Alternative crops as a mitigation measure for elephant crop raiding in the eastern Okavango Panhandle

Tiroyaone A Matsika[1], Joseph A Adjetey[2], Motshwari Obopile[2], Anna C Songhurst[3], Graham McCulloch[3], Amanda Stronza[3]*

[1]Department of wildlife and aquatics, Botswana University of Agriculture & Natural Resources, Private Bag 0027, Gaborone, Botswana
[2]Department of Crop Sciences and Soils, Botswana University of Agriculture & Natural Resources, Gaborone, Botswana
[3]Ecoexist Trust, Maun, Botswana; Texas A&M University, 534 John Kimbrough Blvd, College Station, TX 77843, USA; Zoology Department, University of Oxford, United Kingdom
*corresponding author: albertinahmatsika@gmail.com

Abstract

Elephant crop raiding causes food losses to subsistence farmers in the eastern Okavango Panhandle in Botswana. This study evaluated the effectiveness of using alternative crops such as groundnut (*Arachis hypogaea* L.), cowpea (*Vigna unguiculata* (L.) Walp), safflower (*Carthamus tinctorius* L.) and chilli (*Capsicum frutescens*) as a strategy to reduce elephant crop raiding. The study further evaluated the effectiveness of safflower and chilli as potential buffer crops against elephant raiding. Maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* (L.) Moench) were controls, being crops typically targeted by elephants in crop raiding incidents. A randomized complete block design experiment was conducted on a major elephant corridor in December 2018. The study compared the frequency of elephant visitations to plots, crop stand at harvest, crop losses, and actual and expected yield to determine crop resilience to elephant damage. The percentage of plants damaged differed significantly, with the lowest damage observed in chilli and the highest in maize. Non-buffered maize and sorghum suffered the worst damage. The lowest damage to legumes was in chilli-buffered crops with the highest damage in safflower-buffered crops. Chilli consistently deterred elephants from damaging crops when incorporated into the cropping systems. Therefore, we conclude, farmers should grow chilli in combination with both legumes (groundnut and cowpea), and cereals (maize and sorghum), which need to be buffered with chilli shrubs. Safflower has little effectiveness as an elephant deterrent compared to chilli. Diversifying crops could reduce the number of elephant raids and enable farmers to obtain increased incomes and improve food security.

Résumé

Le maraudage des récoltes par les éléphants causent des pertes de nourriture aux agriculteurs de subsistance dans l'est de l'Okavango au Botswana. Cette étude a évalué l'efficacité de l'utilisation de cultures alternatives telles que l'arachide (*Arachis hypogaea* L.), le niébé (*Vigna unguiculata* (L.) Walp), le carthame (*Carthamus tinctorius* L.) et le piment (*Capsicum frutescens*) comme stratégie de réduction du maraudage des récoltes par les éléphants. L'étude a en outre évalué l'efficacité de cultures de carthame et de piment en tant que zones tampons potentielles contre le maraudage par les éléphants. Le maïs (*Zea mays* L.) et le sorgho (*Sorghum bicolor* (L.) Moench) ont été choisies comme cultures témoins, étant des cultures typiques ciblées par les éléphants lors d'incidents de maraudages. Une expérience en blocs aléatoires complets a été réalisée sur un couloir majeur d'éléphants en décembre 2018. L'étude a comparé la fréquence des visites d'éléphants dans les parcelles, la récolte finale, les pertes de cultures, le rendement réel et attendu pour déterminer la résilience des cultures aux dommages causés par les éléphants. Le pourcentage de plantes endommagées différait considérablement, les dégâts les plus faibles étaient au piment et les plus élevés au maïs. Le maïs et le sorgho sans zones tampons ont subi les pires dégâts. Les dommages les plus faibles aux légumineuses ont été observés dans les cultures avec des zones tampons au piment, les dégâts les plus élevés ont été observé dans les cultures avec des zones tampons au carthame. Le piment dissuadait systématiquement les éléphants (*Loxodonta africana*) d'endommager les cultures lorsqu'ils étaient incorporés dans les systèmes de culture. Par conséquent, les agriculteurs devraient cultiver du piment en combinaison avec à la fois les légumineuses (arachide et niébé) et les céréales (maïs et sorgho), qui doivent être cultivées avec des arbustes à piment comme zones tampons. Le carthame a peu de valeur dans la dissuasion des éléphants par rapport au piment. La diversification des cultures pourrait permettre aux agriculteurs réduire le nombre de raids d'éléphants et permettre aux agriculteurs d'obtenir des revenus accrus et d'améliorer la sécurité alimentaire.

Introduction

Human–elephant conflict (HEC) is a complex problem in many parts of Africa and Asia where elephants co-exist with people. Crop raiding is often the most prevalent form of HEC, whose aftermaths may include food insecurity, poverty (Gontse et al. 2018), loss of livelihood, injury and sometimes death (Mayberry 2015). Farmers adopt a range of strategies to reduce crop raiding by elephants, including selection of elephant resistant crops and cropping layouts. However, Sitati et al. (2005) report that elephants become habituated to deterrents; therefore, combining different methods increases the efficiency of mitigation measures. Interestingly, elephants are found to damage different crop types differently, even when they are grown in the same fields. This variation indicates that elephants may intentionally select certain crop types over others (Monney et al. 2010; Hoare 2012). Previous studies have also shown that elephants feed on different parts of plants; usually they target fruit over the vegetative component of the plant (Nyirenda et al. 2013).

Elephants can be deterred by crops that are unpalatable to them. Crops such as ginger (*Zingiber officinale* Roscoe), garlic (*Allium sativum* L.), onion (*Allium cepa* L.) and lemongrass (*Cymbopogon citratus* Stapf) have all been used to deter elephants from raiding crops in Zambia (Gross et al. 2016). Currently, the most commonly used elephant deterrent crop is chilli (*Capsicum frutescens*). Chilli fruits contain high concentrations of capsaicin, and have been used as effective repellents to elephant invasions into farms (Nyirenda et al. 2013; Karidozo and Osborn 2015). Dried and processed seedpods are processed into products such as briquettes (in Botswana; Pozo et al. 2017), sprays (in Zambia; Nyirenda et al. 2013) and grease for application to fences (in Tanzania; Chang'a et al. 2016). The use of these chilli by-products has been highly successful. However, very few studies report the incorporation of live chilli crops in the actual cropping system. In one such study (Parker and Osborn 2006), elephants did not raid the trial plots; however it was not clear whether this result could be attributed to unsuccessful elephant raiding due to the deterrent effect of chilli (and not simply the unpredictability of elephant raiding behaviour).

The efficacy of many mitigation measures fades with time as elephants adjust to these measures. Sitati et al. (2005) recommend alternating combinations of mitigation measures to prevent elephants becoming tolerant to a chilli deterrent and its efficacy from fading. This study assesses the effectiveness of safflower (*Carthamus tinctorius* L.) as a complementary deterrent to chilli. Its spiky inflorescence and leaves (Emongor 2010) are known to deter cattle and medium-sized wildlife and could could also be a deterrent to elephants. Emongor (2010) attest to the ability of safflower to thrive in semi-arid environments. Most importantly, safflower has a range of uses including as food, medicine and as a cash crop (Emongor 2010). Therefore, it could be easily adapted in Botswana by local farmers with minimal costs and complications.

In addition to chilli and safflower, we tested the deterrent effect of the food crops groundnut (*Arachis hypogaea* L.) and cowpea (*Vigna unguiculata* (L.) Walp), which may be less palatable to elephants because of their hidden underground pods and poor pod visibility, respectively.

Many studies have shown that elephants raid crops predominantly at night due to fear of detection (Songhurst 2012). This timing makes guarding of fields difficult and deterrents that can be effective through both day and night are preferable. Unpalatable crops could provide such a deterrent (Gross et al. 2016). Elephants reportedly often raid the edges of fields, while not damaging the inner portions of fields. This behaviour may be linked to fear, with elephants favouring the less risky part of the field (Songhurst et al. 2015). Therefore, it seems worthwhile to test the use of unpalatable or less preferred crops as buffer crops to protect the edges of fields, thereby discouraging elephants from penetrating fields to access more palatable crops.

Drawing on the findings of previous studies (e.g. Nyirenda et al. 2013; Karidozo and Osborn 2015), the selective destruction by elephants of certain crops while sparing others thus forms the core of this study. The study evaluated the deterrent effects of chilli, safflower, groundnut and cowpea, using the food crops maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* (L.) Moench) as controls. In addition, we tested the effectiveness of chilli and sufflower when planted as buffer crops on the margins of fields containing the four food crop species. We compared the results of these 14 experimental treatements (six stand-alone crops and eight combinations with buffer crops). To summarize, the first objective was to evaluate the cultivation of chilli, groundnuts, safflower and cowpeas as an elephant crop raiding management strategy. The second objective of this study was to assess the effectiveness of safflower and chilli as elephant deterrents when planted as buffer crops on the margins of fields.

Methodology

Study area

The study was carried out in the Ngamiland District of Botswana in elephant corridor 40 (fig. 1). This is the corridor most frequented by elephants during their daily movements between dry inland areas and the Okavango Delta, which is the main watercourse supplying the eastern Okavango Panhandle and marks the boundary between Botswana and Namibia (Songhurst et al. 2015). Elephant movements are constrained by two further physical barriers: the 'Buffalo Fence', which transverses Botswana to the north, and the Delta to the south. Wildlife Management Areas (NG11 and NG12) cover most of the eastern Okavango area, sustaining a very large elephant population (estimated to be 15,429 in 2015; Songhurst et al. 2016) that is almost as large as the human population (16,306 in 2010; Statistics Botswana 2011). Botswana is an upper middle-income country and the Okavango Delta area is a prime hub for the tourism industry. The tourism sector and agriculture contribute 12% and 4% to the country's economy respectively, of the latter, 80% is from beef production. (World Bank 2019 figures). The villagers in the Delta region practise small-scale, rain-fed and subsistence farming as a primary source of livelihood. In addition to subsistence agriculture, the principal source of livelihood in the area is work in the tourism sector. The climate is dry and hot, with annual rainfall

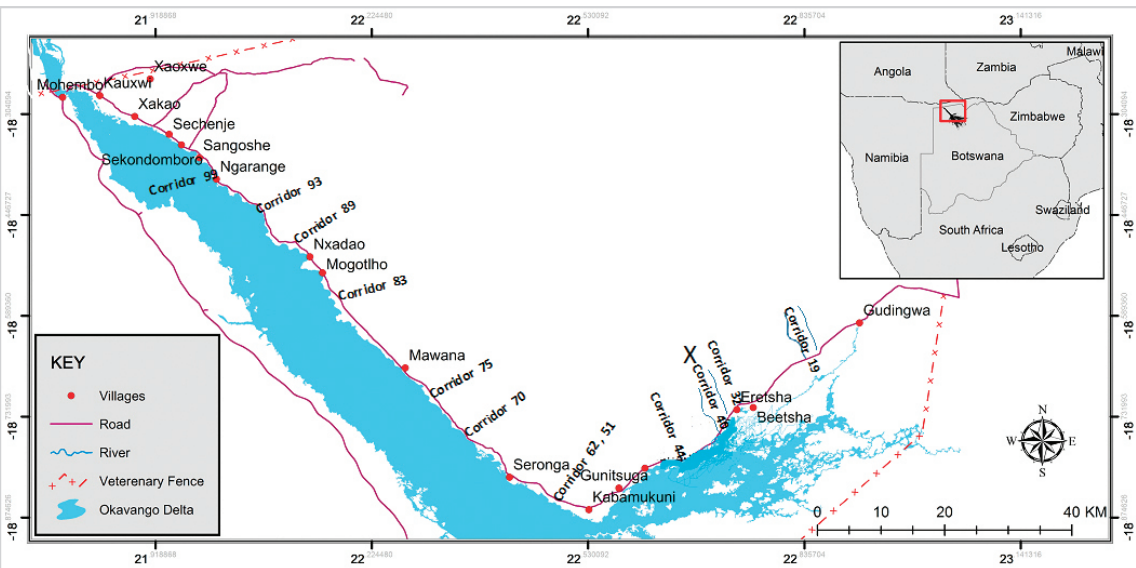

Figure 1. Location of the study area (corridor 40, marked with an X) in the eastern Okavango Panhandle, Botswana.

erratic ranging from 120 mm to 210 mm and maximum mean monthly temperatures exceeding 30°C (e.g. 31.8°C and 33.4°C in 2013/2014 and 2014/2015 respectively; DMSB 2016). Due to the proximity to the Delta, human–wildlife conflict is a recurrent phenomenon in the area and, for the farming community, elephants have become major pests (Songhurst et al. 2016).

Experimental design and treatments

Randomized complete block designs (RCBD) consisting of treatments and controls were placed on corridor 40. RCBD is a common design used in agricultural experiments whereby comparative trial units are gathered into blocks and/or replicates. It is used to control the confounding impacts of spatial variation on experimants (Oehlert 2010). The main food crops used were cowpea and groundnut, in addition to maize and sorghum as controls, while chilli and safflower were used as deterrent crops. Food crops were buffered with deterrent crops or grown without buffering as shown in fig. 2. Each experimental block measured 150 m × 100 m. The plot size for stand-alone crops was 20 m × 5 m while buffered plots were provided with an additional 2 m buffer zone. There was a 46 m space between the two rows of the experimental units. Inter-row spacing was 0.75 m for sorghum, maize, cowpea and groundnuts and safflower and 1.5 m for chilli. The spacing between plants in a row was 0.2 m for cowpea, groundnut, safflower and chilli, 0.3 m for sorghum and 0.5 m for maize. The crop layout plot was repeated at four different locations within elephant corridor 40, each location constituting a replicate. Fields were fenced with goat-proof mesh wires to simulate farmers' fields and to minimise interference from other animals. Crops were planted in December 2018 and monitored until harvesting time around May 2019, as per the traditional rain-dictated growing season. Neither fertilizers nor pesticides were applied in this experiment, in line with local practices.

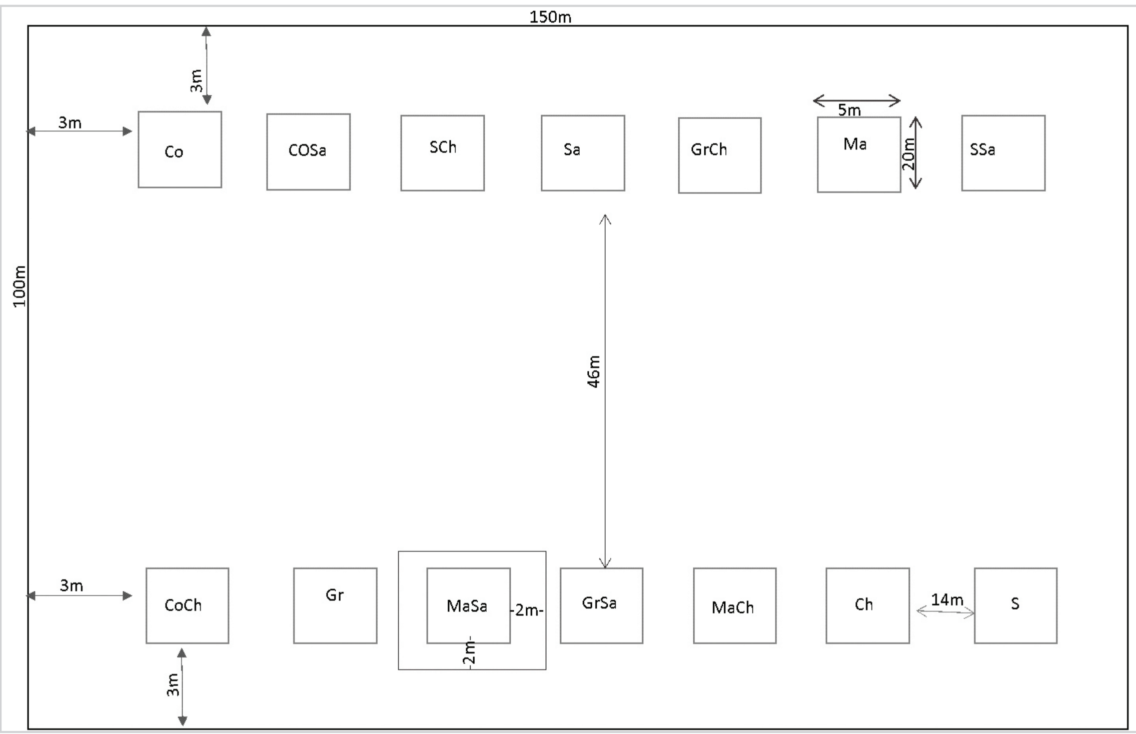

Figure 2. The layout of test plots with treatments randomized in each experimental block (bottom) on the corridor (top). Stand-alone crops: Ma (maize); S (sorghum); Co (cowpea); Gr (groundnut); Ch (chilli); Sa (safflower). Crops buffered with deterrent crops: MaSa (safflower buffering maize); SSa (safflower buffering sorghum); CoSa (safflower buffering cowpea); GrSa (safflower buffering groundnut); MaCh (chilli buffering maize); SCh (chilli buffering sorghum); CoCh (chilli buffering cowpea); and GrCh (chilli buffering groundnut).

Quantifying crop damage and crop resilience to elephant raids

The principal researcher and a community enumerator visited and assessed plots damage every two days in the mornings from December to May (fig. 3). The IUCN data collection protocol (Hoare 1999) was used to collect data on crop raiding incidents whenever elephant visits were observed. Elephant visits were identified by the presence of elephant footprints and elephant dung, elephant sightings by people, trampling of crops, and partial destruction of plants such as maize cobs or leaves. Crop loss and damage for each treatment were assessed quantitatively. The number of plants damaged as a percentage of the total crop stand was used to evaluate elephant damage. Combinations of test crop plot visitation and resultant damage were used to establish the test crops' resilience to elephant raiding or damage.

At the end of the cropping season (May), yield data were collected by harvesting plants from three inner rows in each plot, weighing and converting to kilograms per hectare. Sorghum, maize, safflower, and cowpea were threshed and weighed. Whole chillis and unshelled pods of groundnut were weighed to determine the yields. Plants remaining in the harvested area were counted and used to estimate the actual yield. The extent of crop damage, yield and frequencies of elephant visitation to the plots were used to assess crop preference and tolerance by elephants.

Figure 3. Farmer tending field of Safflower.

Data analysis

Yield data were analysed using R version 3.5.1 + R studio statistical package to test significance for the effects of crop species and buffering with chilli and safflower.

Non-parametric tests, i.e. one-way ANOVA and the Kruskal-Wallis chi-square test, were used to determine whether raiding of the test plot was independent of other factors such as the presence of other contiguous test plots. For the Kruskal-Wallis chi-square test, the elephant raid (successful or otherwise) on a particular plot was the independent unit of analysis. Chi-square was calculated as:

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

where O is the observed value, and E is the expected value.

ANOVA and the Kruskal-Wallis chi-square test could only show that test crops were damaged similarily or differently. However, these tests do not provide information on the magnitude and significance of differences between specific treatments. To this end, mean separation tests, i.e. the Tukey multiple comparisons of means and least significant difference (LSD) test, were used for pairwise comparison of different crop species and treatments of the same crop.

Pairwise proportional tests were used to determine the likelihood of elephants entering the main experimental block and accessing the test plots. The proportion of elephants successfully entering the test plot (PS) was calculated as:

$$PS = \frac{Y}{n}$$

where n = the total number that elephants came to the main experimental plot, and Y = the number of elephants that successfully entered the test plot. The likelihood of elephants who came to the experimental plot not visiting the test plot was therefore 1 minus the chances of entry elephants entering the test plot. A higher PS indicates a greater likelihood that elephants within the experimental plot will come into a field growing that particular crop.

Non-elephant losses were assessed separately by counting crop plants lost as results of other occurrences such as heat extremes and damage by other animals.

Results

Crop damage by elephants

Elephants visited the main experimental block on 43 occasions, while the number of visits to individual test plots ranged from 11 to 24 (see Table 1 and the discussion below). The percentage of plants damaged by elephants varied significantly among crop species (F = 94.11, df = 5, p < 0.0001). Calculation of the mean percentage of plants damaged demonstrated that maize (96.25%) was the most damaged, followed by sorghum (83.25%), safflower (72.50%) cowpeas (34.25%), groundnuts (24.75%) and chilli (33.75%). These results were confirmed by the χ^2 test, which indicated that the damage to different crops was independent of each other (χ^2 = 22.03, df = 5, p = 0.0005). Tukey multiple comparisons of means indicated the existence of significant differences (at a 95% confidence level) in the amount of damage between all pairs of individual crop species, apart from 'cowpea vs. chilli' (Table 1).

Pairwise proportional tests determined the likelihood of an elephant entering the experimental block proceeding to each of the individual test plots. The type of crop grown significantly influenced the likelihood of an elephant visiting a particular test plot (F = 4.95, df = 11, p = 0.0001). Elephants visited non-buffered crop plots more than buffered plots, and safflower-buffered crops more than chilli-buffered plots. Sorghum (56%) plots were visited most frequently, following by maize (47%) cowpea (44%), safflower (37%), and groundnut (33%). Elephants visited chilli plots less frequently compared to all the other crop types (26%) (Table 2).

Even though chilli was a better deterrent of elephants compared to safflower, it was the most susceptible crop to other causes of damage, especially high temperatures (38–41°C as in February 2019) (fig. 4). Safflower was the second most susceptible crop to non-elephant damage. Of the two cereals sorghum was less resilient to non-elephant damage than maize; the legumes, groundnut and cowpea were the most resilient to non-elephant damage. However, differences in the amount of non-elephant crop loss among test plots were not significant (F = 1.11, df = 13, p = 0.47).

Table 1. Pairwise comparison of elephant damage on crops in the 2018/2019 season.

Crop comparison	Mean difference	Lower bound	Upper bound	p-value
Cowpea vs. chilli	0.50	–8.31	9.31	1.000
Groundnut vs. chilli	–9.00	–17.81	–0.19	0.044
Maize vs. chilli	62.50	53.69	71.31	0.001
Safflower vs. chilli	38.75	29.94	47.56	0.001
Sorghum vs. chilli	49.50	40.69	58.31	0.001
Groundnut vs. cowpea	–9.50	–18.31	–0.69	0.030
Maize vs. cowpea	62.00	53.19	70.81	0.001
Safflower vs. cowpea	38.25	29.44	47.06	0.001
Sorghum vs. cowpea	49.00	40.19	57.81	0.001
Maize vs. groundnut	71.50	62.69	80.31	0.001
Safflower vs. groundnut	47.75	38.94	56.56	0.001
Sorghum vs. groundnut	58.50	49.69	67.31	0.001
Safflower vs. maize	–23.75	–32.56	–14.94	0.001
Sorghum vs. maize	–13.00	–21.81	–4.19	0.002
Sorghum vs. safflower	10.75	1.94	19.56	0.012

Table 2. Successful entries into the the test plots as a proportion of total entries to the experimental block.

Treatments	Total visits to the main plot (*n*)	Number of successful entries into the plot (*Y*)	Proportion of successful entries	p-value
Sorghum	43	24	0.56	0.001
Maize	43	20	0.47	0.001
Cowpea	43	19	0.44	0.001
Groundnut	43	14	0.33	0.001
Safflower	43	16	0.37	0.001
Chilli	43	11	0.26	0.005
Sorghum-Safflower	43	24	0.56	0.001
Maize-Safflower	43	17	0.40	0.001
Cowpea-Safflower	43	16	0.37	0.001
Groundnut-Safflower	43	14	0.33	0.001
Sorghum-Chilli	43	14	0.33	0.05
Maize-Chilli	43	10	0.23	0.001
Cowpea-Chilli	43	14	0.33	0.001
Groundnut-Chilli	43	15	0.35	0.001

Susceptibility to non-elephant damage

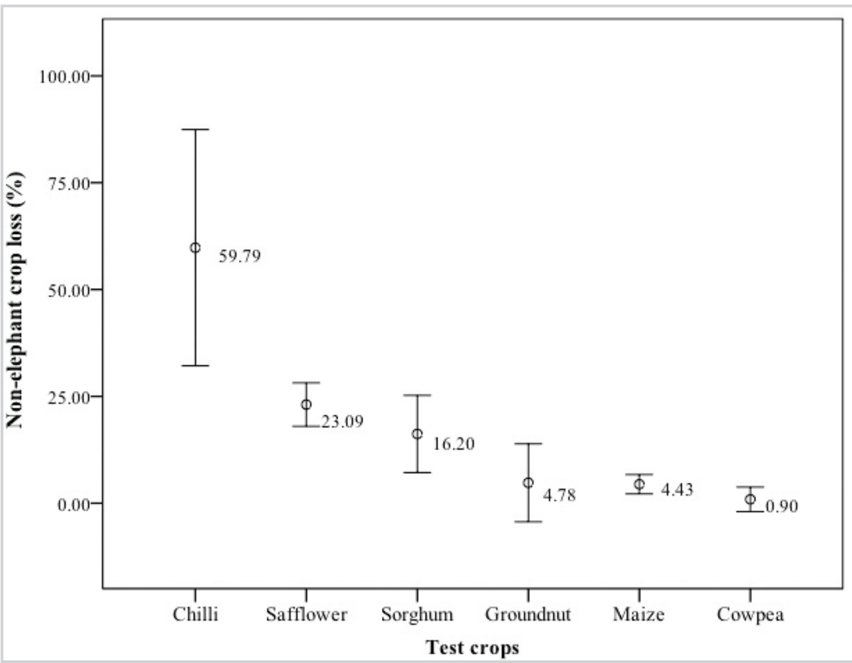

Figure 4. Percentage of crops lost due to non-elephant factors such as high temperatures and other pests such as birds and squirrels. Circles indicate means (n = 4 replicates) and the bars show standard deviation.

Impacts of buffering crops with chilli and safflower

The Tukey and LSD tests showed that non-buffered cereal crops (sorghum and maize) suffered more damage by elephants than non-buffered non-cereal crops (cowpea and groundnut) (fig. 5). Damage to maize and sorghum was significantly reduced by the chilli buffering and, to a lesser degree by safflower buffering. The average proportion of sorghum plants damaged by elephant was 83.75% without buffering 59.0% with chilli buffering and 71.75% with safflower buffering. The Tukey test showed that buffering sorghum with either chilli or safflower led to a significant decrease in damage caused by elephants ($F = 31.42$, df = 2, $p < 0.001$). The Kruskal-Wallis chi-square test showed that sorghum treatment damage to elephants was statistically independent ($\chi^2 = 9.85$, df = 2 $p = 0.007$). The average proportion of maize plants damaged by elephant was 95.50% without buffering, 51.25% with chilli buffering and 82.50% with safflower buffering ($F = 117.3$, df = 2, $p < 0.001$). The Kruskal-Wallis chi-squared test showed that maize treatment damage to elephants was statistically independent ($\chi^2 = 9.85$, df = 2, $p < 0.007$).

Effects of buffering were different for legumes (cowpea and groundnut) than for cereals. Safflower-buffered legumes were damaged to a greater extent than non-buffered crops, while chilli conferred additional protection (fig. 5). The average proportion of cowpea plants damaged was 34.25% without buffering, 23.50% with chilli buffering, and 46.00% with safflower buffering. These differences were statistically significant ($F = 20.56$, df = 2, $p < 0.0004$). The average proportion of groundnut plants damaged

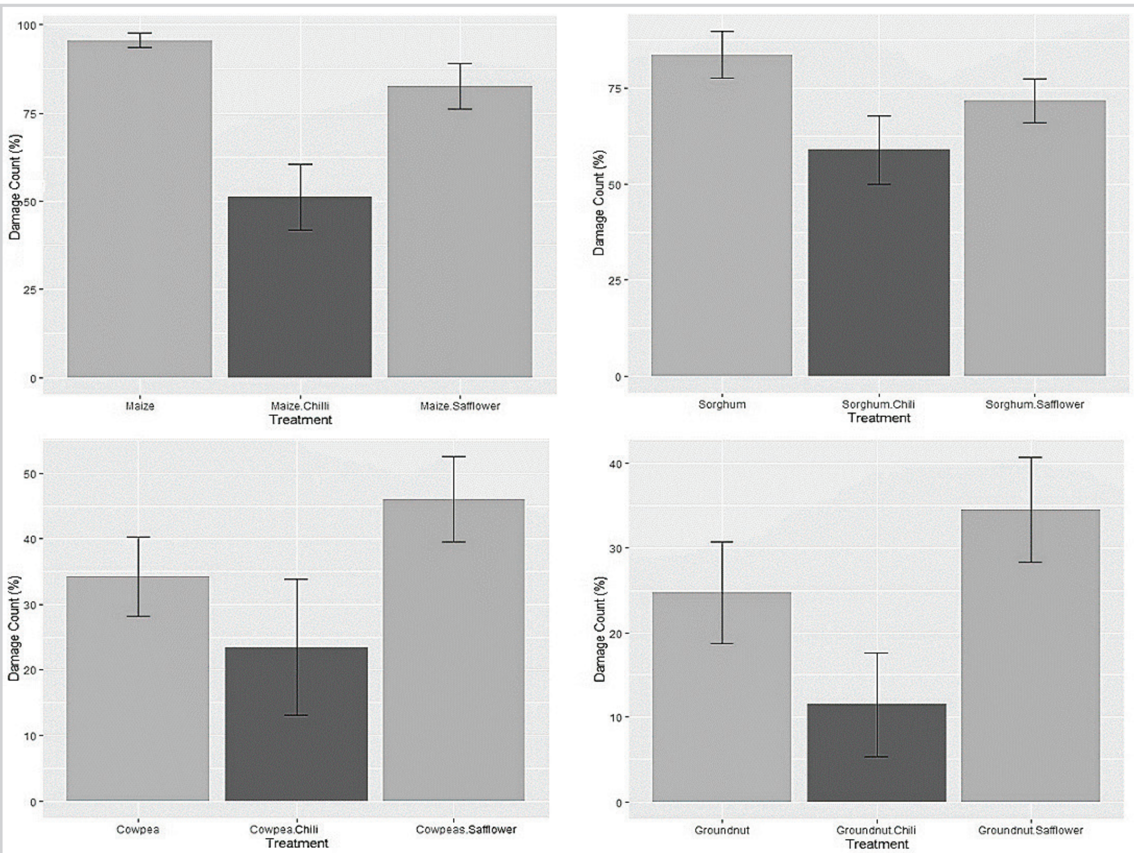

Figure 5. Comparisons of means and the extent of elephant damage (%) to non-buffered, safflower-buffered, and chilli-buffered food crops in the 2018/2019 season. Column heights indicate means (n = 4 replicates) and bars show standard deviations.

was 24.75% without buffering, 11.50% with chilli buffering, and 34.50% it safflower buffering (F = 31.42, df = 2, p < 0.00003). The Kruskal-Wallis chi-square test showed that both cowpea (χ^2 = 9.85, df = 2, p = 0.007) and groundnut (χ^2 = 9.85, df = 2, p < 0.007) treatment damage by elephants were statistically independent.

Using the LSD test, we established that chilli-buffered crops had significantly higher yields compared to the safflower-buffered and non-buffered counterparts (fig. 6). There was a significant yield variation between chilli-buffered and non-buffered crops for maize (F = 33.47, df = 2, p < 0.001), sorghum (F = 5.72, df = 2, p = 0.025), cowpea (F = 12.96, df = 2, p = 0.002) and groundnut (F = 13.07, df = 2, p = 0.002) treatments. By contrast, safflower-buffered cereals had only slightly higher yields than their non-buffered counterparts, while yields of safflower-buffered legumes were significantly lower compared to their non-buffered counterparts.

Discussion

This study found that all crops may be damaged by elephants passing through agricultural areas. However, the damage varied significantly between

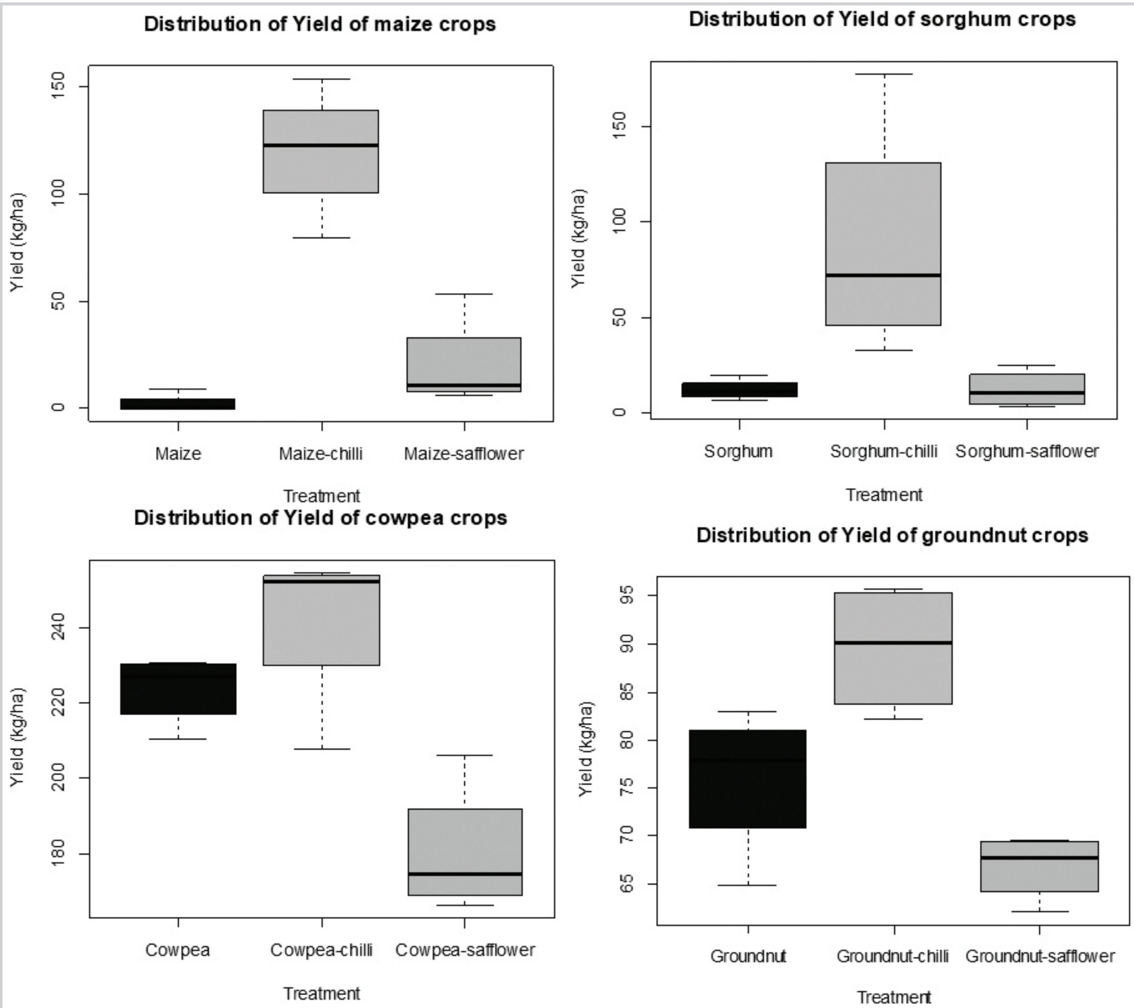

Figure 6. Comparison of yield between non-buffered, chilli-buffered and safflower-buffered crops of maize, sorghum, groundnut and cowpea grown on elephant corridors in the 2018/2019 season. In the bar-and-whisker plots, the thick line shows the mean (n = 4 replicates), the upper and lower edges of the bar show standard deviation, and the whiskers indicate maximum and minimum values.

different types of crops. Maize and sorghum were the most damaged by elephants, followed by safflower, cowpeas, groundnuts and chilli. Our findings agree with those of previous studies where cereals (Monney et al. 2010), maize (Gross et al. 2016) and sorghum were preferred by elephants and consumed more than other crops. This preference for high-calorie crops makes fields of maize and sorghum vulnerable to elephant damage, which can causing severe food loss to subsistence farmers. Maize, sorghum, groundnut, cowpea and safflower all have high calorific content (e.g. Dwivedi 2003; Emongor et al. 2013), but our results showed that elephants preferred maize, sorghum and safflower, while cowpeas and groundnuts suffered less damage.

Elephants tended to ignore the safflower initially, possibly because it was a novel crop in our study area, hence new to the elephants. However, once they had discovered it, elephants consumed significant amounts of safflower; more than cowpea, for example, even though cowpea was visited more often. In fact, its use as a buffer for cowpea and groundnut led to increased consumption of these two crops. It is likely that the high calorific content and, possibly, palatability of safflower increased the elephants' predisposition towards its consumption. Contrary to the hypothesis, the spiky mature inflorescence and leaves of safflower did not deter elephants from feeding on the crop. The increased interest in safflower towards the end of the study period could also be associated with the formation and maturity of oil-containing seeds, which were probably more attractive as a food source than the vegetative stage.

Secondary plant metabolites may also influence how a crop is perceived by elephants. For instance, a safflower kernel contains around 45% oil and safflower has been used to produce palatable animal feed with high amounts of oils and proteins (Emongor 2010). Phytochemical analysis by Khamar and Jasrai (2014) reports high levels of polyunsaturated fatty acids in safflower compared to other oil crops, which suggests some metabolites as possible attractants. However, no research on elephant–safflower interaction was found in the literature review. We suggest further study to examine the phytochemical profile of safflower to confirm the actual component of the plant that attracts elephants to this crop. The ability of chilli to act as an elephant deterrent is related to the capsaicin resin, concentrated in the fruit, rather than the vegetative parts (Dagnoko et al. 2013). Similarly, cowpeas often contain antinutritional elements such as tannins and protease inhibitors (Jain et al. 2009), which negatively affect their taste or digestibility. Hence, incorporating such crops into the cropping systems could increase their resilience to elephant raids.

Elephants rarely visited the chilli plot or fed on it; however, they inflicted damage on chilli plants out of spite, by uprooting of plants and trampling. The deterrent effects of chilli was evident since crops buffered with chilli were consumed less compared to those buffered with safflower and non-buffered crops. Even though chilli-buffered groundnut was visited more frequently than non-buffered and safflower-buffered groundnut treatments, it was the least damaged among groundnut treatements. Moreover, while the frequency of elephant visitation to the sorghum-chilli and the cowpea-chilli plots was the same, the damage to chilli-buffered sorghum was double that of chilli-buffered cowpea. These findings suggest that elephants were prepared to overcome their aversion to chilli, but only in order to reach highly platable crops such as maize and sorghum. Our results are in line with those of Karidozo and Osborn (2015) and Pozo et al. (2018), who identify chilli as an effective elephant repellent. However, this study stands out since we integrated live chilli crop into the cropping system rather than using chilli by-products.

It is important to acknowledge that both morphological and chemical characteristics influence the type and extent of crop damage. Elephants showed a predisposition to taller crops, from which they could pick cobs/fruit easily, only consuming some part of these taller crops. Groundnuts and safflower were the only crops, which were consumed entirely by elephants. Even though legumes have high caloric content compared to cereals, their morphological characteristics (i.e. the leafy structure of cowpeas and the underground pods of groundnuts) made them less attractive to elephants, and thus less susceptible to damage. Many studies (including Songhurst et al. 2015 and Parker and Osborn 2006) report that elephants avoid human populated areas and cultivated lands since they associate them with danger or risk. It may be inferred that elephants do not risk the time-consuming selection of fruits by either digging groundnuts or searching for pods among the leafy ground-hugging cowpea plants, especially when easily accessible alternatives were available. These findings are consistent with those of Webber et al. (2011), who reported that elephants did not show an interest in digging for groundnuts or the roots of cassava, despite their high calorific content.

The results of this study established the fact that elephants were more likely to visit the non-buffered crops rather than buffered crops. Therefore, the choice of a buffer crop is crucial in the Okavango Panhandle and similar locations. While chilli provided an effective buffer crop, the palatability of safflower meant that it was not effective as a buffer crop. Buffering with a desirable crop such a safflower risks attracting elephants to crops that in themselves are not perceived as desirable. In this study, safflower-buffered cowpea and groundnut sustained more damage than non-buffered legumes, despite being visited less frequently. This suggests that the addition of the safflower buffer possibly motivated elephants to prolong their stay in these legume crops, consequently increasing the amounts of crop loss.

Although elephants cause a more significant damage to crops than other wildlife species in the eastern Okavango, other pests and unfavourable weather also compromised crop productivity. However, the impact was insignificant compared to elephant damage. Nonetheless, it is essential to grow crops that could thrive in this semi-arid area. Cowpea, maize and groundnut were not severely affected by non-elephant damage. The resilience of cowpea and groundnut to pests and climate extremes is well known (Dwivedi et al. 2003). In this study, groundnut yields suffered more damage than cowpea, but mainly from consumption by squirrels rather than elephant damage. The maize crop in the study was not impacted significantly by non-elephant factors. This could simply be because elephants consumed most of the crop, thereby rendering it unavailable for damage by non-elephant factors. Safflower has a high financial potential; however, its attractiveness to elephants makes it a risky crop to grow in the eastern Okavango. Chilli is less desirable to elephants and also has a high economic value (Acaye and Odongo 2018). However, chilli struggled to germinate from seed in the Kalahari soils and had difficulties withstanding harsh weather conditions. Due to the fragility of chilli, farmers need to invest in low-cost techniques to ensure the survival of the crop. These could include net shading, using seedlings rather than directly sowing seed and hardening before transplanting out in the fields.

Conclusion

In summary, cowpeas, groundnuts and chilli were the crops least susceptible to damage by elephants, obviating the need for constant vigilance by farmers. Safflower was attractive to elephants and sustained high levels of damage. Buffering crops with safflower actually increased their risk of being raided, contradicting our initial assumption that safflower would function as an elephant deterrent and a good buffer crop. While chilli performed well as both deterrent and buffer crop, it was highly vulnerable to harsh weather, especially at early vegetative stages of growth.

We recommend that policy makers provide increased incentives for farmers to grow crops such as groundnut and cowpea that are identified in this study as being resilient to elephants. It would also be worthwhile to carry out studies of other potentially viable crops, in particular, legumes such as Bambara groundnuts, in other areas prone to elephant raiding. Identification of viable alternative crops is essential to aid farmers to become more resilient to elephant crop damage to reduce hostility towards elephants, foster peaceful coexistence and improve positive attitudes towards elephant conservation among farmers.

Finally, we recommend futher studies on the cultivation of alternative crops, which are not only unpalatable to elephants but also drought resistant. The combination of crops which are resilient to warming from climatic change but less attractive to wildlife should also help to reduce conflicts between farmers and elephants.

Acknowledgements

This study would not have been possible if it was not for the mutual collaboration between the Botswana University of Agriculture and Natural Resources and Ecoexist Project Botswana. We are grateful for the assistance of the eastern Okavango farmers and village leaders as they permitted us unlimited access to use their abandoned fields on elephant corridors. In addition the authors would like to thank our copy-editor, Andrew Halliday for his editorial assistance and additional content to improve the paper.

References

Acaye G. and Odongo J. 2018. Contributions of African bird's eye chilli (*Capsicum frutescens*) to household income of smallholder farmers in northern Uganda: A case study of Paicho Sub-County, *Asian Journal of Agricultural Extension, Economics & Sociology*, 23(2), pp. 1–9. doi: 10.9734/AJAEES/2018/39829.

Department of Meteorological Services, Botswana. 2016. <http://www.info.bw/~mettest/>. [Accessed: 20 August 2016].

Chang'a A, de Souza N, Muya J, Keyyu J, Mwakatobe A, Malugu L, Ndossi HP, Konuche J, Omondi R, Mpinge A, Hahn N, Palminteri S. and Olson D. 2016. Scaling-up the use of chili fences for reducing human-elephant conflict across landscapes in Tanzania, *Tropical Conservation Science*, 9(2), pp. 921–930.

Dagnoko S, Yaro-Diarisso N, Sanogo PN, Adetula O, Dolo-Nantoumé A, Gamby-Touré K, Traoré-Théra A, Katilé S. and Diallo-Ba D. 2013. Overview of pepper (*Capsicum spp.*) breeding in West Africa, *African Journal of Agricultural Research*, 8(13), pp. 1108–1114. doi: 10.5897/AJAR2012.1758.

Dwivedi SL, Crouch JH, Nigam SN, Ferguson ME. and Paterson AH. 2003. Molecular breeding of groundnut for enhanced productivity and food security in the semi- arid tropics: opportunities and challenges, *Advances in Agronomy*, pp. 153–221. doi: 10.1016/S0065-2113(03)80004-4.

Emongor V. 2010. Safflower (*Carthamus tinctorius L.*) The underutilized and neglected crop: A review, *Asian Journal of Plant Sciences*, 9(6), pp. 299–306.

Emongor V, Oagile O. and Kedikanetswe, B. 2013. Effects of plant population on growth, development and oil yield of safflower, *Journal of Agricultural Science and Technology*, 3(5B), pp. 321. Available at: https://search.proquest.com/openview/d4ba91e946a147f0ca5118b31395a7e7/1.pdf?cbl=2029907&pq-origsite=gscholar [Accessed: 11 June 2019].

Gontse, K, Mbaiwa, JE. and Thakadu, OT. 2018. Effects of wildlife crop-raiding on the livelihoods of arable farmers in Khumaga, Boteti sub-district, Botswana, *Development Southern Africa*, 35(6), pp. 791–802. doi: 10.1080/0376835X.2018.1495061.

Gross, EM, McRobb, R. and Gross, J. 2016. Cultivating alternative crops reduces crop losses due to African elephants, *Journal of Pest Science*, 89(2), pp. 497–506. doi: 10.1007/s10340-015-0699-2.

Hoare, R. 2012. Lessons from 15 years of human-elephant conflicts mitigation: management considerations involving biological, physical and governance issues in Africa', *Pachyderm*, 51(51), pp. 60–74.

Hoare, RE. 1999. A standardised data collection and analysis protocol for human-elephant conflict situations in Africa, *Document prepared for the IUCN African Elephant Specialist Group's Human–Elephant Conflict Working Group*, Nairobi, Kenya.

Jain, AK, Kumar, S. and Panwar, JDS. 2009. Antinutritional factors and their detoxification in pulses-A review, *Agricultural Research and Communication Centre*, 30(1), pp. 64–70. Available at: www.arccjournal.com/indianjournals.com [Accessed: 18 August 2019].

Karidozo, M. and Osborn, FV. 2015. Community based conflict mitigation trials: Results of field tests of chilli as an elephant deterrent, *Journal of Biodiversity & Endangered Species*, 3(1), pp.(144). doi: 10.4172/2332-2543.1000144.

Khamar, RR. and Jasrai, YT. 2014. Biochemical and phytochemical analysis of selected plant oils, *International Research journal of Chemistry*, 4, pp. 64–72. Available at: http://irjc.petsd.org [Accessed: 18 August 2019].

Madison S. 2019. Botswana's tourism sector grows 3.4% in 2018: report; https://www.iol.co.za/business-report/international/botswanas-tourism-sector-grows-34-in-2018-report-20094771 [Accessed 28.08.20].

Mayberry, A. 2015. Human dimensions of human-elephant conflict in Botswana: Exploring visible and hidden well-being impacts, (Doctoral dissertation), University of Guelph, Canada. pp. 125.

Monney, KA, Dakwa, KB. and Wiafe, ED. 2010. Assessment of crop-raiding situation by elephants (*Loxodonta africana cyclotis*) in farms around Kakum conservation area, Ghana, *International Journal of*

Biodiversity and Conservation, 2(9), pp. 243–249.

Nyirenda V, Myburgh W. and Reilly, B. 2013. Predicting environmental factors influencing crop-raiding by African elephants (*Loxodonta africana*) in the Luangwa Valley, eastern Zambia, *African Journal of Environmental Science and Technology*, 6(10), pp. 391–400. doi: 10.5897/.

Oehlert, GW. 2010. A first course in design and analysis of experiments. University of Minnesota ISBN 0-7167-3510-5.

Parker GE. and Osborn FV. 2006. Investigating the potential for chilli *Capsicum spp.* to reduce human-wildlife conflict in Zimbabwe, *Oryx*, 40(03), pp. 343. doi: 10.1017/S0030605306000822.

Pozo RA, Cusack JJ, McCulloch G, Stronza A, Songhurst A. and Coulson T. 2018. Elephant space-use is not a good predictor of crop-damage, *Biological Conservation*, (228). doi: 10.1016/j.biocon.2018.10.031.

Rusinamhodzi L, Corbeels M, Nyamangara J. and Giller KE. 2012. Maize-grain legume intercropping is an attractive option for ecological intensification that reduces climatic risk for smallholder farmers in central Mozambique, *Field Crops Research*, 136, pp. 12–22. doi: 10.1016/j.fcr.2012.07.014.

Sitati NW, Walpole MJ. and Leader-Williams N. 2005. Factors affecting susceptibility of farms to crop-raiding by African elephants: Using a predictive model to mitigate conflict, *Journal of Applied Ecology*, 42(6), pp. 1175–1182. doi: 10.1111/j.1365-2664.2005.01091.x.

Songhurst A. and Coulson T. 2013. Exploring the effects of spatial autocorrelation when identifying key drivers of wildlife crop-raiding, *Ecology and evolution*, 4(5), pp. 582–593. doi: 10.1002/ece3.837.

Songhurst A, McCulloch G. and Coulson T. 2015. Finding pathways to human–elephant coexistence: a risky business, *Oryx*, 50(04), pp. 713–720. doi: 10.1017/S0030605315000344.

Webber CE, Sereivathana T, Maltby MP. and Lee PC. 2011. Elephant crop-raiding and human-elephant conflict in Cambodia: crop selection and seasonal timings of raids, *Flora and Fauna International*, 45(2). doi: 10.1017/S0030605310000335.

World Bank, country factfile 2020. https://www.worldbank.org/en/country/botswana/overview [Accessed 28.08.20].