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Crop damage by vertebrates in Latin America: current knowledge and potential future management directions

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Crop damage by vertebrates in Latin America: current knowledge and potential future management directions

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RESUMO

Conhecimento prévio. A lavoura é um dos usos da terra mais extensos do mundo, e a superfície que cobre ainda está aumentando. Muitas espécies de vertebrados se alimentam de cultivos e isso tem causado um aumento nos conflitos entre humanos e animais silvestres envolvendo danos a plantações. Os danos as plantações prejudicam a economia das comunidades locais e causam retaliação contra os vertebrados responsáveis de várias formas, incluindo práticas letais como caça e envenenamento. O controle letal pode causar a extirpação local de algumas espécies, afetando processos e padrões ecológicos. Portanto, é necessário encontrar alternativas não letais que protejam tanto as economias locais quanto a fauna nativa. Pesquisas sobre esse tema já foram realizadas na África e na Ásia com foco em grupos de vertebrados como elefantes e primatas, e algumas alternativas não letais, como repelentes à base de pimenta e colmeias estão sendo investigadas. No entanto, existem poucas pesquisas sobre esse assunto na América do Sul e Central. O objetivo da revisão foi avaliar o conhecimento atual e apontar para futuras direções de pesquisa.

Métodos. Revisamos a literatura científica disponível relatando danos a colheitas por vertebrados na América Central, América do Sul, e o Caribe publicada entre 1980 e 2020, por meio de pesquisas sistemáticas na Web of Science, Scopus e Google Scholar. Analisamos a distribuição temporal e geográfica dos estudos, espécies de cultivos e vertebrados envolvidos, e as técnicas de proteção de cultivos utilizadas e sua eficácia.

Resultados. Apenas 88 estudos sobre danos a cultivos por vertebrados na América Latina foram recuperados, mas há uma tendência crescente no número de estudos publicados ao longo do período avaliado. A maioria dos estudos foi realizada em quatro países: Brasil, Argentina, e Costa Rica. Mamíferos de quatro ordens (Rodentia, Carnivora, Artiodactyla e

Primates) e três ordens de aves (Passeriformes, Columbiformes e Psittaciformes) foram os grupos de vertebrados que danificam plantações mais representados. O cultivo de maior destaque foi o milho presente em 47% dos artigos e interagindo com 16 das 20 ordens de vertebrados representadas na revisão. Outros cultivos com interações com vertebrados foram arroz, sorgo e cana-de-açúcar. O método de proteção de cultivos mais citado foi o controle letal como a caça ou o envenenamento. As técnicas não letais foram menos prevalentes. Menos da metade dos estudos que citaram o uso de técnicas de proteção indicaram sua eficácia, e apenas 10 avaliaram realizando experimentos científicos e relatando seus resultados.

Conclusões. A pesquisa sobre danos a plantações por vertebrados ainda é pouco representada na América Central e do Sul. Há uma necessidade de pesquisas baseadas em experimentos robustos que visem tanto encontrar técnicas de proteção de cultivos que minimizem os danos aos vertebrados e efetivamente reduzam os danos às lavouras. Enquanto isso ainda está se desenvolvendo, a perdida e fragmentação de habitats precisam ser interrompidas para que os vertebrados nativos sejam menos propensos a recorrer às plantações para se alimentar.

Palavras-chave: Ataques a cultivos; conflito homem-animal silvestre; proteção de cultivos; esquemas agroambientais; dano por animais; dano por aves; dano por mamíferos

ABSTRACT

Background. Crop farming is one of the most extensive land uses in the world, and the surface it covers is still increasing. Many vertebrate species feed on crops and this has caused an increase in human-wildlife conflicts involving crop-feeding. Crop-feeding damages the economy of local communities and causes retaliation against the responsible vertebrates in several forms, including lethal practices such as hunting and poisoning. Lethal control may cause the local extirpation of some species, affecting ecological processes and patterns. Therefore, it is necessary to find non-lethal alternatives that protect both the local economies and native wildlife. Research into this has already been carried out in Africa and Asia focusing on vertebrate groups such as elephants and primates, and some non-lethal alternatives, such as chili-based repellents and beehives are being investigated. However, there is very little research regarding this topic in Central and South America. The goal of the review was to assess current knowledge and point at future research directions.

Survey methodology. We reviewed the available scientific literature reporting crop damage by vertebrates in Central America, South America, and the Caribbean, published between 1980 and 2020, through systematic searches on Web of Science, Scopus and Google Scholar. We analyzed the temporal and geographical distribution of the studies, crop and vertebrate species included, crop protection techniques used and their effectiveness.

Results. Only 88 studies on crop damage by vertebrates in Latin America were retrieved, but there is an increasing trend in the number of studies published over time. Most of the studies took place in four countries: Brazil, Argentina, Mexico, and Costa Rica. Mammals from four orders (Rodentia, Carnivora, Artiodactyla, and Primates) and three orders of birds (Passeriformes, Columbiformes, and Psittaciformes) were the most represented groups of crop-feeding vertebrates. The most prominent crop was corn featuring in 47% of the studies and interacting with 16 of the 20 vertebrate orders represented in our review. Other notable crops were rice, sorghum, and sugarcane. The most reported method for protecting crops was lethal control through hunting or poisoning. Non-lethal techniques were less prevalent. Less than half of the studies that mentioned the use of protection techniques gave an indication of their effectiveness, and only 10 studies evaluated it by performing scientific experiments and reporting their results.

Conclusions. Research on crop-feeding by vertebrates is still underrepresented in Central and South America. There is a need for research based on robust experimentation that aims to find crop protection techniques that minimize harm to vertebrates and effectively reduce damages to crops. While this is still developing, habitat loss and fragmentation needs to be halted so that native vertebrates are less likely to turn to crops for food.

Keywords: Crop feeding; human-wildlife conflict; crop protection; agri-environment schemes; animal damage; bird damage; mammal damage

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CAPÍTULO I

INTRODUÇÃO GERAL

Os danos aos cultivos agrícolas são um problema mundial. Estima-se que 73% da produção primária líquida de terras agrícolas globais é perdida antes da colheita (Alexander et al., 2017). Uma das principais causas são os danos provocados por organismos vivos que produzem perdas de rendimento global de 17% a 30% para cinco cultivos principais (trigo, arroz, milho, batata e soja) (Savary et al., 2019). No entanto, a maioria das pesquisas tem se concentrado em invertebrados (Dhaliwal, Jindal & Dhawan, 2010; Oliveira et al., 2014) ou patógenos (Bebber & Gurr, 2015; McDonald & Stukenbrock, 2016), com muito menos atenção aos vertebrados que danificam as plantações. As pesquisas sobre pragas de vertebrados têm sido feitas principalmente em roedores (Lauret et al., 2020; Singleton et al., 2010; Stenseth et al., 2003) e aves (Anderson et al., 2013; de Mey, Demont & Diagne, 2012; Kale et al., 2014; Montràs-Janer et al., 2019). No entanto, existem outros grupos de vertebrados que podem causar grandes danos aos cultivos, como elefantes (Kiffner et al., 2021), primatas (Siljander et al., 2020) ou ungulados (Bevins et al., 2014).

A questão dos danos aos cultivos é de grande importância por causa da elevada demanda por produtos agrícolas que existe em todo o mundo. A agricultura é um dos usos da terra mais extensos no planeta. Em 2015, 12,2% da superfície terrestre estava dedicada a campos de cultivo, ocupando uma área estimada de 1,591 bilhões de hectares em todo o mundo, 198 milhões de hectares dos quais estavam na América Latina (Goldewijk et al., 2017). E muito provavelmente, a quantidade de terra necessária aumentará no futuro. O'Neill et al. (2015) propõem cinco narrativas divergentes para o desenvolvimento global no século 21, chamadas de caminhos socioeconômicos compartilhados (SSP). O SSP2 representa um cenário de linha de base onde as tendências globais continuam sem mudar marcadamente dos padrões históricos; das outras quatro narrativas. O SSP1 representa mudanças em direção à sustentabilidade, e o SSP3 representa o pior cenário. Se o desenvolvimento global continuar sem mudanças drásticas (SSP2), a superfície da Terra usada para o cultivo deverá aumentar em até 400 milhões de hectares até o ano 2100; se o cenário SSP3 for seguido, o aumento pode chegar a mais de 700 milhões de hectares, e se a rota SSP1 for tomada, a superfície terrestre cultivada permanecerá em um nível semelhante ou diminuirá potencialmente (Fig.1; Riahi et al., 2017).

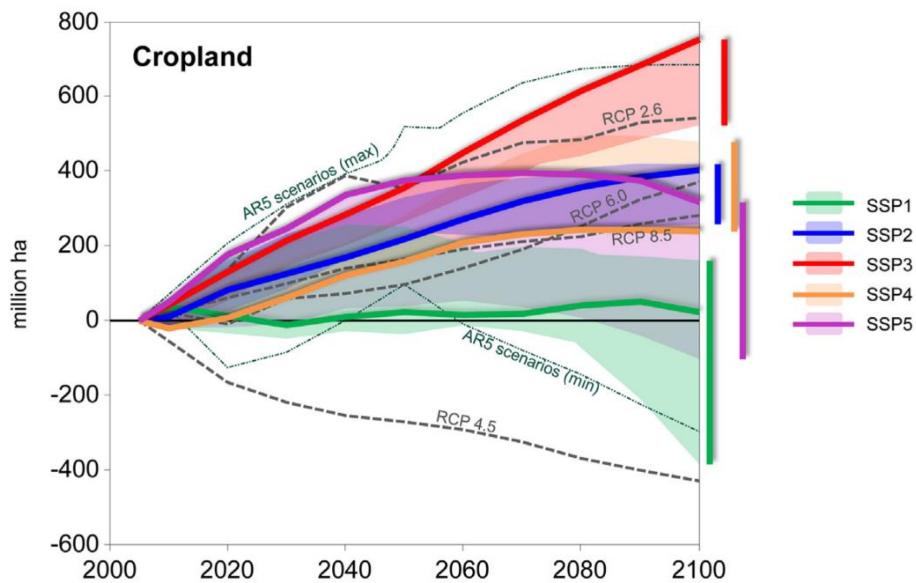

Figura 1. Riahi et al., 2017. Mudanças na área de cultivo para os cenários marcadores do SSP (linhas grossas) e intervalos de outros cenários não-marcadores (áreas coloridas). As mudanças são mostradas em relação ao ano base de 2010 = 0. Além dos cenários de linha de base do SSP, também o desenvolvimento dos RCPs (van Vuuren et al., 2011) e a gama dos cenários AR5 do IPCC são mostrados (Clarke et al, 2014).

Enquanto a demanda por cultivos aumenta, também se espera que os danos aos cultivos aumentem devido às mudanças climáticas e ao aquecimento global. O incremento das temperaturas aumentará as taxas metabólicas e o crescimento populacional de insetos, aumentando a incidência de pragas agrícolas (Deutsch et al., 2018). Eventos climáticos extremos que danificam as lavouras também serão mais frequentes e intensos (Lesk, Rowhani & Ramankutty, 2016). Finalmente, os agricultores podem ser forçados a mudar suas práticas de cultivo de forma a reduzir o rendimento da safra (Tito, Vasconcelos & Feeley, 2018).

A expansão das terras agrícolas, junto com outros tipos de intensificação do uso da terra, causa a destruição e fragmentação do habitat natural. Isso pode alterar a abundância e a distribuição de espécies de vertebrados (Ramesh & Downs, 2015; Said et al., 2016) e os expõe a cultivos agrícolas que podem usar como fontes de alimento, seja porque estão prontamente disponíveis e fáceis de consumir ou porque suas fontes naturais de alimentos são reduzidas (Cervo & Guadagnin, 2020; de Freitas et al., 2008). Isso pode causar conflitos entre humanos e animais silvestres, como ataques a plantações (Jorgenson & Sandoval-A., 2005; Mekonnen et al., 2018). A danificação de plantações por vertebrados pode gerar diversos problemas sociais, econômicos e ecológicos. Os danos às colheitas podem pôr em perigo a segurança alimentar das comunidades de agricultores (Barirega et al., 2010; Raphela & Pillay, 2021) e prejudicar as economias locais (Gontse, Mbaiwa & Thakadu, 2018). Também geram percepções negativas das espécies invasoras de plantações (Escobar-Lasso et al., 2020) e podem reduzir a tolerância das comunidades afetadas à vida silvestre (Campbell-Smith et al., 2010; Virtanen et al., 2021). A redução da tolerância pode levar as comunidades a se tornarem contra as iniciativas de conservação (Mogomotsi et al.,

2020) e gerar desconfiança em relação àqueles que as aplicam (Dakwa, 2016). Finalmente, a danificação de plantações coloca as espécies que estão envolvidas em perigo de retaliação por parte dos agricultores (Compaore et al., 2020; Kendall, 2011).

Ao sofrer danos às suas plantações, os agricultores podem favorecer uma ação letal contra as espécies responsáveis a fim de evitar mais perdas econômicas (Abrahams, Peres & Costa, 2018; Canavelli, Swisher & Branch, 2013; Cossios, Ridoutt & Donoso, 2018; Lima et al., 2019; Linz et al., 2015). Se a espécie for vulnerável, como espécies raras ou de reprodução lenta, o abate retaliatório pode resultar em extinções locais (Hockings & McLennan, 2016) que podem ter efeitos de longo prazo no ecossistema. Além das ameaças que o controle letal representa para as espécies-alvo, também há outras desvantagens. A caça é o método mais comum de controle letal, mas pode ser ineficaz contra espécies que têm ciclos de vida curtos e altas taxas reprodutivas, que é o caso de muitos invasores de plantações prevalentes, como os roedores (Hein & Jacob, 2015). A caça também pode alterar os padrões de movimento e regimes de atividade de espécies de vertebrados (Little et al., 2016; McGrath, Terhune II & Martin, 2018), o que modifica a intensidade e a área afetada por danos à cultivos. O envenenamento é outro método popular de controle de pragas, mas seu uso pode ter efeitos desastrosos nas populações das espécies-alvo (Lima et al. 2019), tem consequências graves para espécies não-alvo, como predadores ou necrófagos (Baudrot et al., 2020; Kalaivanan et al., 2011), e afeta negativamente a saúde humana (Rani et al., 2021). Portanto, é necessário encontrar técnicas não letais de proteção de cultivos que possam proteger efetivamente os cultivos enquanto preservam as espécies de vertebrados que os danificam (King et al., 2017).

O estudo de conflitos entre humanos e animais silvestres envolvendo cultivos concentrou-se principalmente na África e na Ásia, com foco em elefantes (Nsonsi et al., 2018) e, mais recentemente, primatas (Siljander et al., 2020). Nas últimas décadas várias técnicas de proteção não letal se mostraram eficazes na prevenção de ataques a plantações por elefantes incluindo métodos baseados em pimenta (Chang'a et al., 2016; Osborn, 2002), uso colmeias de abelhas (King, Douglas-Hamilton & Vollrath, 2011; Ngama et al., 2016) e reprodução de som de predadores (Thuppil & Coss, 2016). Tem havido relatos dessas técnicas não sendo tão eficazes quanto o esperado (Gunaryadi & Hedges, 2017; Kiffner et al., 2021), mas no geral essas técnicas ajudaram a proteger os meios de subsistência locais e a conservar a vida silvestre (Chang'a et al., 2016; King et al., 2017). No caso dos primatas, o teste de técnicas de proteção não letal não foi tão difundido, mas existem alguns exemplos de medidas eficazes, como o uso de redes para proteger árvores frutíferas (Campbell-Smith, Sembiring & Linkie, 2012).

Ao contrário da África e da Ásia, há uma escassa literatura científica sobre ataques a cultivos por vertebrados nas Américas. A América Latina é uma região do mundo que está sendo desproporcionalmente afetada pelo aumento global da superfície das terras agrícolas. É uma região "produtora" onde o cultivo da safra está aumentando para exportar o produto para regiões "consumidoras", como Europa e América do Norte, onde a superfície dedicada a agricultura está diminuindo (Creutzig et al., 2019). A América Latina também é uma das regiões de maior biodiversidade da Terra. Por exemplo, sete dos 35 hotspots de biodiversidade globais estão na América Latina: Mesoamérica, Ilhas do Caribe, Mata Atlântica, Cerrado, Florestas Temperadas Valdivianas, Tumbes – Chocó – Magdalena, e Andes Tropicais (Mittermeier et al., 2011). Quando medidas de risco de expansão agrícola, riqueza de biodiversidade e insegurança alimentar se combinam, fica claro que a América Latina é uma das regiões do mundo que apresenta maior risco de conflito entre biodiversidade e segurança alimentar (depois de algumas regiões da África e do Sudeste da Ásia) (Fig.2; Molotoks et al., 2017).

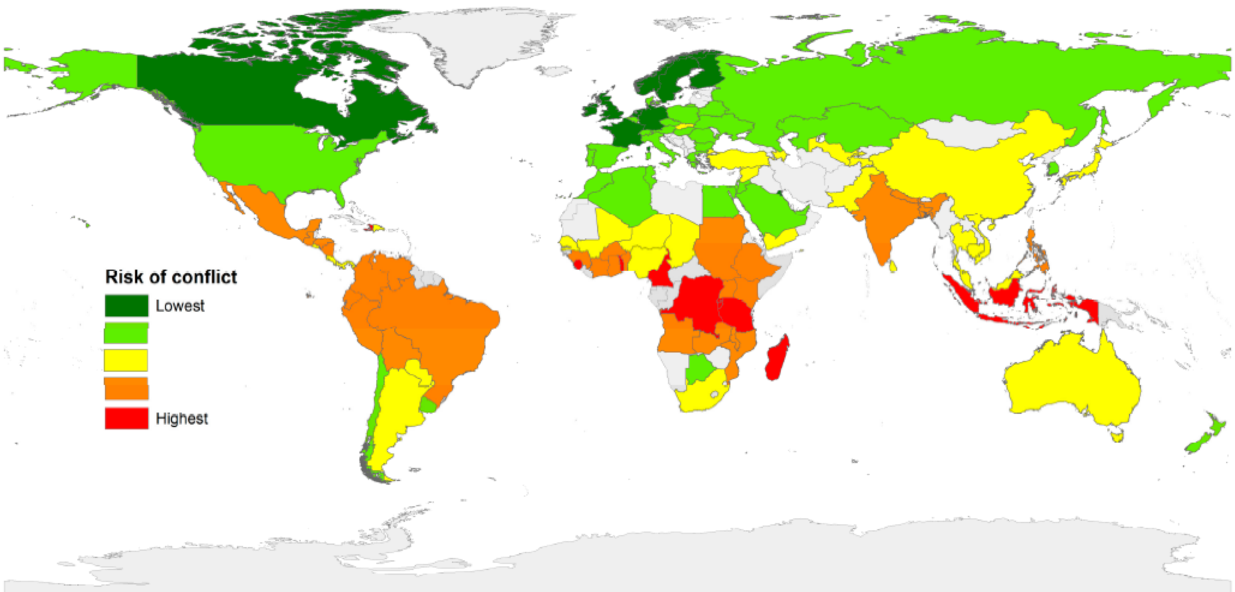

Figura 2. Molotoks et al., 2017. Índice de risco de conflito entre segurança alimentar e biodiversidade. Elaborado usando o 2016 Global Food Security Index (The Economist Intelligence Unit, 2016) e o National Biodiversity Index do Global Biodiversity Outlook (Secretariat of the Convention of Biological Diversity, 2001).

Considerando-se o alto risco de conflito entre segurança alimentar e biodiversidade na maioria dos países latino-americanos, é alarmante que a produção científica sobre danos às lavouras de vertebrados na região seja tão escassa. Além disso, na literatura disponível, a maioria dos estudos que fazem referência a técnicas de proteção de cultivos são letais, como a caça (Cossios, Ridoutt & Donoso, 2018; Rosa, Wallau & Pedrosa, 2018) ou o envenenamento (Espinoza & Rowe, 1979; Villafaña Martín et al., 1999). Existem poucos estudos que testaram a eficácia de técnicas de proteção de cultivos não letais usando experimentos científicos (Avery, Tillman & Laukert, 2001; Castillo-López et al., 2017; Mitchell & Bruggers, 1985; Pérez & Pacheco, 2006; 2014; Robles et al., 2003; Rodriguez et al., 1995). Esses poucos estudos estão longe de ser suficientes para produzir evidências confiáveis sobre quais técnicas de proteção não letal podem funcionar em diferentes grupos de vertebrados atacantes de plantações na América Latina e podem ser usadas para reduzir o conflito homem-vida silvestre e favorecer a coexistência.

O objetivo desta dissertação foi revisar a literatura publicada sobre danos aos cultivos por vertebrados na América Latina. Determinamos quais grupos de vertebrados estão mais envolvidos nos ataques a cultivos, avaliamos a efectividade de diferentes técnicas de proteção de cultivos e destacamos as principais lacunas de conhecimento. Em última análise, discutimos as técnicas de proteção de cultivos que podem minimizar os danos às espécies de invasores vertebrados e efetivamente reduzir os danos aos cultivos. Os métodos e resultados deste estudo são apresentados, no formato de um artigo científico a ser submetido para o periódico PeerJ.

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CAPÍTULO I

Crop damage by vertebrates in Latin America: current knowledge and potential future management directions

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Abstract

Background

Crop farming is one of the most extensive land uses in the world, and the surface it covers is still increasing. Many vertebrate species feed on crops and this has caused an increase in human-wildlife conflicts involving crop-feeding. Crop-feeding damages the economy of local communities and causes retaliation against the responsible vertebrates in several forms, including lethal practices such as hunting and poisoning. Lethal control may cause the local extirpation of some species, affecting ecological processes and patterns. Therefore, it is necessary to find non-lethal alternatives that protect both the local economies and native wildlife. Research into this has already been carried out in Africa and Asia focusing on vertebrate groups such as elephants and primates, and some non-lethal alternatives, such as chili-based repellents and beehives are being investigated. However, there is very little research regarding this topic in Central and South America. The goal of the review was to assess current knowledge and point at future research directions.

Survey methodology

We reviewed the available scientific literature reporting crop damage by vertebrates in Central America, South America, and the Caribbean, published between 1980 and 2020, through systematic searches on Web of Science, Scopus and Google Scholar. We analyzed the temporal and geographical distribution of the studies, crop and vertebrate species included, crop protection techniques used and their effectiveness.

Results

Only 88 studies on crop damage by vertebrates in Latin America were retrieved, but there is an increasing trend in the number of studies published over time. Most of the studies took place in four countries: Brazil, Argentina, Mexico, and Costa Rica. Mammals from four orders (Rodentia, Carnivora, Artiodactyla, and Primates) and three orders of birds (Passeriformes, Columbiformes, and Psittaciformes) were the most represented groups of crop-feeding vertebrates. The most prominent crop was corn featuring in 47% of the studies and interacting with 16 of the 20 vertebrate orders represented in our review. Other notable crops were rice, sorghum, and sugarcane. The most reported method for protecting crops was lethal control through hunting or poisoning. Non-lethal techniques were less prevalent. Less than half of the studies that mentioned the use of protection techniques gave an indication of their effectiveness, and only 10 studies evaluated it by performing scientific experiments and reporting their results.

Conclusions

Research on crop-feeding by vertebrates is still underrepresented in Central and South America. There is a need for research based on robust experimentation that aims to find crop protection techniques that minimize harm to vertebrates and effectively reduce damages to crops. While this is still developing, habitat loss and fragmentation needs to be halted so that native vertebrates are less likely to turn to crops for food.

Key words: Crop feeding; human-wildlife conflict; crop protection; agri-environment schemes; animal damage; bird damage; mammal damage

Introduction

Agriculture is one of the most extensive land uses, and by 2015 it covered ~37.4% of the global land area, of which 12.2% was dedicated to crops, occupying an estimate of 1.6 billion hectares worldwide, of which 198 million hectares are in Latin America (Goldewijk et al., 2017). The amount of land needed for crops in the future will depend largely on how global societies and economies develop (Stehfest et al., 2019). O'Neill et al. (2017) proposed five diverging narratives for global development in the 21st century, called Shared Socioeconomic Pathways. If global development continues without drastic changes the land surface used to grow crops will need to increase by up to 400 million hectares by 2100, but in a worse scenario the increase could be up to more than 700 million hectares (Riahi et al., 2017). The projected change in cropland cover is not homogeneous worldwide but depends on the role that different regions take. Latin America is the perfect example of a "producer" region where crop land cover and production is expanding largely for exportation to "consumer" regions (Europe and North America) where agricultural land cover is decreasing (Creutzig et al., 2019).

One of the reasons that so much land cover is needed for crop cultivation is the inefficiency of the production system by which much of the product is either lost or wasted. It has been estimated that 73% of the net primary production of global croplands is lost before harvest (Alexander et al., 2017). Damages by living organisms are one of the leading causes of crop losses worldwide, as pathogens and pests are estimated to produce global yield losses of 17.2% to 30% for five major crops (wheat, rice, maize, potato, and soy) (Savary et al., 2019). There is a lack of estimates on global crop losses caused by vertebrates, but damage to crops caused by birds and mammals is one of the most common factors of conflict between humans and vertebrates worldwide (Torres, Oliveira & Alves, 2018). Crop losses are expected to rise in the future due to climate change and global warming by increasing the incidence of pests (Deutsch et al., 2018), increasing the frequency and intensity of extreme weather events that reduce crop production (Lesk, Rowhani & Ramankutty, 2016), or forcing a change to less efficient cultivation practices (Tito, Vasconcelos & Feeley, 2018).

The expansion of human activities and intensification of land use produces an encroachment on natural areas altering their extension and distribution through habitat loss and fragmentation, which may change the distribution and abundance of vertebrate species (Ramesh & Downs, 2015; Said et al., 2016; Zhang et al., 2017). The reduction of food sources due to habitat loss and degradation favors wild animals to feed on crops, increasing their interactions with human communities and human-wildlife conflicts (Jorgenson & Sandoval-A., 2005; McKinney, 2019; Mekonnen et al., 2018). Crop-feeding compromises the food security of local communities and damages economies that rely on agriculture (Barirega et al., 2010; Gontse, Mbaiwa & Thakadu, 2018; Hill, 2000; Raphela & Pillay, 2021). Additionally, it represents a serious problem to conservation efforts by reducing human tolerance to wildlife (Campbell-Smith et al., 2010; Sifuna, 2005; Virtanen et al., 2021), turning farmers against conservation initiatives (Dakwa, 2016; Mogomotsi et al., 2020; Osborn & Parker, 2003; Redpath, Bhatia & Young, 2015) and putting crop-feeding species in danger of retaliation from farmers (Compaore et al., 2020; Kendall, 2011; Zimmermann et al., 2009).

When suffering damages to their crops farmers may favor lethal action against the culprit species to prevent further economic losses (Abrahams, Peres & Costa, 2018; Canavelli, Swisher & Branch, 2013; Cossios, Ridoutt & Donoso, 2018; Lima et al., 2019; Linz et al., 2015) or to make a compensatory profit (Scotson, Vannachomchan & Sharp, 2014). If the species is vulnerable, such as rare or slow-reproducing species, retaliatory culling may result in local extirpation of the species (Hockings & McLennan, 2016). Such extinctions may have far-reaching effects on the ecosystem if the species is an essential part of the food web or plays important ecological roles such as seed-dispersal, with their disappearance causing cascade effects in the community (Castillo-López et al., 2017). Furthermore, the use of poison to kill crop-damaging vertebrates can have severe consequences not only for the targeted species (Lima et al., 2019), but also for other animals that may consume them, such as predators or scavengers (Baudrot et al., 2020; Kalaivanan et al., 2011), and even affect the health of human communities and cause social conflicts (Rani et al., 2021). Thus, there is a need to find non-lethal crop protection techniques that can effectively protect crops while preserving the vertebrate species that damage them. By mitigating crop-feeding conflicts local economies can be protected while reducing risks to wildlife conservation (King et al., 2017).

In the past the study of human-wildlife conflicts involving crops has been mostly concentrated in Africa and Asia, focusing mainly on elephants (Mayberry, Hovorka & Evans, 2017; Naughton-Treves & Treves, 2005; Nsonsi et al., 2018; Sitati et al., 2003) and more recently primates (Hockings & Sousa, 2013; Marchal & Hill, 2009; Mc Guinness & Taylor, 2014; Priston, Wyper & Lee, 2012; Siljander et al., 2020; Wallace & Hill, 2012), as these vertebrate groups have caused the most concern regarding crop-feeding in those continents (Siljander et al., 2020). During the last decades non-lethal protection techniques that have been shown to be effective in deterring crop-feeding by elephants include chili (*Capsicum*) based methods (Chang'a et al., 2016; Osborn, 2002), using beehives (King, Douglas-Hamilton & Vollrath, 2011; King et al., 2009; Ngama et al., 2016), and playing predator growls (Thuppil & Coss, 2016). There are examples of chili-fences failing to increase the proportion of elephant attacks repelled (Gunaryadi & Hedges, 2017; Hedges & Gunaryadi, 2010) and of beehives not preventing occasional widespread damage to crops (Kiffner et al., 2021), but overall these techniques have generally helped protect local livelihoods and conserve wildlife (Chang'a et al., 2016; King et al., 2017). For primates, despite garnering significant attention in recent years, few non-lethal protection techniques have been tested, with some exceptions such as the use of nets that has been found to be effective in reducing fruit consumption by orangutans (Campbell-Smith, Sembiring & Linkie, 2012), or some preliminary trials with plant substances used as feeding deterrents on macaques (O'Brien & Hill, 2018).

Unlike in Africa and Asia, there is a scarce scientific literature on crop-feeding by vertebrates in Central and South America. From the available literature only a few studies reference crop protection techniques, of which most focus on lethal methods such as hunting (Cossios, Ridoutt & Donoso, 2018; Naughton-Treves et al., 2003; Rosa, Wallau & Pedrosa, 2018) or poisoning (Espinoza & Rowe, 1979; Villafaña Martín et al., 1999). The use of lethal control to manage crop-damaging bird populations in the continent has been shown to be ineffective (Linz et al., 2015). The development and testing of non-lethal crop protection techniques that could be effective in the context of the Latin America is lacking. However, there are few studies that have tested the effectiveness of non-lethal crop protection techniques using scientific experiments (Avery, Tillman & Laukert, 2001; Castillo-López et al., 2017; Mitchell & Bruggers, 1985; Pérez & Pacheco, 2006; 2014; Robles et al., 2003; Rodriguez et al., 1995).

In this paper we review the published literature on crop damage by vertebrates in Latin America. The rationale of this paper takes origin from the need to collect the available scientific knowledge on the topic to set the groundwork for future research that can lead to the development of effective non-lethal protection techniques, and to a mitigation of human-vertebrate conflicts in Latin America. We attempt to determine which groups of vertebrates are the most involved with crop-feeding, assess the effectiveness of different crop protection techniques, and highlight key knowledge gaps. This review can be used by a broad audience, from researchers to conservation practitioners, and from subsistence to commercial farmers.

Survey methodology

We reviewed the available scientific literature reporting crop damage by vertebrates in Central America, South America, and the Caribbean. We followed the Preferred Reporting Items for Systematic Reviews (PRISMA) guidelines (Page et al., 2021). One of the authors (ACH) conducted systematic searches on three databases: Scopus, Web of Science (core collection) and Google Scholar in November 2021. In Scopus and Web of Science search strings were created using three categories of terms (vertebrates, crop damage, and location) with Boolean operators AND between categories and OR within categories: "Vertebrate*" or "Wildlife" or "Mammal*" or "Bird*" or "Reptile*" or "Amphibian*" or "Fish*", "Crop*" or "Crop damage*" or "Crop raid*" or "Crop loss*" or "Crop protection" or "Agriculture" or "Subsistence", and "Neotropic*" or "South America" or "Central America" or "Mexico" or "Guatemala" or "Honduras" or "Panama" or "Caribbean" or "Nicaragua" or "El Salvador" or "Costa Rica" or "Venezuela" or "Colombia" or "Ecuador" or "Guyana" or "French Guiana" or "Suriname" or "Brazil" or "Peru" or "Bolivia" or "Chile" or "Argentina" or "Paraguay" or "Uruguay." This search string was applied to study titles, abstracts, and keywords. In Google Scholar the total 1,176 possible combinations of terms from the three categories were searched individually and the software Publish or Perish (Harzing, 2007) was used to retrieve the search results. The searches on the three databases covered the publishing period of four decades (1980-2020). Searches were performed only in English but when studies written in Spanish, Portuguese or French were returned they were also considered for the review.

Titles and abstracts of all results returned by the searches were screened for potential relevance. Only records pertaining to studies that were performed in countries of Central America, South America, or the Caribbean; that fully or partially focused on vertebrate species; and that involved damages to food crops caused by said vertebrate species were retained. Records that did not meet all three of these criteria were rejected. A similar procedure was used with the results returned from Google Scholar but considering only the first 50 records obtained from each search. Systematic reviews commonly conduct their searches only on commercial databases (e.g., Scopus and Web of Science) (Haas & Lortie, 2020; Miguel, Butterfield & Lortie, 2020; van Wilgen et al., 2018). But we chose to search Google Scholar as it forms a powerful addition to other traditional search methods (Haddaway et al., 2015). While searching records in Google Scholar, systematic reviews typically screen the first 50-100 search records (Duarte, Norris & Michalski, 2018; Haddaway et al., 2015; Hughes et al., 2014). The authors (ACH and FM) conducted independent reviews of the studies assessed for eligibility during the screening phase and discarded PhD or MSc theses, technical reports and off-topic studies. Although grey literature can have relevant data and information, we also found that adding it in systematic reviews has its drawbacks. The main challenge is associated with limited time and resources (Mahood, Van Eerd & Irvin, 2014) as searches in multiple search engines may be required (Paez, 2017). Additionally adding grey literature to systematic reviews may introduce problems related with reproducibility of methodology to be systematic as there is scant information about how searches for grey literature are executed (Mahood, Van Eerd & Irvin, 2014). However, in order to minimize bias in our systematic review we included conference proceedings (McAuley et al., 2000). The number of studies excluded and those retained were recorded for each of the screening stages according to the PRISMA statement (Page et al., 2021).

The selected studies were shorted into one or more of the following categories: (1) Crop damage evaluation, if the damage caused to crops by vertebrates in the area was assessed; (2) Crop protection experiment, if an experiment testing the effectiveness of crop protection techniques was performed; (3) Protection technique evaluation, if the study analyzed the effectiveness or feasibility of a particular protection technique but no experiment was conducted; (4) Farmer perception, if interviews with local farmers were used to assess their knowledge and/or opinions; (5) Pest species or outbreak overview, if the article reports on general information about one or several species considered to be pests or on specific outbreaks; (6) Crop-feeding species behavior, if the study focused on the diet or other behavioral aspects of the vertebrate species.

ACH extracted the following data from the selected studies: (a) date of publication, (b) country or countries where the study took place, (c) geographical coordinates of the study sites, (d) presence or absence of maps of the study area, (e) type of plantation (commercial, subsistence, or other), (f) crop species included in the study, (g) crop-damaging vertebrate species or taxa included in the study, (h) methods used to identify the vertebrate taxa, (i) methods used to quantify crop damage, (j) methods used to reduce damage to crops, (k) effectiveness of the protection methods (effective, not effective, or not evaluated). The lack of data or presence of unclear information for each of those points was also recorded. We determined that a study was conducted on subsistence plantations when the article explicitly informed it or when it implied that all or most of the crops produced were used to maintain the farmer's family and community. Studies were classified as conducted on commercial plantations when the article implied that the crops were raised mainly to obtain an economic profit. The techniques used to reduce crop damage were classified into 13 categories: hunting, poisoning, biological control, reproductive control, chemical repellents, agricultural practices, vigilance, physical barriers, acoustic deterrents, visual deterrents, olfactory deterrents, palatable deterrents, and capture and relocation. The protection techniques evaluated in each study were considered "effective" or "not effective" when the study provided experimental results regarding the effectiveness of the techniques, when the study included interviews with farmers concerning the effectiveness of the techniques, or when the study showed other evidence attesting to the effectiveness of the techniques. Otherwise, the effectiveness of the techniques reported was classified as "undetermined".

The vertebrate species and taxa were grouped by taxonomical order. An importance value was calculated for each order. The number of taxa of each order featured in each article were counted and then the totals were summed up to produce the final importance value for each order. Thus, every appearance by a taxon of the same order in an article was counted. An ecological network figure showing the interactions between vertebrate orders and crop genera was plotted using bipartite package for R (Dormann, Gruber & Fründ, 2008). For this purpose, when there was more than one vertebrate taxon of the same order in a study it was considered as a single interaction. The importance values attributed to the different vertebrate orders do not always correlate to their weight on the interaction network, as these parameters represent two different traits of the orders. The importance value reflects the number of appearances of each order's taxa in the reviewed literature, while for the network only one interaction between a vertebrate order and a crop genus was counted per study, independently of the number of taxa from that order that were reported in the study. Thus, orders that have a high importance value because they are widely represented in the literature but only interact with a few crop genera, will have comparatively little weight on the interaction network. The vertebrate status category of all species that could be identified in the review follows the IUCN Red list of Threatened Species (IUCN, 2021).

The geographic coordinates of the studies were used to produce a distribution map using ArcGIS 10.5.1 (ESRI, 2017). When studies failed to provide the exact geographic coordinates of the study area, we used Google Earth to obtain an approximate coordinate supported by maps of the study area and/or key landmarks such as towns or protected areas reported in the study that could be clearly distinguished on Google Earth images. When studies provided geographical coordinates in another system, we converted them into decimal degrees. For studies with more than one coordinate in the same study area we represented the mean position between the study sites (Laufer, Michalski & Peres, 2013). When studies reported more than one study area and the distance between them was more than 50 km, we plotted more than one point for the same study (Duarte, Norris & Michalski, 2018). The locations of the study sites were plotted over a Satellite-derived cover data and shaded relief with ocean bottom from the Natural Earth Dataset (http://naturalearthdata.com/) and with freely available data of cropland distribution (Massey et al., 2017).

Results

Compilation of studies

The searches returned 94 records that fulfilled all initial selection criteria, an additional three records previously known to the authors were included. From the 97 records seven were excluded due to being grey literature: six were MSc or PhD theses and one was a technical report. Two additional records were excluded because they studied damage by vertebrates to silo bags (Zufiaurre, Abba & Bilenca, 2020) and to farming machinery (Álamo Iriarte, Sartor & Bernardos, 2019) and not to crops directly. After this process, 88 studies were included in the final analyses (Fig. 1).

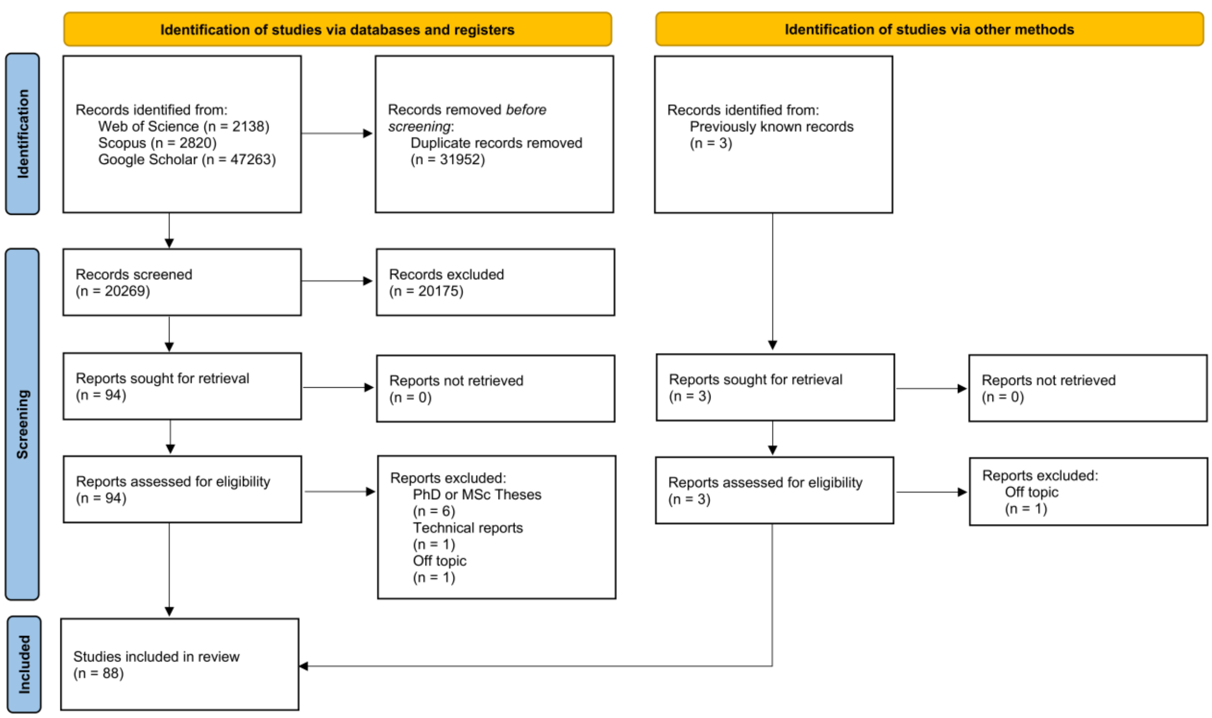

Figure 1. PRISMA flow diagram for the systematic review included in the analyses.

Geographic and temporal distribution of studies

The temporal distribution of the studies showed that there was an increase in the number of studies published on the topic since the 1980s. Only 16 studies (18%) were published before the year 2000 and 52 (59%) were published in the last decade (2011-2020). The year with the most studies published was 2018 with 10 (11%) studies (Fig. 2). The studies were scattered across most of Central and South America, including some in the Caribbean (Fig. 3). The study sites were found across areas with different proportions of land cover by crops (Fig. 3). The countries with the highest number of studies were Brazil (n = 23), Argentina (n = 14), and Mexico (n = 10). The other countries where studies were carried out were Costa Rica (n = 9); Peru, Bolivia, and Uruguay (n = 6); Colombia and Venezuela (n = 5); Barbados (n = 3); Cuba and Puerto Rico (n = 2); and Belize, Dominican Republic, and Saint Kitts and Nevis (n = 1) (Table S1).

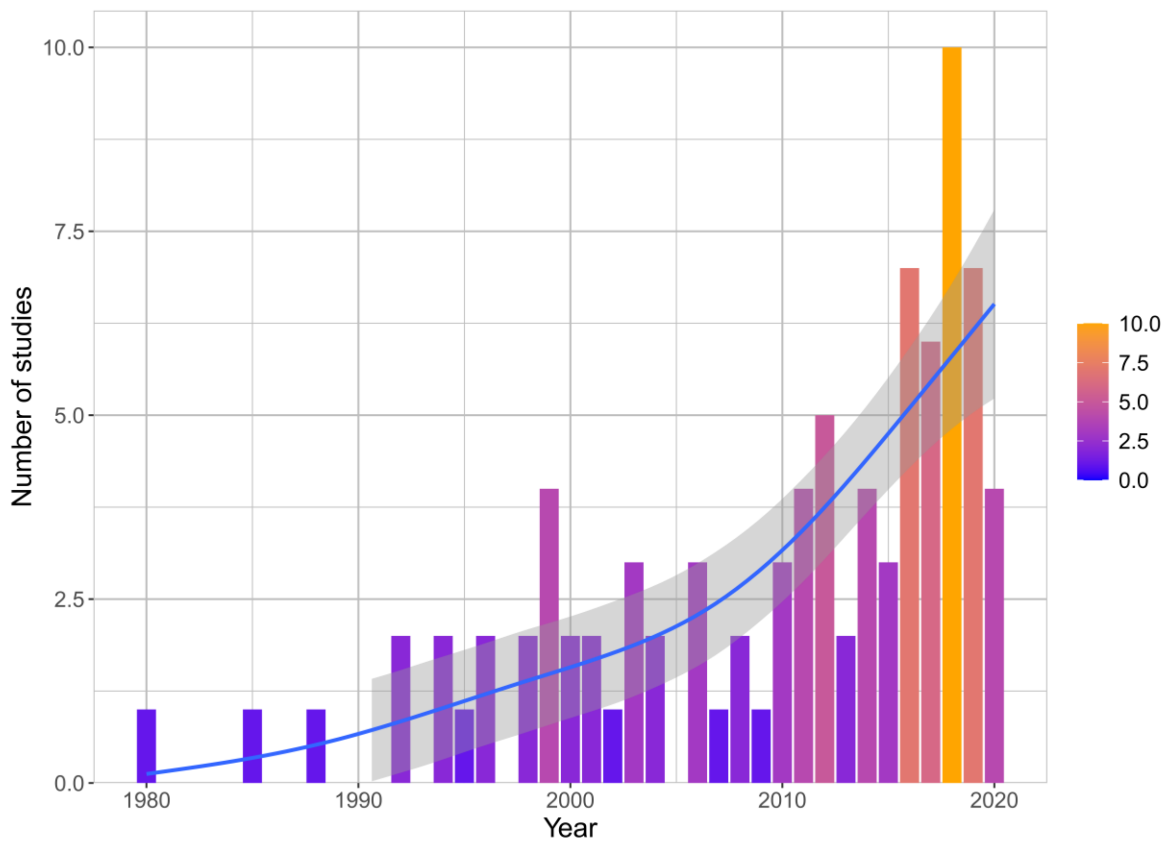

Figure 2. Annual number of studies on crop damage by vertebrates in Latin America from 1980 to 2020. The color gradient is proportional to the number of studies in each year. The blue line depicts the trendline and the shaded area represents the 95% confidence interval.

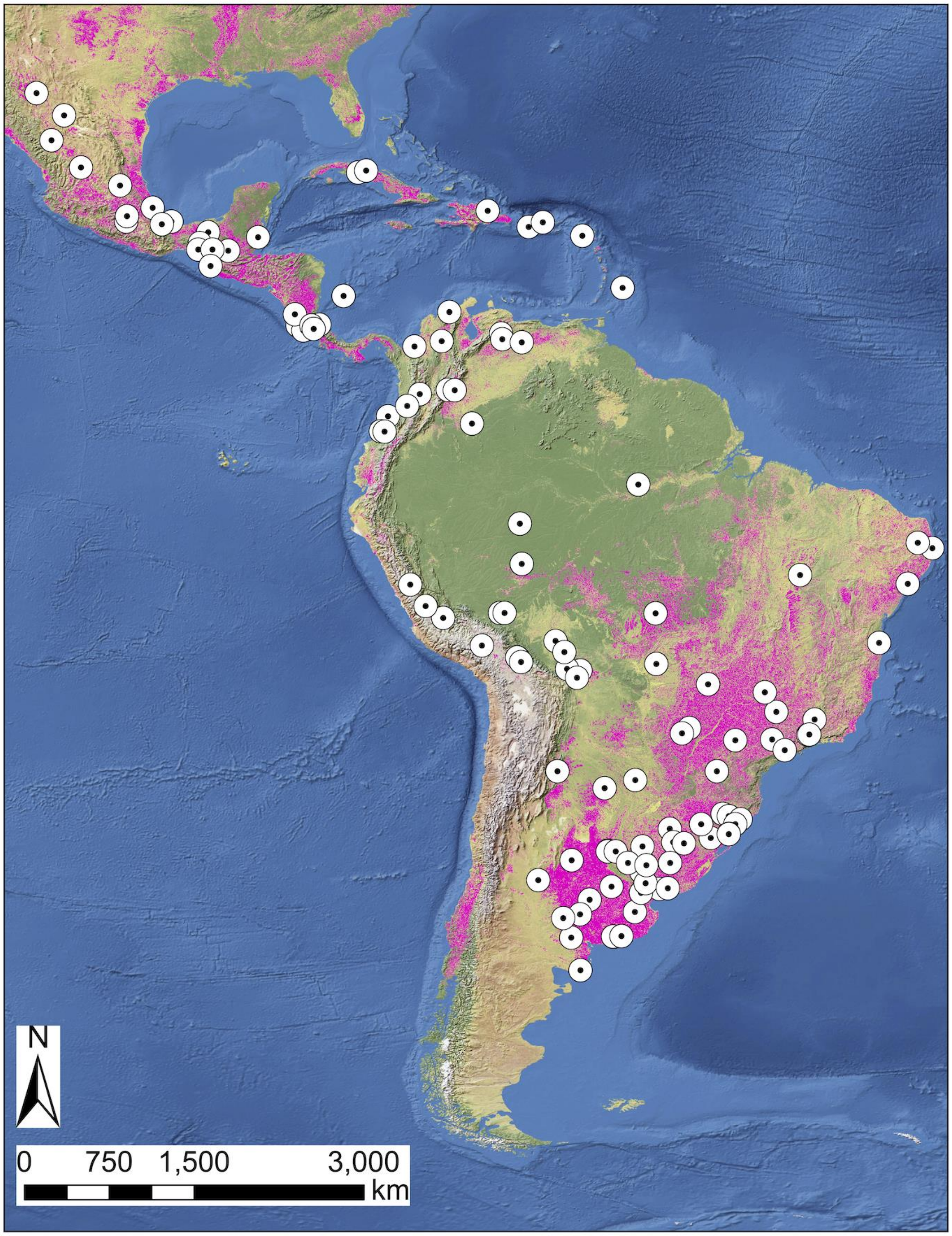

Figure 3. Spatial distribution of studies on crop damage by vertebrates in Latin America. The white circles represent the locations of the study sites for each article. The magenta areas represent surface covered by crops.

Type of crop plantations and studies

The majority of the studies were carried out on commercial plantations (n = 50, 57%), followed by subsistence or semi-subsistence plantations (n = 18, 20%). The remaining studies were conducted on experimental fields (n = 5), a harvesting concession (n = 1), a laboratory (n = 1), and areas for which we could not reliably determine the type of plantation (n = 13).

From the six categories that studies were categorized into depending on their focus the one that had the highest number of studies was "Crop damage evaluation" with 41 studies (47%), followed by "Farmer perception" with 34 studies (39%), and "Crop-feeding species behavior" with 23 studies (26%). The other three categories had fewer studies: "Crop protection experiment" and "Pest species or outbreak overview" that included 10 studies (11%) each, and "Protection technique evaluation" that had just five studies (6%) (Table S1).

Vertebrates and crops

A total of 201 crop-damaging vertebrate taxa were studied in the 88 reviewed studies, and all of them were mammals, birds, or reptiles (Table S2). The number of taxa included in each study varied greatly, ranging from 1 to 17, and 50 (57%) studies focused on a single vertebrate species. The mammal taxa represented nine different orders: Rodentia (52 taxa), Primates (12 taxa), Carnivora (11 taxa), Artiodactyla (7 taxa), Cingulata (6 taxa), Didelphimorphia (6 taxa), Lagomorpha (2 taxa), Perissodactyla (2 taxa), and Chiroptera (1 taxon). The bird taxa represented 10 orders: Passeriformes (58 taxa), Columbiformes (13 taxa), Psittaciformes (13 taxa), Anseriformes (6 taxa), Piciformes (5 taxa), Gruiformes (2 taxa), Galliformes (1 taxon), Cariamiformes (1 taxon), Cuculiformes (1 taxon) and Strigiformes (1 taxon). Finally, there was just one reptile taxon from the order Squamata

(Table S2). The most represented order among the reviewed studies was Rodentia with an importance value of 91, followed by Passeriformes (76), Columbiformes (34), Carnivora (26), Psittaciformes (22), Artiodactyla (21), and Primates (20) (Fig. 4). All other orders had an importance value below 10 (Fig. 4).

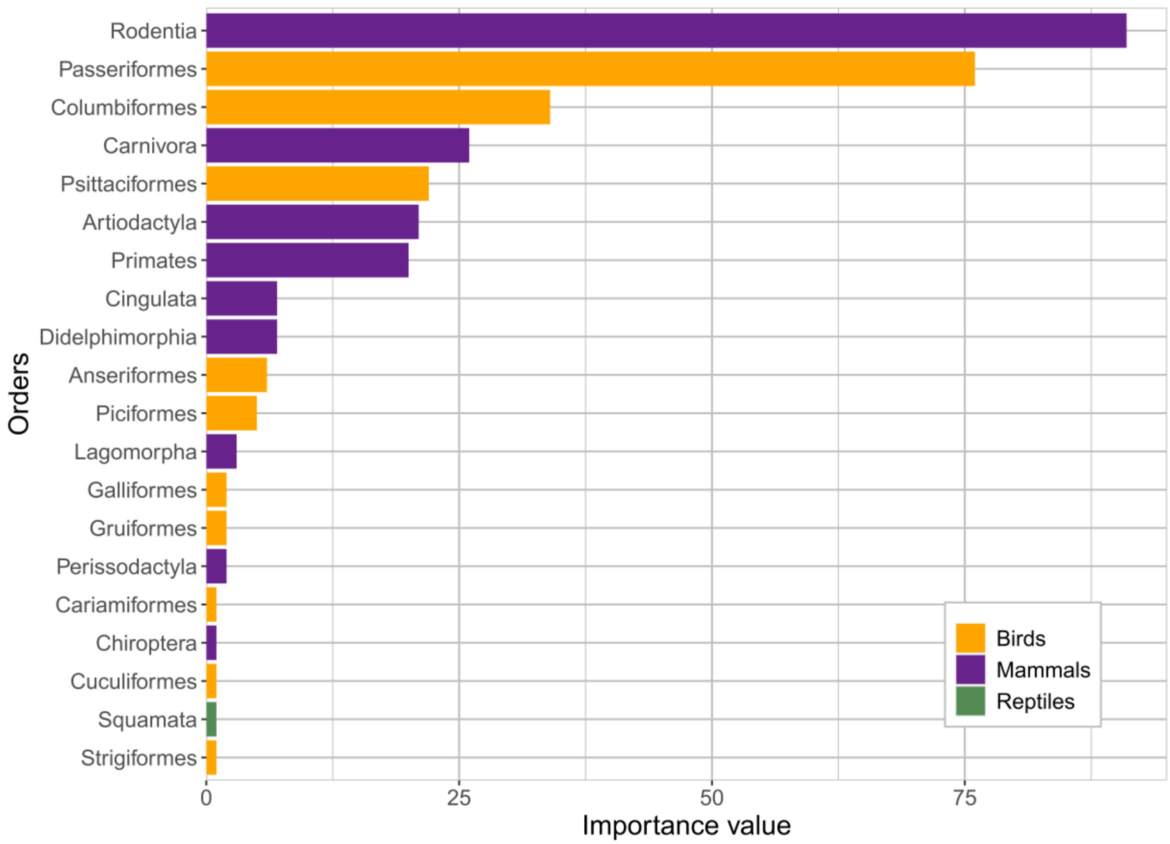

Figure 4. Importance value of the vertebrate orders represented in the studies. The importance value was calculated by counting the number of taxa of each vertebrate order featured in each article and then summing up the totals. Mammal, bird, and reptile orders are represented in purple, yellow, and green respectively.

Across all reviewed studies, 67 genera of crops were reported to suffer damages by vertebrates, with the number of genera per study varying from 1 to 31. Thirty-six studies included only one crop genus, and nine did not specify which crops were affected by vertebrates. The most prominent crop in the studies was corn (*Zea* sp.), which featured in 41 (47%) studies and interacted 16 of the 20 vertebrate orders represented in our review, but most predominantly with Artiodactyla, Rodentia, and Psittaciformes (in 14, 13, and 10 studies, respectively) (Fig. 5). The second most represented crop was rice (*Oryza* sp.), which appeared in 22 (25%) studies and was mainly damaged by Passeriformes and Rodentia (9 and 8 studies, respectively) (Fig. 5). Sorghum (*Sorgum* sp.) was reported to suffer damages in 17 (19%) studies, mainly by three bird orders: Columbiformes (6 studies) and, Passeriformes and Psittaciformes (4 studies each). Sugarcane (*Saccharum* sp.) was mentioned in 13 (15%) studies and interacted with three mammal orders: Primates (7 studies), Rodentia (5), and Artiodactyla (2) (Fig. 5). Both, soy (*Glycine* sp.) and bananas (*Musa* sp.), were mentioned in 12 (14%) studies each. Soy was damaged mostly by Columbiformes (5 studies) and Artiodactyla (3) (Fig. 5). Bananas interacted most with Primates (6 studies), Rodentia (4), and Carnivora (3) (Fig. 5). Wheat (*Triticum* sp.) was mentioned in 11 (13%) studies which reported damages mainly by Columbiformes (5 studies) and Psittaciformes (3). Beans (*Phaseolus* sp.) appeared in 10 (11%) studies and suffered damages caused mainly by Rodentia (4 studies) and Primates (3). Sunflowers (*Helianthus* sp.) and manioc (*Manihot* sp.) were included in 9 (10%) studies each. Sunflowers interacted mostly with Psittaciformes (5 studies) and Columbiformes (4). Finally, manioc was damaged mainly by Artiodactyla and Rodentia (5 studies each), and by Primates (3) (Fig. 5).

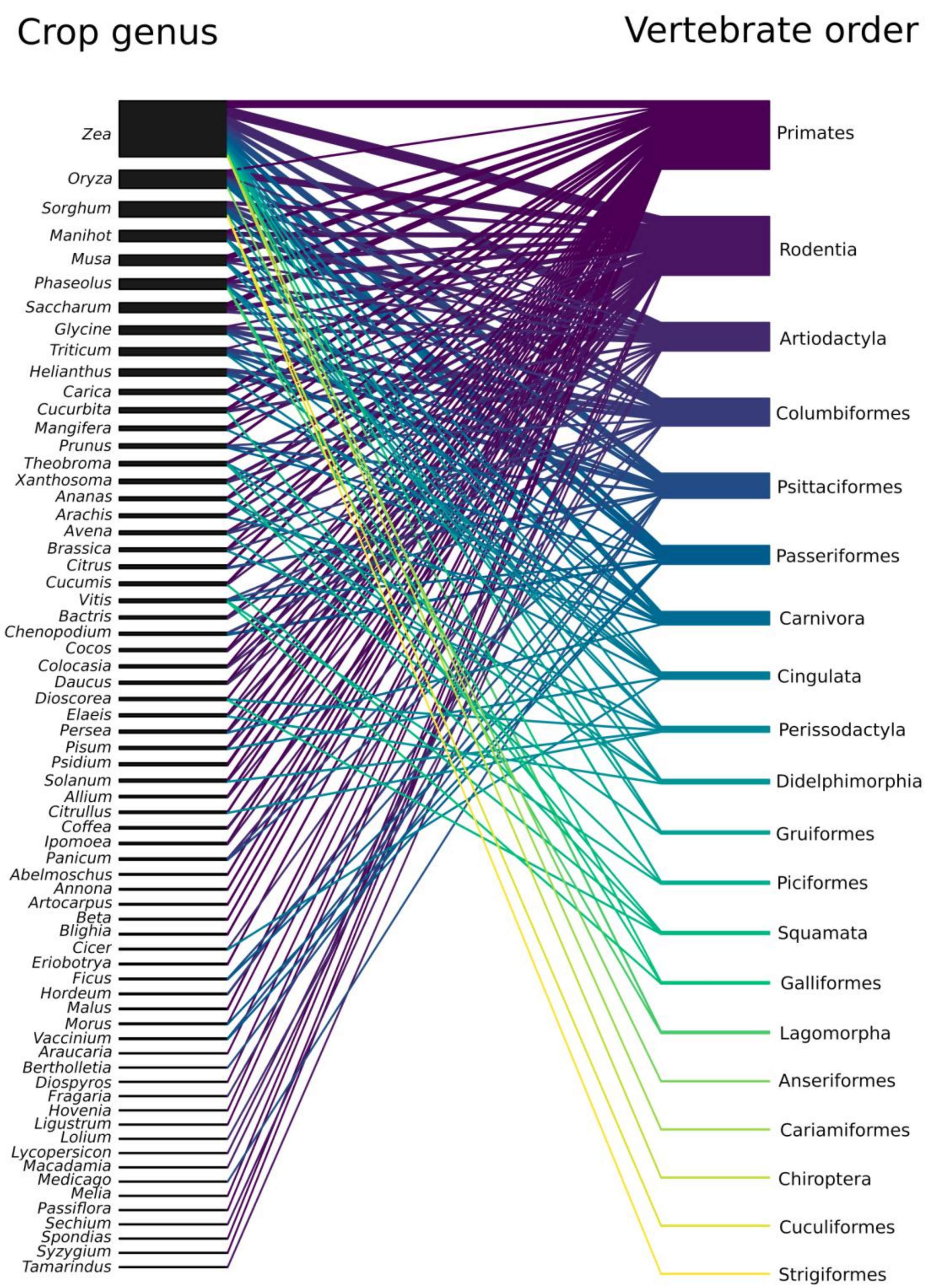

Figure 5. Network of interactions between vertebrate orders and crop genera found within the 88 studies included in this review. Each article in which a vertebrate order was documented to cause

damages to a crop genus is counted as one interaction. The width of the nodes is proportional to the number of interactions that each crop genus or vertebrate order had in total. Similarly, the width of each link is proportional to the number of interactions of its particular pair.

Of the 176 vertebrate taxa that could be identified at species level from our review, only 18 were not categorized as Least Concern (LC), being four species considered Endangered (EN), seven species considered Vulnerable (VU), five species categorized as Near Threatened (NT), and two as Data Deficient (DD) (IUCN, 2021). All threatened or DD species were mammals except for one psittacine species, *Amazona aestiva*, categorized as NT. The mammal species that are not categorized as LC are eight primates (EN - *Leontopithecus chrysomelas* and *Sapajus flavius*, VU - *Alouatta guariba, Alouatta palliata* and *Cebus capucinus*, NT - *Sapajus libidinosus, Sapajus nigritus*, and *Erythrocebus patas*), three rodents (EN - *Callistomys pictus*, VU - *Oryzomys laticeps* and DD - *Dasyprocta variegata*), one carnivore (VU - *Tremarctos ornatus*), two even-toed ungulates (VU - *Tayassu pecari* and DD - *Mazama americana*), two odd-toed ungulates (EN - *Tapirus bairdii* and VU - *Tapirus terrestris*) and one cingulate (NT - *Dasypus hybridus*) (IUCN, 2021).

Protection techniques

From the reviewed studies over half (n = 55, 63%) tested or mentioned a range of diverse techniques used to protect crops from vertebrates (Table S3). The most frequently used control method was hunting (either with weapons, dogs, or traps), which was mentioned in 29 (53%) of the studies that mentioned protection techniques (Fig. 6). Other techniques that were widely represented in the studies were the use of poisons and agricultural practices, which were reported in 19 (35%) studies each (Fig. 6). The following poisonous substances were reported: herbicides, rodenticides, organo-phosphide insecticides, sodium monofuroacetate, coumarin, pyriminil, diphacinone, biorat, estricinina, methyl bromide, metomil, aluminium phosphate, zinc phosphide, parathion, chlorpyrifons, monocrotophos, endrin, mevinphos, dicrotophos, CPT, CPTH, thallium sulfate, coumatetralyl, brodifacoum, and carbofuran. Agricultural practices included field clearing, time of planting or harvest, changing the location or the type of crops, altering the density of the crops, using barrier crops or firebreaks, and providing alternative food sources. Acoustic deterrents were reported in 14 (25%) studies (Fig. 6) and included firecrackers, gas cannons, firearms, yelling, sirens, predator sounds, distress calls, and horns. Visual deterrents were used in 12 (22%) studies (Fig. 6) and consisted of scarecrows, reflective objects, smoke, fire, flags, predator outlines, balloons, calcium carbonate paint, and carpenter's chalk. Chemical repellents were reported in 11 (20%) studies (Fig. 6) and included anthraquinone, methiocarb, methyl anthranilate, bidrim, thrimethacarb, dimethyl, methyl anthranilate, synergized aluminum, ammonium sulfate, copper oxalate, copper oxychloride, condensed tannins, avitrol, and soap. Vigilance by people or guard dogs was mentioned in 10 (18%) studies. Physical barriers such as nets, fences, electric fences, trenches, metal bands, and wire mesh were included in eight (15%) studies (Fig. 6). Biological control in the form of introducing infectious diseases, introducing or attracting predators, or reducing suitable habitat was mentioned in five (9%) studies (Fig. 6). Reproductive control and olfactory repellants were used in three (5%) studies each (Fig. 6). The kinds of reproductive control mentioned were the use of sterilants, nest burning, and egg destruction. The olfactory repellents mentioned were creolin, *Tabebuia* extract, and human odors. Capture and relocation was mentioned in two (4%) studies (Fig. 6). Finally, *Capsicum* as a palatable deterrent was used in one (2%) study (Fig. 6).

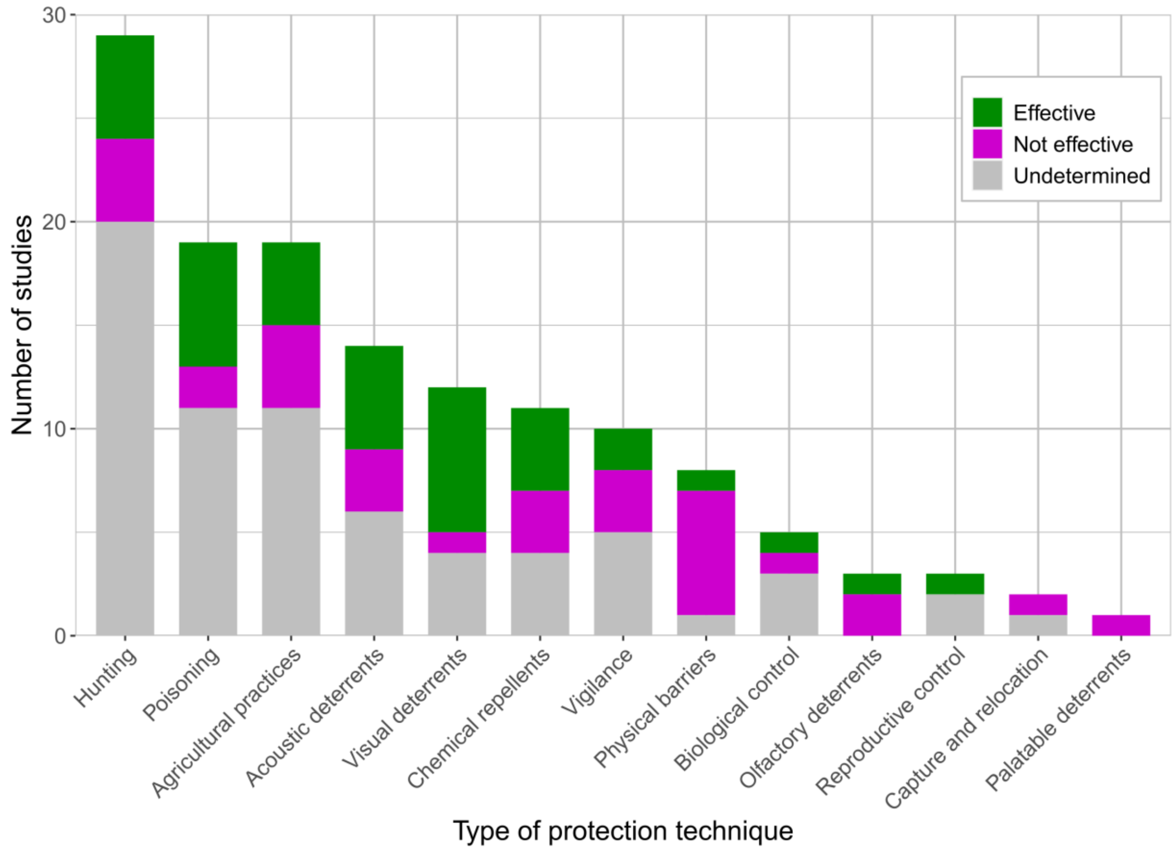

Figure 6. Number of studies that used or mentioned each type of crop protection technique. Grey color on the bars represents the proportion of studies that did not determine the effectiveness of the protection techniques, magenta represents the proportion of studies that determined the protection techniques to not be effective, and green represents the proportion of studies that determined the protection techniques to be effective.

Quality of the information reported

The methodology used to identify vertebrate taxa responsible for crop-feeding and to quantify damages to crops varied greatly among studies. The most common identification methods used were interviewing farmers and direct observation (n = 32 studies each), followed by interpretation of indirect signs (n = 19). Less used methods were usage of previous knowledge (n = 11), trapping or hunting (n = 9), looking at stomach or crop contents (n = 5), camera traps and radiotelemetry (n = 3 each), using distribution maps (n = 2), and using museum specimens and stable isotope analyses (n = 1 each). For quantifying crop damages the most common method used was measuring the proportion of damaged crops (i.e. area, plants, fruits, production), which was used in 35 studies. Interviews with local farmers were used to estimate crop damages in 22 studies. Seven studies estimated the economic cost of crop destruction, another six looked at stomach or crop contents, and two studies used models to predict damages.

Of the 55 studies that mentioned the use of protection techniques 24 provided an indication of their effectiveness, the other 31 studies only listed or alluded to damage control methods used in their settings (Fig. 6, Table S3). Of the 24 studies that did evaluate the effectiveness of the protection techniques only 10 did it by performing experiments and reporting their results. The remaining studies either conveyed effectiveness by asking farmers about it in surveys (8 studies), or the authors discussed the effectiveness of the control methods but did not perform experiments to test them (6 studies).

Discussion

Our literature review on crop damage by vertebrates across Latin America showed that (1) despite an increase in the number of studies published in the last decade this research topic is largely overlooked in the region; (2) several vertebrate taxa are involved in crop-feeding, but only a few orders were mostly represented in the reviewed studies; (3) despite the wide range of different types of crop protection techniques, lethal control by hunting or poisoning was the most prevalent; (4) only a fraction of the studies that mentioned protection techniques measured their effectiveness, and a minority performed scientific experiments. We first turn to describe the geographical and temporal distributions of studies, then we explore type of studies, interactions between vertebrates and crops, and protection techniques. Finally, we discuss further directions and implications of management that could help reduce crop damage and human-vertebrate conflicts in Latin America.

Geographic and temporal distribution of studies

Our results showed that crop damage by vertebrates in Central and South America did not receive much attention in the published literature before the year 2000, with most of the studies published after 2011. Considering the overall 2.3 fold increase in scientific literature production worldwide from 1,067,910 articles in 2000 to 2,554,373 articles in 2018 (World Bank Data, 2021b), the number of articles on vertebrate crop damage in Latin America is growing faster. Despite this increase in published articles, it is still an emerging discipline considering the projections of crop land expansion (Riahi et al., 2017), and the fact that in Latin America crop land cover and production is expanding, compared with a decrease in agricultural land cover in Europe and North America (Creutzig et al., 2019).

The country with the most studies was Brazil, which is likely a consequence of its large territorial area and extensive research production. Brazil is both, the largest country in Central and South America and the one that produces the largest amount of scientific and technical journal studies (60,148 in 2018, placing 18th world-wide) (World Bank Data, 2021b). Another important factor may be crop production rates, data for crop production (cereals fruits, vegetables, sugar crops, roots and tubers, treenuts, fibre crops, and oil crops) in 2019 places Brazil at the top of the list of Latin-American countries (FAO, 2021). Argentina and Mexico were the next two countries with the highest number of studies, both are also large countries with high scientific and crop production rates (FAO, 2021; World

Bank Data, 2021b). The studies in these two countries were focused on specific vertebrate groups. All but one of the studies conducted in Argentina were on crop damages by birds with two species being the most frequent: the eared dove (*Zenaida auriculata*) and the monk parakeet (*Myiopsitta monachus*). Meanwhile, half of the studies from Mexico focused on agricultural rodent pests.

Costa Rica is an interesting case, it has a small territorial area and scientific production compared with other countries in Central and South America (only 507 articles published in 2018) (World Bank Data, 2021b). Similarly, it is placed near the bottom for almost all crop categories produced in 2019 (FAO, 2021). Despite this, a relatively large number of studies on crop damages by vertebrates from the country have been published. Thus, our review indicated a higher interest on the topic of crop-feeding by vertebrates in Costa Rica when compared to the other countries in Latin America.

It is important to highlight that the number of published studies in a country is not directly proportional to the severity of the issue of crop damage by vertebrates, as there are many smaller countries that have little to no scientific production but have the conditions to potentially be the most affected by this type of human-wildlife conflict. Countries such as the Guianas, most Central American countries, and many Caribbean island-nations, had no published studies on the topic, but are simultaneously rich in wildlife biodiversity (Mittermeier et al., 2011; Myers et al., 2000), and have high rates of poverty (Fisher & Christopher, 2007; World Bank Data, 2021a). Crop-feeding is an ecosystem disservice derived from high biodiversity (Ango et al., 2014; Naughton-Treves et al., 2003), and it can damage the economy of already vulnerable communities (Gontse, Mbaiwa & Thakadu, 2018; Raphela & Pillay, 2021). The combination of these factors increases the risk of conflict between biodiversity conservation and food security (Molotoks et al., 2017). Therefore, research on crop-feeding should be performed in these countries in the future.

Type of crop plantations and studies

Over half of all studies from our review were concentrated in commercial crop plantations. This is somewhat expected as commercial plantations generally have much larger areas (Felix et al., 2014; Lima et al., 2019; Lobão & Nogueira-Filho, 2011) compared with smaller subsistence plantations (Can-Hernández et al., 2019; Chaves & Bicca-Marques, 2017; Naughton-Treves et al., 2003). Moreover, crop losses caused on subsistence plantations tend to be more tolerated by landowners as their main objective is not linked with profit (Chaves & Bicca-Marques, 2017; Rocha & Fortes, 2015; Spagnoletti et al., 2017). This also reflects on the tendency of landowners to use lethal control to protect their crops, as almost all the studies from commercial plantations that mentioned protection techniques included some kind of lethal control whereas in subsistence plantations, this proportion was much smaller. However, there are also examples of communities that engage in hunting to defend their subsistence crops (Can-Hernández et al., 2019; Cossios, Ridoutt & Donoso, 2018).

From all reviewed studies, almost half of them evaluated the magnitude of crop damage by vertebrates, but only 17% focused on crop protection techniques. Moreover, a large proportion of the studies used interviews with local farmers to collect data and evaluate their perceptions. This same method was the most used for the identification of crop-feeding vertebrates and the second most used method for the quantification of crop damages. However, interviews were only corroborated with alternative methods in few studies, which could be an inherent bias in the reported crop damage. Involving local communities and stakeholders in research can have positive effects for nature conservation (Beierle & Konisky, 2001; Young et al., 2013) and makes data collection over large areas possible (Michalski et al., 2020; Michalski & Peres, 2017). Farmer's perceptions and knowledge are a central part of studies on crop damage and conservation strategies. However, relaying on the perception of farmers on crop damage can be misleading as their ideas of which species are responsible for damaging crops or how extensive losses are may not properly reflect reality (Albarracín & Aliaga-Rossel, 2018; Flores-Armillas et al., 2020; Hill, 2004) and have been shown to not be proportional to the scale of the problem (Simonsen, Tombre & Madsen, 2017). Therefore, relying almost only on interviews of local farmers for data generation may result in an incorrect assessment of the conflict, which coupled with an exaggerated perception of damages caused by vertebrates may lead to an increase in the use of lethal methods for retaliation (Can-Hernández et al., 2019). Studies that perform field validation of crop damages are important and more effort towards some type of field validation must be allocated in future studies in this topic.

Vertebrates and crops

From all the 201 vertebrate taxa that were identified in the studies as causing crop damages, Rodentia was the order of vertebrates that had the highest importance value. Rodents have long been considered as some of the worst pests for crops worldwide (Lauret et al., 2020; Stenseth et al., 2003). This concurs with our results where they were shown to cause damages to 34 crop genera, affecting corn the most (Felix et al., 2014; Ferraz et al., 2003). Early studies on crop-damages and pest-control in Latin America focused on rodents (Espinoza & Rowe, 1979) and they have continued to be the main focus of research during the time period included in our review (Felix et al., 2014; Ferraz et al., 2003; Sánchez-Cordero & Martínez-Meyer, 2000; Santos, 2018). Rodents can cause extensive damage to crops and have often been the target of lethal control (Hilje, 1992; Villafaña Martín et al., 1999). Three rodent species (paca - *Cuniculus paca*, capybara - *Hydrochoerus hydrochaeris*, and hispid cotton rat – *Sigmodon hispidus*) were amongst the ones that appeared in the largest number of studies.

The second order of mammals with the highest importance value was Carnivora. Within this order, three species (*Nasua narica*, *Nasua nasua* and *Procyon lotor*), all belonging to the Procyonidae were recorded in several studies. These species were often among the most concerning for farmers (Castillo-Chinchilla et al., 2018) and among the most damaging species, particularly to corn (Can-Hernández et al., 2019; Flores-Armillas et al., 2020).

The Artiodactyla order appeared to be more generalist, affecting 18 different crop genera. They mostly interacted with corn and manioc, often causing extensive damages (Abrahams, Peres & Costa, 2018; Pérez & Pacheco, 2014; Romero-Balderas et al., 2006). Among the even-toed ungulates two species (collared peccary - *Pecari tajacu* and wild boars - *Sus scrofa*) had the highest number of appearances in all studies. Wild boars are invasive in much of the world including Latin America, they cause extensive crop damages worldwide (Bevins et al., 2014), and can have many deleterious effects on native biodiversity around the globe, even driving some species to extinction (Risch, Ringma & Price, 2021). In our review, all studies focusing on wild boars were from Brazil, where boars have been found to dominate local communities shortly after invasion (Doutel-Ribas et al., 2019) and consume large amounts of cultivated grains (Cervo & Guadagnin, 2020). Lethal methods for wild boar control have been legal in the country since 2013 and hunting is widespread (Rosa, Wallau & Pedrosa, 2018). Most farmers agree that the species should be eradicated (Pereira, Rosa & Zanzini, 2019).

Primates were the order that interacted with the highest number of crop genera (43), with corn being the top crop interaction followed by sugar cane and bananas. Primates feeding on crops was often perceived as tolerable by farmers and they rarely used lethal control measures against them (Chaves & Bicca-Marques, 2017; Lins & Ferreira, 2019; McKinney, 2019; Rocha & Fortes, 2015; Spagnoletti et al., 2017), this might be due to them often targeting crops that are not used commercially, which could favor a peaceful coexistence between humans and non-human primate crop-feeders (Chaves & Bicca-Marques, 2017; Rocha & Fortes, 2015; Spagnoletti et al., 2017). Tolerance of crop-feeding by primates might also be motivated by their resemblance of humans, which causes empathy (Dore, Eller & Eller, 2018; Rocha & Fortes, 2015). Lethal control of primates was only recorded in the case of invasive vervet monkeys (*Chlorocebus aethiops*) in Barbados, where they cause damages to a variety of crops and campaigns to reduce the population have been conducted (Boulton, Horrocks & Baulu, 1996). Lethal control of primates is also not frequent in Africa or Asia with most farmers using non-lethal techniques (Marchal & Hill, 2009; Mc Guinness & Taylor, 2014; Siljander et al., 2020).

Similarly to rodents, birds have long been considered agricultural pests and damages to crops by them causes concern globally (Anderson et al., 2013; de Mey, Demont & Diagne, 2012; Kale et al., 2014; Montràs-Janer et al., 2019). These perceptions have often motivated lethal control methods in an effort to reduce bird populations, however, these methods are often not successful (Linz et al., 2015). Among the studies included in this review the trend of negative perceptions by farmers and usage of lethal or reproductive control has continued (Basili & Temple, 1999; Bucher & Ranvaud, 2006; Canavelli, Swisher & Branch, 2013), although in some cases non-lethal protection techniques have been tested with positive results (Avery, Tillman & Laukert, 2001; Robles et al., 2003). Some studies have found that bird species that feed on crops such as sheldgeese (*Chloephaga* sp.) or mourning doves (*Zenaida macroura*) offset their negative impact by feeding on weeds, which benefits crop production (García & Peiró, 2016; Gorosábel et al., 2019).

Among birds, Passeriformes was the order with the highest importance value, being the second most recorded order overall after Rodentia. Despite this, none of its taxa appeared in more than three different studies and most of their interactions were concentrated on corn and rice. Columbiformes were reported to cause damages to a wider set of crop genera including corn, sorghum, wheat, soy, rice, and sunflowers. Two of the most prominent crop pests in Latin America belong to this order: the eared dove (*Zenaida auriculata*) that appeared in 12 studies, and two species of pigeons (*Patagioenas maculosa* and *P. picazuro*) that cumulatively appeared in nine studies. Damages by Psittaciformes were concentrated mostly on corn, followed by sunflowers. Another one of the main bird pest species in the continent is a psittacine, the monk parakeet (*Myiopsitta monachus*) that was reported in eight studies. These three pests (doves, pigeons, and parakeets) cause extensive damages to agricultural crops in many countries but their study has taken place mostly in Argentina and Uruguay where they have been the subject of many damage control methods (Bruggers, Rodriguez & Zaccagnini, 1998; Canavelli, Aramburú & Zaccagnini, 2012).

The Order that had the most threatened species was Primates. Thus, it is a good prospect for their conservation that farmers in Latin America tend to tolerate crop-feeding by primates and seldom use lethal control against them (Chaves & Bicca-Marques, 2017; Lins & Ferreira, 2019; McKinney, 2019). The other species that were not considered of least concern were not abundant in the literature, appearing in only one or two studies. However, even not being frequently cited in the revised literature, some of these species were reported to cause extensive damages or to be of great concern to farmers. For example, in a Peruvian study, the Brazilian tapir (*Tapirus terrestris*) was an infrequent crop-feeder but caused the largest proportion of damages per affected field, and it was hunted by locals to offset crop loses (Naughton-Treves et al., 2003). The cacao-rat (*Oryzomys laticeps*) was found to be the species that caused the most damages and generated the highest number of complaints from farmers in the Brazilian Atlantic Forest, where farmers used lethal control methods against it (Lobão & Nogueira-Filho, 2011). The white-lipped peccary (*Tayassu pecari*) causes damages to corn plantations in the Brazilian state of Mato Grosso, and farmers periodically cull the local population using firearms, traps, and mass poisoning (Lima et al., 2019). Lastly, the Andean bear (*Tremarctos ornatus*) caused low damages on banana and plantain crops in Colombia but generated strong negative attitudes among locals towards their presence and conservation efforts (Escobar-Lasso et al., 2020). The human-wildlife conflicts in which these threatened species are involved may hinder conservation efforts by reducing the tolerance of local farmers to them and motivating lethal control.

Protection techniques

In our review, many types of crop protection techniques were reported, but lethal control of crop-feeding populations, associated with hunting and poisoning, was the most used protection method. Farmers may turn to lethal control after trying other protection techniques without success (Lima et al., 2019), and they tend to perceive hunting or poisoning as the most effective damage control methods (Abrahams, Peres & Costa, 2018; Canavelli, Swisher & Branch, 2013; Lima et al., 2019). Despite this, few studies provided reliable evidence that lethal control effectively reduces crop damages. From the 29 studies that reported hunting as a control measure only nine evaluated its effectiveness and only one of them managed to perform experiments. Pérez & Pacheco (2014) reported a reduction on crop damages (from 27.61% to 4.59%) in hunted crop fields when compared to control plots, but the effectiveness of hunting was only slightly better that when using non-lethal alternatives (combination of agricultural practices, olfactory and visual deterrents, and vigilance).

The use of hunting as the main technique to reduce crop damages poses a series of problems. Firstly, many of the most prevalent crop-feeders are species that have short life cycles and high reproductive rates, such as rodents, which makes them able to recover faster from reductions in population size (Hein & Jacob, 2015). Hunting may also cause targeted species to modify their movement patterns and activity regimes (Béchet et al., 2003; Keuling, Stier & Roth, 2008; Little et al., 2016; McGrath, Terhune II & Martin, 2018), which might alter the area and intensity in which they cause crop damages. Lastly, trapping has been reported to be the most effective way of hunting to reduce vertebrate populations, but acquiring and maintaining traps can be costly economically and in terms of human labor (Rosa, Wallau & Pedrosa, 2018). Even in situations where hunting is not an effective method to protect crops, it can provide farmers with alternative sources of food or income (Naughton-Treves et al., 2003) or grant social status (Cossios, Ridoutt & Donoso, 2018), which could explain its popularity as a protection technique among farmers.

The effectiveness of the use of poisons to control crop damages was evaluated in eight out of 19 studies that mentioned it. Six of the studies deemed that the use of poisons is effective in reducing crop damages, three of which did it by performing experiments. Generally, poisons are considered an easy way to reduce populations of crop-feeding species, but their use can cause several environmental problems. Vulnerable species can be seriously harmed when targeted using poisons. Lima et al. (2019) received reports of hundreds of white-lipped peccaries (*Tayassu pecari*) being killed at once through the use of poisonous substances. Similarly, bird species that roost in large groups, such as Dickcissels (*Spiza americana*), can be killed by the thousands when their nesting sites or watering holes are poisoned (Basili & Temple, 1999). Furthermore, poisons can also have severe consequences for non-target species that may consume them (Lima et al., 2019) and for carnivores and scavengers that feed on the carcasses of poisoned animals (Baudrot et al., 2020; Kalaivanan et al., 2011). Additionally to the dangers that chemical pesticides pose for the environment, they can also be a serious threat to the health of human workers and consumers (Rani et al., 2021).

In order to protect the environment and native wildlife as well as the interests of local communities, alternative methods to lethal control need to be tested and developed. From our review, only seven studies performed experiments to test the effectiveness of non-lethal crop protection techniques. Wire mesh exclosures significantly reduced damage by wildlife to manioc and walusa but not to corn in Bolivia (Pérez & Pacheco, 2006). Some laboratory experiments on Dickcissels captured in Venezuela tested the effectiveness of chemical repellents in reducing rice consumption, and found that both methiocarb and anthraquinone reduced consumption by 70% (Avery, Tillman & Laukert, 2001). Mitchell & Bruggers (1985) also tested the effectiveness of Methiocarb as a chemical repellent, as well as olfactory (*Tabebuia* extract) and visual (blue carpenter's chalk) deterrents in reducing damages to cacao by woodpeckers in the Dominican Republic, but their results were inconclusive. Rodriguez et al. (1995) compared the effectiveness of methiocarb with that of a visual deterrent (calcium carbonate paint) in reducing eared dove damages to sunflowers and found that the latter was much more effective. Robles et al. (2003) found that using reflective objects as a visual deterrent was more effective in reducing bird damages to quinoa than the chemical repellent Bidrim. The effectiveness of a palatable repellent (*Capsicum*) and an olfactory repellent (Creolin) in reducing wildlife damages to corn in Colombia were tested, but no significant differences between treatments and control were found (Castillo-López et al., 2017). Thus, the use of non-lethal control techniques has been little tested and explored and it should be advanced in order to promote the maintenance of biodiversity and safety of crop plantations either for commercial or subsistence use.

The results of our literature review point out to a gap in knowledge about vertebrate-crop conflicts in Latin America. However, it is important to highlight that there are two aspects of the methodology that we followed that could bias our results. Firstly, we did not include most kinds of grey literature in our review, and there might be more knowledge on the topic to be found on reports, and MSc or PhD theses that are not published in scientific journals. However, conference proceeding were included in our review to minimize this bias (McAuley et al., 2000). Another shortcoming of our methodology is that we only performed searches using terms in English, while this is the main language used for scientific communication and publication it is not the predominant language spoken in Latin America. We did include studies that were returned by searches using terms in English but were written in Spanish, Portuguese or French. However, there could be more studies on the topic that would only be found by performing searches using terms in languages spoken in Latin America. Despite these limitations, we believe that our review offers an accurate depiction of the published scientific literature on the topic of crop damages by vertebrates in Latin America.

Implications for management and future directions

Human-wildlife conflicts are now a more pressing topic than ever, due to the simultaneous reduction of natural spaces and global human population growth. Damages to crops are one of the most prominent reasons for conflict since it affects the food security and economy of local communities. Despite this, the study of crop-feeding by vertebrates in Central and South America is still emerging and the body of literature on the topic is still limited. There is a lack of standardized methodologies to perform studies on crop damages, an over-reliance on farmer perceptions, and a lack of consensus over which protection techniques are preferable. From our review, only 10 studies in the last four decades performed experiments to test the effectiveness of crop protection techniques, seven of which tested non-lethal methods. There is a tendency for farmers to prefer lethal control methods that can endanger vertebrate populations, harm the environment, and affect human health. We consider that there is a need to start testing non-lethal crop protection techniques in Latin America, as it is already happening in Africa or Asia. Reliable and extensive experimentation should be carried out in different settings across Latin America to test which techniques work on the different groups of vertebrates and crops that are involved in crop-feeding in the region.

Finding techniques that effectively protect crops from vertebrates without killing them is essential to solving this type of conflicts in a way that preserves both the environment and the interests of local communities. However, crop protection alone will not be able to solve the issue as it is only treating the symptoms and not the cause of the problem. Effective non-lethal protection methods need to be combined with a reduction of natural habitat loss and fragmentation so that wild animals do not have to turn to agricultural products for food. Pairing effective non-lethal crop protection techniques with the conservation of natural spaces will reduce human-wildlife conflicts and help improve the quality of life of local communities while protecting native wildlife. This is a difficult challenge due to the current levels of population growth, production systems, and lifestyles that demand an ever-increasing amount of land for food production worldwide. Global development needs to shift to a more sustainable pathway by applying far-reaching systemic changes to food production and consumption that decrease the amount of land surface needed for agriculture and allow us to share the land with natural areas where wildlife can survive without generating conflict with humans.

Conclusions

Research on crop damages by vertebrates in Latin America is scarce but our review of the published literature did provide some relevant insights. Most of the studies published on the last four decades were concentrated in a few countries (Brazil, Argentina, Mexico, and Costa Rica), and we suggest that studies on the subject should be carried out in other countries of Latin America that could potentially be greatly affected by crop-feeding. Vertebrates from 20 orders were involved in crop-feeding and seven of them were the most represented (Rodentia, Passeriformes, Columbiformes, Carnivora, Psittaciformes, Artiodactyla, and Primates). Damages were reported to 67 genera of crops, but most interactions were concentrated on just 10, with corn being the most prominent. Lethal control methods were favored by farmers and are perceived as the most effective way to reduce crop damages by vertebrates. However, most studies did not quantify the effectiveness of protection techniques, and only a minority tested protection methods through experimentation, while many relied on farmer perceptions. Lethal control can have negative consequences for wildlife, the environment, and human health. There is a need to find effective non-lethal protection techniques that minimize damage to wildlife and protect local economies. In order to achieve it, methodologies for the study of crop-feeding need to be standardized, and wide-spread experimentation needs to be performed across Latin America and other regions across the globe.

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Supporting Information

Table S1: List of the 88 reviewed studies with geographical data.

Including information on the type of study that they are, their country, whether coordinates and a map of the study area are provided, the coordinates of the locations plotted in Figure 3, and notes about how these coordinates were obtained.

Study	**Type of study**	**Country**	**Exact Coordinates**	**Map provided**	**Plotted locations (Latitude, longitude)**	**Notes**
Abba et al. (2015)	Crop-feeding species behavior	Argentina	No	Yes	-34.4169, -60.4072 -35.4281, -62.1458 -36.6042, -62.9100 -36.4214, -58.5411 -38.3842, -60.2508	Approximate middle point for each of the regions found using Google Earth, based on provided map.
Abrahams et al. (2018)	Crop damage evaluation, Farmer perception	Brazil	No	Yes	-5.5544, -67.7015	Approximate middle point found using Google Earth, based on provided map.
Albarracín and Aliaga-Rossel (2018)	Crop damage evaluation, Farmer perception	Bolivia	No	Yes	-16.5669, -67.6094	Approximate middle point found using GE.
de Almeida-Jácomo et al. (2013)	Crop-feeding species behavior	Brazil	Yes	Yes	-18.3167, -52.7500	-
Aris et al. (2008)	Farmer	Peru	Yes	No	-13.0614, -73.7769	Locations within 50

Study	Type of study	Country	Exact Coordinates	Map provided	Plotted locations (Latitude, longitude)	Notes
	perception					km of each other, Approximate middle point found using Google Earth.
Arroyo-Quiroz et al. (2017)	Farmer perception	Mexico	No	Yes	21.3050, -99.4564	Approximate location found using GE, based on named reserve.
Avery et al. (2001)	Crop protection experiment	Venezuela	No	No	9.5440, -69.1864	Ex-situ experiment, approximate location of where birds where captured found using Google Earth.
Barceló et al. (2012)	Farmer perception	Mexico	No	Yes	28.6562, -106.1021 26.8883, -103.9347 24.9104, -104.9132 22.7636, -102.5886	Approximate locations found using GE, based on named places.
Basili and Temple (1999a)	Crop damage evaluation, Farmer perception	Venezuela	No	No	9.0950, -69.0992	Approximate location found using Google Earth, based on named region.
Basili and Temple (1999b)	Crop-feeding species behavior, Farmer perception	Venezuela	No	Yes	9.0950, -69.0992	Approximate location found using Google Earth, based on named region.
Berón et al. (2020)	Crop damage evaluation	Argentina	Yes	Yes	-31.5550, -60.6769	-
Bou et al. (2016)	Crop damage evaluation	Uruguay	No	Yes	-31.9892, -58.1075 -32.5636, -57.9856 -33.2633, -58.0219	Approximate locations found using Google Earth, based on

Study	Type of study	Country	Exact Coordinates	Map provided	Plotted locations (Latitude, longitude)	Notes
					-34.2083, -57.6803 -34.5911, -56.6089	provided map.
Boulton et al. (1996)	Crop damage evaluation, Farmer perception	Barbados	No	Yes	13.1882, -59.5353	Country-wide study, used central point for Barbados.
Bruggers et al. (1998)	Pest species or outbreak overview	Argentina, Uruguay	No	Yes	-31.2167, -57.9333	Approximate location found using GE, based on named region.
Bucher and Ranvaud (2006)	Pest species or outbreak overview	Argentina, Colombia, Uruguay, Bolivia, Brazil	No	No	-32.2953, -63.5825 -32.5169, -59.1042 -33.8761, -66.2375 -26.5847, -60.9542 -25.2489, -64.7183 3.8025, -76.6431 -17.8131, -63.1575 -23.5528, -46.6411 -25.2406, -52.0297	Approximate locations found using GE, based on named regions.
Calamari et al. (2018)	Crop-feeding species behavior	Argentina	No	Yes	-31.6181, -60.7063	Approximate middle point of study region found using GE.
Canavelli et al. (2012)	Pest species or outbreak overview, Protection technique evaluation	Argentina	No	Yes	-38.4530, -63.5989	Country-wide study, used central point for Argentina.
Canavelli et al. (2013)	Farmer perception	Argentina	No	No	-31.6125, -60.0783	Approximate location found using Google

Study	Type of study	Country	Exact Coordinates	Map provided	Plotted locations (Latitude, longitude)	Notes
						Earth, based on named region.
Canavelli et al. (2014)	Crop damage evaluation	Argentina	No	Yes	-31.6125, -60.0783	Approximate location found using GE, based on named region.
Can-Hernandez et al. (2019)	Farmer perception, Crop damage evaluation	Mexico	No	Yes	17.5911, -92.4550	Locations within 50 km of each other, approximate middle point found using Google Earth.
de Carvalho et al. (2019)	Farmer perception	Brazil	No	Yes	-21.1311, -44.2533	Approximate middle point found using Google Earth, based on provided map.
Castillo-Chinchilla et al. (2018)	Farmer perception	Costa Rica	Yes	Yes	10.1900, -85.3644	-
Castillo-Lopez et al. (2017)	Crop protection experiment, Farmer perception, Crop damage evaluation	Colombia	No	No	5.0773, -73.4215	Locations within 50 km of each other, approximate middle point found using Google Earth, based on named cities.
Cervo and Guadagnin (2020)	Crop-feeding species behavior	Brazil	No	Yes	-16.7197, -56.8389 -28.6318, -51.5735 -28.7965, -51.0955 -29.0479, -50.1435 -29.4419, -50.5797 -29.7914, -55.7813	Approximate locations found using Google Earth, based on named cities.

Study	Type of study	Country	Exact Coordinates	Map provided	Plotted locations (Latitude, longitude)	Notes
					-30.8722, -55.5208 -30.9734, -54.6670 -30.5459, -52.5247	
Chaves and Bicca-Marques (2017)	Crop damage evaluation, Crop-feeding species behavior, Farmer perception	Brazil	Yes	Yes	-30.1985, -51.0915	Locations within 50 km of each other, approximate middle point found using Google Earth.
Cornejo (2000)	Crop damage evaluation, Crop protection experiment	Mexico	No	No	19.54205, -96.884908	Approximate location found using GE, based on named city.
Corrêa et al. (2018)	Crop-feeding species behavior	Brazil	Yes	Yes	-30.2392, -51.0897	-
Cossios et al. (2018)	Farmer perception	Peru	Yes	Yes	-10.4076, -76.3943	Locations within 50 km of each other, approximate middle point found using Google Earth.
Costán & Sarasola (2017)	Crop-feeding species behavior	Argentina	Yes	No	-36.9136, -64.2614	-
Dardanelli et al. (2016)	Crop-feeding species behavior	Argentina	No	Yes	-32.5169, -59.1042	Approximate location found using GE, based on named region.
Dore et al. (2018)	Farmer perception	Saint Kitts and Nevis	No	Yes	17.3154, -62.7428	Island-wide study, approximate middle-point found using GE.
Doutel-Ribas et	Protection	Brazil	Yes	Yes	-21.5454, -54.2273	Locations within 50

Study	Type of study	Country	Exact Coordinates	Map provided	Plotted locations (Latitude, longitude)	Notes
al. (2019)	technique evaluation, Crop-feeding species behavior					km of each other, Approximate middle point found using Google Earth.
Eiris and Barreto (2009)	Crop-feeding species behavior	Venezuela	Yes	No	8.8453, -67.5428	-
Engeman et al. (2010)	Farmer perception, Crop damage evaluation	Puerto Rico	No	No	18.0383, -67.0061	Approximate location found using GE, based on named region.
Escobar-Lasso et al. (2020)	Farmer perception, Crop damage evaluation	Colombia	No	Yes	4.7283, -75.6361	Approximate locations found using Google Earth, based on provided map.
Felix et al. (2014)	Crop damage evaluation, Crop-feeding species behavior, Farmer perception	Brazil	Yes	Yes	-22.2217, -54.8064	-
Ferraz et al. (2003)	Crop damage evaluation	Brazil	Yes	Yes	-22.7083, -47.6417	-
Flores-Armillas et al. (2020)	Farmer perception, Crop damage evaluation	Mexico	No	Yes	18.4640, -98.9731	Approximate middle point found using Google Earth.
de Freitas et al. (2008)	Crop-feeding species behavior	Brazil	No	No	-20.5125, -47.3083	Approximate middle point found using Google Earth.

Study	Type of study	Country	Exact Coordinates	Map provided	Plotted locations (Latitude, longitude)	Notes
García and Peiró (2016)	Crop-feeding species behavior, Crop damage evaluation	Cuba	Yes	Yes	22.3634, -80.557167	-
Gonzalez and Acosta-Perez (2002)	Crop damage evaluation	Mexico	No	No	18.8729, -98.9141	Approximate location found using GE, based on named city.
Gorosábel et al. (2019)	Crop damage evaluation	Argentina	Yes	No	-38.3739, -60.2797 -38.3480, -59.6183	-
Hilje (1992)	Pest species or outbreak overview	Costa Rica	No	No	9.9168, -84.0743	Country-wide study, used central point for Costa Rica
Horrocks and Baulu (1988)	Protection technique evaluation	Barbados	No	No	13.1882, -59.5353	Country-wide study, used central point for Barbados.
Horrocks and Baulu (1994)	Farmer perception, Crop damage evaluation	Barbados	No	No	13.1882, -59.5353	Country-wide study, used central point for Barbados.
Ibañez et al. (2016)	Crop damage evaluation	Argentina	Yes	No	-34.8833, -58.0667	-
Key and de la Piedra Constantino (1992)	Protection technique evaluation	Mexico	No	Yes	16.7460, -93.1296 16.2351, -93.2563 16.2327, -92.1304 14.9114, -92.2780	Approximate locations found using GE, based on named cities.
Lima et al. (2019)	Pest species or outbreak overview, Farmer	Brazil	No	Yes	-12.6764, -56.9236	State-wide study, used approximate central point of Mato Grosso, found using Google

Study	Type of study	Country	Exact Coordinates	Map provided	Plotted locations (Latitude, longitude)	Notes
	perception					Earth.
Lins and Ferreira (2018)	Crop-feeding species behavior	Brazil	Yes	No	-7.5164, -34.9203	Error in provided coordinates, approximate location found using Google Earth, based on mentioned city.
Lobão and Nogueira-Filho (2011)	Crop damage evaluation, Farmer perception	Brazil	Yes	No	-15.0308, -39.1611	Locations within 50km of each other, approximate middle point found using Google Earth.
López-Torres et al. (2012)	Crop-feeding species behavior	Puerto Rico	Yes	Yes	18.3915, -65.8611	Locations within 50 km of each other, approximate middle point found using GE.
Loza-del-Carpio et al. (2016)	Crop damage evaluation	Peru	Yes	No	-15.2333, -70.7167	-
Marchand (2016)	Farmer perception	Brazil	No	Yes	-2.4546, -58.2689	Locations within 50 km of each other, Approximate middle point found using Google Earth, based on provided map.
McKinney (2011)	Crop-feeding species behavior	Costa Rica	Yes	Yes	9.7956, -84.9208	-
McKinney (2019)	Crop-feeding species behavior	Costa Rica	No	Yes	9.7956, -84.9208	Coordinates taken from another study by the same author in the

Study	Type of study	Country	Exact Coordinates	Map provided	Plotted locations (Latitude, longitude)	Notes
						same wildlife refuge.
Melo and Cheschini (2012)	Crop damage evaluation	Brazil	No	No	-18.9488, -48.2174	Approximate location found using GE, based on named place
Mendonça et al. (2011)	Farmer perception	Brazil	Yes	Yes	-7.0767, -36.0611	-
Mitchell and Bruggers (1985)	Crop damage evaluation, Crop protection experiment	Dominican Republic	No	No	19.2981, -70.2564	Approximate location found using Google Earth, based on named city.
Monge (1999)	Crop damage evaluation	Costa Rica	No	Yes	9.9168, -84.0743	Country-wide study, used central point for Costa Rica.
Monge-Meza (2011)	Pest species or outbreak overview	Costa Rica	No	Yes	10.2489, -83.6392	Approximate location found using Google Earth, based on named region.
Monge-Meza and Orozco (2010)	Crop damage evaluation	Costa Rica	Yes	No	11.0667, -85.5833	-
Monge-Meza et al. (2014)	Crop damage evaluation	Costa Rica	Yes	No	10.1833, -84.2667	-
Naughton-Treves et al. (2003)	Crop-feeding species behavior, Crop damage evaluation	Peru	No	Yes	-12.6564, -69.2710	Approximate location found using Google Earth, based on provided map.
Parra et al. (2012)	Crop damage evaluation	Venezuela	Yes	No	-8.7500, -67.5333	-
Pereira et al.	Farmer	Brazil	No	Yes	-22.2971, -44.7009	Locations within

Study	Type of study	Country	Exact Coordinates	Map provided	Plotted locations (Latitude, longitude)	Notes
(2019)	perception					50km of each other, approximate middle point found using Google Earth.
Pérez and Pacheco (2006)	Crop protection experiment, Crop damage evaluation	Bolivia	No	Yes	-16.2034, -67.8367	Approximate middle point found using Google Earth, based on named town.
Pérez and Pacheco (2014)	Crop protection experiment, Crop damage evaluation	Bolivia	No	No	-16.1986, -67.8994	Approximate middle point found using Google Earth, based on places named in article.
Ranvaud et al. (2001)	Crop-feeding species behavior	Brazil	Yes	Yes	-22.7833, -50.5833	-
Renfrew and Saavedra (2007)	Crop-feeding species behavior, Farmer perception	Bolivia	Yes	Yes	-17.2186, -62.8952 -17.1133, -63.9375 -14.8797, -64.8525	Locations in each area within 50km of each other, approximate middle points found using Google Earth, based on study site coordinates.
Renfrew et al. (2017)	Crop-feeding species behavior	Argentina, Bolivia	Yes	No	-15.7610, -64.1570 -25.9240, -58.5350	-
Robles et al. (2003)	Crop damage evaluation, Crop protection experiment	Peru	Yes	No	-12.1167, -75.2000	-
Rocha and	Farmer	Brazil	Yes	No	-29.4472, -53.2806	-

Study	Type of study	Country	Exact Coordinates	Map provided	Plotted locations (Latitude, longitude)	Notes
Fortes (2015)	perception					
Rodriguez and Avery (1996)	Pest species or outbreak overview	Uruguay	No	No	-32.5228, -55.7672	Country-wide study, used central point for Uruguay.
Rodriguez et al. (1995)	Crop protection experiment, Crop damage evaluation	Uruguay	No	No	-34.1209, -57.7018 -32.6984, -57.6357	Approximate locations found using GE, based on named cities.
Rodriguez et al. (2004)	Farmer perception, Crop damage evaluation	Uruguay	No	No	-34.5425, -55.9434	Approximate location found using GE, based on named region.
Romero-Balderas et al. (2006)	Crop damage evaluation, Farmer perception	Mexico	No	Yes	16.1370, -90.8916	Locations within 50 km of each other, Approximate middle point found using Google Earth, based on provided map.
Rosa et al. (2018)	Protection technique evaluation	Brazil	Yes	Yes	-22.3500, -44.7833 -30.8833, -55.5167	-
Sanchez et al. (2016)	Crop damage evaluation	Argentina	No	Yes	-41.0461, -62.8730	Approximate location found using Google Earth, based on provided map.
Sanchez-Cordero and Martinez-Meyer (2000)	Pest species or outbreak overview	Mexico	No	Yes	18.4572, -95.3997	Study involves the whole state, location of central point of the state.

Study	Type of study	Country	Exact Coordinates	Map provided	Plotted locations (Latitude, longitude)	Notes
Santos (2018)	Pest species or outbreak overview, Farmer perception	Brazil	No	No	-10.3326, -36.8667	Approximate location found using Google Earth, based on named region.
Saucedo et al. (2010)	Farmer perception, Crop damage evaluation	Cuba	No	Yes	22.4950, -79.9206	Approximate location found using GE, based on named region.
Spagnoletti et al. (2017)	Farmer perception, Crop damage evaluation	Brazil	Yes	Yes	-9.6313, -45.4303	Locations within 50km of each other, approximate middle point found using Google Earth.
Trivedi et al. (2004)	Crop damage evaluation	Peru	Yes	No	-12.6508, -68.9278	-
Valencia (1980)	Crop damage evaluation, Crop protection experiment	Colombia	No	Yes	12.5405, -81.7043 2.9683, -78.1844 1.7874, -78.7648 11.2724, -73.3093	Approximate locations found using GE, based on provided map.
Valencia et al. (1994)	Pest species or outbreak overview	Colombia	No	Yes	12.5405, -81.7043 1.7569, -78.4639 2.3992, -71.4950 5.0567, -72.8864 8.5331, -76.0842 8.9544, -73.9036	Approximate locations found using GE, based on provided map.
Villa et al. (1998)	Crop-feeding species behavior	Mexico	No	No	18.2386, -96.1417	Approximate middle point found using GE.
Villafana-Martin	Crop protection	Costa Rica	No	No	9.91681, -84.07426	No location

Study	Type of study	Country	Exact Coordinates	Map provided	Plotted locations (Latitude, longitude)	Notes
et al. (1999)	experiment					information provided. Used central point for Costa Rica, found using Google Earth.
Waters (2015)	Farmer perception	Belize	No	No	17.19167, -88.49889	Country-wide study. Used approximate central point for Belize, found using Google Earth.

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Table S2: List of vertebrate species reported to produce crop damages across the 88 reviewed studies.

Including information on the number of studies they appear on, the crop genera they interact with and the protection techniques that have been used on them.

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	Not effective	Undetermined
Mammals / Artiodactyla	*Mazama americana*	1	*Manihot*	-	-	Hunting (Weapons, Dogs, Traps), Vigilance (People), Visual deterrents (Scarecrows), Agricultural practices (Field clearing, Firebreaks), Physical barriers (Netting), Acoustic deterrents (Yelling)
Mammals / Artiodactyla	*Mazama* sp.	1	-	-	Agricultural practices (Field clearing), Physical barriers (Fencing)	-
Mammals / Artiodactyla	*Odocoileus virginianus*	4	*Zea*, *Phaseolus*, *Cucurbita*, *Cicer*	-	-	Hunting (Weapons), Poisoning, Chemical repellents (Soap), Visual deterrents (Reflective objects,

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	**Not effective**	**Undetermined**
						Scarecrows), Acoustic deterrents (Firecrackers), Vigilance (People, Guard dogs)
Mammals / Artiodactyla	*Pecari tajacu*	7	*Bactris, Colocasia, Manihot, Musa, Phaseolus, Xanthosoma, Zea*	Physical barriers (Wire mesh exclosures), Hunting, Agricultural practices (Field clearing), Olfactory deterrents (Human odors), Visual deterrents (Flags), Vigilance (People)	Agricultural practices (Field clearing), Physical barriers (Fencing)	Acoustic deterrents (Firecrackers, Firearms, Yelling), Hunting (Undetermined, Weapons, Dogs, Traps), Vigilance (People), Agricultural practices (Field clearing, Firebreaks), Physical barriers (Fencing, Netting), Visual deterrents (Scarecrows).
Mammals / Artiodactyla	*Sus scrofa*	5	*Avena, Cucurbita, Daucus, Fragaria, Glycine, Lolium, Oryza, Saccharum, Sorghum, Zea, Manihot*	-	Acoustic deterrents (Firecrackers, Gas cannon), Visual deterrents (Scarecrows, Reflective objects), Vigilance (People, Guard dogs), Physical barriers (Fencing, Netting), Chemical repellents, Hunting,	Hunting (undetermined, dogs, weapons, traps)

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	**Not effective**	**Undetermined**
					Agricultural practices (Providing alternative food sources)	
Mammals / Artiodactyla	*Tayassu pecari*	2	*Glycine*, *Zea*, *Sorghum*, *Panicum*	Hunting (Weapons, Dogs, Traps), Poisoning (Carbofuran)	Physical barriers (Electric fencing, Trenches), Agricultural practices (Providing alternative food sources, Barrier crops), Acoustic deterrents (Firecrackers)	-
Mammals / Artiodactyla	*Tayassu* sp.	1	-	-	-	Hunting
Mammals / Carnivora	*Cerdocyon thous*	1	*Zea*	-	-	Hunting
Mammals / Carnivora	*Conepatus chinga*	3	*Zea*	-	-	Hunting (Weapons, Traps), Acoustic deterrents (Fireworks), Vigilance (People)
Mammals / Carnivora	*Eira barbara*	1	-	-	-	Hunting
Mammals / Carnivora	*Mustela frenata*	1	-	-	-	-
Mammals / Carnivora	*Nasua narica*	6	*Zea*, *Phaseolus*, *Arachis*, *Carica*,	-	-	Hunting (Undetermined, Weapons, Traps), Poisoning, Chemical

Class/Order	**Vertebrate taxon**	**Number of studies**	**Crop genera**	**Protection techniques**		
				Effective	**Not effective**	**Undetermined**
			Persea, Mangifera, Musa			repellents (Soap), Visual deterrents (Reflective objects, Scarecrows), Acoustic deterrents (Firecrackers, Firearms), Vigilance (People, Guard dogs)
Mammals / Carnivora	*Nasua nasua*	4	*Carica, Colocasia, Manihot, Musa, Zea*	Physical barriers (Wire mesh exclosures), Hunting, Agricultural practices (Field clearing), Olfactory deterrents (Human odors), Visual deterrents (Flags), Vigilance (People)	Acoustic deterrents (Firecrackers, Gas cannon), Visual deterrents (Scarecrows, Reflective objects), Vigilance (People), Physical barriers (Fencing, Netting), Chemical repellents, Hunting, Agricultural practices (Providing alternative food sources)	-
Mammals / Carnivora	*Procyon cancrivorus*	1	*Musa*	-	-	Hunting (Undetermined, Traps), Acoustic deterrents (firecrackers, firearms)
Mammals / Carnivora	*Procyon lotor*	5	*Zea*	-	-	Hunting (Undetermined, Weapons), Poisoning,

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	**Not effective**	**Undetermined**
						Chemical repellents (Soap), Visual deterrents (Reflective objects, Scarecrows), Acoustic deterrents (Firecrackers), Vigilance (People, Guard dogs)
Mammals / Carnivora	Procyonidae	1	*Zea*	-	-	Hunting (Weapons), Poisoning, Chemical repellent (Soap), Visual deterrents (Reflective objects, Scarecrows), Acoustic deterrents (Firecrackers), Vigilance (People, Guard dogs)
Mammals / Carnivora	*Tremarctos ornatus*	2	*Musa*, *Zea*	-	Physical barriers (Fencing)	Hunting, Acoustic deterrents (Fireworks), Vigilance (People)
Mammals / Carnivora	*Urocyon cinereoargenteus*	1	*Zea*	-	-	-
Mammals / Chiroptera	Chiroptera	1	*Zea*	-	Palatable deterrents (Chile), Olfactory deterrents (Creolina)	-
Mammals / Cingulata	*Cabassous unicinctus*	1	*Manihot, Phaseolus,*	-	-	Hunting (Undetermined, Traps),

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	**Not effective**	**Undetermined**
			Theobroma			Acoustic deterrents (firecrackers, firearms)
Mammals / Cingulata	*Chaetophractus villosus*	1	*Glycine, Helianthus, Triticum, Zea*	-	-	-
Mammals / Cingulata	*Dasypus hybridus*	1	*Glycine, Helianthus, Triticum, Zea*	-	-	-
Mammals / Cingulata	*Dasypus novemcinctus*	2	*Manihot, Phaseolus, Theobroma, Cicer, Pisum*	-	-	Hunting (Undetermined, Traps), Acoustic deterrents (firecrackers, firearms)
Mammals / Cingulata	*Dasypodidae* sp.	1	*Zea*	-	Acoustic deterrents (Firecrackers, Gas cannon), Visual deterrents (Scarecrows, Reflective objects), Vigilance (People), Physical barriers (Fencing, Netting), Chemical repellents, Hunting, Agricultural practices (Providing alternative food	-

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	**Not effective**	**Undetermined**
					sources)	
Mammals / Cingulata	*Euphractus sexcinctus*	1	*Manihot, Phaseolus, Theobroma*	-	-	Hunting (Undetermined, Traps), Acoustic deterrents (firecrackers, firearms)
Mammals / Didelphimorphia	*Didelphis aurita*	1	*Elaeis*	-	-	Hunting (Undetermined, Traps), Acoustic deterrents (firecrackers, firearms)
Mammals / Didelphimorphia	*Didelphis marsupialis*	1	*Zea*	-	Palatable deterrents (Chile), Olfactory deterrents (Creolina)	-
Mammals / Didelphimorphia	*Didelphis* sp.	2	*Manihot*	Hunting, Agricultural practices (Field clearing), Olfactory deterrents (Human odours), Visual deterrents (Flags), Vigilance (People)	Acoustic deterrents (Firecrackers, Gas cannon), Visual deterrents (Scarecrows, Reflective objects), Vigilance (People), Physical barriers (Fencing, Netting), Chemical repellents, Hunting, Agricultural practices (Providing alternative food sources)	-
Mammals / Didelphimorp	*Didelphis virginiana*	1	*Zea*	-	-	-

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	Not effective	Undetermined
hia						
Mammals / Didelphimorphia	*Metachirus nudicaudatus*	1	*Theobroma*	-	-	Hunting (Undetermined, Traps), Acoustic deterrents (firecrackers, firearms)
Mammals / Didelphimorphia	*Philander opossum*	1	*Arachis*	-	-	-
Mammals / Lagomorpha	Leporidae	2	*Zea*, *Phaseolus*	-	Palatable deterrents (Chile), Olfactory deterrents (Creolina)	-
Mammals / Lagomorpha	*Sylvilagus floridanus*	1	-	-	-	-
Mammals / Perissodactyla	*Tapirus bairdii*	1	*Arachis, Brassica, Citrullus, Dioscorea, Phaseolus, Solanum, Zea*	-	-	Hunting
Mammals / Perissodactyla	*Tapirus terrestris*	1	-	-	-	Hunting
Mammals / Primates	*Alouatta guariba*	2	*Araucaria, Citrus, Diospyros, Eriobotrya, Psidium, Morus,*	-	-	-

Class/Order	**Vertebrate taxon**	**Number of studies**	**Crop genera**	**Protection techniques**		
				Effective	**Not effective**	**Undetermined**
			Syzygium, *Hovenia*, *Melia*, *Ligustrum*			
Mammals / Primates	*Alouatta palliata*	2	*Mangifera*	-	-	-
Mammals / Primates	*Allouatta* sp.	1	*Zea*	-	Acoustic deterrents (Firecrackers, Gas cannon), Visual deterrents (Scarecrows, Reflective objects), Vigilance (People), Physical barriers (Fencing, Netting), Chemical repellents, Hunting, Agricultural practices (Providing alternative food sources)	-
Mammals / Primates	*Cebus capucinus*	2	*Cocos*, *Elaeis*, *Musa*	-	-	-
Mammals / Primates	*Chlorocebus aethiops*	4	*Annona*, *Mangifera*, *Spondias*, *Carica*, *Psidium*,	-	Hunting (Firearms, Traps)	Vigilance (Dogs), Hunting (Traps), Agricultural practices (Kind of crops, Location of crops,

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	**Not effective**	**Undetermined**
			Arachis, *Passiflora*, *Malus*, *Pisum*, *Musa*, *Prunus*, *Zea*, *Cucumis*, *Blighia*, *Manihot*, *Persea*, *Daucus*, *Ipomoea*, *Cucurbita*, *Solanum*, *Artocarpus*, *Phaseolus*, *Abelmoschus*, *Dioscorea*, *Citrus*, *Colocasia*, *Brassica*, *Allium*, *Beta*, *Saccharum*			Alternative food sources, Field clearing)
Mammals / Primates	*Erythrocebus patas*	1	*Cucurbita*, *Citrullus*,	-	-	Agricultural practices (Kind of crops)

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	**Not effective**	**Undetermined**
			Cucumis, *Carica*, *Musa*, *Zea*			
Mammals / Primates	*Leontopithecus chrysomelas*	1	*Musa*	-	-	Hunting (Undetermined, Traps), Acoustic deterrents (firecrackers, firearms)
Mammals / Primates	*Macaca mulatta*	1	*Cucurbita*, *Citrullus*, *Cucumis*, *Carica*, *Musa*, *Zea*	-	-	Agricultural practices (Kind of crops)
Mammals / Primates	*Sapajus apella*	2	*Zea*	Physical barriers (Wire mesh exclosures), Hunting, Agricultural practices (Field clearing), Olfactory deterrents (Human odors), Visual deterrents (Flags), Vigilance (People)	-	-
Mammals / Primates	*Sapajus flavius*	1	*Saccharum*	-	-	-
Mammals / Primates	*Sapajus libidinosus*	2	*Sacharum*, *Ananas*, *Carica*, *Mangifera*,	Vigilance (People, Guard dogs), Acoustic deterrents (Yelling, Firearms),	-	-

Class/Order	**Vertebrate taxon**	**Number of studies**	**Crop genera**	**Protection techniques**		
				Effective	**Not effective**	**Undetermined**
			Citrullus, Manihot, Musa, Oryza, Phaseolus, Zea	Visual deterrents (Scarecrows, Fire), Agricultural practices (Early planting)		
Mammals / Primates	*Sapajus nigritus*	1	*Zea*	Agricultural practices (Early planting, Crop location)	Vigilance (Guard dogs), Acoustic deterrents	-
Mammals / Rodentia	Rodentia	1	*Avena, Coffea, Oryza, Phaseolus, Saccharum, Sorghum, Tritichum, Zea*	Hunting, Agricultural practices (Field clearing), Olfactory deterrents (Human odors), Visual deterrents (Flags), Vigilance (People)	-	-
Mammals / Rodentia	*Callistomys pictus*	1	*Musa*	-	-	Hunting (Undetermined, Traps), Acoustic deterrents (firecrackers, firearms)
Mammals / Rodentia	*Chilomys instans*	1	*Zea*	-	Palatable deterrents (Chile), Olfactory deterrents (Creolina)	-
Mammals / Rodentia	*Cuniculus paca*	7	*Colocasia, Manihot, Theobroma, Xanthosoma*	Physical barriers (Wire mesh exclosures), Hunting, Agricultural practices	-	Hunting (Undetermined, Weapons, Traps, Dogs), Poisoning, Chemical

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	Not effective	Undetermined
			, Zea	(Field clearing), Olfactory deterrents (Human odors), Visual deterrents (Flags), Vigilance (People)		repellents (Soap), Visual deterrents (Reflective objects, Scarecrows), Acoustic deterrents (Firecrackers, Firearms, Yelling), Vigilance (People, Guard dogs), Agricultural practices (Field clearing, Firebreaks), Physical barriers (Netting)
Mammals / Rodentia	*Dasyprocta aguti*	1	*Manihot*	-	-	Hunting (Undetermined, Traps), Acoustic deterrents (firecrackers, firearms)
Mammals / Rodentia	*Dasyprocta fuliginosa*	1	*Manihot*	-	-	Hunting (Weapons, Dogs, Traps), Vigilance (People), Visual deterrents (Scarecrows), Agricultural practices (Field clearing, Firebreaks), Physical barriers (Netting), Acoustic deterrents (Yelling)
Mammals / Rodentia	*Dasyprocta punctata*	1	*Manihot, Xanthosoma*	Hunting, Agricultural practices (Field	-	-

Class/Order	**Vertebrate taxon**	**Number of studies**	**Crop genera**	**Protection techniques**		
				Effective	**Not effective**	**Undetermined**
			, Zea	clearing), Olfactory deterrents (Human odors), Visual deterrents (Flags), Vigilance (People)		
Mammals / Rodentia	*Dasyprocta* sp.	1	-	-	Agricultural practices (Field clearing), Physical barriers (Fencing)	-
Mammals / Rodentia	*Dasyprocta variegata*	2	*Colocasia, Manihot, Xanthosoma, Zea*	Physical barriers (Wire mesh exclosures)	-	Hunting
Mammals / Rodentia	*Dinomys branickii*	1	*Xanthosoma, Zea*	Hunting, Agricultural practices (Field clearing), Olfactory deterrents (Human odors), Visual deterrents (Flags), Vigilance (People)	-	-
Mammals / Rodentia	Echimyidae	1	*Manihot*	-	-	Hunting (weapons, dogs, traps), Vigilance (People), Visual deterrents (Scarecrows), Agricultural practices (Field clearing, Firebreaks), Physical barriers (Netting),

Class/Order	**Vertebrate taxon**	**Number of studies**	**Crop genera**	**Protection techniques**		
				Effective	**Not effective**	**Undetermined**
						Acoustic deterrents (Yelling)
Mammals / Rodentia	*Handleyomys chapmani*	1	*Saccharum*	-	-	-
Mammals / Rodentia	*Holochilus brasiliensis*	1	*Oryza*	-	-	-
Mammals / Rodentia	*Holochilus sciureus*	3	*Oryza*	-	-	Hunting (dogs), Poisoning (Rodenticides, Organo-phosphide insecticides)
Mammals / Rodentia	*Hydrochoerus hydrochaeris*	6	*Bactris, Glycine, Manihot, Oryza, Phaseolus, Saccharum, Zea*	-	Acoustic deterrents (Firecrackers, Gas cannon), Visual deterrents (Scarecrows, Reflective objects), Vigilance (People), Physical barriers (Fencing, Netting), Chemical repellents, Hunting, Agricultural practices (Providing alternative food sources, Field clearing)	Hunting (Undetermined, Traps), Acoustic deterrents (firecrackers, firearms)
Mammals / Rodentia	*Microtus mexicanus*	1	-	-	-	-
Mammals /	Muridae	2	*Colocasia,*	Physical barriers	-	-

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	**Not effective**	**Undetermined**
Rodentia			*Xanthosoma*, *Zea*	(Wire mesh exclosures)		
Mammals / Rodentia	*Nectomys squamipes*	1	*Theobroma*	-	-	Hunting (Undetermined, Traps), Acoustic deterrents (firecrackers, firearms)
Mammals / Rodentia	*Oligoryzomys fulvescens*	1	-	-	-	-
Mammals / Rodentia	*Oligoryzomys* sp.	1	*Oryza*	-	-	-
Mammals / Rodentia	*Orthogeomys cavator*	3	*Musa*, *Bactris*	Hunting (Traps)	Biological control (Infectious disease, Introduction of predators), Poisoning (Estricnina, Methyl bromide, Metomil, Aluminium phosphate)	Poisoning (Metomil), Hunting (Firearms, Traps), Biological control (Attracting predators)
Mammals / Rodentia	*Orthogeomys cherriei*	3	*Manihot*, *Musa*, *Bactris*, *Colocasia*, *Xanthosoma*, *Zea*, *Saccharum*, *Phaseolus*, *Theobroma*, *Coffea*,	Hunting (Traps)	Biological control (Infectious disease, Introduction of predators), Poisoning (Estricnina, Methyl bromide, Metomil, Aluminium phosphate)	Poisoning (Metomil), Hunting (Firearms, Traps), Biological control (Attracting predators)

Class/Order	**Vertebrate taxon**	**Number of studies**	**Crop genera**	**Protection techniques**		
				Effective	**Not effective**	**Undetermined**
			Oryza			
Mammals / Rodentia	*Orthogeomys heterodus*	3	*Musa*, *Bactris*, *Daucus*, *Allium*, *Solanum*, *Zea*, *Pisum*, *Brassica*, *Avena*, *Persea*	Hunting (Traps)	Biological control (Infectious disease, Introduction of predators), Poisoning (Estricnina, Methyl bromide, Metomil, Aluminium phosphate)	Poisoning (Metomil), Hunting (Firearms, Traps), Biological control (Attracting predators)
Mammals / Rodentia	*Orthogeomys hispidus*	3	*Zea*, *Saccharum*	Poisoning (Sodium monofuroacetate)	-	-
Mammals / Rodentia	*Orthogeomys* sp.	1	*Coffea*	-	-	Poisoning (Zinc phosphide and Diphacinone)
Mammals / Rodentia	*Orthogeomys underwoodi*	3	*Musa*, *Bactris*, *Tamarindus*	Hunting (Traps)	Biological control (Infectious disease, Introduction of predators), Poisoning (Estricnina, Methyl bromide, Metomil, Aluminium phosphate)	Poisoning (Metomil), Hunting (Firearms, Traps), Biological control (Attracting predators)
Mammals / Rodentia	*Oryzomys couesi*	2	*Saccharum*	-	-	-
Mammals / Rodentia	*Oryzomys laticeps*	1	*Manihot*, *Theobroma*	-	-	Hunting (Undetermined, Traps), Acoustic deterrents (firecrackers, firearms)

Class/Order	**Vertebrate taxon**	**Number of studies**	**Crop genera**	**Protection techniques**		
				Effective	**Not effective**	**Undetermined**
Mammals / Rodentia	*Oryzomys melanotis*	1	-	-	-	-
Mammals / Rodentia	*Pappogeomys merriami*	1	-	-	-	-
Mammals / Rodentia	*Peromyscus aztecus*	1	-	-	-	-
Mammals / Rodentia	*Peromyscus leucopus*	1	-	-	-	-
Mammals / Rodentia	*Peromyscus levipes*	1	-	-	-	-
Mammals / Rodentia	*Peromyscus maniculatus*	1	-	-	-	-
Mammals / Rodentia	*Peromyscus mexicanus*	1	*Zea*	-	-	-
Mammals / Rodentia	*Rattus norvegicus*	1	*Zea*, *Saccharum*, *Theobroma*	-	-	Poisoning (Zinc phosphide and Diphacinone)
Mammals / Rodentia	*Rattus rattus*	4	*Zea*, *Saccharum*, *Theobroma*, *Cocos*	Poisoning (Pyriminil, Coumarin and Diphacinone), Agricultural practices (Field clearing)	Physical barriers (Metal bands)	Poisoning (Zinc phosphide and Diphacinone)
Mammals / Rodentia	*Reithrodontomys fulvescens*	1	-	-	-	-
Mammals / Rodentia	*Reithrodontomys megalotis*	1	-	-	-	-

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	**Not effective**	**Undetermined**
Mammals / Rodentia	*Reithrodontomys mexicanus*	1	-	-	-	-
Mammals / Rodentia	*Reithrodontomys sumichrasti*	1	-	-	-	-
Mammals / Rodentia	Sciuridae	1	*Zea*, *Phaseolus*	-	-	Poisoning (Herbicides)
Mammals / Rodentia	*Sciurus aestuans*	1	*Theobroma*	-	-	Hunting (Undetermined, Traps), Acoustic deterrents (firecrackers, firearms)
Mammals / Rodentia	*Sciurus aureogaster*	3	*Zea*	-	-	Hunting (weapons), Poisoning, Chemical repellents (Soap), Visual deterrents (Reflective objects, Scarecrows), Acoustic deterrents (Firecrackers), Vigilance (People, Guard dogs)
Mammals / Rodentia	*Sciurus granatensis*	2	*Musa* ,*Theobroma* , *Cocos*, *Daucus*, *Zea*, *Oryza*	-	Palatable deterrents (Chile), Olfactory deterrents (Creolina)	Hunting (Firearms, Traps)
Mammals /	*Sciurus* sp.	1	*Manihot*,	Hunting, Agricultural	-	-

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	**Not effective**	**Undetermined**
Rodentia			*Zea*	practices (Field clearing), Olfactory deterrents (Human odors), Visual deterrents (Flags), Vigilance (People)		
Mammals / Rodentia	*Sciurus variegatoides*	2	*Musa*, *Theobroma*, *Cocos*, *Daucus*, *Zea*, *Oryza*, *Carica*, *Persea*, *Mangifera*, *Pisum*, *Macadamia*, *Sechium*	-	-	Hunting (Firearms, Traps)
Mammals / Rodentia	*Sigmodon alstoni*	6	*Oryza*, *Zea*, *Saccharum*, *Theobroma*, *Cucumis*, *Ipomoea*, *Ananas*	Poisoning (Biorat)	-	Poisoning (Zinc phosphide and Diphacinone)
Mammals / Rodentia	*Sigmodon hirsutus*	1	*Arachis*	-	-	-
Mammals / Rodentia	*Sigmodon hispidus*	2	*Ananas*, *Cucumis*, *Ipomoea*,	Poisoning (Biorat)	-	Poisoning (Zinc phosphide, Thallium sulfate, Endrin,

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	**Not effective**	**Undetermined**
			Coffea, *Phaseolus*, *Arachis*, *Sorghum*, *Lycopersicon*, *Oryza*, *Saccharum*, *Zea*, *Elaeis*			Coumatetralyl, Brodifacoum), Biological control (Attracting predators)
Mammals / Rodentia	*Thomomys umbrinus*	1	-	-	-	-
Mammals / Rodentia	*Zygodontomys brevicauda*	2	*Oryza*, *Elaeis*, *Zea*, *Shorgum*	-	-	-
Birds / Anseriformes	*Chloephaga picta*	1	*Triticum*	-	-	-
Birds / Anseriformes	*Chloephaga poliocephala*	1	*Triticum*	-	-	-
Birds / Anseriformes	*Chloephaga rubidiceps*	1	*Triticum*	-	-	-
Birds / Anseriformes	*Chloephaga* sp.	1	*Triticum*	-	-	-
Birds / Anseriformes	*Dendrocygna sp.*	1	*Oryza*	-	-	-
Birds / Anseriformes	*Netta* sp.	1	*Oryza*	-	-	-
Birds / Cariamiformes	*Cariama cristata*	1	*Zea*	-	Acoustic deterrents (Firecrackers, Gas	-

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	Not effective	Undetermined
					cannon), Visual deterrents (Scarecrows, Reflective objects), Vigilance (People), Physical barriers (Fencing, Netting), Chemical repellents, Hunting, Agricultural practices (Providing alternative food sources)	
Birds / Columbiformes	*Columba livia*	1	*Vitis*	Hunting (Firearms), Poisoning (Carbofuran), Visual deterrents (Flags, Scarecrows), Acoustic deterrents (Fireworks, Cannons, Distress calls), Chemical repellents (Methiocarb, Anthraquinone)	-	-
Birds / Columbiformes	*Columbina passerina*	1	*Sorghum*	-	-	-
Birds / Columbiforme	*Columbina talpacoti*	1	*Sorghum*	-	-	-

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	Not effective	Undetermined
s						
Birds / Columbiformes	*Leptotila verreauxi*	1	*Chenopodium*	Visual deterrents (Reflective objects), Acoustic deterrents, Chemical repellents (Bidrim)	-	-
Birds / Columbiformes	*Metriopelia ceciliae*	2	*Chenopodium*	Visual deterrents (Reflective objects), Acoustic deterrents, Chemical repellents (Bidrim)	-	-
Birds / Columbiformes	*Metriopelia melanoptera*	1	*Chenopodium*	-	-	-
Birds / Columbiformes	*Patagioenas maculosa*	4	*Chenopodium*, *Glycine*, *Helianthus*, *Triticum*, *Sorghum*, *Zea*, *Oryza*, *Hordeum*	-	-	Poisoning (Carbofuran, Parathion, Chlorpyrifos, Monocrotophos, Endrin, Mevinphos, Dicrotophos, CPT, CPTH), Hunting (Firearms), Chemical repellents (Methiocarb, Trimethacarb, Dimethyl, Methyl anthranilate, Synergized aluminum ammonium sulfate, Copper oxalate, Copper oxychloride,

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	**Not effective**	**Undetermined**
						Condensed tannins, Avitrol), Reproductive control (Sterilants), Biological control (Suitable habitat reduction), Agricultural practices (Time of harvest, Alternative food sources, Kind of crops)
Birds / Columbiformes	*Patagioenas picazuro*	1	*Glycine*, *Helianthus*, *Triticum*, *Sorghum*, *Zea*, *Oryza*, *Hordeum*	Hunting (Firearms), Poisoning (Carbofuran), Visual deterrents (Flags, Scarecrows), Acoustic deterrents (Fireworks, Cannons, Distress calls), Chemical repellents (Methiocarb, Anthraquinone)	-	Poisoning (Carbofuran, Parathion, Chlorpyrifos, Monocrotophos, Endrin, Mevinphos, Dicrotophos, CPT, CPTH), Hunting (Firearms), Chemical repellents (Methiocarb, Trimethacarb, Dimethyl, Methyl anthranilate, Synergized aluminum ammonium sulfate, Copper oxalate, Copper oxychloride, Condensed tannins, Avitrol), Reproductive control (Sterilants), Biological control

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	Not effective	Undetermined
						(Suitable habitat reduction), Agricultural practices (Time of harvest, Location of crops, Kind of crops)
Birds / Columbiforme s	*Patagioenas* sp.	1	*Sorghum*, *Zea*	-	Acoustic deterrents (Firecrackers, Gas cannon), Visual deterrents (Scarecrows, Reflective objects), Vigilance (People), Physical barriers (Fencing, Netting), Chemical repellents, Hunting, Agricultural practices (Providing alternative food sources)	-
Birds / Columbiforme s	*Zenaida asiatica*	1	*Sorghum*	-	-	-
Birds / Columbiforme s	*Zenaida auriculata*	12	*Chenopodiu m*, *Glycine*, *Helianthus*, *Triticum*, *Sorghum*, *Zea*, *Oryza*,	Visual deterrents (Reflective objects, Calcium carbonate paint, Flags, Scarecrows), Acoustic deterrents	Poisoning	Poisoning (Carbofuran, Parathion, Chlorpyrifos, Monocrotophos, Endrin, Mevinphos, Dicrotophos, CPT, CPTH), Hunting

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	**Not effective**	**Undetermined**
			Hordeum, *Panicum*, *Avena*, *Brassica*, *Vitis*	(Fireworks, Cannons, Distress calls, Chemical repellents (Bidrim, Methiocarb, Anthraquinone), Hunting (Firearms), Poisoning (Carbofuran),		(Firearms), Chemical repellents (Methiocarb, Trimethacarb, Dimethyl, Methyl anthranilate, Synergized aluminum ammonium sulfate, Copper oxalate, Copper oxychloride, Condensed tannins, Avitrol), Reproductive control (Sterilants), Biological control (Suitable habitat reduction), Agricultural practices (Time of harvest, Kind of crops, Alternative food sources, Location of crops)
Birds / Columbiforme s	*Zenaida macroura*	2	*Oryza*, *Phaseolus*, *Zea*, *Sorghum*	-	-	-
Birds / Cuculiformes	*Crotophaga ani*	1	*Sorghum*	-	-	Agricultural practices (Time of harvest, Location of crops)
Birds / Galliformes	*Penelope obscura*	2	*Phaseolus*, *Zea*, *Vitis*	Hunting (Firearms), Poisoning	Acoustic deterrents (Firecrackers, Gas	-

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	Not effective	Undetermined
				(Carbofuran), Visual deterrents (Flags, Scarecrows), Acoustic deterrents (Fireworks, Cannons, Distress calls), Chemical repellents (Methiocarb, Anthraquinone)	cannon), Visual deterrents (Scarecrows, Reflective objects), Vigilance (People), Physical barriers (Fencing, Netting), Chemical repellents, Hunting, Agricultural practices (Providing alternative food sources)	
Birds / Gruiformes	*Aramides saracura*	1	*Zea*	-	Acoustic deterrents (Firecrackers, Gas cannon), Visual deterrents (Scarecrows, Reflective objects), Vigilance (People), Physical barriers (Fencing, Netting), Chemical repellents, Hunting, Agricultural practices (Providing alternative food sources)	-
Birds / Gruiformes	*Grus canadensis*	1	*Zea*, *Avena*, *Sorghum*,	-	-	Acoustic deterrents, Visual deterrents

Class/Order	**Vertebrate taxon**	**Number of studies**	**Crop genera**	**Protection techniques**		
				Effective	**Not effective**	**Undetermined**
			Triticum			(Scarecrows), Agricultural practices (Time of harvest), Hunting (Firearms)
Birds / Passeriformes	*Agelaius phoeniceus*	1	*Oryza*	-	-	-
Birds / Passeriformes	*Chrysomus ruficapillus*	2	*Oryza*	-	-	Poisoning (Parathion)
Birds / Passeriformes	*Cyanocorax cristatellus*	1	*Zea*	-	Acoustic deterrents (Firecrackers, Gas cannon), Visual deterrents (Scarecrows, Reflective objects), Vigilance (People), Physical barriers (Fencing, Netting), Chemical repellents, Hunting, Agricultural practices (Providing alternative food sources)	Chemical repellents (Methiocarb), Agricultural practices (Field clearing)
Birds / Passeriformes	*Cyanocorax yncas*	1	*Zea*	-	Palatable deterrents (Chile), Olfactory deterrents (Creolina)	-
Birds / Passeriformes	*Dives atroviolaceus*	1	*Sorghum*	-	-	-

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	**Not effective**	**Undetermined**
Birds / Passeriformes	*Dives dives*	1	*Zea*	-	-	Hunting (weapons), Poisoning, Chemical repellents (Soap), Visual deterrents (Reflective objects, Scarecrows), Acoustic deterrents (Firecrackers), Vigilance (People, Guard dogs)
Birds / Passeriformes	*Dolichonyx oryzivorus*	2	*Glycine*, *Oryza*, *Sorghum*	Acoustic deterrents (Firecrackers, Firearms, Yelling), Visual deterrents (Smoke)	-	Biological control (Attracting Predators), Poisoning, Visual deterrents (Reflective objects)
Birds / Passeriformes	*Furnarius rufus*	1	*Vitis*	Hunting (Firearms), Poisoning (Carbofuran), Visual deterrents (Flags, Scarecrows), Acoustic deterrents (Fireworks, Cannons, Distress calls), Chemical repellents (Methiocarb, Anthraquinone)	-	-
Birds / Passeriformes	*Geospizopsis plebejus*	1	*Chenopodium*	-	-	-

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	Not effective	Undetermined
Birds / Passeriformes	*Gnorimopsar chopi*	3	*Oryza*, *Zea*, *Sorgum*	Vigilance (People, Guard dogs), Acoustic deterrents (Yelling, Firearms), Visual deterrents (Scarecrows, Fire), Agricultural practices (Early planting)	Acoustic deterrents (Firecrackers, Gas cannon), Visual deterrents (Scarecrows, Reflective objects), Vigilance (People), Physical barriers (Fencing, Netting), Chemical repellents, Hunting, Agricultural practices (Providing alternative food sources)	Agricultural practices (Time of harvest, Location of crops)
Birds / Passeriformes	*Icterus chrysater*	1	*Zea*	-	Palatable deterrents (Chile), Olfactory deterrents (Creolina)	-
Birds / Passeriformes	*Lonchura malacca*	1	*Sorghum*	-	-	-
Birds / Passeriformes	*Lonchura punctulata*	1	*Sorghum*	-	-	-
Birds / Passeriformes	*Mimus gilvus*	1	*Zea*	-	Palatable deterrents (Chile), Olfactory deterrents (Creolina)	-
Birds / Passeriformes	*Mimus saturninus*	2	*Ficus*, *Vitis*	Hunting (Firearms), Poisoning (Carbofuran), Visual deterrents (Flags,	-	-

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	Not effective	Undetermined
				Scarecrows), Acoustic deterrents (Fireworks, Cannons, Distress calls), Chemical repellents (Methiocarb, Anthraquinone)		
Birds / Passeriformes	*Molothrus aeneus*	1	*Oryza*	-	-	-
Birds / Passeriformes	*Molothrus ater*	1	*Oryza*	-	-	-
Birds / Passeriformes	*Molothrus bonariensis*	1	*Vitis*	Hunting (Firearms), Poisoning (Carbofuran), Visual deterrents (Flags, Scarecrows), Acoustic deterrents (Fireworks, Cannons, Distress calls), Chemical repellents (Methiocarb, Anthraquinone)	-	-
Birds / Passeriformes	*Molothrus* sp.	1	*Glycine*, *Helianthus*, *Triticum*, *Sorghum*, *Oryza*, *Zea*	-	-	Poisoning (Parathion)
Birds /	*Paroaria*	1	*Ficus*	-	-	-

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	**Not effective**	**Undetermined**
Passeriformes	*coronata*					
Birds / Passeriformes	*Passer domesticus*	3	*Ficus, Sorghum, Vitis*	Hunting (Firearms), Poisoning (Carbofuran), Visual deterrents (Flags, Scarecrows), Acoustic deterrents (Fireworks, Cannons, Distress calls), Chemical repellents (Methiocarb, Anthraquinone)	-	-
Birds / Passeriformes	*Passerina caerulea*	1	*Oryza*	-	-	-
Birds / Passeriformes	*Passerina cyanea*	1	*Sorghum*	-	-	-
Birds / Passeriformes	*Pheucticus aureoventris*	1	*Zea*	-	Palatable deterrents (Chile), Olfactory deterrents (Creolina)	-
Birds / Passeriformes	*Phrygilus punensis*	1	*Chenopodium*	-	-	-
Birds / Passeriformes	*Pipraeidea bonariensis*	1	*Ficus*	-	-	-
Birds / Passeriformes	*Pitangus sulphuratus*	2	*Ficus, Vitis*	Hunting (Firearms), Poisoning (Carbofuran), Visual deterrents (Flags, Scarecrows),	-	-

Class/Order	**Vertebrate taxon**	**Number of studies**	**Crop genera**	**Protection techniques**		
				Effective	**Not effective**	**Undetermined**
				Acoustic deterrents (Fireworks, Cannons, Distress calls), Chemical repellents (Methiocarb, Anthraquinone)		
Birds / Passeriformes	*Psarocolius montezuma*	1	*Zea*	-	-	Hunting (weapons), Poisoning, Chemical repellents (Soap), Visual deterrents (Reflective objects, Scarecrows), Acoustic deterrents (Firecrackers), Vigilance (People, Guard dogs)
Birds / Passeriformes	*Pseudoleistes* sp.	1	*Glycine*, *Helianthus*, *Triticum*, *Sorghum*, *Oryza*, *Zea*	-	-	-
Birds / Passeriformes	*Psilorhinus morio*	2	*Zea*	-	-	Hunting (weapons), Poisoning, Chemical repellents (Soap), Visual deterrents (Reflective objects, Scarecrows), Acoustic deterrents

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	**Not effective**	**Undetermined**
						(Firecrackers), Vigilance (People, Guard dogs)
Birds / Passeriformes	*Quiscalus mexicanus*	2	*Zea*, *Oryza*	-	-	Hunting (weapons), Poisoning, Chemical repellents (Soap), Visual deterrents (Reflective objects, Scarecrows), Acoustic deterrents (Firecrackers), Vigilance (People, Guard dogs)
Birds / Passeriformes	*Rhopospina fruticeti*	1	*Chenopodium*	-	-	-
Birds / Passeriformes	*Saltator coerulescens*	1	*Ficus*	-	-	-
Birds / Passeriformes	*Sicalis flaveola*	1	*Sorghum*	-	-	Agricultural practices (Time of harvest, Location of crops)
Birds / Passeriformes	*Sicalis luteola*	1	*Chenopodium*	-	-	-
Birds / Passeriformes	*Sicalis* sp.	1	*Glycine*, *Helianthus*, *Triticum*, *Sorghum*, *Oryza*, *Zea*	-	-	-

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	**Not effective**	**Undetermined**
Birds / Passeriformes	*Sicalis uropigyalis*	1	*Chenopodium*	-	-	-
Birds / Passeriformes	*Spinus atratus*	1	*Chenopodium*	-	-	-
Birds / Passeriformes	*Spinus spinescens*	1	*Chenopodium*	Visual deterrents (Reflective objects), Acoustic deterrents, Chemical repellents (Bidrim)	-	-
Birds / Passeriformes	*Spiza americana*	3	*Oryza*, *Sorghum*	Chemical repellent (Anthraquinone, Methiocarb), Poisoning, Acoustic deterrents (Firecrackers, Sirens, Horns, Yelling, Firearms), Visual deterrents (Flags, Scarecrows, Reflective objects, Smoke), Biological control (Attracting predators)	Chemical repellent (Methyl anthranilate)	Poisoning, Hunting (Firearms)
Birds / Passeriformes	*Sporophila lineola*	1	*Sorghum*	-	-	Agricultural practices (Time of harvest, Location of crops)
Birds / Passeriformes	*Sporophila nigricollis*	1	*Sorghum*	-	-	Agricultural practices (Time of harvest,

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	**Not effective**	**Undetermined**
						Location of crops)
Birds / Passeriformes	*Sporophila sp.*	1	*Sorghum*	-	-	Agricultural practices (Time of harvest, Location of crops)
Birds / Passeriformes	*Sturnus vulgaris*	1	*Vaccinium, Morus, Prunus*	-	-	-
Birds / Passeriformes	*Thraupis episcopus*	1	*Zea*	-	Palatable deterrents (Chile), Olfactory deterrents (Creolina)	-
Birds / Passeriformes	*Thraupis sayaca*	1	*Ficus*	-	-	-
Birds / Passeriformes	*Thraupis* sp.	1	-	-	Acoustic deterrents (Firecrackers, Gas cannon), Visual deterrents (Scarecrows, Reflective objects), Vigilance (People), Physical barriers (Fencing, Netting), Chemical repellents, Hunting, Agricultural practices (Providing alternative food sources)	-
Birds / Passeriformes	*Turdus amaurochal*	2	*Ficus*, *Vitis*	Hunting (Firearms), Poisoning	-	-

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	**Not effective**	**Undetermined**
	inus			(Carbofuran), Visual deterrents (Flags, Scarecrows), Acoustic deterrents (Fireworks, Cannons, Distress calls), Chemical repellents (Methiocarb, Anthraquinone)		
Birds / Passeriformes	*Turdus chiguanco*	2	*Chenopodium, Zea*	-	-	Hunting, Acoustic deterrents (Fireworks), Vigilance (People)
Birds / Passeriformes	*Turdus fuscater*	1	*Zea*	-	Palatable deterrents (Chile), Olfactory deterrents (Creolina)	-
Birds / Passeriformes	*Turdus rufiventris*	1	*Vitis*	Hunting (Firearms), Poisoning (Carbofuran), Visual deterrents (Flags, Scarecrows), Acoustic deterrents (Fireworks, Cannons, Distress calls), Chemical repellents (Methiocarb, Anthraquinone)	-	-
Birds / Passeriformes	*Tyrannus melancholic*	1	*Sorghum*	-	-	Agricultural practices (Time of harvest,

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	Not effective	Undetermined
	us					Location of crops)
Birds / Passeriformes	*Tyrannus savana*	-	*Vitis*	Hunting (Firearms), Poisoning (Carbofuran), Visual deterrents (Flags, Scarecrows), Acoustic deterrents (Fireworks, Cannons, Distress calls), Chemical repellents (Methiocarb, Anthraquinone)	-	-
Birds / Passeriformes	*Volatinia jacarina*	2	*Oryza*, *Sorghum*	-	-	Agricultural practices (Time of harvest, Location of crops)
Birds / Passeriformes	*Zonotrichia capensis*	3	*Chenopodium*, *Vitis*	Visual deterrents (Reflective objects, Flags, Scarecrows), Hunting (Firearms), Poisoning (Carbofuran), Acoustic deterrents (Fireworks, Cannons, Distress calls), Chemical repellents (Methiocarb, Anthraquinone, Bidrim)	-	-

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	**Not effective**	**Undetermined**
Birds / Passeriformes	*Zonotrichia leucophrys*	1	*Sorghum*	-	-	-
Birds / Piciformes	*Colaptes campestris*	1	*Vitis*	Hunting (Firearms), Poisoning (Carbofuran), Visual deterrents (Flags, Scarecrows), Acoustic deterrents (Fireworks, Cannons, Distress calls), Chemical repellents (Methiocarb, Anthraquinone)	-	-
Birds / Piciformes	*Dryocopus lineatus*	1	*Zea*	-	-	-
Birds / Piciformes	*Melanerpes candidus*	1	*Zea*	Vigilance (People, Guard dogs), Acoustic deterrents (Yelling, Firearms), Visual deterrents (Scarecrows, Fire), Agricultural practices (Early planting)	-	-
Birds / Piciformes	*Melanerpes striatus*	1	*Theobroma*	-	Hunting, Chemical repellents (Methiocarb), Visual deterrents (Carpenter's chalk), Olfactory	-

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	**Not effective**	**Undetermined**
					deterrents (Tabebuia extract)	
Birds / Piciformes	*Ramphastos toco*	1	-	-	Acoustic deterrents (Firecrackers, Gas cannon), Visual deterrents (Scarecrows, Reflective objects), Vigilance (People), Physical barriers (Fencing, Netting), Chemical repellents, Hunting, Agricultural practices (Providing alternative food sources)	-
Birds / Psittaciformes	*Amazona aestiva*	1	*Citrus*	-	-	-
Birds / Psittaciformes	*Amazona albifrons*	1	*Zea*	-	-	Hunting (weapons), Poisoning, Chemical repellents (Soap), Visual deterrents (Reflective objects, Scarecrows), Acoustic deterrents (Firecrackers), Vigilance (People, Guard dogs)

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	**Not effective**	**Undetermined**
Birds / Psittaciformes	*Ara* sp.	1	*Bertholletia*	-	-	-
Birds / Psittaciformes	*Aratinga* sp.	1	*Zea*	-	-	Hunting, Acoustic deterrents (Fireworks), Vigilance (People)
Birds / Psittaciformes	*Brotogeris chiriri*	2	*Zea*, *Sorghum*	Vigilance (People, Guard dogs), Acoustic deterrents (Yelling, Firearms), Visual deterrents (Scarecrows, Fire), Agricultural practices (Early planting)	-	Agricultural practices (Time of harvest, Location of crops)
Birds / Psittaciformes	*Cyanoliseus patagonus*	1	*Avena*, *Helianthus*, *Triticum*, *Zea*	-	-	-
Birds / Psittaciformes	*Diopsittaca nobilis*	1	*Sorghum*	-	-	Agricultural practices (Time of harvest, Location of crops)
Birds / Psittaciformes	*Eupsittula aurea*	1	*Zea*	Vigilance (People, Guard dogs), Acoustic deterrents (Yelling, Firearms), Visual deterrents (Scarecrows, Fire), Agricultural practices (Early planting)	-	-

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	Not effective	Undetermined
Birds / Psittaciformes	*Forpus xanthopterygius*	1	*Sorghum*	-	-	Agricultural practices (Time of harvest, Location of crops)
Birds / Psittaciformes	*Myiopsitta monachus*	8	*Glycine*, *Helianthus*, *Medicago*, *Panicum*, *Sorghum*, *Triticum*, *Zea*, *Oryza*, *Ficus*, *Citrus*, *Prunus*, *Vaccinium*, *Vitis*	Reproductive control (Nest destruction), Hunting (Firearms), Poisoning (Carbofuran), Visual deterrents (Flags, Scarecrows), Acoustic deterrents (Fireworks, Cannons, Distress calls), Chemical repellents (Methiocarb, Anthraquinone)	Chemical repellents, Physical barriers, Agricultural practices (Early planting, Field clearing, Providing alternative food sources), Capture and relocation	Poisoning (Carbofuran, Parathion, Chlorpyrifos, Monocrotophos, Endrin, Mevinphos, Dicrotophos, CPT, CPTH, Insecticides), Hunting (Firearms, Traps), Chemical repellents (Methiocarb, Trimethacarb, Dimethyl, Methyl anthranilate, Synergized aluminum ammonium sulfate, Copper oxalate, Copper oxychloride, Condensed tannins, Avitrol), Reproductive control (Nest burning, Egg destruction, Sterilants), Agricultural practices (Kind of crops, Time of harvest, Location of crops, Field clearing, Crop density, Alternative food

Class/Order	Vertebrate taxon	Number of studies	Crop genera	Protection techniques		
				Effective	**Not effective**	**Undetermined**
						sources), Biological control (Suitable habitat reduction), Acoustic deterrents (Cannons, Fireworks, Predator sounds), Visual deterrents (Reflective objects, Predator outlines, Balloons), Vigilance (People), Capture and relocation
Birds / Psittaciformes	*Pionus senilis*	1	*Zea*	-	-	-
Birds / Psittaciformes	*Psittacara leucophthalmus*	2	*Sorghum*, *Zea*	-	Acoustic deterrents (Firecrackers, Gas cannon), Visual deterrents (Scarecrows, Reflective objects), Vigilance (People), Physical barriers (Fencing, Netting), Chemical repellents, Hunting, Agricultural practices (Providing alternative food sources)	Agricultural practices (Time of harvest, Location of crops)
Birds /	Psittacidae	1	*Zea*	-	-	-

Class/Order	**Vertebrate taxon**	**Number of studies**	**Crop genera**	**Protection techniques**		
				Effective	**Not effective**	**Undetermined**
Psittaciformes						
Birds / Strigiformes	*Athene cunicularia*	1	*Sorghum*	-	-	Agricultural practices (Time of harvest, Location of crops)
Reptiles / Squamata	*Iguana iguana*	1	*Dioscorea*, *Xanthosoma*, *Cucurbita*, *Cucumis*	-	-	-

Table S3: List of the 88 reviewed studies with species and crop protection data.

Including information on the crop taxa in each study, the vertebrate taxa that interact with them, the protection techniques used, and the efficiency of the protection techniques.

Study	Crop taxa	Vertebrate taxa	Protection techniques	Efficiency
Abba et al. (2015)	*Glycine max*, *Zea mays*, *Helianthus annuus*, *Triticum aestivum*	*Chaetophractus villosus*, *Dasypus hybridus*	None	-
Abrahams et al. (2018)	*Manihot esculenta*	*Dasyprocta fuliginosa*, *Pecari tajacu*, *Cuniculus paca*, *Mazama americana*, Echimyidae	Hunting (weapons, dogs, traps), Vigilance (People), Visual deterrents (Scarecrows), Agricultural practices (Field clearing, Firebreaks), Physical barriers (Netting), Acoustic deterrents (Yelling)	Not quantified
Albarracín and Aliaga-Rossel (2018)	*Zea mays*	*Tremarctos ornatus*, *Aratinga* sp., *Turdus chiguanco*, *Conepatus chinga*	Hunting, Acoustic deterrents (Fireworks), Vigilance (People)	Not quantified
de Almeida-Jácomo et al. (2013)	*Zea* sp., *Glycine* sp., *Sorghum* sp., *Panicum* sp.	*Tayassu pecari*	Hunting	Not quantified
Aris et al. (2008)	Undetermined	*Conepatus chinga*	Hunting	Not quantified
Arroyo-Quiroz et al. (2017)	*Zea* sp., *Phaseolus* sp., *Arachis* sp., *Carica* sp., *Persea* sp., *Mangifera* sp., *Musa* sp., *Cucurbita* sp., *Cicer* sp., *Pisum* sp.	Sciuridae, Leporidae, Muridae, Psittacidae, *Nasua narica*, *Urocyon cinereoargenteus*, *Odocoileus virginianus*,	Poisoning (Herbicides)	Not quantified

Study	Crop taxa	Vertebrate taxa	Protection techniques	Efficiency
		Procyon lotor, *Dasypus novemcinctus*, *Didelphis virginiana*, *Rattus rattus*		
Avery et al. (2001)	*Oryza sativa*	*Spiza americana*	Chemical repellent (Anthraquinone, Methyl anthranilate, Methiocarb)	Varying
Barceló et al. (2012)	*Zea* sp., *Avena* sp., *Sorgum* sp., *Triticum* sp.	*Grus canadensis*	Acoustic deterrents, Visual deterrents (Scarecrows), Agricultural practices (Time of harvest), Hunting (Firearms)	Not quantified
Basili and Temple (1999a)	*Oryza* sp., *Sorghum* sp.	*Spiza americana*	Poisoning, Acoustic deterrents (Firecrackers, Sirens, Horns, Yelling, Firearms), Visual deterrents (Flags, Scarecrows, Reflective objects, Smoke), Biological control (Attracting predators)	Effective
Basili and Temple (1999b)	*Oryza* sp., *Sorghum* sp.	*Spiza americana*	Poisoning, Hunting (Firearms)	Not quantified
Berón et al. (2020)	*Ficus carica*	*Myiopsitta monachus*, *Pitangus sulphuratus*, *Mimus saturninus*, *Turdus amaurochalinus*, *Turdus rufiventri*, *Thraupis sayaca*, *Pipraeidea bonariensis*, *Paroaria coronate*, *Saltator coerulescens*, *Passer domesticus*	None	-
Bou et al. (2016)	*Glycine max*	*Zenaida auriculata*, *Patagioenas picazuro*, *Patagioenas maculosa*	None	-
Boulton et al. (1996)	*Annona* sp., *Mangifera* sp., *Carica* sp., *Psidium*	*Chlorocebus aethiops*	Hunting (Firearms, Traps)	Not effective

Study	Crop taxa	Vertebrate taxa	Protection techniques	Efficiency
	sp., *Arachis* sp., *Malus* sp., *Pisum* sp., *Musa* sp., *Prunus* sp., *Zea* sp., *Cucumis* sp., *Blighia* sp., *Manihot* sp., *Perse asp*., *Daucus* sp., *Ipomoea* sp., *Cucurbita* sp., *Solanum* sp., *Artocarpus* sp., *Phaseolus* sp., *Saccharum* sp., *Abelmoschus* sp., *Dioscorea* sp., *Citrus* sp., *Brassica* sp., *Allium* sp., *Beta* sp.			
Bruggers et al. (1998)	*Glycine* sp., *Helianthus* sp., *Triticum* sp., *Sorghum* sp., *Zea* sp., *Oryza* sp., *Citrus* sp., *Hordeum* sp., *Malus* sp., *Pyrus* sp., *Prunus* sp.	*Zenaida auriculata*, *Patagioenas picazuro*, *Patagioenas maculosa*, *Myiopsitta monachus*, *Molothrus* sp., *Chrysomus ruficapillus*, *Pseudoleistes* sp., *Sicalis* sp., *Chloephaga* sp., *Dendrocygna* sp., *Netta* sp., *Amazona aestiva*	Poisoning (Carbofuran, Parathion, Chlorpyrifos, Monocrotophos, Endrin, Mevinphos, Dicrotophos, CPT, CPTH), Hunting (Firearms), Chemical repellents (Methiocarb, Trimethacarb, Dimethyl, Methyl anthranilate, Synergized aluminum ammonium sulfate, Copper oxalate, Copper oxychloride, Condensed tannins, Avitrol), Reproductive control (Sterilants), Agricultural practices (Kind of crops, Time of harvest), Biological control (Suitable habitat reduction)	Not quantified
Bucher and Ranvaud (2006)	*Sorghum* sp., *Helianthus* sp., *Oryza* sp., *Zea* sp., *Tritichum* sp., *Hordeum* sp., *Glycine* sp.	*Zenaida auriculata*	Poisoning	Not effective

Study	Crop taxa	Vertebrate taxa	Protection techniques	Efficiency
Calamari et al. (2018)	Undetermined	*Zenaida auriculata*, *Myiopsitta monachus*	None	-
Canavelli et al. (2012)	*Zea* sp., *Helianthus* sp., *Sorgum* sp., *Triticum* sp., *Oryza* sp., *Citrus* sp., *Prunus* sp., *Vaccinium* sp.			
Canavelli et al. (2013)	*Zea* sp., *Helianthus* sp., *Glycine* sp., *Triticum* sp., *Sorghum* sp., *Medicago* sp., *Panicum* sp.	*Myiopsitta monachus*	Hunting (Weapons, Traps), Poisoning, Reproductive control (Nest destruction), Chemical repellents, Physical barriers, Agricultural practices (Early planting, Field clearing, Providing alternative food sources), Capture and relocation	Varying
Canavelli et al. (2014)	*Zea* sp., *Helianthus* sp.	*Myiopsitta monachus*	Agricultural practices (Time of harvest, Crop density, Kind of crops)	Not quantified
Can-Hernandez et al. (2019)	*Zea mays*	*Quiscalus mexicanus*, *Psilorhinus morio*, *Psarocolius montezuma*, *Amazona albifrons*, *Dives dives*, *Nasua narica*, *Procyon lotor*, Procyonidae, *Sciurus aureogaster*, *Cuniculus paca*, *Odocoileus virginianus*	Hunting (Weapons), Poisoning, Chemical repellent (Soap), Visual deterrents (Reflective objects, Scarecrows), Acoustic deterrents (Firecrackers), Vigilance (People, Guard dogs)	Not quantified
de Carvalho et al. (2019)	*Zea mays*, *Phaseolus* sp., *Sorghum bicolor*, *Oryza sativa*, *Saccharum* sp., Fruits, Vegetables	*Psittacara leucophthalmus*, *Hydrochoerus hydrochaeris*, *Penelope obscura*, *Patagioenas* spp., *Sus scrofa*, *Nasua nasua*, *Thraupis* spp., *Ramphastos*	Acoustic deterrents (Firecrackers, Gas cannon), Visual deterrents (Scarecrows, Reflective objects), Vigilance, Physical barriers (Netting, Fencing), Chemical repellents, Hunting, Agricultural practices (Providing alternative food sources)	Not effective

Study	Crop taxa	Vertebrate taxa	Protection techniques	Efficiency
		toco, *Aramides saracura*, *Gnorimopsar chopi*, *Cyanocorax cristatellus*, *Cariama cristata*, *Dasypodidae* spp., *Didelphis* sp., *Allouatta* sp.		
Castillo-Chinchilla et al. (2018)	Undetermined	*Procyon lotor*, *Nasua narica*, *Odocoileus virginianus*, *Cebus capucinus*, *Alouatta palliata*, *Mustela frenata*, *Sylvilagus floridanus*, *Sciurus variegatoides*	None	-
Castillo-Lopez et al. (2017)	*Zea mays*	*Sciurus granatensis*, *Chilomys instans*, *Didelphis marsupialis*, *Cyanocorax yncas*, *Icterus chrysater*, *Turdus fuscater*, *Mimus gilvus*, *Pheucticus aureoventris*, *Thraupis episcopus*, Leporidae, Chiroptera	Palatable deterrent (Chile), Olfactory deterrent (Creolina)	Not effective
Cervo and Guadagnin (2020)	*Avena sativa*, *Sorghum bicolor*, *Lolium* sp., *Zea mays*, *Oryza sativa*, *Glycine max*	*Sus scrofa*	Hunting (Weapons, Dogs, Traps)	Not quantified
Chaves and Bicca-Marques (2017)	*Psidium guajava*, *Eriobotrya japonica*, *Diospyros kaki*, *Citrus reticulata*, *Araucaria*	*Alouatta guariba clamitans*	None	-

Study	Crop taxa	Vertebrate taxa	Protection techniques	Efficiency
	angustifolia, *Citrus sinensis*			
Cornejo (2000)	*Saccharum* sp.	*Orthogeomys hispidus*	Poisoning (Sodium monofuroacetate)	Effective
Corrêa et al. (2018)	*Morus nigra*, *Eriobotrya japonica*, *Psidium guajava*, *Syzygium cumini*, *Hovenia dulcis*, *Melia azedarach*, *Ligustrum lucidum*	*Alouatta guariba*	None	-
Cossios et al. (2018)	Undetermined	*Conepatus chinga*	Hunting	Not quantified
Costán & Sarasola (2017)	*Panicum miliaceum*, *Triticum aestivum*, *Helianthus annus*, *Avena sativa*, *Zea may*, *Sorghum bicolor*	*Zenaida auriculata*	None	-
Dardanelli et al. (2016)	*Glycine max*, *Triticum* sp., *Zea* sp., *Brassica* sp.	*Zenaida auriculata*, *Patagioenas maculosa*, *Patagioenas picazuro*, *Myiopsitta monachus*	Agricultural practices (Harvest time, Alternative food sources)	Not quantified
Dore et al. (2018)	Undetermined	*Chlorocebus aethiops*	Vigilance (Dogs)	Not quantified
Doutel-Ribas et al. (2019)	Undetermined	*Sus scrofa*	Vigilance (Guard dogs)	Not effective
Eiris and Barreto (2009)	*Oryza* sp.	*Holochilus sciureus*	Poisoning (Rodenticides, Organo-phosphide insecticides)	Not quantified
Engeman et	*Cucurbita* sp., *Citrullus*	*Macaca mulatta*,	Agricultural practices (Kind of crops)	Not

Study	Crop taxa	Vertebrate taxa	Protection techniques	Efficiency
al. (2010)	sp., *Cucumis* sp., *Carica* sp., *Musa* sp., *Zea* sp.	*Erythrocebus patas*		quantified
Escobar-Lasso et al. (2020)	*Musa sapientum, Musa paradisiaca*	*Tremarctos ornatus*	Fencing	Not effective
Felix et al. (2014)	*Oryza sativa*, *Zea mays*, *Saccharum*, *Glycine max*	*Hydrochoerus hydrochaeris*	None	-
Ferraz et al. (2003)	*Zea mays*	*Hydrochoerus hydrochaeris*	None	-
Flores-Armillas et al. (2020)	*Zea mays*	*Nasua narica*, *Odocoileus virginianus*, Birds	None	-
de Freitas et al. (2008)	*Zea mays*, *Saccharum officinarum*	*Sapajus libidinosus*	None	-
García and Peiró (2016)	*Oryza sativa*, *Phaseolus vulgaris*, *Zea mays*	*Zenaida macroura*	None	-
Gonzalez and Acosta-Perez (2002)	*Oryza* sp.	*Molothrus aeneus*, *Molothrus ater*, *Quiscalus mexicanus*, *Agelaius phoeniceus*, *Passerina caerulea*, *Volatinia jacarina*	None	-
Gorosábel et al. (2019)	*Triticum* sp.	*Chloephaga rubidiceps*, *Chloephaga poliocephala*, *Chloephaga picta*	None	-
Hilje (1992)	*Persea americana*, *Oryza sativa*, *Pisum sativum*, *Avena sativa*, *Musa paradisiaca*, *Theobroma cacao*,	*Orthogeomys cavator*, *Orthogeomys cherriei*, *Orthogeomys heterodus*, *Orthogeomys underwoodi*, *Sigmodon hispidus*, *Sciurus*	Poisoning (Metomil, Zinc phosphide, Thallium sulfate, Endrin, Coumatetralyl, Brodifacoum), Hunting (Firearms, Traps), Agricultural practices (Field clearing), Biological control (Attracting predators)	Not quantified

Study	Crop taxa	Vertebrate taxa	Protection techniques	Efficiency
	Coffea arabica, *Saccharum officinarum*, *Allium cepa*, *Cocos nucifera*, *Sechium edule*, *Phaseolus vulgaris*, *Macadamia integriflora*, *Zea mays*, *Colocasia esculenta*, *Mangifera indica*, *Arachis hypogaea*, *Elaeis guineensis*, *Solanum tuberosum*, *Carica papaya*, *Bactris gasipaes*, *Ananas comosus*, *Musa paradisiaca*, *Brassica oleracea*, *Sorghum bicolor*, *Tamarindus indica*, *Xanthosoma violaceum*, *Manihot esculenta*, *Lycopersicon esculentum*, *Daucus carota*, *Cucurbita moschata*	*granatensis*, *Sciurus variegatoides*		
Horrocks and Baulu (1988)	Undetermined	*Chlorocebus aethiops*	Hunting (Traps)	Not effective
Horrocks and Baulu (1994)	*Annona* sp., *Mangifera* sp., *Spondias* sp., *Carica* sp., *Psidium* sp., *Arachis*	*Chlorocebus aethiops*	Hunting (Traps), Agricultural practices (Kind of crops, Location of crops, Alternative food sources, Field clearing),	Not quantified

Study	Crop taxa	Vertebrate taxa	Protection techniques	Efficiency
	sp., *Passiflora* sp., *Malus* sp., *Pisum* sp., *Musa* sp., *Prunus* sp., *Zea* sp., *Cucumis* sp., *Blighia* sp., *Manihot* sp., *Persea* sp., *Daucus* sp., *Ipomoea* sp., *Cucurbita* sp., *Solanum* sp., *Artocarpus* sp., *Phaseolus* sp., *Abelmoschus* sp., *Dioscorea* sp., *Citrus* sp., *Colocasia* sp., *Brassica* sp., *Allium* sp., *Beta* sp., *Saccharum* sp.			
Ibañez et al. (2016)	*Vaccinium* sp., *Morus* sp., *Prunus* sp.	*Sturnus vulgaris*	None	-
Key and de la Piedra Constantino (1992)	*Zea* sp., *Saccharum* sp., *Theobroma* sp., *Coffea* sp.	*Rattus rattus*, *Rattus norvegicus*, *Sigmodon hispidus*, *Orthogeomys* sp.	Poisoning (Zinc phosphide and Diphacinone)	Not quantified
Lima et al. (2019)	*Zea mays*, *Glycine max*	*Tayassu pecari*	Hunting (Weapons, Dogs, Traps), Poisoning (Carbofuran), Physical barriers (Electric fencing, Trenches), Agricultural practices (Providing alternative food sources, Barrier crops), Acoustic deterrents (Firecrackers)	Varying
Lins and Ferreira (2018)	*Saccharum* sp.	*Sapajus flavius*	None	-
Lobão and	*Theobroma cacao*,	*Oryzomys laticeps*, *Pecari*	Hunting (Weapons, Traps), Acoustic	Not

Study	Crop taxa	Vertebrate taxa	Protection techniques	Efficiency
Nogueira-Filho (2011)	*Manihot esculenta*, *Musa* sp., *Phaseolus* sp., *Zea mays*, *Bactris gasipaes*, *Carica papaya*, *Elaeis* sp.	*tajacu*, *Cuniculus paca*, *Metachirus nudicaudatus*, *Nectomys squamipes*, *Sciurus aestuans*, *Dasyprocta aguti*, *Hydrochoerus hydrochaeris*, *Nasua nasua*, *Callistomys pictus*, *Leontopithecus chrysomelas*, *Procyon cancrivorus*, *Didelphis aurita*, *Euphractus sexcinctus*, *Dasypus novemcinctus*, *Cabassous unicinctus*	deterrents (Firecrackers, Firearms)	quantified
López-Torres et al. (2012)	*Dioscorea* sp., *Xanthosoma* sp., *Cucurbita* sp., *Cucumis* sp.	*Iguana iguana*	None	-
Loza-del-Carpio et al. (2016)	*Chenopodium quinoa*	*Patagioenas maculosa*, *Sicalis uropigyalis*, *Zenaida auriculata*, *Zonotrichia capensis*, *Geospizopsis plebejus*, *Phrygilus punensis*, *Rhopospina fruticeti*, *Sicalis luteola*, *Metriopelia melanoptera*, *Turdus chiguanco*, *Metriopelia ceciliae*, *Spinus atratus*	None	-
Marchand	Undetermined	*Pecari tajacu*, *Dasyprocta*	Agricultural practices (Field clearing),	Not effective

Study	Crop taxa	Vertebrate taxa	Protection techniques	Efficiency
(2016)		spp., *Hydrochoerus hydrochaeris*, *Mazama* spp.	Physical barriers (Fencing)	
McKinney (2011)	*Elaeis guineensis*, *Cocos nucifera*, *Musa acuminata*	*Cebus capucinus*	None	-
McKinney (2019)	*Mangifera indica*	*Alouatta palliata*	None	-
Melo and Cheschini (2012)	*Sorghum bicolor*	*Athene cunicularia*, *Patagioenas picazuro*, *Columbina talpacoti*, *Zenaida auriculata*, *Crotophaga ani*, *Diopsittaca nobilis*, *Psittacara leucophthalmus*, *Brotogeris chiriri*, *Forpus xanthopterygius*, *Tyrannus melancholicus*, *Sporophila lineola*, *Sporophila nigricollis*, *Sporophila* sp., *Volatinia jacarina*, *Sicalis flaveola*, *Gnorimopsar chopi*	Agricultural practices (Time of harvest, Location of crops)	Not quantified
Mendonça et al. (2011)	*Zea* sp.	*Cerdocyon thous*	Hunting	Not quantified
Mitchell and Bruggers (1985)	*Theobroma cacao*	*Melanerpes striatus*	Hunting, Chemical repellents (Methiocarb), Visual deterrents (Carpenter's chalk), Olfactory deterrents (Tabebuia extract)	Not effective/ Inconclusive
Monge (1999)	*Bactris gasipaes*	*Orthogeomys cherriei*, *Orthogeomys heterodus*, *Orthogeomys cavator*,	None	-

Study	Crop taxa	Vertebrate taxa	Protection techniques	Efficiency
		Orthogeomys underwoodi		
Monge-Meza (2011)	*Musa* sp.	*Orthogeomys cherriei*, *Orthogeomys heterodus*, *Orthogeomys cavator*, *Orthogeomys underwoodi*	Biological control (Infectious disease, Introduction of predators), Poisoning (Estricnina, Methyl bromide, Metomil, Aluminium phosphate), Hunting (Traps)	Varying
Monge-Meza and Orozco (2010)	*Ananas comusus*	*Philander opossum*	None	-
Monge-Meza et al. (2014)	*Arachis hypogaea*	*Sigmodon hirsutus*	None	-
Naughton-Treves et al. (2003)	Undetermined	*Tapirus terrestris*, *Eira barbara*, *Hydrochoerus hydrochaeris*, *Cuniculus paca*, *Pecari tajacu*, *Dasyprocta variegata*	Hunting	Not quantified
Parra et al. (2012)	*Oryza sativa*	*Holochilus sciureus*, *Zygodontomys brevicauda*, *Sigmodon alstoni*, *Oligoryzomys* sp.	None	-
Pereira et al. (2019)	*Zea mays*, *Saccharum* sp., *Daucus carota*, *Fragaria* sp., *Cucurbita* sp.	*Sus scrofa*	Hunting	Not quantified
Pérez and Pacheco (2006)	*Manihot esculenta*, *Colocasia esculenta*, *Xanthosoma* sp., *Zea mays*	*Dasyprocta variegata*, *Pecari tajacu*, *Cuniculus paca*, *Nasua nasua*, *Sapajus apella*, Birds, Muridae	Physical barriers (Wire mesh exclosures)	Effective
Pérez and	*Manihot esculenta*,	*Pecari tajacu*, *Dasyprocta*	Hunting, Agricultural practices (Field	Effective

Study	Crop taxa	Vertebrate taxa	Protection techniques	Efficiency
Pacheco (2014)	*Xanthosoma* sp., *Zea mays*	*punctata*, *Cuniculus paca*, *Dinomys branickii*, *Nasua nasua*, *Didelphis* sp., *Sciurus* sp., *Sapajus apella*, Rodentia, Birds	clearing), Olfactory deterrents (Human odors), Visual deterrents (Flags), Vigilance (People)	
Ranvaud et al. (2001)	*Zea mays*, *Oryza sativa*, *Triticum aestivum*, *Glycine max*	*Zenaida auriculata*	None	-
Renfrew and Saavedra (2007)	*Oryza sativa*, *Sorghum bicolor*, *Glycine max*	*Dolichonyx oryzivorus*	Acoustic deterrents (Firecrackers, Firearms, Yelling), Visual deterrents (Reflective objects, Smoke), Biological control (Attracting predators), Poisoning	Effective / Not quantified
Renfrew et al. (2017)	*Oryza sativa*	*Dolichonyx oryzivorus*	Poisoning	Not quantified
Robles et al. (2003)	*Chenopodium quinoa*	*Zenaida auriculata*, *Metriopelia ceciliae*, *Leptotila verreauxi*, *Spinus spinescens*, *Zonotrichia capensis*	Visual deterrents (Reflective objects), Acoustic deterrents, Chemical repellents (Bidrim)	Effective
Rocha and Fortes (2015)	*Zea mays*	*Sapajus nigritus*	Agricultural practices (Early planting, Crop location), Vigilance (Guard dogs), Acoustic deterrents	Varying
Rodriguez and Avery (1996)	*Oryza sativa*	*Chrysomus ruficapillus*	Chemical repellents (Methiocarb), Agricultural practices (Field clearing)	Not quantified
Rodriguez et al. (1995)	*Helianthus* sp.	*Zenaida auriculata*	Chemical repellents (Methiocarb), Visual deterrent (Calcium carbonate paint)	Effective
Rodriguez et al. (2004)	*Vitis* sp.	*Patagioenas picazuro*, Pitangus sulphuratus, *Turdus amaurochalinus*,	Hunting (Firearms), Poisoning (Carbofuran), Visual deterrents (Flags, Scarecrows), Acoustic deterrents	Effective

Study	Crop taxa	Vertebrate taxa	Protection techniques	Efficiency
		Passer domesticus, *Mimus saturninus*, *Turdus rufiventris*, *Colaptes campestris*, *Zenaida auriculata*, *Columba livia*, *Zonotrichia capensis*, *Myiopsitta monachus*, *Furnarius rufus*, *Penelope obscura*, *Tyrannus savana*, *Molothrus bonariensis*	(Fireworks, Cannons, Distress calls), Chemical repellents (Methiocarb, Anthraquinone)	
Romero-Balderas et al. (2006)	*Zea mays*	*Procyon lotor, Pecari tajacu, Nasua narica, Cuniculus paca, Sciurus aureogaster, Orthogeomys hispidus, Peromyscus mexicanus, Pionus senilis, Dryocopus lineatus, Psilorhinus morio*	None	-
Rosa et al. (2018)	*Saccharum* sp., *Zea mays, Manihot esculenta*	*Sus scrofa*	Hunting (Weapons, Dogs, Traps)	Not quantified
Sanchez et al. (2016)	*Helianthus* sp., *Zea mays*, *Triticum* sp., *Avena sativa*	*Cyanoliseus patagonus*	None	-
Sanchez-Cordero and Martinez-Meyer (2000)	*Zea mays, Saccharum* sp., *Coffea* sp., *Phaseolus* sp., *Oryza sativa, Avena sativa, Sorghum bicolor, Tritichum* sp.	*Sciurus aureogaster, Microtus mexicanus, Oligoryzomys fulvescens, Oryzomys couesi, Oryzomys melanotis, Peromyscus aztecus, Peromyscus leucopus, Peromyscus*	None	-

Study	Crop taxa	Vertebrate taxa	Protection techniques	Efficiency
		levipes, Peromyscus maniculatus, Reithrodontomys fulvescens, Reithrodontomys megalotis, Reithrodontomys mexicanus, Reithrodontomys sumichrasti, Sigmodon hispidus, Orthogeomys hispidus, Pappogeomys merriami, Thomomys umbrinus		
Santos (2018)	*Oryza sativa*	*Holochilus sciureus*	Hunting (Dogs)	Not quantified
Saucedo et al. (2010)	*Sorghum bicolor*	*Passer domesticus, Lonchura malacca, Lonchura punctulata, Dives atroviolaceus, Passerina cyanea, Zonotrichia leucophrys, Columbina passerina, Zenaida macroura, Zenaida asiatica*	None	-
Spagnoletti et al. (2017)	*Zea mays, Oryza* sp., *Phaseolus sp., Manihot esculenta, Musa* sp., *Mangifera indica, Citrullus lanatu, Ananas comosus, Carica papaya*	*Sapajus libidinosus, Brotogeris chiriri, Gnorimopsar chopi, Melanerpes candidus, Eupsittula aurea*	Vigilance (People, Guard dogs), Acoustic deterrents (Yelling, Firearms), Visual deterrents (Scarecrows, Fire), Agricultural practices (Early planting)	Effective
Trivedi et al. (2004)	*Bertholletia excelsa*	*Ara* sp.	None	-
Valencia	*Cocos nucifera*	*Rattus rattus*	Poisoning (Pyriminil, Coumarin and	Varying

Study	Crop taxa	Vertebrate taxa	Protection techniques	Efficiency
(1980)			Diphacinone), Agricultural practices (Field clearing), Physical barriers (Metal bands)	
Valencia et al. (1994)	*Oryza* sp., *Cocos* sp., *Elaeis* sp., *Zea* sp., *Sorghum* sp.	*Rattus rattus*, *Holochilus brasiliensis*, *Sigmodon hispidus*, *Zygodontomys brevicauda*	None	-
Villa et al. (1998)	*Saccharum* sp.	*Sigmodon hispidus*, *Oryzomys couesi*, *Handleyomys chapmani*	None	-
Villafana-Martin et al. (1999)	*Cucumis sativus*, *Ipomoea batata*, *Ananas camusus*	*Sigmodon hispidus*	Poisoning (Biorat)	Effective
Waters (2015)	*Phaseolus* sp., *Zea mays*, *Musa* sp., *Brassica oleracea*, *Ananas comosus*, *Solanum tuberosum*, *Citrullus lanatus*, *Dioscorea alata*	*Tapirus bairdii*, *Nasua narica*, *Procyon lotor*, *Tayassu* sp.	Hunting	Not quantified

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CONSIDERAÇÕES FINAIS

- A pesquisa sobre danos a cultivos por vertebrados na América Latina ainda é muito incipiente, mas o interesse pelo tema está aumentando na última década.
- A maioria dos estudos encontrados em nossa revisão está localizada em quatro países (Brasil, Argentina, México e Costa Rica). Estudos sobre o assunto devem ser realizados em outros países da América Latina, como a maioria dos países da América Central e do Caribe, que podem potencialmente ser muito afetados por ataques de vertebrados a plantações.
- Vertebrados de 16 ordens diferentes estiveram envolvidos em ataques a plantações e cinco deles foram os mais representados (Rodentia, Passeriformers, Columbiformes, Carnivora, Psittaciformes, Artiodactyla, and Primates).
- Danos foram relatados em 67 gêneros de plantas cultivadas, mas a maioria das interações concentrou-se em apenas oito (milho, mandioca, arroz, banana, feijão, cana-de-açúcar, soja, sorgo, trigo e girassol), com o milho sendo o mais proeminente.
- Os métodos de controle letal foram os mais utilizados pelos agricultores e são percebidos como a forma mais eficaz de reduzir os danos aos cultivos por vertebrados.
- A maioria dos estudos não quantificou a eficácia das técnicas de proteção, e apenas uma minoria testou os métodos de proteção por meio de experimentação, enquanto muitos foram baseados nas percepções dos agricultores.
- É necessário encontrar técnicas de proteção não letais eficazes que minimizem os danos à vida silvestre e protejam as economias locais.

- As metodologias para o estudo dos danos a cultivos por vertebrados precisam ser padronizadas, e uma ampla experimentação precisa ser realizada na América Latina e em outras regiões do globo.