling period (cultivar A4/A16 -□, cultivar A268-○ and cultivar 344/741- ◇).

In addition to a prolonged availability of resources, the structural characteristics of macadamia nuts may also influence the level of rodent damage sustained by the A4/A16 cultivar. In mature nuts, rodents access the kernel of the fruit by gnawing through the hard outer shell of the nut. As shown in the results, the outer shells of nuts belonging to cv. A4/A16 are much thinner compared to the other experimental cultivars. Given this, it is possible that nuts belonging to cv. A4/A16 may be more susceptible to rodent damage than either cv. 344/741 or cv.A268. Unlike previous studies (Elmouttie and Wilson, 2005; Horskins et al., 1998; White et al., 1997) which identified the temporal stability of adjacent non-crop habitats as the major driving factor behind the pattern of crop damage caused by *R. rattus*, this study has revealed that rodent populations appear to be responding to the extended availability of resources within the orchard system that has resulted from the introduction of a range of new cultivars. The results of this study suggest that temporal rodent foraging patterns and the subsequent crop damage can be viewed as direct responses to the presence and availability of resources within macadamia orchards. Although this study did not gather information regarding rodent abundances in the study region, previous research has demonstrated that abundance levels tend to reach a maximum during late summer and early autumn (Ramsey and Wilson, 2000). In the context of the current study, this would suggest that rodents would be reaching maximum abundance during the November and March sampling periods, and this is precisely when maximum damage was found to occur. The timing of peak rodent abundances however will vary among different habitats depending on the pattern of resource availability occurring within that habitat. Future studies should therefore be aimed at identifying any seasonal patterns occurring within macadamia orchards in rodent abundances as well as rodent damage and nut resource availability.

## Material and methods

### *Study Sites*

The study was conducted in the Bundaberg region, south east Queensland, Australia. This region was selected as being representative of a more recently established growing region than that of previous Australian studies. The region generally experiences tropical to subtropical conditions with plentiful summer rainfall and is now recognised internationally as one of the most productive macadamia growing regions in Australia (Boyd and Gardiner, 2005). Three geographically independent macadamia farms were used in the study. Farm 1 situated just south of the township of Bundaberg (24°57'7.71"S, 152°21'43.60"E), whilst farms 2 and 3 were situated to the north of Bundaberg, at (24°47'18.42"S, 152°16'7.34"E), and (24°50'35.19"S, 152°17'23.78"E) respectively. Macadamia farms in this region are typically composed of several orchard blocks. Orchard blocks are usually 3-5ha in size and, unlike Hawaiian orchards, are generally planted entirely with a single cultivar or two cultivars with similar characteristics (Wallace et al., 1996). Orchard blocks are typically separated by roads, windbreaks or headlands all of which are maintained in order to minimise rodent infestations and allow for efficient farm machinery use. In the current study, orchard blocks were chosen from the three farms and a single study site established within each orchard block (Figure 1). Study sites were located within orchard blocks which were positioned adjacent to highly modified, stable habitats as defined by White et al. (1997). These types of habitats are regularly mowed and maintained free of debris that could provide refuge or food resources for rodents. Sites were selected on the basis of orchard block similarities including cropping practices, planting density (8 x 4m), orchard age (15-20 year old plants), and orchard maintenance so that cultivar was the only site based variable.

General farming practices and orchard maintenance activities continued at all sites during the study. Rodent control however ceased six months prior to experimentation and for the duration of the study in all sites, resulting in stabilised rodent populations for the entirety of the study (Tobin et al., 1994). Other studies have also demonstrated a quick recovery times for rodent populations in tropical agricultural settings following the application of rodenticide controls (Lacher and Goldstein, 1997).

### *Sampling Design*

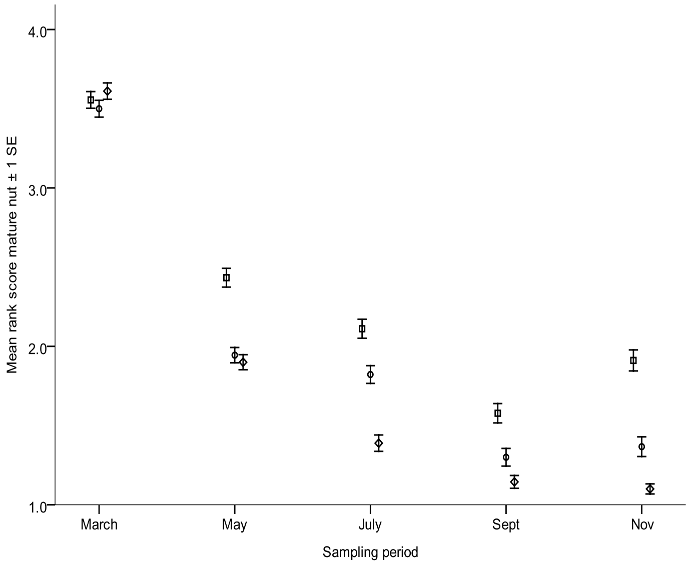

**Fig 3.** Mean mature nut availability for each sampling period across each cultivar assessed on a 4 point Likert scale (cultivar A4/A16 -□, cultivar A268-○ and cultivar 344/741-◇).

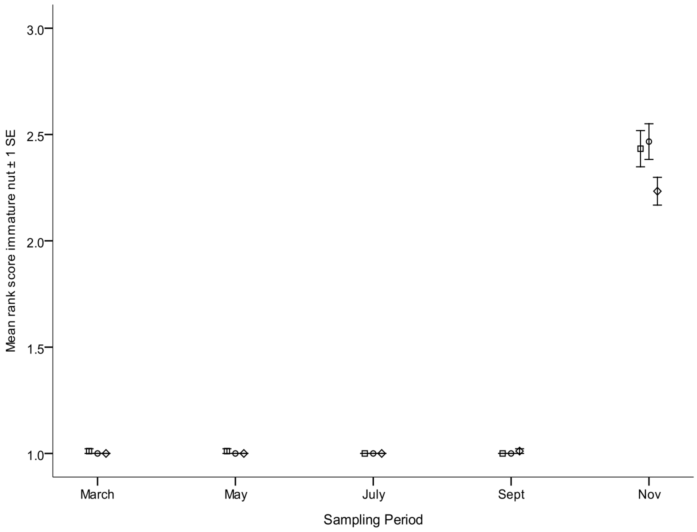

**Fig 4.** Mean immature nut availability for each sampling period across each cultivar assessed on a 4 point Likert scale (cultivar A4/A16 -□, cultivar A268-○ and cultivar 344/741-◇).

Three replicate sites were chosen for each of the three experimental cultivars (cv. A4/A16, cv. 344/741 or cv. A268), resulting in nine independent study sites. Each study site was approximately 0.5ha in size and was planted on an 8x4m planting density which allowed for a consistent sampling grid to be established. This sampling grid was approximately 32m wide, 150m long and included three orchard rows (Figure 1). Study sites were separated by a distance of at least 1.5km by a range of habitats including other orchard blocks, roads and headlands such that rodent populations inhabiting study sites could be considered independent. Sampling points were assigned at every fourth tree along an orchard row, resulting in 3 rows each with 10 sampling points to give 30 sampling points for each study site. Rodent damage and nut abundance were recorded at the same sampling point during each bimonthly sampling period.

Five sampling periods were conducted from March 1st 2010 to November 1st 2010, encompassing a complete *Macadamia integrifolia* fruiting season (Nagao et al., 1992). Harvest season generally extends from early April through to September in the Bundaberg region. Sampling was carried out in regular bimonthly periods and each sampling period lasted 7 consecutive days. During each sampling period, measures of rodent damage and nut abundance were recorded at all sites. When yields were highest throughout the season, a sample of mature nuts from each study site were collected and shell thickness data recorded.

### *Cultivars*

The three experimental cultivars chosen were cv. A268, cv. A4/A16 and cv. 344/741. Each of the three farms used in the study contained representative orchard blocks planted with the study cultivars. These cultivars were selected based on their high planting frequency in the study region. Cv. A4 and A16 are generally planted together within an orchard block and were considered as a single cultivar due to their similarities in nut production, abundance and abscission rates. Similarly, cultivars 344 and 741 were also considered a single cultivar for the purpose of the study. Study sites were planted with one of the three study cultivars only.

### *Damage*

Damage estimates were conducted once during each sampling period, at all 30 sampling points in each of the nine study sites. Single point estimates were calculated using a $1m^2$ quadrat, placing it on the orchard floor at each sampling point and recording the proportion of damaged nuts present. In order to maintain consistency, estimates were conducted at the same location during each sampling period. The total number of mature nuts within the $1m^2$ quadrat, both damaged and undamaged, were recorded and a proportion of damaged nuts was calculated for each sampling point at all nine experimental blocks. Nuts were not removed after each sampling period; however harvesting occurred directly after each experimental sampling period. Nuts counted within a sampling period therefore represented approximately 2 months of nut fall data.

### *Resource Assessment*

Relative nut availability was recorded at the same 30 sampling points at each site at which damage estimates were made. This was done using floristic surveys and estimating the relative abundance of immature nuts and mature nuts within the canopy of the orchard above each sampling point. Measures of nut availability were achieved by assigning each sampling point with an abundance score for each developmental stage (flowers, immature nuts and mature nuts). Abundance scores were based on a four point Likert scale ranging from 1 to 4, with 1 representing none visible and 4 representing peak abundance (1=none, 2=few, 3=several, 4=many). Scores were assigned to each sampling point at all nine sites once during each of the five sampling periods. Nut shell thickness was also assessed for each cultivar. Thirty samples from each site were collected when nuts were most abundant. Mature nuts that had already abscised were used for this comparison. Shell thickness was determined by breaking open the shells, removing the kernel and measuring the width of the shell at a constant position halfway from the abscission point and the seed micropyle. Shell thickness data from three replicate sites were combined to achieve a mean shell thickness for each experimental cultivar.

### *Data Analysis*

The experimental design requires a repeated measures analysis of variance with cultivar as the fixed effect and sampling period and site as the random effects. Damage estimates however were not normally distributed, even after transformation and were therefore compared among cultivar as well as sampling period using the Friedman test for related samples. Pairwise comparisons were used to determine where significant differences occurred among cultivars and sampling periods. Resource availability was ranked at all 30 positions in each site and compared among both cultivars and sampling periods using the Friedman test in association with the post hoc Wilcoxon Signed rank test. Mean shell thickness was compared between cultivars using an analysis of variance.

## Conclusions

The range of cultivars now available to Australian growers has transformed the Australian macadamia production landscape such that the process of crop damage caused by rodents no longer conforms to that demonstrated in previous Australian research. This study has established that damage is no longer directly related to the condition of adjacent non crop habitats but rather that the process is influenced by cultivar type. Clearly this raises issues for rodent control within Australian macadamia orchards. A number of strategies have been suggested to help minimise damage to nuts in Hawaiian macadamia orchards, where crop damage tends to occur year round. These strategies may be of assistance to Australian growers given the similarities in the crop damage process. They have included early season harvest and processing, application of chemical treatments to promote nut abscission and condense the harvesting period, as well as using tree shakers to minimize sticktight density in large-scale productions. Growers should carefully consider the cultivars chosen for the establishment of new orchards and in particular, aim to reduce the period of time for which mature nut is available to rodents within the orchard canopy.
Given that current rodent management strategies are based on previously observed relationships between crop damage and adjacent non crop habitats, further investigation will be required to determine effective control strategies in newer Australian orchards.

## Acknowledgments

The authors are grateful to both Hinkler Farms and Hancock Farms for their assistance and support throughout the year**.**

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