# Agrolandscape structure and damage caused by red squirrels to cocoa pods

Estructura del agropaisaje y daño causado por ardillas rojas a mazorcas de cacao

Instrutura da agropaisagem y dano causado por esquilos vermelhos às vagens de cacau

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## Abstract

Cocoa is a strategic resource because it hosts high biodiversity, and it is a reliable source of foreign exchange. In Venezuela, fungi and red squirrels mainly affect its productivity. The objective was to evaluate the influence of the cocoa crop structure on the level of damage caused by red squirrels on the pods. The vegetation structure was defined in 15 farms assessing the cocoa tree biomass, the magnitude of shade tree cover, number of associated crops, presence of alternative fruit trees, and the type of ecological succession present in the surrounding. The % of damage was calculated, and nonparametric tests were used to process data. The damage was higher in crops with less shade cover, a more abundant number of associated crops, and alternative fruit trees. Squirrels used the cocoa pods opportunistically but preferred other fruits. It is concluded that pods can be a complementary food for squirrels to the extent that the cocoa plantation is more complex and has a connection with the forest. Shade cover did not directly influenced squirrels, but it is crucial for bird predators which are more sensitive to disturbance.

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## Resumen

El cacao es un recurso estratégico porque aloja una biodiversidad alta y es una fuente confiable de divisas. En Venezuela su productividad se ve afectada principalmente por hongos y ardillas rojas. El objetivo fue evaluar la influencia de la estructura del cultivo de cacao sobre el nivel de daño causado por ardillas a las mazorcas. La estructura de la vegetación se definió en 15 fincas midiendo la biomasa del árbol de cacao, la magnitud de la cobertura de los árboles de sombra, el número de cultivos asociados, la presencia de árboles frutales alternativos y el tipo de sucesión ecológica presente en el entorno. Se calculó el % de daño y se usaron pruebas no paramétricas para procesar los datos. El daño fue mayor en cultivos con menor cobertura de sombra, mayor número de cultivos asociados y de frutales alternativos. Las ardillas usaron las bayas de cacao de manera oportunista, pero prefirieron otros frutos. Las mazorcas pueden constituir alimentos complementarios para las ardillas en la medida en que la plantación de cacao es más compleja y tiene una conexión con el bosque. La cobertura de sombra no influyó directamente en las ardillas, pero puede ser crucial para las aves depredadoras que son más sensibles a las perturbaciones.


**Palabras clave**: biomasa, conectividad, *Notosciurus granatensis*, Mérida, *Theobroma cacao*, sombra, Venezuela


## Resumo

O cacau é um recurso estratégico porque abriga alta biodiversidade e é uma fonte confiável de divisas. En Venezuela su productividad se ve afectada principalmente por hongos y squilos. O objetivo é avaliar a influência da estrutura do cultivo de cacau no nível do dano causado por esquilos às mazorcas. A estrutura da vegetação é definida em 15 fazendas midiendo a biomasa do árbol de cacau, a magnitude da cobertura das árboles de sombra, o número de cultivos associados, a presença de árboles frutas alternativas e o tipo de sucessão ecológica presente no entorno. Foi calculado el % de daño e foram utilizadas testes não paramétricas para processar os dados. El daño fue mayor en cultivos com menor cobertura de sombra, maior número de cultivos associados e de frutas alternativas. Os squilos ussaram as bagas de cacau de manera oportunista, pero prefirieron outros frutos. Conclui-se que as vainas podem ser o alimento complementar para los squilos na medida em que a plantação de cacau é mais completa e tem uma conexão com o bosque. A cobertura de sombra não influenciou diretamente nos squilos, mas é crucial para as aves depredadoras que são mais sensíveis às perturbações.


**Palavras-chave**: biomassa, conectividade, Mérida, *Notosciurus granatensis,* sombra, *Theobroma cacao,* Venezuela

## Introduction

The vegetation structure in the agrolandscape refers to the composition of species and the spatial setup of plants, both in the horizontal and vertical planes (Gidoin *et al*., 2015). Plant species have different growth forms (Verbeeck *et al*., 2019), and a greater diversity of them implies increased complexity (Gough, 2020). The vegetation structure and the biodiversity are linked, and they control critical ecosystem's attributes (Walter *et al*., 2021).

The agrolandscape attributes influence the abundance, density, and magnitude of the damage caused by vertebrates (Holloway *et al*., 2012; Daghela *et al*., 2013; Garcés-Restrepo and Saavedra-Rodríguez, 2013). On the other hand, since the agrolandscape can be shaped by agricultural management, this management might affect the damage caused by pests and diseases, thus understanding how these animals respond to crop management becomes essential (Canavelli *et al*., 2014; Milosavljevic *et al*., 2016).

Although few works relate the vegetation structure with the level of damage caused by small arboreal rodents, this parameter seems to determine the abundance of many species (Craig and Gese, 2013). In the specific case of squirrels, a higher number of shade trees contribute to forming a greater structural complexity that favors colonization and permanence (Wilson *et al.,* 2008). In the same way, the tree branches facilitate their mobility (Flaherty *et al*., 2012; Holloway *et al*., 2012), as well as the construction of their nests (Holloway and Malcolm, 2007).

Cocoa crop hosts a higher biodiversity in agroforestry systems (Cassano *et al*., 2011; Sonwa *et al*., 2018) compared to traditional crops. However, how the structure of the cocoa farm determines the level of rodent damage to the pods is almost unknown.

Smith and Nott (1988) found that squirrels find shelter in cocoa crops with extended shade cover. Monge and Hilje (2006) noted that the squirrel *Sciurus variegatoides* varies its diet depending on the tree's architecture, which determines its protection and access to food. On the other hand, Alves de Sousa Silva *et al*. (2008) found that the small mammal diversity in cocoa agroforestry systems in Brazil, was favored by the structural complexity of the crops conditioned by a greater diversity of niches. In their study, structural complexity was limited to shade cover.

In the neotropics, the red squirrel (*Notosciurus granatensis*) causes considerable damage to cocoa pods, and its geographic distribution coincides with that of this crop (Warren and Emmandie, 1993).

The objective was to evaluate the influence of the cocoa plantation structure on the level of damage caused to the pods by red squirrels using the following response variables: the cocoa biomass, the magnitude of shade cover, the number of associated crops, the presence of alternative fruit trees, and the type of ecological succession present in the surrounding vegetation. The study started from the hypothesis that the magnitude of the damage caused by squirrels increases with the structural complexity.

## Materials and methods

### Agroecological area

The study was carried out in cocoa farms at the Cordillera de Mérida characterized by mountainous landscapes with hills, cones, and valleys with slopes ranging 3-30°, shaped by quaternary erosion on tertiary formations. The soils are weakly acidic, with good drainage, quite weathered and moderately fertile in the steepest areas, but very fertile in the plains (Vivas, 1992). According to Huber *et al*. (2010), the area was initially composed of two kinds of vegetation: semi-deciduous forests, with trees up to 35 m tall, and two tree strata, up to 800 m.a.s.l.; and evergreen forests, located between 800 and 1800-2000 m.a.s.l.

### Population and sample

The population was 1,068 cocoa-producing farms established in the study area (Portillo *et al*., 1995). The study was carried out in 15 farms located in Mesa Bolívar, Mesa Julia, Río Frio and Zea, located between 300 and 900 m.a.s.l (table 1). Farms were selected by their accessibility and by having the consent of the farm owner.

**Table 1. Relative location of the cacao farms in Merida state, Venezuela.**

| Farm name | Coordinates N/W | Parish | Municipality |
|---|---|---|---|
| Santa Lucia | 8°28'50"/71°37'80" | Mesa Bolivar | Antonio Pinto Salinas |
| San Rafael | 8°28'41"/71°37'84" | Mesa Bolivar | Antonio Pinto Salinas |
| Mi Refugio | 8°27'88"/71°38'12" | Mesa Bolivar | Antonio Pinto Salinas |
| La Vega | 8°30'92"/71°38'74" | Mesa Bolivar | Antonio Pinto Salinas |
| La Escondida | 8°27'94"/71°38'76" | Mesa Bolivar | Antonio Pinto Salinas |
| Los Manzanos | 8°30'92"/71°38'75" | Mesa Bolivar | Antonio Pinto Salinas |
| La Florida | 8°28'33"/71°39'28" | Mesa Bolivar | Antonio Pinto Salinas |
| La Trinidad | 8°27'54"/71°39'47" | Mesa Bolivar | Antonio Pinto Salinas |
| Canaima | 8°58'25"/71°15'59" | Mesa Julia | Caracciolo Parra y Olmedo |
| La Esperanza | 8°54'27"/71°18'42" | Río Frio | Caracciolo Parra y Olmedo |
| El Rosal | 8°53'26"/71°18'35" | Río Frio | Caracciolo Parra y Olmedo |
| La Montaña | 8°52'40"/71°18'03" | Río Frio | Caracciolo Parra y Olmedo |
| Los Taguanes | 8°56'70" /71°14'75" | Río Frio | Caracciolo Parra y Olmedo |
| La Hedionda | 8°24'44"/71°47'37" | Zea | Zea |
| Labradores | 8°23'25"/71°47'88" | Zea | Zea |

**Crop characteristics**

Most crops have 2 ha or fewer; criollo cocoas predominate, although it is common to find hybrids and, less frequently, foreign cocoas, with plants separated 3 x 3 m, and weeds controlled mainly using mechanical methods. Most farms have a reduced shade cover (figure 1A), low richness of shade trees in two strata: the upper one made up of native trees (figure 1B), mainly cedar (*Cedrela odorata*), pardillo (*Cordia alliodora*), and bucare (*Erythrina poeppigiana*), although caraño (*Protium* sp.), jobo (*Spondias mombin*) and higueron (*Ficus* spp.) trees are sometimes found; and a lower stratum made up mainly of *E. poeppigiana*, and guamo (*Inga* spp.), with some sparse surure (*Myrcia fallax*) and yagrumo (*Cecropia* spp.), and even exotic species such as bamboo (*Bambusa vulgaris*).

In some cases, a third vertical layer in the shade vegetation was found (figure 1C), made up of fruit trees: avocado (*Persea americana*), soursop (*Annona muricata*), orange (*Citrus cinensis*), mandarin (*Citrus reticulata*), lemon (*Citrus auratiifolia*), banana (*Musa AAA*) and plantain banana (*Musa AAB*).

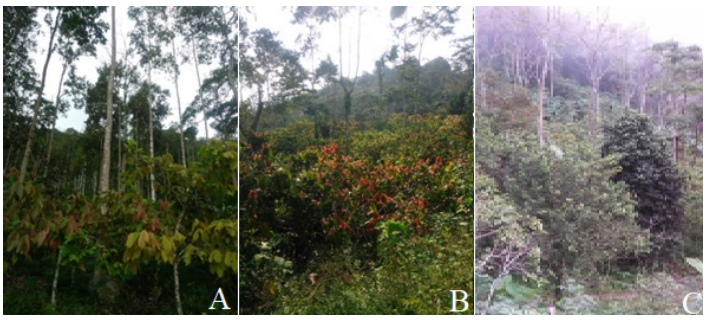


**Figure 1. Cocoa crops with permanent shade made up of timber trees in the upper stratum (A) and intermediate (B), and of fruit trees in the lower stratum (C).**

Source: Misael Molina.

Observing the shape and size of the holes left by the squirrels after biting the cocoa pods (figure 2A) and by woodpeckers (figure 2B) after pecking the fruits, the damage was attributed to these rodents, discarding the birds.

**Sampling and evaluation**

Twelve plants were randomly selected in each farm, and during the rainy season of 2018 and the dry season of 2021, the number of pods bitten by the squirrels and the total number of pods occurring in the plant were counted twice (once in each season). Then, the percentage of damage was calculated. Likewise, during the dry season of 2021 the following independent variables were measured: biomass of cocoa trees, shade vegetation cover, number of associated crops and number of alternative fruit trees. Also, the type of ecological succession in the surrounding vegetation was observed and was classified in three categories: other cocoa plantations, stubble, secondary forests, and grasslands; when different types were occurring, the dominant one (i.e., more than 50% of crop perimeter) was considered.

The cocoa biomass was calculated using the equation derived by Huy *et al*. (2016) for tropical trees: $AGB = N*0.06*DBH^{2.30}*H^{0.50}*WD^{0.80}$, where AGB is aboveground biomass, N is the number of plants.ha$^{-1}$, DBH is plant diameter at breast height, H is plant height, and WD is cocoa wood density (0.42 g.(cm$^3$)$^{-1}$).


**Figure 2. Cocoa pods damaged by squirrels (A) and woodpeckers (B), note size and shape of hole.**

Source: Misael Molina.

The shade vegetation cover was measured selecting randomly one hectare in each farm which was then divided into 100 grids of 10 x 10 m. Then 15 of these grids were randomly selected to take a low-angle photograph from the center of each grid. The same person always took the photographs using a ZTE Blade V20 cell phone, leveling the phone horizontally and consistently placing it at face height. Subsequently, using the ImageJ program (Ferreira and Dasband, 2012), each photograph was converted to a binary format to have black and white images, and the percentage of black pixels represents the surface covered by shade vegetation. The average of these 15 values was taken as the percentage of shade vegetation cover in every farm.

Furthermore, the number of associated crops on each farm was counted, and the presence of alternative fruit trees (trees other than cocoa that produce fruits consumed by squirrels) was verified.

**Statistical data processing**

The independent quantitative variables were standardized to reduce differences due to scales: mean and standard deviation were calculated, and then the original value was subtracted from the mean

and this result was divided by the standard deviation. Then, variables were organized into four categories each as follows: four groups for the biomass of the cocoa plants (I: 12,810-103,000; II: 104,000-207,000; III: 208,000-311,000; IV: 312,000-425,000 kg.ha$^{-1}$), four groups for the cover of shade vegetation (I: 18-34; II: 35-51; III: 52-68; IV: >69%), four groups for the number of associated crops (I: 0-1; II: 2-3; III: 4-5; IV: 6-7), and four groups for the ecological succession present in the surrounding vegetation (I: other cocoa crops; II: stubbles; III: secondary forests; IV: grasslands). Only presence of alternative fruits was organized into two groups (I: present; II: absent).

A Kruskal-Wallis Analysis of Variance for independent samples was run for the variables with four categories, and a Kolmogorov test for the independent samples of the presence/absence of alternative fruits. The program SPSS20 was used to process data (IBM, 2011).

## Results and discussion

**Level of damage by red squirrels**

The average level of damage was 6.33% for the farms located in Mesa Bolivar, 13% for Mesa Julia, 3.20% for Rio Frio, and 5.30 for Zea (table 2). These results contrast with those of López *et al*. (2014), who found losses between 26 and 34% for Nicaragua, and those of Mollineau *et al*. (2008), who reported losses higher than 30% for Trinidad and Tobago, despite including farms with similar management conditions than those evaluated in this research. Although our values are lower than those reported by these authors, it is significant for Merida producers since they face a crisis reflected through scarcity and high costs of agro-inputs and labor.

**Table 2. Calculated values for the structural variables of cocoa farms and the damage caused by red squirrels to the cocoa pods in Merida state, Venezuela.**

| Location | Farm name | % damage | Bss* cocoa | Nº associated crops | % shade cover | Succession category |
|---|---|---|---|---|---|---|
| Mesa Bolivar | Santa Lucia | 3.73 | 78930 | 2 | 49.10 | 2 |
| | La Candelaria | 4.77 | 140950 | 0 | 66.03 | 2 |
| | Mi Refugio | 24.94 | 12810 | 2 | 42.33 | 3 |
| | La Vega | 4.56 | 314110 | 7 | 35.31 | 3 |
| | La Escondida | 4.48 | 232560 | 4 | 66.19 | 2 |
| | Los Manzanos | 5.61 | 74440 | 1 | 46.06 | 2 |
| | La Florida | 2.51 | 145650 | 2 | 41.76 | 4 |
| | La Trinidad | 0.00 | 247300 | 5 | 18.60 | 4 |
| Mesa Julia | Canaima | 13 | 107800 | 1 | 34.80 | 3 |
| Rio Frio | La Esperanza | 2.27 | 215400 | 1 | 54.24 | 3 |
| | El Rosal | 1.60 | 248630 | 3 | 83.93 | 2 |
| | Los Taguanes | 1.86 | 424550 | 4 | 67.58 | 1 |
| | La Montaña | 7.06 | 92550 | 4 | 63.23 | 3 |
| Zea | La Hedionda | 7.56 | 85860 | 3 | 58.34 | 3 |
| | Labradores | 3.04 | 132670 | 4 | 44.65 | 3 |

Bss: biomass (kg.ha$^{-1}$). Succession categories: 1 other cocoa crops; 2 stubbles; 3 secondary forests; 4 grasslands).

**Cocoa biomass**

The biomass of cocoa pods ranged 12,810-424,550 kg.ha$^{-1}$, but there were not statistically significant differences ($p>0.05$) in the level of damage among the four categories.

**Shade coverage**

Similarly, there were not statistically significant differences ($p>0.05$) in the level of damage among the categories of shade trees (figure 3). However, shade cover and damage level showed a negative correlation ($r = -0.046$). Shade trees contribute to forming a greater structural complexity that favors the presence and mobility of squirrels through the branches (Flaherty *et al.,* 2012; Holloway *et al*., 2012), and the construction of nests (Holloway and Malcolm, 2007). Therefore, a higher level of damage could be expected in crops with great shade cover. But our results indicate the opposite, also contrasting with the work of Smith and Nott (1998), who argued that squirrels find protection in cocoa crops with extensive shade cover.

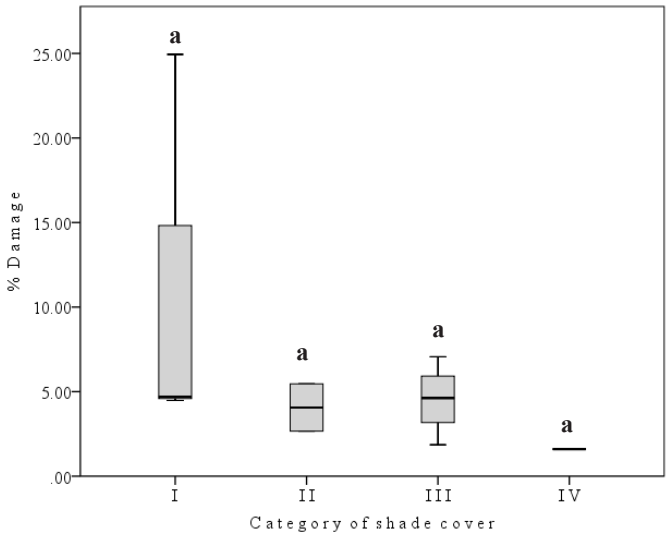


**Figura 3. Relation between the level of damage (%) by red squirrels and the shade cover in cacao farms of Merida state, Venezuela.** The categories of shade cover are: I: 18-34%, II: 35-51%, III: 52-68%, IV: >69%. Same letters indicate non-significant statistical differences (p>0,05).

However, the results might be explained within the theoretical framework of the prey-predator relationship. On one hand, birds of prey are known to be primarily predators of squirrels (wildlifeonline.me.uk/article/squirrel-predators), and on the other hand, some squirrels can get used to interacting with humans (Engelhardt and Weladji, 2011; Kittendorf and Danzer, 2021). Nevertheless, while squirrels exhibit behavioral elasticity to take advantage of resources in human-altered landscapes, raptors are sensitive to the scarcity of shaded areas (Sagorski and Swihart, 2021; Tinajero *et al*., 2017). Therefore, squirrels learn to recognize the risk of both predation by birds and direct harm from humans and can weigh the predation risks against the advantage of staying close to a safe and good-quality food source (Badrie *et al*., 2015) and transmit that information to the progeny (Engelhardt and Weladji, 2011; Uchida *et al*., 2017; Uchida, 2019). As a result, a greater abundance of squirrels can be found in these places (Engel *et al*., 2020), thus it is reasonable to find a higher level of damage in areas with less shade cover but

having more abundant food. Also, they might find safe escape routes against predators since the high connectivity between cocoa plants and surrounding vegetation guarantees it. However, an extensive shade cover does not seem to guarantee a higher connectivity to facilitate red squirrel mobility. In this study that mobility occurred between the cocoa plants, but not through the branches of the middle and upper strata.

**Number of associated crops**

The magnitude of the damage did not differ ($p>0.05$) between the categories of associated crops. However, it was higher in farms with two to three associated crops (category II, figure 4). It was expected that the damage would increase as the amount of intercropping was reduced; a correlation test corroborated this trend ($r = -0.20$) but was not significant ($p>0.05$). This result seems to indicate that not the number, but the type of crops may shape the rodent's occurrence, since some of them are fruit trees highly valuable for them (Reher *et al*., 2016), such as avocado (*P. americana*). That is why damage was more distributed among the different crops.

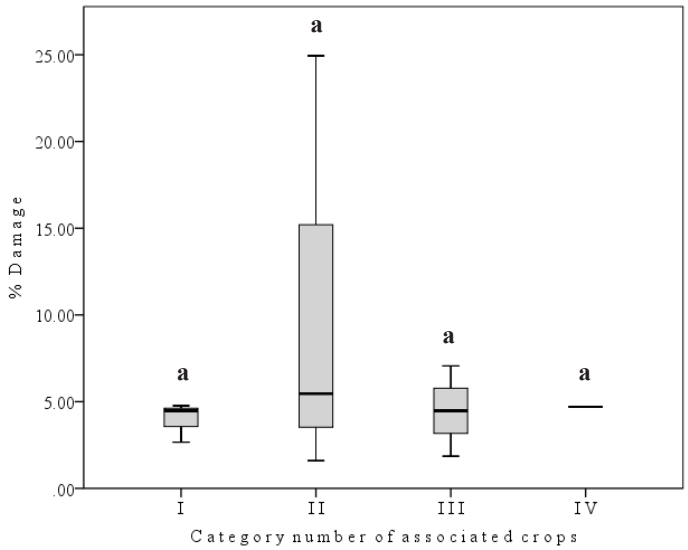


**Figure 4. Relationship between the level of damage (%) by red squirrels and the number of associated crops in cocoa farms of Merida state, Venezuela.** Same letters indicate non-significant statistical differences ($p>0.05$). The categories of associated crops are I: 0 to 1, II: 2 to 3, III: 4 to 5, IV: 6 to 7.

**Presence of alternative fruit trees**

The magnitude of the damage was higher in crops with alternative fruits, but differences were non-significant ($p>0.05$) to that in farms without these fruits. Squirrels are known to respond to the presence of fruit trees (Monge and Hilje, 2006). For *N. granatensis*, there are no detailed studies published yet, although Reher *et al*. (2016) pointed out that the abundance of *Sciurus vulgaris* is related to the existence of food sources. However, according to Monge and Hilje (2006) the damage is diluted when crops are diverse because squirrels are opportunistic and take advantage of easily accessible resources. Therefore, cocoa pods might appear only as alternative food for squirrels when their preferred fruits are not available.

**Ecological succession present in the surrounding vegetation**

The level of damage did not differ ($p>0.05$) among the categories of the surrounding vegetation. The damage was minimal or inexistent when pastures surrounded the cocoa plantations, but it was greater when surrounded by forest. Particularly, damage was significantly higher when farms were surrounded by some kind of forest (figure 5). This result is consistent with the highest damage founded in crops with less shade cover. On the other hand, the damage observed in crops surrounded by secondary forests had a similar value to that of other cocoa crops. Forest-dwelling squirrels feed opportunistically on cocoa pods and alternative fruits, as occurs with *Sciurus aestuans* (Alvarenga and Talamoni, 2006) and *S. variegatoides* (Monge and Hilje, 2006). Silva-Ferreira *et al*. (2020) founded that forest remnants are essential to support mammalian populations in cocoa crops. Mobility within and between the crop and the forest is critical (Monge and Hilje, 2006; Mäkeläinen *et al.,* 2016), which in the crops studied here were guaranteed by the overlap between branches of different plants.

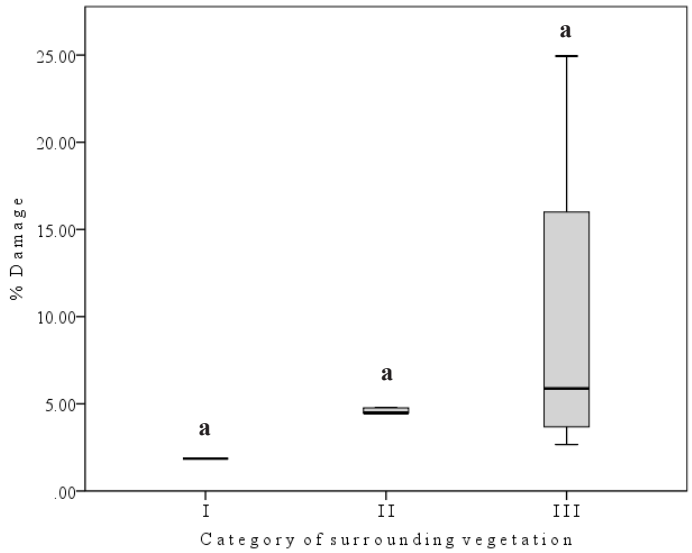


**Figure 5. Relationship between the magnitude of the damage (%) by red squirrels and the type of surrounding vegetation of cocoa farms in Merida state, Venezuela.** I: other cocoa plantations, II: stubble, III: secondary forests. Different letters indicate significant statistical differences ($p<0.05$).

Because these rodents play the role of prey for several vertebrate species, mainly birds of prey, they avoid open habitats like the grasslands, where the risk of predation is high (Potash *et al*., 2019).

## Conclusions

The damage to cocoa pods was higher in crops with less shade cover, with more associated crops, and with the presence of alternative fruit trees. Shade cover did seem to indirectly influence squirrels by favoring the presence of bird predators, which are more sensitive to disturbance. It seemed that red squirrels use the cocoa pods opportunistically, only when their preferred fruits are not available, and therefore ripe cocoa fruits are a complementary food for squirrels.

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