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The potential of medicinal and aromatic plants (MAPs) to reduce crop damages by Asian Elephants (*Elephas maximus*)

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A B S T R A C T

In all 13 Asian range countries of the wild Asian elephant (*Elephas maximus* L.), farmers suffer from crop damages caused by this endangered and highly protected species. As elephants are lured by highly nutritional crop types into agricultural lands, measures to deter or repel them from the high attraction will always be costly and labour intensive. The cultivation of crops, which are less attractive to elephants, yet economically viable for local farmers could lead to a new direction of land-use and income generation in human-elephant conflict areas. In this study, seven medicinal and aromatic plants (MAPs) containing higher amounts of specific plant secondary compounds were explored for their attractiveness to wild Asian elephants against a control of rice (*Oryza sativa* L.) and maize (*Zea mays* L.). The results show that chamomile (*Matricaria chamomilla* L.), coriander (*Coriandrum sativum* L.), mint (*Mentha arvensis* L.), basil (*Ocimum basilicum* L.), turmeric (*Curcuma longa* L.), lemon grass (*Cymbopogon flexuosus* (Nees ex Steud.) W. Watson) and citronella (*Cymbopogon winterianus* Jowitt.) were less attractive and were not consumed by elephants compared to rice. Damages to the MAPs occurred only through trampling, with mint being most prone to being trampled. Other wildlife species, however, were observed to feed on lemon-grass. Long-term learning effects and the eventual palatability of crops with less efficient antifeedants need to be further explored. This study, however, gives first evidence that MAPs bear a high potential for a secure income generation in and close to Asian elephant habitats. Furthermore, the strategic plantation of crops unattractive and attractive to elephants could lead to new land-use strategies and improve functionality of elephant corridors.

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1. Introduction

Asian elephants (*Elephas maximus* L.) inhabit an area of more than 870 000 km^2 of land in 13 Asian countries (Choudhury et al., 2008; Leimgruber et al., 2003), with India holding 60% of the total wild population of an estimated 38 500–52 500 elephants (Sukumar, 2006). About 50% of the Asian elephant's geographic range is characterized by agriculture. The other half can be considered wildlands, which are increasingly surrounded and isolated by agriculture (Leimgruber et al., 2003). The remaining fragments of natural forests and grasslands, are bordering directly on agricultural fields where highly nutritional crops as rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.) or maize (*Zea mays* L.) are farmed. Elephants are lured to these crop fields by highly attractive staple crops, especially during the maturing growth stage (Gross E.M., unpublished data). Large amounts of crop damages are reported from India (Madhusudan, 2003), Sri Lanka (Santiapillai et al., 2010), Indonesia (Hedges et al., 2005) and Nepal (Pant et al., 2015). Compared to the national level of crop losses through other pests like weeds, insects or rodents (Oerke, 2006), crop losses due to elephants may not be as economically important, however the catastrophic character of elephant invasions and the constraints to react on them due to the high conservation status of elephants (IUCN Red List endangered) (Choudhury et al., 2008), making this a serious agricultural and conservation issue.

Multiple techniques have been implemented across the Asian

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and African elephant ranges to prevent them from entering crop fields or to scare them away when they were found feeding on the farms. Mitigation strategies for crop damages includes shooing away elephants through noise or fire, protecting fields with chilli smoke, construction of electric fences or using bees in hive fences to prevent elephant intrusions (Hoare, 2012). All of these methods are highly labour and/or cost intensive. Thus, in agricultural areas, which face great crop damages through large herbivores, especially elephants, new approaches to crop protection are needed (Gross and Gündermann, 2016).

Nepal has a long tradition in farming medicinal and aromatic plants (MAPs), which are sold as herbal raw material or are further processed into essential oils (Olsen, 1998). It was shown recently that such MAPs, plants which contain higher amounts of secondary plant products, were less attractive to elephant (*Loxodonta africana* Blumenbach) than maize (Gross et al., 2016). However, these plants may not be completely unpalatable or even repellent to them, but their chemical compounds (antifeedants) could cause avoidance behaviour. The selection of appropriate, less attractive or even unpalatable crops might be a solution for the agricultural sector in or close to elephant dwelled habitats to tackle these conflicts (Gross et al., 2016). As local farmers reported that elephants did not consume MAPs on their fields, the cultivation of such crops increased in agricultural areas adjacent to Bardia National Park in Nepal (Thapa and Chapman, 2010) and in Sri Lanka (Santiapillai et al., 2010).

The first scientifically testing of the attractiveness of different crop types towards elephants has been reported recently from Zambia (Gross et al., 2016). Based on this to this study, a similar experiment was conducted at the western boundary of the Bardia National Park in Nepal. Here we describe the first experiments on testing the attractiveness of aromatic crops for elephants in Asia.

2. Material and methods

2.1. Study site

The experiment was conducted at the western boundary of Bardia National Park (968 km^2), in the lowlands of Nepal. The subtropical monsoon climate is characterized by heavy rainfalls between July to October, the mean annual rainfall is around 1500 mm (Dinerstein, 1979). The vegetation in the south-western part of the park is characterized by tropical deciduous Sal forest, early riverine forests and tall grass flood plains (Jackson et al., 1994). Bardia is known for its high abundance of wildlife species, such as spotted deer (*Axis axis* Erxleben), hog deer (*Axis porcinus* Zimmermann) and barking deer (*Muntiacus muntjak* Zimmermann) and holds the largest number of resident Asian elephants in Nepal as well as a growing population of reintroduced Greater one-horned rhinoceros (*Rhinoceros unicornis* L.) (Flagstad et al., 2012; Wegge et al., 2009). The natural border between the national park and the western buffer zone is formed by the Geruwa River, a tributary of the Karnali River. Large wildlife species regularly cross this river to feed on crops cultivated in the buffer zone.

2.2. Test plot locations

The three test plots were located at the western bank of the Geruwa River, between the western boundary of the national park and private farmland (Fig. 1). The test plot Janaknagar (JA) was located in the northern 28° 34′ 29,604″ N, 81° 14′ 48,48″ E, test plot Gola (GO) in the middle 28° 31′ 23,808″ N, 81° 13′ 43,5″ E, and the test plot Bajpur (BA) in the southern part 28° 25′ 5988″ N, 81° 12′ 8136″ E of the study area. These sites were chosen based on the frequently observed movements of elephants from the national park to the farmlands, especially during the monsoon season when paddy and maize are cultivated (Gross E.M., unpublished data).

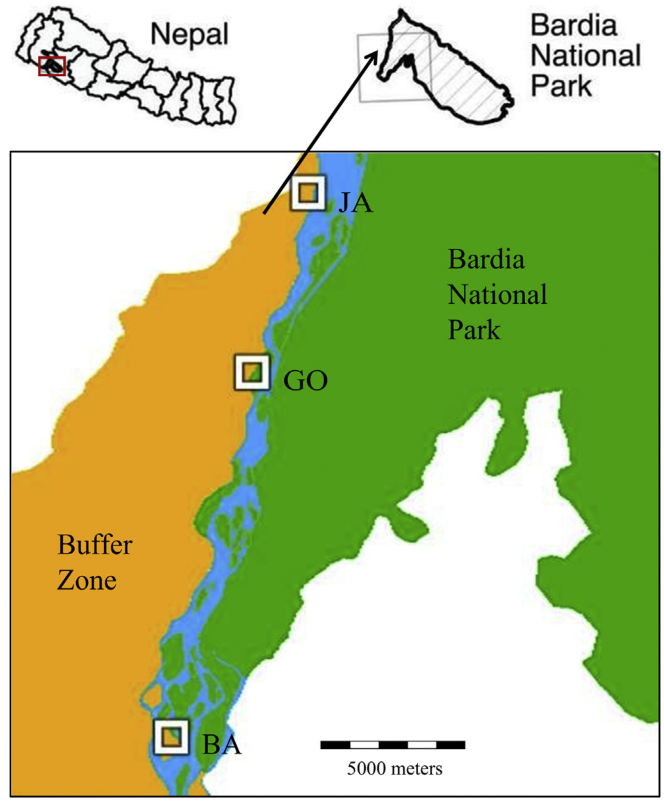

Fig. 1. Map of test plot locations in Nepal at the border of Bardia National Park (natural habitat: green) and Western Buffer Zone (farmland and villages: yellow). Test plots are indicated as white squares (JA: Janaknagar, GO: Gola, BA: Bajpur). *Source:* Author's screenshot from Google Earth 1/1/2017. Overview maps produced by Eva Klebelsberg using Quantum GIS Geographic Information System, Version 2.14.3 Essen. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.3. Experimental design

Seven crops (basil (*Ocimum basilicum* L.), chamomile (*Matricaria chamomilla* L.), citronella (*Cymbopogon winterianus* Jowitt.), coriander (*Coriandrum sativum* L.), lemon grass (*Cymbopogon flexuosus* (Nees ex Steud.) W. Watson), mint (*Mentha arvensis* L.) and turmeric (*Curcuma longa* L.) containing essential oils (MAPs) were selected for all three test plots (Table 1) as well as the staple crops rice and maize, which are frequently damages by elephants in Nepal (Thapa, 2010) and were chosen as a positive control. For all crop types locally available cultivars were selected, based on ecological suitability and common utilization in the study area.

Rice was used as control on two plots (JA and GO) and maize at BA. Measuring 82.5 m in length and 33.5 m in width, the test plot consisted of 60 squares measuring 5 by 5 m (Fig. 2). Paths of 50 cm were left open between the squares. In the centre, 36 squares of essential oil crops were located in a plot of 32.5 m × 32.5 m. Each test crop species appeared once in each row, being distributed in a randomized block-design. On the right and left edges of the test plot, three rows of six squares of rice (JA, GO) or maize (BA) were located. Between the maize and the test crops, a space of 11.5 m was left open and cleared, so elephants could choose to either feed on the control or test squares. This design was developed to avoid an accidental destruction of essential oil crops by elephants when

Table 1
Species of MAPs and control crops tested on test plots in 2012 and 2013 on their attractiveness towards elephants. Crude protein (CP) content, as well as plant secondary metabolites (PSM) and their proven effects on foragers including sources are presented. n/a = information not available/not applicable.

Crop type	CP	PSM	Effect on foragers	Source
Basil *(Ocimum basilicum)*	3%	Phenylpropenes: eugenol, methyl eugenol and estragol; methyl chavicol	Hepatotoxic, can cause convulsions, diarrhoea, nausea, unconsciousness, dizziness, or rapid heartbeat to humans	Fujisawa et al., 2001; Joshi, 2014; Thompson et al., 1998
Chamomile *(Matricaria chamomilla)*	NA	120 different PSMs Flowers: apigenin, quercetin, patuletin, luteolin and their glucosides (all flavonoids) Essential oil: terpene bisabolol, farnesene, chamazulene, flavonoids (including apigenin, quercetin, patuletin and luteolin) and coumarin	Bisabolol deterrent to mice but not to voles and haresEmesis and nausea in mammals	Hansen et al., 2015, 2016; Mann and Staba, 1986; McKay and Blumberg, 2006; Reichardt et al., 1990; Singh et al., 2005
Citronella *(Cymbopogon winterianus)*	2%	Geraniol, Citral, geranyl acetate	Geraniol, linalool, and citronella are repellent against mosquitoes	Chen and Viljoen, 2010
Coriander *(Coriandrum sativum)*	2%	Leaves: decanal, trans-2-decanal Seeds: linalool, geraniol, terpine-4-ol, alpha-terpineol, limonene, alpha-pinene, camphene, myrcene	n/a	Mandal and Mandal, 2015
Lemongrass *(Cymbopogon flexuosus)*	2%	Unusual C-glycosides of the flavones luteolin and chrysoeriol, as well as caffeic acid, chlorogenic acids and geraniol	Luteolin can cause emesis and nausea in mammals	Chen and Viljoen, 2010; Yu et al., 2010
Mint *(Mentha arvensis)*	4%	Menthol, menthone, decanol, limonene, up to 42 minor constituents	Stimulate the cold-sensitive receptors in mucous membrane and skin	Eccles, 1994; Singh et al., 2005
Turmeric *(Curcuma longa)*	8%	235 compoundsMain curcumin (diarylheptanoid) and also monoterpenes like limonene etc.	n/a	Li et al., 2011
Rice *(Oryza sativa)*	10.3%	Oxalic acid in rice straw	Excessive feeding of rice straw produces harmful effects to grazers, as calcium is bound	Patel, 1966
Maize *(Zea mays)*	7.9%	n/a	n/a	Holm, 1973

approaching attractive control crops. The total area of essential oil crops (36 squares) was the same as of the attractive control (2×18 squares). The test plot was placed with the long side towards the national park boundary, which was the direction elephants were expected to approach the test plot from.

Plantation started with chamomile, coriander and mint in mid-February 2013, followed by basil in the beginning of April. Chamomile and coriander were harvested at the end of April, after which turmeric was planted on the former coriander plots in the beginning of June. Rice and maize cultivation started with the onset of rains in late June, followed by lemon grass and citronella to be planted at the end of July. At the end of October, all crops were harvested and monitoring came to a halt. In early 2014, the cultivation started again, following the scheme of 2013 and was carried on until the end of October 2014.

Chamomile, coriander and maize were seeded by hand, while rice, basil, lemon grass and citronella were planted by seedlings. For turmeric, cuttings of the bulbs were used and for mint, cut suckers were planted. All seeds and saplings were purchased from local farmers. In the beginning of 2013 for the test plots JA and GO, the number of plants per each square was 1024 for rice ($n = 36\ 864$), whereas in BA the number of maize plants per square was 120 ($n = 4320$). For all three test plots, the number of chamomile plants were 2500 per square ($n = 15\ 000$), coriander 5000 per square ($n = 30\ 000$), mint 144 per square ($n = 864$), basil per square 88 ($n = 528$), turmeric 96 per square ($n = 576$), and for lemon grass and citronella 130 per square ($n = 780$ each).

Monitoring was carried out weekly from 18th March 2013 onwards to the end of October 2014 with an interruption from November 2013 to April 2014. Human presence, comprising local farmers employed to irrigate and weed the plots (neither fertilizers nor pesticides were applied), were limited (roughly 1 h during the

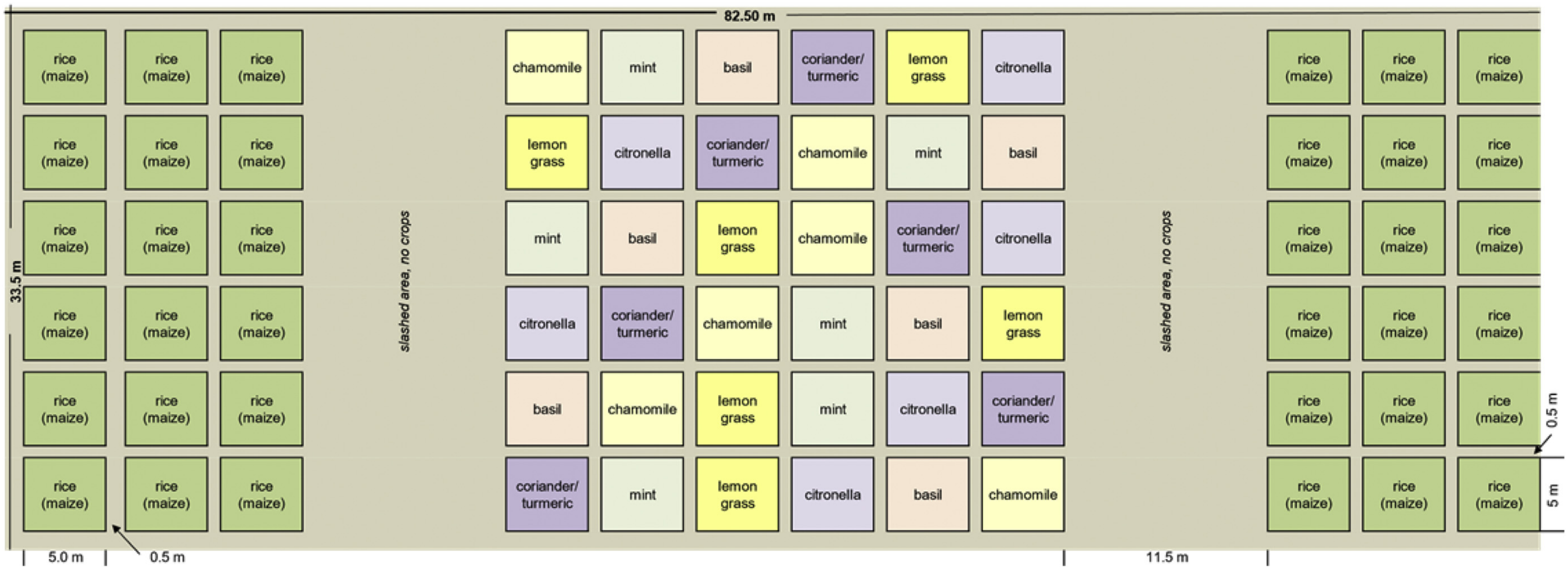

Fig. 2. Illustration of the test plot design at JA and GO with rice as control crop, whereas maize served as the control crop in BA.

day every three days) during the dry months from March to June; otherwise the plots were undisturbed.

Monitoring was conducted 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, wildlife presence or absence based on animal foot prints, feeding marks or droppings on the plot was observed. 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 entered into an excel sheet and the total number of damaged plants, mean number of damaged plants and standard deviation were calculated.

All crops were left in the fields until their respective harvest times. Harvest was carried out by local farmers and yields for each crop type were measured by weight. For the calculation of potential revenues, the local market prices during the time of harvest were used.

2.4. Statistical analysis

Damaged plants were compared between control and test crops at harvest time by Wilcoxon Mann-Whitney rank sum tests. The statistical analysis between the trampled test crop species was done by Kruskal-Wallis chi-squared tests and, due to significant results, followed by post hoc tests. Here, pairwise comparisons using Bonferroni corrected Wilcoxon rank sum tests were applied.

For statistical analysis, data of test plots with the same set up (GO and JA both with rice as control) were pooled; data for BA (maize as control) were analysed separately. Statistical tests were performed using RStudio version 3.2.5 (R CoreTeam, 2016).

3. Results

Within the 431 days of the experiment in 2013 and 2014, each test plot was visited by the Red Caps more than 60 times. On 18 of the monitoring days, presence of wildlife was registered on either of the three test plots. Besides the Asian elephant, observed animal species included the Greater one-horned rhinoceros (*Rhinoceros unicornis*), the blue bull (*Boselaphus tragocamelus*) and the spotted deer (*Axis axis*), which all caused damages to the crops (Table 2). Elephants were observed eleven times on the test plots, exclusively in the year 2013. For this reason, the data analysed for crop preferences by elephants refer to the 2013 data (273 days) only.

Elephants entered the test plots either alone or in pairs but were never observed in larger groups. They caused damages to both test crops and control (rice or maize). However, a higher percentage of all test crops survived the elephant visit when compared to the control crops rice or maize (Fig. 3). Elephants exclusively fed on the control crop rice (81.3 ± 151.9; 3.97%) but did not consume any of the MAPs ($U = 0$, $p = 0.000625$). Test crops (MAPs) only damaged by trampling (32.9 ± 84.7; 1.42%), but rice was not damaged by trampling only ($U = 72$, $p = 0.001849$).

Rice or maize, however, was exclusively damaged through feeding upon. Chamomile, coriander, mint, basil, and turmeric were all trampled by elephants to some extent, with a maximum of 5.32% for mint. No difference was observed in the intensity of trampling between any of these crop types. Lemon grass and citronella were the only crops that were not at all trampled by elephants (Table 3).

Rhinos visited the test plots three times in 2013 only. They entered the fields alone or in pairs and damaged rice through feeding, and mint, lemon grass and citronella through trampling. Shortly before the harvest of lemon grass, a small portion of lemon grass was consumed by one rhino. Due to the low case numbers, these observations could not be compared statistically.

The test plot BA, with maize as control crop, was excluded from statistical analysis, as it was visited only once by a rhino and once by an elephant.

Chamomile and coriander were the first crops to be harvested at the end of April. The quality of chamomile was very good and obtained a harvest of 1450 kg/ha in GO and JA, with wildlife damages taken into consideration (Table 4). As coriander did not germinate and grow properly, this crop type was excluded from the calculation of revenues. All other test crops and the rice were harvested in JA and GO in the first week of November 2013. Basil and mint obtained the highest yields with 21 681 kg and 11 191 kg respectively. The lowest yields of the test crops were obtained by citronella and lemon grass (2924 kg and 2881 kg respectively). With 2073 kg per ha rice obtained the smallest yield. Plants containing essential oils

Table 2
Visits of wildlife ($n = 18$) on three test plots (JA, GO and MA) during two monitoring periods (year 2013: 273 days, year 2014: 158 days). Damages crops and type of damage are mentioned.

Monitoring days	Date	Test plot	Wildlife observed	Crops damaged
Year 2013				
34	18.03.2013	JA	1 elephant	Coriander and chamomile trampled
41	25.03.2013	JA	2 elephants	Coriander and chamomile trampled
48	01.04.2013	JA	1 elephant	Coriander and chamomile trampled
52	05.04.2013	GO	1 elephant	None
137	17.06.2013	GO	1 elephant	Mint and basil trampled
155	05.07.2013	JA	2 elephants	Rice eaten, basil and turmeric trampled
157	07.07.2013	GO	1 elephant	Rice eaten
189	08.08.2013	BA	1 elephant	Maize eaten
196	15.08.2013	JA	1 elephant	Rice eaten, turmeric trampled
199	18.08.2013	GO	1 elephant	Rice eaten
206	25.08.2013	GO	2 rhinos	Rice eaten, mint trampled
223	11.09.2013	JA	1 rhino	Rice eaten, lemon grass and citronella trampled
264	22.10.2013	GO	2 elephants	Rice eaten, mint, basil and turmeric trampled
273	31.10.2013	BA	1 rhino	Lemon grass eaten and trampled
Year 2014				
23	26.04.2014	JA	1 blue bull	lemon grass partly eaten
114	26.07.2014	JA	12 spotted deer	maize eaten
131	12.08.2014	JA	15 spotted deer	maize eaten
132	13.08.2014	BA	10 spotted deer	maize eaten

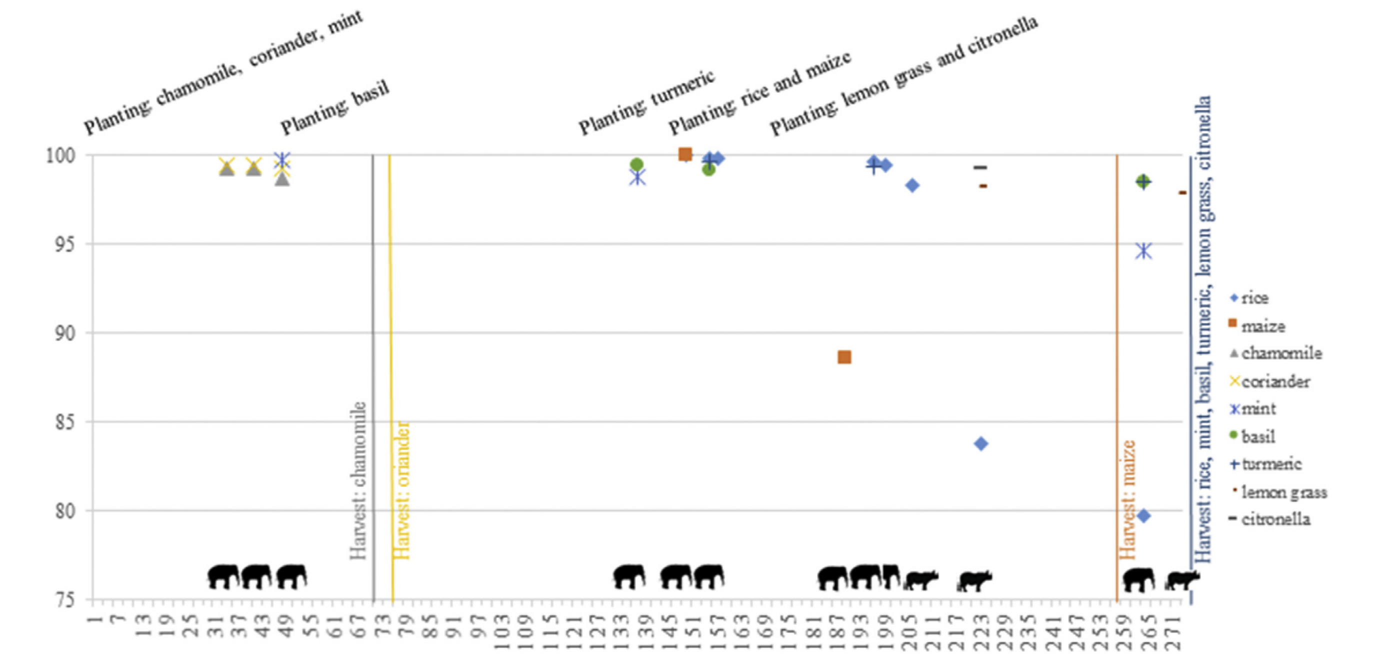

Fig. 3. Percentage of survived crops (scale starting at 75%) throughout the time (days) of the experiment. Harvest dates per crop type are indicated as vertical lines. Planting dates are indicated on top, elephant symbols stand for elephant damages, rhino symbols stand for rhino damages.

Table 3
Mean ± standard deviation of elephant damage per square to seven MAP species in JA and GO test plots in 2013.[a]

	Mint	Basil	Turmeric	Chamomile	Coriander	Lemongrass	Citronella
Eaten	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trampled	15.3 ± 22.3 (5.32%)[a]	4.0 ± 7.6 (2.27%)[a]	4.2 ± 6.5 (2.17%)[a]	97.3 ± 117.4 (1.95%)[a]	109.7 ± 165.8 (1.1%)[a]	0.0	0.0

[a] The percentage of damaged crop plants referring to the total number of the respective crop type is indicated in brackets. The statistical analyses were done between the test crops with damaged plants up to harvest time by Kruskal–Wallis chi-squared tests (trampled: $c^2 = 13.443$, df = 6, p = 0.0365) followed by post hoc tests (asymptotic Wilcoxon Mann–Whitney rank sum test; trampled chamomile vs. coriander: $Z = 0$, $p > 0.05$; trampled chamomile vs. mint $Z = -2.37$, $p > 0.01$; trampled chamomile vs. basil: $Z = -2.23$, $p > 0.01$; trampled chamomile vs. turmeric: $Z = -2.23$, $p > 0.01$; trampled coriander vs. mint: $Z = -1.44$, $p > 0.05$; trampled coriander vs. basil: $Z = -1.08$, $p > 0.05$; trampled coriander vs. turmeric: $Z = -1.08$, $p > 0.05$; trampled mint vs. basil: $Z = -0.27$, $p > 0.05$, trampled mint vs. turmeric: $Z = -0.199$, $p > 0.05$; trampled basil vs. turmeric: $Z = 0$, $p > 0.05$). Same superscript letters indicate no significant differences in means between elephant damages.

Table 4
Crop yields at harvest time on the test plots JA and GO in 2013 and calculation of potential revenues based on local market prices. n/a = not applicable as not used for production of essential oils.

	Harvest amount on test plots (kg/ha)	Yield of essential oil (kg/ha)	Local market price (USD/kg)	Production cost (USD/kg)	Total revenue (USD/ha)
Turmeric	8682	n/a	0,15	0,00	1270,10
Basil	21 681	124	12,54	140,00	1259,00
Chamomile	1450	5	240,34	108,00	973,52
Rice	2073	n/a	0,25	0,00	519,91
Mint	11 191	23	16,72	38,00	339,52
Lemon Grass	2881	15	14,63	22,00	197,44
Citronella	2924	15	14,63	22,00	197,44

Prices for rice and turmeric refer to raw materials, prices for chamomile, mint, basil, turmeric, lemon grass and citronella refer to their essential oils.

(chamomile, mint, basil, lemon grass and turmeric) were processed to essential oils in local steam distilleries. Yields per kg of raw material varied between 2.5 kg/ha for chamomile, and 124.36 kg/ha for basil. Market prices for crops (rice and turmeric) and essential oils varied strongly, with turmeric being the cheapest crop type (0.15 USD/kg) and chamomile oil the most valuable essential oil (240.34 USD/kg). For the production of essential oils, 10% of the gross revenue was subtracted, leading to revenues ranging from 197.44 USD/ha for citronella and lemon grass to 1270.10 USD/ha for turmeric. Rice in comparison brought a low to medium income of 519.91 USD/ha.

4. Discussion

The objective of this field experiment was to gain certainty on whether MAPs are less attractive for consumption to elephants or not. Despite the low number of visits by elephants in the test plots, our results provide evidence that elephants prefer feeding on rice but not on MAPs.

Elephants are generalist herbivores, which are able to consume many different plant species throughout the seasons, making their choice depending on palatability and acceptability (Heady, 1964) and avoid large numbers of plant species due to toxic or unpalatable plant secondary metabolites (PSM) (Owen-Smith and Chafota, 2012). It has been recently shown that elephants rely on olfaction to locate food (Plotnik et al., 2014) and to distinguish between preferred and avoided natural forage by odour (Schmitt, 2016). In the present experiment, MAPs have been used containing antifeedants, chemical compounds that produce a strong scent and taste, and in some cases also toxins (Table 1). We assume that the odours evaporated from MAPs have an influence on the choice of feeding (or not) upon them. Also, the lower content of crude protein of MAPs compared to rice (Table 1) might have an influence. As shown by Schmitt (2016), the crude protein content however, does not seem to drive elephant feeding choices.

Many plant species are defended against herbivores with the production of PSMs, and their odour, flavour, and palatability provides the basis for foraging selections in mammalian herbivores (Hansen et al., 2016). PSMs play a key role in this interaction and can act as antifeedants through regulating the food intake of herbivores (Dearing et al., 2005). PSMs are found in high amounts in MAPs adversely influencing the physiology of their consumers.

The PSM produced by leave parts, flowers and seeds of tested MAPs are mainly terpenoids, especially mono- and sesquiterpenes (Table 1), some of them being well-known insect repellents. Different plant parts can also contain essential oil, differing in their chemical constituents (Singh et al., 2005).

All MAPs used in this experiment contain multiple PSMs which may have a repellent activity against elephants. However, it must be taken into consideration that these compounds are mainly identified in the extracted essential oils of the plants and are not necessarily found in all plant parts. Their content and composition characterizes the repellent abilities and can differ between flower, stem, leaves and seeds within the same plant. Further examination of which compound may influence an elephant's avoidance of them is required. Furthermore, it has to be understood that MAPs could be repellent, but not deterrent to elephants. As observed in the test plots, elephants may pass through fields with unattractive crops without feeding, but they may cause damage through trampling.

The experiment was designed to gain insight on the elephant's crop choice when exposing it to a variety of MAPs and an attractive crop type. As elephants can cause damage to crops only by walking over them, we chose to separate the attractive control crop from the test crops. To decrease spatial effects, test crops were mixed randomly. In this experimental design, the attractiveness of MAPs is exclusively tested against an attractive crop type. Insights on elephant's crop choice in case no highly attractive crops were available are not given. Further, in case of strongly deterrent effects of one MAP this could influence the choice of the neighbouring crops. To gain more certainty about the attractiveness, repellent or deterrent capabilities of MAPs, more tests focussing on single crop types as well as feeding and olfactory experiments with elephants, as described by Schmitt (2016), are needed.

Our test plots were visited by elephants during the dry as well as the rainy season. As control crops were available on the fields in the rainy season only, typical dry season crops such as coriander and chamomile were present on the fields without control crops in their vicinity. During the five dry season visits, the elephants, however, only damaged crops by passing through the field, thus maintaining low levels of damage. During these visits, chamomile had grown to 30–40 cm in height, while coriander had a lower height, not exceeding 10–15 cm. During the dry season, food availability in the natural habitat is reduced and elephants in Bardia consumed more browse than grass (Steinheim et al., 2005). Asian elephants generally prefer grass or browse from 50 cm height onwards. They are, however, able to feed on freshly sprouting grasses or on tender short grasses growing beneath the coarse swards of tall grasses (Sukumar, 1989). Therefore, generally the elephants would have been able to consume crops below 50 cm. In the rainy season, elephants visited the test plot six times, consuming rice from the 7th day after planting onwards. Rice plants by that time did not exceed a height of 20 cm. Although elephants consumed rice every time they entered the test plots, they only partly damaged the control crops. This happened even though rice from August onwards had the ideal feeding height of over 50 cm and no disturbance occurred. On a similar test plot in Zambia in 2011, the control crop of maize was completely consumed by elephants within two months (Gross et al., 2016). In the experiment in Zambia, the MAP lemon grass was, to some extent, consumed by elephants, when leaving them in the field even after the scheduled harvest time. This exposure without control crop and during the main dry season was not conducted in Nepal. To demonstrate further that lemon grass and citronella are unpalatable to Asian elephants, further research needs to be conducted. Further, the damage of crops by passing elephants without feeding should also be considered. Some fragile crops, like mint, are more prone to trampling than other more robust crops like turmeric, citronella or lemon grass.

Rhino in contrast was observed in the BA test plot feeding on lemon grass in 2013 and blue bull fed on lemon grass in the JA test plot in 2014. Hence, in wildlife rich areas, the possibility of damage by wildlife during the selection of lemon grass as a crop needs to be considered.

The use of crops unattractive to elephants as a buffer between their natural habitat and rural land could be a step forward for land use planning along National Parks in Asia. In highly fragmented landscapes with patches of remaining forest habitats interspersed with agricultural land, the systematic planting of MAPs in rural areas, where elephants should not roam, in combination with the creation of highly attractive corridors (with highly preferred natural food plants) might be an option for reducing heavy conflicts between people and elephants.

Besides the suitability of crops regarding biotic and abiotic factors, the economic value and marketability plays a major role for the crop choice of farmers. Turmeric is a high-value perennial cash crop that is used for food and medical purposes and is cultivated over large parts of Asia, with India being the primary exporter (Gupta et al., 2013). Despite the comparably low price per kg, the highest revenues per ha were obtained in the test plot with turmeric. Revenues could even be increased through value adding processes (e.g. polishing) or following standards or good agricultural practice (Booker et al., 2016).

Mint, lemon grass and citronella can be farmed perennially and harvested several times per year, multiplying yields and revenues (Rajeswara Rao, 1999; Tajidin, 2012). Through production oriented farming, much higher revenues could be generated in general through the cultivation of MAPs compared to the traditional staple crops. Small scale subsistence farmers may be reluctant to change from the traditional staple crop rice to MAP cash crops. However, if losses of staple crops to wildlife are substantial and marketability of MAPs is ensured, the choice for the safer and more profitable crop types seems reasonable. Further, the globally expanding interest in MAPs (Barata et al., 2016; Kala, 2015) provides a high potential for marketability with relatively stable prices, at a reasonably high level in Nepal, India and other range countries of the Asian elephant (Booker et al., 2016).

5. Conclusions and management implications

The results of our field experiments show that the tested MAPs crops were less attractive to Asian elephants than rice. However, in case PSM defended plants were still palatable, they could start feeding on them to some extent under nutritional stress, as demonstrated in field trials in Zambia (Gross et al., 2016). As elephants visited our test plots only in one of two years, no firm conclusion can be drawn on the potential of behaviour change after long term exposure. To demonstrate that elephants will not habitually raid MAPs, long term studies with larger sample sizes of elephant visits need to be conducted.

Further, our results demonstrate that MAPs bear a high potential for a secure income, especially in and close to elephant habitats. To decrease crop damage by elephants, MAPs could be planted systematically into areas elephants should not enter. At the same time, protecting zones and corridors, which are rich in nutritional plants and forming a suitable habitat, could be created, similarly to push- and pull-strategies which are commonly used for insect pests (Gross and Gündermann, 2016).

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