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Cultivating alternative crops reduces crop losses due to African elephants

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Abstract Throughout the sub-Saharan African countries, in which populations of the African Elephant *(Loxodonta africana)* exist, farmers come into conflict with these pachyderms. Attracted by nutritious crops on the fields they destroy substantial amounts of harvest by crossing through the plantations and feeding on the crops. As this species is protected and listed as a threatened species by the IUCN Red List and therefore must not be killed, new ways need to be found to repel or not attract the pachyderms to fields. The replacement of crops, which are attractive to elephants by such, which are not attractive, might be a solution for the agricultural sector in and close to elephant habitats. A field experiment has been conducted to test the attractiveness of potential alternative crops (ginger, onion, garlic, and lemon grass) compared to a control plot with maize as a very attractive crop. Elephants visited both, the test crops and the control of maize and completely destroyed the maize 6 weeks prior to its harvest time. In contrast, the test crops were only slightly damaged, mostly through trampling. In a very late state of the experiment lemon grass and ginger were consumed by the elephants in small quantities. Yields that have been obtained from the test crops would have exceeded the yields of the maize. The selection of crops which are less attractive to large herbivores such as elephants needs to be considered as a strategy to reduce conflicts between farmers and endangered wildlife species.

Keywords Crop raiding · Human-elephant conflict · Lemon grass · *Loxodonta africana* · Ginger · Garlic · Unpalatable crops

Key message

- The African Elephant (*Loxodonta africana*) causes crop losses to farmers in African countries but lethal control is not an option due to its protection status.
- Crops bearing chemical defense (lemon grass, ginger, garlic) are less attractive to elephants and therefore hold a higher economic value.
- To gain more certainty on the long-term non-palatability of alternative crops research on this topic needs to be encouraged.

Introduction

Being rich in wildlife and large wilderness areas, Zambia is one of the Southern African top destinations for Safari tourism. Although the country's main income comes from services, mining, and other industries, agriculture is an important economic sector with 10.8 % of the GDP (World bank 2013). Today over 70 % of the Zambian farmers live from small-scale subsistence farming (Hichaambwa and Jayne 2014), especially on maize, sorghum, cassava, ground-nuts, and sweet-potatoes (Jayne et al. 2007). The average farm size for smallholders is 0.68–1.43 ha (Jayne et al. 2008); the soil is cultivated by hand or, in areas where

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Tse-tse flies are not abundant, by oxen (Haggblade and Tembo 2003). The Zambian climate ranges from semi-arid to semi-humid with annual rainfall of 650–1000 mm (Baudeon et al. 2007). Besides the food insecurity through drought, pests like the Red Locust *Nomadacris septemfasciata* (Okhoba et al. 2012), the African Armyworm *Spodoptera exempta* (Guerrero et al. 2014; Cheke and Tucker 1995) or the Red-billed Quelea *Quelea* quelea (Bruggers and Elliot 1989; Jones et al. 1999) can cause considerable losses to smallholders. In the vicinity of conservation areas, however, another agricultural pests occur, the African Elephant (*Loxodontha africana*) (Schmutterer 1969). Throughout sub-Saharan Africa these large pachyderms come into conflict with farmers (Hoare 1999), when they destroy their fields, crops, harvests, or even houses (Kiiru 1995). Although their abundance is limited, where elephants step into farmland they can cause large damages within a very short time (Naughton-Treves 1998). For this reason crop damages by elephants are largely seen as a catastrophic event (Thirgood et al. 2005). Besides the losses of crop damage that often cover more than 50 % of a farm's crops (Sam et al. 2005), people fear the risk of getting injured by the pachyderms, when they want to protect their fields. Many attempts are made to guard farms and crops with different methods such as barriers, scaring devices or even lethal methods (Hoare 1995; Osborn and Parker 2003; Treves et al. 2009). The most commonly used strategy on smallholders' farms in sub-Saharan Africa is the personal guarding by farmers in their fields (Sitati and Walepole 2006). This activity, however, is time-consuming, giving the farmers only little time to sleep during months they actually have to use their manpower in weeding, plowing, and harvesting (Ngure 1995). Further, they risk being attacked by angry elephants or hungry predators (Quigley and Herrero 2005).

As an alternative to engage time and efforts to protect highly attractive crops, such as maize or sorghum, that deliver high nutrition to elephants, it could be a wise approach to rather cultivate crops that elephants do not prefer (Parker and Osborn 2006). If such crops being unattractive or even unpalatable to elephants and still being suitable to the soils and other environmental factors existed, the risk of high damages could be reduced. The commercialization of the alternative crops is another important aspect to consider, in order to secure safe income and to avoid encounters with elephants.

It is a common belief that plants containing essential oils are unattractive or even repellent to elephants (Thapa 2010). The cultivation of such crops at the border of National Parks is known from Asian countries, like Nepal and India (Martin and Martin 2010). Unfortunately, systematic approaches to test the attractiveness of these crops are not found in scientific literature. If those crops are used for the production of essential oils or herbal teas they can hold a high potential for the safe income in areas frequently damaged by pachyderms (Tiller 2010). For this reason, a first systematic test was run in South Luangwa, Zambia. We planted maize as control plant and four alternative crops in an experimental area and recorded the damage caused by elephants, the amount of harvested crops and their total revenue calculated from the local market prices.

The location for this test was chosen in an area where crop damages through elephants occur frequently. Within one kilometer radius, 75 conflict events were caused by elephants in the years 2009 and 2010 (Gross EM, unpublished data) and in which farmers are suffering from high losses to the pachyderms.

Materials/methods

Study area

The study was carried out in the Lupande Game Management Area (GMA), East of South Luangwa National Park, Zambia. The Luangwa valley is known for its high abundance of wildlife species such as zebra, buffalo, impala as well as the top predators as lions, leopards, and hyena and the large herbivores, like hippopotamus and the African elephant (Ndholvu and Balakrishnan 1991). Wildlife ranges freely throughout South Luangwa National Park (9050 km^2) and the adjacent GMA (4950 km^2) (Jachmann and Billiouw 1997), without fences. The only natural boarder is the river Luangwa that shapes the whole landscape, but is crossed easily by most of the large mammals, especially during the dry season. The study area is located in the agro-ecological zone I of Zambia, defined by the FAO, with mean annual rainfall $<$830 mm per year (Nyirenda et al. 2011).

Test plot location

Located at the Western edge of a large traditional farming block, the test plot was exposed directly toward the Miombo woodlands (Fig. 1; 13°15.777′S, 31°47.903′E). This site was chosen due to its location close to a regularly used farming area facing large amounts of crop losses to elephants, and its exposure toward the natural habitat of elephants. Being located about 100 meters away from the operational farming block a direct exposure to wildlife was enabled. Neither guarding nor any other human presence took place on the test plot during night time. The test plot was directly surrounded by uncultivated area. About 350 meters toward north-east and 530 meters toward east river Matizye meanders, supplying the farming block with water throughout the year. The small influent Kabila is located

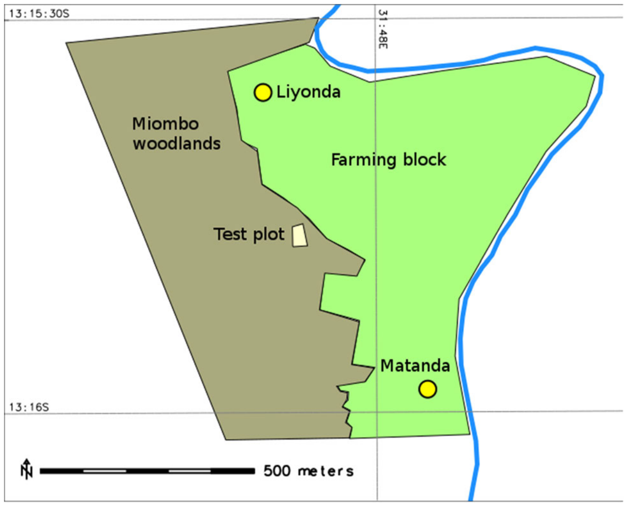

Fig. 1 Map of test plot location

just 40 meters east of the test plot, carrying water only during heavy rains of the rain season (December to March). The closest village, Liyonda, is located 350 meters to the north, and Matanda, located 360 m toward south-east.

Experimental design

For our test plot, we chose two crops containing essential oils (ginger *(Zingiber officinale)*, lemon grass *(Cymbopogon citratus))* and two crops having a strong smell (garlic *(Allium sativum)* and onion *(Allium cepa))*, as these crops are locally available and used in small scale by farmers. For this reason, they hold a certain potential for sale on local markets as well as being suitable for the local climate and soil. Maize being a staple food in the area and being raided regularly by elephants (Nyirenda et al. 2011) was used as positive (attractive) control.

Measuring 50 m in length and 25 m in width the test plot was set up of 48 squares measuring 3.5 by 3.5 meters (Fig. 2). Paths of 50 cm were left open between the squares. In the center 24 squares of potentially alternative crops were located in a plot of 4 m × 6 m. Each variety of the test crops appeared once in each row, being distributed in a randomized block-design. On the right and left edges of the test plot two rows of 6 squares of maize were located. Between the maize and the test crops a space of 8.5 m was left open and cleared. This design was developed to avoid an accidental destruction of alternative test crops through elephants when approaching attractive control crops. The total area of potentially alternative crops (24 squares) was the same as of the attractive control (2 × 12 squares).

With the onset of rains in December 2010 all crops were planted. Maize and onion were seeded by hand, lemon grass was planted by saplings, garlic was planted by cloves and ginger by cuttings of the bulbs. All seeds and saplings were purchased from local farmers. Depending on germination success the numbers of crop plants per square varied. In the beginning of February 2011, the number of plants per each square was exactly 20 for maize ($n = 480$), the number of garlic plants ranged from 86 to 150 per square ($n = 771$), for ginger from 55 to 78 ($n = 406$), and for lemon grass from 22 to 27 ($n = 152$). The germination of onion failed in all plots ($n = 0$).

Monitoring was carried out during two periods. The first monitoring period (14.01. to 31.05.2011) was conducted until the harvest time of the latest crop (ginger), monitoring period 2 started subsequently and ended on 23.09.2011. The test plot was visited for monitoring every three days; weeding was done at the same time. Besides this human presence of about one hour every three days during day time, the test plot was abandoned. Neither watering nor plant treatment took place.

Monitoring was done by a trained field staff of the Awely Red Cap project, a non-governmental project aiming at finding solutions to human-wildlife conflicts (Gross and Fulconis 2009). During each monitoring visit, it was observed whether wildlife had shown presence on the plot or not. This was determined by animal foot prints, feeding marks or droppings. Further, it was observed whether tracks of elephants were found within 500 meters to the test plot. Any presence of wildlife was captured in a standardized form. If any crops were damaged by wildlife a second detailed form was used. The number of damaged plants was enumerated on each square and the type of damage was specified for each plant. All data were then entered into an excel sheet and the total number of damaged plants, mean number of damaged plants, and standard deviation were calculated.

Besides the damages also actual and potential yields and rating of quality was registered for the regular harvest date. The two most promising types of crops were then left on the field and regularly monitored in monitoring period 2.

Statistics

The statistical analyses were done between the test crops with remaining plants at harvest time (monitoring period 1, only onions excluded) by Kruskal–Wallis chi-squared tests and within each test crop species by Kruskal–Wallis chi-squared tests followed by post hoc tests (asymptotic Wilcoxon Mann–Whitney rank sum test). The statistical analyses within the two test crops ginger and lemon grass after harvest time (monitoring period 2) were done over all by Kruskal–Wallis rank sum tests and due to the significant results followed by post hoc tests. Here pairwise comparisons using bonferroni corrected Wilcoxon rank sum test were applied. The differences between the two plant

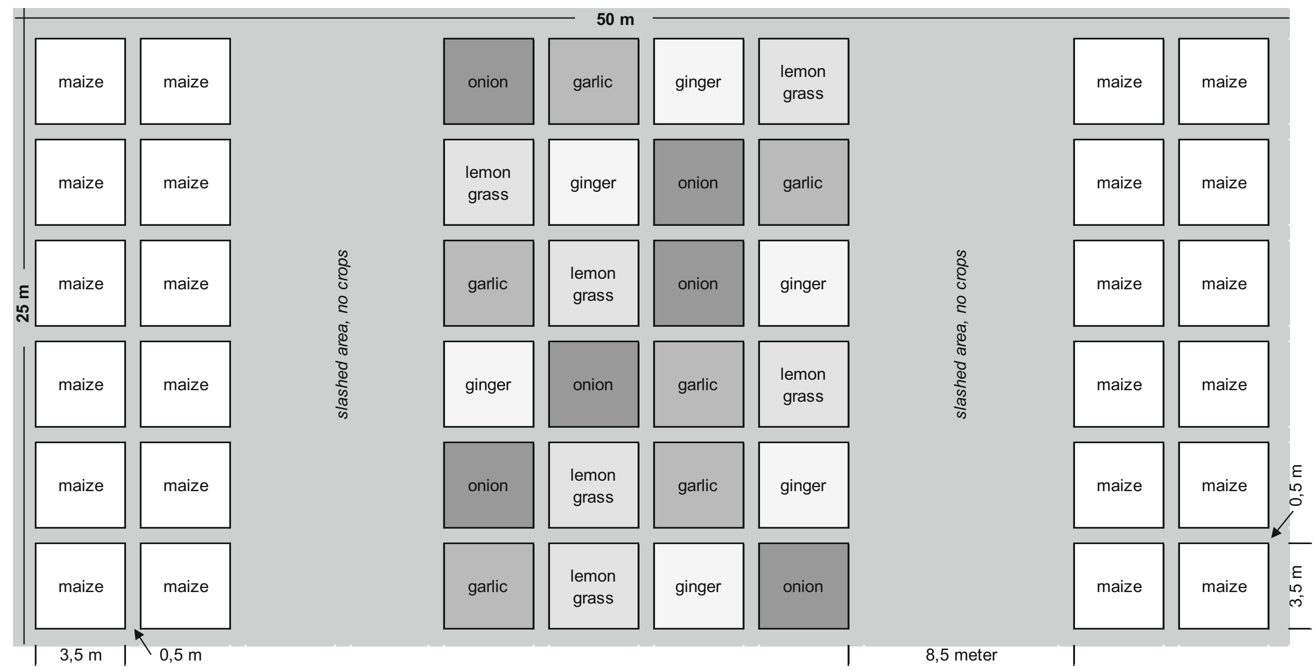

Fig. 2 Illustration of the test plot

species were calculated by asymptotic Wilcoxon Mann–Whitney rank sum tests. For statistical analyses, the software package RStudio Version 0.99.467—© 2009-2015 RStudio Inc., was used.

Results

Within the monitoring period 1 (138 days), the test plot was visited 49 times by the enumerator. On 33 of the monitoring days presence of wildlife on either or both the test or the control fields was registered. Besides the African elephant observed animal species ranged from baboons *(Papio cynocephalus)* over bushpig *(Potamochoerus larvatus)* and bushbuck *(Tragelaphus scriptus)* to lions *(Panthera leo)*. Damage to the test and control crops however was only caused by elephants. Within the monitoring period 2 (108 days) the test plot was visited 12 times by the enumerator.

In total 18 visits of elephants were recorded during both monitoring periods, visiting either alone or in groups of up to seven individuals (Table 1). They damaged both, the maize as well as the test crops. However, a much higher percentage of all test crops survived the elephant visit, compared to maize (Fig. 3). Within four elephant visits (with group sizes of two to seven individuals) the maize was completely destroyed, not a single plant survived (Table 1). By then, the maize had grown up to 1.40 m, but still was immature. The normal harvest time would have been 5–6 weeks later.

The test crops were damaged to a smaller extent and remained on the field until the scheduled harvesting time (Fig. 3). None of the test plants were completely eaten by the pachyderms, but some damages however occurred. Whereas the maize was completely eaten by the animals, without any plant survival, the test crops were mainly trampled (Table 2). Lemon grass appeared to be the most trampled crop, followed by garlic and ginger, but the differences were not statistically significant (Table 2). Elephants also tasted some parts of ginger and lemon grass plants (partly eaten), but they did not so for garlic.

The potential yields for each crop type were estimated for each particular harvest date (Table 3). Local market prices during the time of harvest were used for calculation. Maize would have been harvested mid-April, but the whole field was destroyed. Garlic was harvested on the 5th of May, with poor quality and low yields (Table 3). Lemon grass and ginger however performed well and their quality was very good. Their potential yields were calculated on the regular harvest days. Lemon grass would have been harvested on the 17th of May, ginger on the 31st of May. Due to its good yields (10.9 kg/ha) and high local marked value ginger holds the highest potential to achieve high revenues (35.1 US$/ha), followed by lemon grass (21.9 US$/ha).

Ginger and lemon grass were left on the test plot for further study purposes (monitoring period 2). In mid-June elephants started to graze parts of the lemon grass and ginger plants for the first time (Table 4). During one occasion in mid-June (Table 1: 16.06.2011) several lemon

Table 1 Visits of elephants on the test plot during two monitoring periods

Monitoring days	Date	No. of elephants on test plot	Crops partly or totally eaten
Monitoring period 1			
Day 33	15.02.2011	2	Maize
Day 47	01.03.2011	7	Maize
Day 49	03.03.2011	4	Maize
Day 54	08.03.2011	7	Maize completely eaten
Day 77	31.03.2011	4	None
Day 83	06.04.2011	2	None
Day 96	19.04.2011	3	None
Day 107	30.04.2011	3	None
Day 112	05.05.2011	7	None
Day 115	08.05.2011	4	None
Day 117	10.05.2011	5	None
Day 124	17.05.2011	2	Lemon grass
Day 131	24.05.2011	3	Ginger and lemon grass
Monitoring period 2			
Day 154	16.06.2011	4	Ginger and lemon grass
Day 155	17.06.2011	1	None
Day 167	29.06.2011	2	Lemon grass
Day 219	20.08.2011	3	None
Day 246	16.09.2011	2	None

The number of elephants and the consumed crops are given

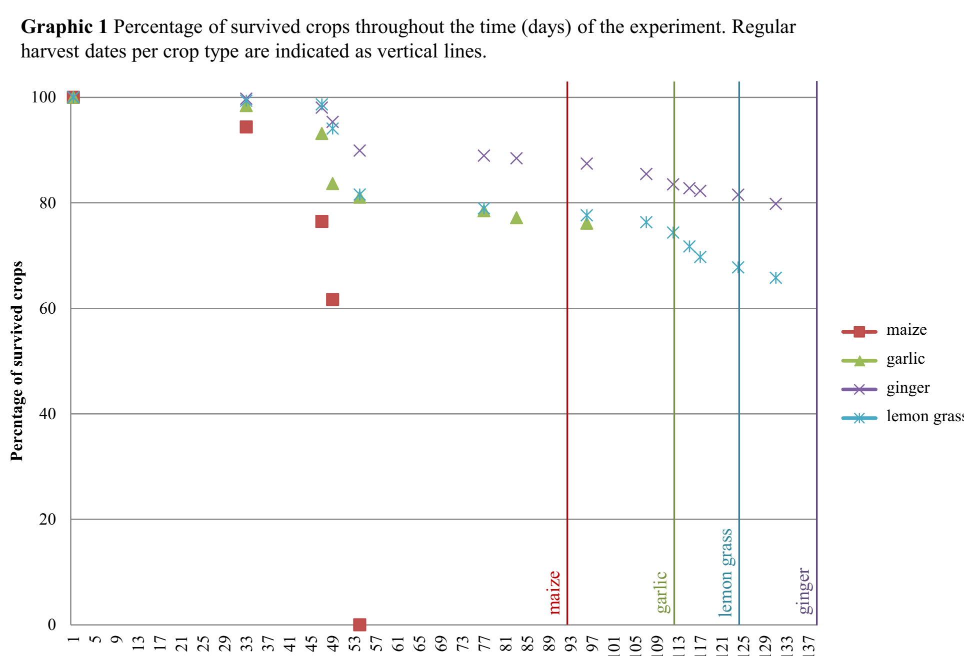

Fig. 3 Percentage of survived crops throughout the time (days) of the experiment. Regular harvest dates per crop type are indicated as vertical lines

grass and ginger plants were even completely consumed by elephants (lemon grass totally eaten 11.0 % and ginger totally eaten 3.5 %). After this single event ginger was not consumed by elephants anymore, lemon grass was consumed in very small quantities. Most of the damages however did not go along with feeding, but with trampling (ginger) and uprooting, without consumption (lemon grass). These differences were statistically significant. Lemon grass was significantly more often uprooted than ginger plants (Table 4).

Table 2 Mean ± standard deviation of plants per square damaged by elephants at scheduled harvest time

	Maize	Garlic	Ginger	Lemon grass
Totally eaten	20.0 ± 0.0 (100 %)	0.0a	0.0a	0.0a
Partly eaten	0.0	0.0 (0 %)a	0.5 ± 1.22 (0.74 %)a	0.67 ± 1.03 (2.63 %)a
Trampled	0.0	30.67 ± 26.24 (23.87 %)b	13.17 ± 4.22 (19.46 %)b	8.17 ± 5.78 (32.24 %)b

Maize was totally eaten 6 weeks prior to scheduled harvest time

The percentage of damaged crop plants referring to the total amount of its crop type is indicated in brackets. Maize $n = 480$ (24 squares), garlic $n = 771$ (6 squares), ginger $n = 406$ (6 squares), lemon grass = 152 (6 squares). The statistical analyses were done between the test crops with remaining plants at harvest time (monitoring period 1) by Kruskal–Wallis chi-squared tests (partly eaten: $\chi^2 = 2.52$, df = 2, $p = 0.28$; trampled: $\chi^2 = 1.13$, df = 2, $p = 0.57$) and within each test crop species by Kruskal–Wallis chi-squared tests (garlic: $\chi^2 = 16.13$, df = 2, $p < 0.001$; ginger: $\chi^2 = 14.84$, df = 2, p < 0.001; lemon grass: $\chi^2 = 14.21$, df = 2, $p < 0.001$) followed by post hoc tests (asymptotic Wilcoxon Mann–Whitney rank sum test; Totally eaten vs. partly eaten: ginger: $Z = -1.00$, $p > 0.05$; lemon grass: $Z = -1.48$, $p > 0.05$; partly eaten vs. trampled: garlic: $Z = -3.0767$, $p < 0.01$; ginger: $Z = -2.9887$, $p < 0.01$; lemon grass: $Z = -2.9341$, $p < 0.01$). Different lowercase letters indicate significant differences in means both within test crop species and between elephant damages

Table 3 Real and calculated yields for scheduled harvest time on the test plot in 2011 and calculation of potential revenues based on local market prices

	Harvest amount on test plot (kg)	Harvest amount (kg/ha)	Local market price (USD/kg)	Total revenue (USD/ha)
Maize	0.0	0	0.54	0
Garlic	1.0	136	15.05	2048
Ginger	80.0	10,884	3.23	35,102
Lemon grass	50.0	6803	3.23	21,939

Table 4 Mean ± standard deviation of plants per square damaged by elephants after scheduled harvest time (monitoring period 2)

	Ginger	Lemon grass
Totally eaten	2.33 ± 3.01 (3.54 %)ab	2.33 ± 2.73 (11.02 %)ac
Partly eaten	1.50 ± 1.64 (2.28 %)ab	3.17 ± 3.13 (14.96 %)ac
Uprooted	0.00 (0.00 %)b	8.83 ± 4.54 (41.73 %)c
Trampled	7.00 ± 3.79 (10.63 %)a	1.67 ± 1.37 (7.87 %)a

The percentage of damaged crop plants referring to the total amount of its crop type is indicated in brackets. Ginger: $n = 395$ (6 squares), lemon grass: $n = 127$ (6 squares). The statistical analyses were done between two test crops after harvest time (monitoring period 2). The differences within plant species were done by Kruskal–Wallis rank sum tests (ginger: $\chi^2 = 18.76$, df = 4, $p < 0.001$; lemon grass: $\chi^2 = 16.74$, df = 4, $p < 0.01$) followed by post hoc tests (Pairwise comparisons using Wilcoxon rank sum test, bonferroni corrected; Within both ginger and lemon grass, only the comparison between uprooted and trampled showed a significant difference). The differences between plant species were calculated by asymptotic Wilcoxon Mann–Whitney Rank Sum Tests. Lemon grass was more often uprooted than ginger ($Z = -3.08$, $p < 0.01$). Different lowercase letters indicate significant differences in means both within test crop species and between elephant damages

Discussion

In African savannah habitats, crop damages by elephants are reported to be especially severe at the beginning of the dry season, when the crops are ripening (Hoare 1995; Bhima 1998; Osborn 2004; Nyirenda et al. 2011). In our test the elephants invaded the plot earlier than this. After the plantation of the test crops and control crop it took only 2 months until the elephants moved into the field for the first time. After having reached a height of about 140 cm, the elephants started to graze on the maize and just walked over the test crops, without tasting them. Here the general browsing height of the African elephant has to be taken into consideration. Average browsing height was measured within 108 and 153 cm in Chobe/Botwana (Stokke and du Toit 1999) and 180–200 cm in Pongola game reserve South Africa (Shannon 2006). Elephants seldom fed on seedlings in south-eastern Tanzania (Malima et al. 2005). During the time of crop raiding of maize in our experiment the alternative test crops were lower in growth (ginger 20–40 cm, lemon grass 30–50 cm, garlic 15 cm). However, African elephants show flexibility in browsing height and are able to feed on short growing plants. In the hot dry season their diet can consist of up to 20 % of roots (Owen-Smith and Chafota 2012) and during the rainy season they shift from browsing to grazing (Field and Ross 1976; Guy 1976). Elephants further consume saplings of their preferred shrub and tree species if they are under 50 cm height (Owen-Smith and Chafota 2012) or even intensively feed on ground level (Wyatt and Eltringham 1975). Feeding on crops in seedling stage however did not take place on our test plot and therewith underlines the findings of Malima et al. (2005).

Within the fourth elephant visit, the immature maize was completely destroyed and eaten, but the test crops were still not consumed before scheduled harvest time. In the following months the elephants visited the test plot seven times without any consumption of the test crops. These results indicate the lower attractiveness of the alternative crops compared to maize, probably not only due to their lower height but also other factors. Crop damages on alternative crops only occurred through trampling. In mid-May, after the scheduled harvest time of garlic, lemon grass, and ginger, the first feeding upon lemon grass was recorded, whereby only a few plants were consumed partly. 1 week later elephants fed upon some ginger plants again. In the following weeks some single individuals of the test crops were even completely consumed. However, after these three incidences the crops were not consumed again. As the elephants did not raid the alternative crops evenly distributed over the test plot, but chose a few plants, which were close to another on the small plots, we obtained a contagious distribution, indicated by high standard deviation.

Elephants are generalist herbivores, consuming over 130 different plant species throughout the seasons in a woodland habitat (Guy 1976) but also avoid large numbers of plant species because of toxic content or chemical defense mechanisms by plant secondary compounds (Owen-Smith and Chafota 2012). Numerous organisms produce chemical compounds for defense, which adversely influence the physiology of their consumers, classified as allomones (Gross 2013). While animals defend themselves against predators, many plant species defend against herbivores by the production of secondary plant compounds. Chemical defenses against mammalian herbivores can be classified either toxins or antifeedants. While toxins are often present in low amounts and poisonous, antifeedants are typically present in higher quantities and not very toxic to herbivores (Kimball and Provenza 2003). Accordingly, the alternative test crops used in the presented experiment are herbaceous plants containing antifeedants, chemical compounds that produce a strong scent and taste, and in some cases also toxins. *Allium* species like garlic and onions are a rich source for sulfur-containing molecules. Alliin (2-propenyl-L-cysteine sulfoxide) e.g., is the precurser of volatile aroma of garlic. The volatile compound allicin is formed by the action of the enzyme alliinase after tissue disruption (Crozier et al. 2008). Allicin protect garlic to pathogens and herbivores. The ingestation of *Allium* can cause deadly toxifications in herbivorous livestock like cattle (Koch 1992). Lemon grass *(Cymbopogon citratus)* contains unusual C-glycosides of the flavones luteolin and chrysoeriol, as well as caffeic acid and chlorogenic acids (Cheel et al. 2005). Some of these constituents e.g.. luteolin can cause emesis and nausea in mammals (Yu et al. 2010). The essential oil of ginger *(Zingiber officinale)* contains the sesquiterpenes (−)-zingiberene, zingiberol, and humulene (α-caryophyllene), as well as the monoterpenes (+)-borneol and cineol which can irritate the mucosa of mammals (Roth et al. 2012).

Generalist herbivores like elephants cannot cope with toxic compounds in the way many specialist can do, due to the huge amount of different toxic compounds they are confronted with (Owen-Smith and Chafota 2012). Thus, generalists avoid highly defended herbaceous plants and prefer plants with lower amounts of toxic compounds like woody plants (Schoonhoven et al. 2005). However, mammalian herbivores possess some biochemical pathways to process secondary plant compounds which consist of primary metabolism, conjugation and elimination. This means that detrimental allomones are transformed into more polar compounds by conjugation of polar groups to the ingested secondary plant compounds and are eliminated by urine or feces (Kimball and Provenza 2003). However, this process is a costly biochemical process. Thus, a herbivore that has consumed plant material high in toxins needs complimentary foods high in proteins and energy (Kimball and Provenza 2003). Furthermore, when mammalian herbivores feed on plants information on olfactory and gustatory signals is processed. Their learning ability integrates the post-ingestive feedback from eating a food item with its flavor. Thus, food intake increases with positive consequences and decreases with negative ones (Kimball and Provenza 2003). It was shown recently that elephants feed selectively on the plant species available to them in a specific environment resulting in avoidance of two-third of these species (Owen-Smith and Chafota 2012).

Elephants have a large olfactory bulb and are able to detect volatile components over long distances. This can be signals from food or volatiles signaling the presence of human predators (Bates et al. 2007). Taking into consideration that their food choice depends on previous experiences they have made, they cautiously taste newly available plants and then decide on its palatability (Sukumar 2003). In our experiment, elephants have tried small amounts of lemon grass and ginger within a few weeks' time on the test plot. After that, they stopped consuming the test crops, but unearthed or trampled them in some minor cases.

Raiding crops on fields is a high-risk behavior of elephants as crops are often located close to human habitations and are protected by people. However, crops such as maize, are more nutritious than wild forage and feeding on them means gaining an energetic and growth pay-off (Chiyo et al. 2011). Taking this "high risk—high gain" behavior into consideration, crops which are less nutritious or chemically defended requiring costly detoxification would imply lower gain and therewith a lower risk-taking behavior. For the choice of alternative crops, their content of nutritions as well as their toxin or antifeedant contents needs to be taken into consideration.

Also the availability of other browse and grasses has an influence on the food choice (Osborn 2004). With the dry season start, which in the study area is in May, the nutrition content of grasses is reduced. This has been identified as a trigger for crop raiding behavior (Osborn 2004). During times where alternatives are getting scarce even less attractive crops might fall into the spectrum of edible crops. However, during the peak of the dry season in August and September only small parts of lemon grass and ginger plants were consumed, although elephants still visited the field regularly. Larger amounts were now just uprooted without consumption.

It can be concluded that garlic, ginger, and lemon grass are less attractive to elephants than maize. However, even though the test crops are less attractive to African elephants, they may not be completely unpalatable or even repellent to them. Depending on the plants species, the repellent activity may differ between leaves, shoots, flowers, or fruits. In chilli plants *(Capsicum annuum and C. frutescens),* which are used in many elephant damage mitigation practices (Parker et al. 2007), the plant as such does not prevent elephant visits. As in contrast to fruits the leaves of chilli plants do not contain remarkable amounts of capsaicin, the alkaloid responsible for causing pain in mammals, it is not surprising that even the leaves of chilli plants are consumed from time to time by elephants (Gross EM, unpublished data). In that case also unattractive crops might get raided. Despite these aspects, these less attractive crops seem to be more suitable in farming areas with high elephant abundance.

The ecological suitability as well as market value of the grown crop has to be taken into consideration when making the crop choice for farming (Parker and Osborn 2006). Although grown in the region and available on markets the onion failed in the stage of germination, probably due to bad seed quality or unsuitable soils. As there is a high local demand for garlic and it can achieve good market prices and therewith holds some potential as cash crop. However, in our test garlic grew with bad qualities, probably due to unsuitable soil and insufficient water availability. Further, the fragile garlic plants are stronger affected by trampling than robust crops like lemon grass. Despite the lack of watering and absence of fertilizers or pesticides, both ginger and lemon grass performed very well on the test plot. Taking into consideration the local market value, lemon grass holds high potentials as an alternative cash crop, followed by ginger with lower market value but high yields. Given the local purchasing power and market access, lemon grass and ginger promise high income compared to the traditionally grown maize. Further research on options for marketing considerable amounts of alternative crops in remote areas of Zambia still needs to be conducted.

In agricultural areas with high abundance of large herbivores, especially elephants, new approaches to crop protection are needed. The IUCN Red List ranks human-elephant conflicts as one of the three major threats to the species survival (Blanc 2008). The selection of appropriate, less attractive or even unpalatable crops is an important step to tackle these conflicts. If the pachyderms do not find nutritious and attractive crops on the farms in their home range, reduction of crop losses is very likely. To foster this approach, however, more detailed studies are needed, to observe the resistance of the crops in long-term and to identify a larger diversity of unattractive crops. Given a good market access these crops should serve both, people and threatened wildlife species.

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Author contribution statement EMG conceived and designed study, analyzed data, wrote ms. RMcR monitored field experiments. JG developed field experiment design, made statistics and wrote ms. All authors read and approved ms.

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