Assessing crop palatability as a tool to mitigate elephant crop raiding: trade-offs and strategies for subsistence farmers in Lower Sagalla, Kenya

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Abstract

Enabling the coexistence of elephants and humans is challenging, especially in areas where elephants venture outside protected areas to raid crops. This creates human-elephant conflict (HEC), jeopardizing farmers' food production and economic security, impeding elephant conservation efforts and threatening the safety of both humans and elephants. Understanding the palatability of different crops to elephants is fundamental for mitigating raiding behaviour, however, species-specific crop palatability remains poorly understood. In this study, we conducted on-site farm experiments and semi-structured interviews to evaluate the suitability and palatability of moringa (*Moringa oleifera*) and sunflowers (*Helianthus sp.*) to African savannah elephants (*Loxodonta africana*) in comparison to the highly palatable and locally valued maize (*Zea mays*). We established 30 experimental plots of the three crops across ten farms in Lower Sagalla, a community adjacent to Tsavo East National Park, that frequently experiences elephant crop raiding. We assessed elephant crop palatability through foraging observations and evaluated agronomic suitability using germination and survival rates. Our findings revealed that farmers were divided in their opinions regarding the palatability of moringa to elephants; however, there was a consensus that sunflowers were non-palatable to them. Our experiments confirmed that both crops were significantly less palatable to elephants than maize. We conclude that cultivating non-palatable crops represents a promising strategy for reducing elephant crop raiding and diversifying livelihoods in Lower Sagalla. Nevertheless, the success of this approach as conservation and livelihood tools depends on favourable climatic conditions, and agricultural, economic, and cultural contexts, which are highly integrated and dynamic. Additional institutional support through agricultural extension services and market development is also necessary for effective implementation.

Résumé

Rendre possible la coexistence des humains et des éléphants représente un défi, en particulier dans les régions où les éléphants s'aventurent hors des zones protégées pour piller les cultures. Ces incidents, qui entraînent des conflits humains-éléphants (CHE) et mettent en péril la production alimentaire des agriculteurs et leur sécurité économique, entravent les efforts de conservation et menacent la sécurité des humains comme des éléphants. Si la compréhension de l'appétence des éléphants à l'égard de différentes cultures est fondamentale pour atténuer les comportements de pillage, l'appétence propre aux espèces envers certains végétaux reste toutefois mal comprise. Dans le cadre de cette étude, nous avons conduit des expériences sur le terrain ainsi que des entretiens semi-structurés afin d'évaluer l'adéquation et l'appétence du moringa (*Moringa*

oleifera) et du tournesol (*Helianthus sp.*) pour les éléphants de savane d'Afrique (*Loxodonta africana*) par rapport au maïs (*Zea mays*), hautement appétant et localement valorisé. Nous avons installé trente parcelles expérimentales de ces trois cultures sur dix fermes du Lower Sagalla au Kenya, une communauté contigüe au parc national de Tsavo East qui subit de fréquents pillages de la part des éléphants. Nous avons examiné l'appétence de ces cultures par le biais d'observations du comportement alimentaire des éléphants, et évalué l'adéquation agronomique de ces végétaux selon leur taux de germination et de survie. Nos résultats révèlent que les agriculteurs avaient des opinions divergentes quant à l'appétence du moringa pour les éléphants, mais il y existait toutefois un consensus autour de la non-appétence des tournesols. Notre expérience a confirmé que les deux cultures étaient nettement moins appétentes que le maïs. Nous en concluons que la culture de végétaux non appétants représente une stratégie prometteuse afin de réduire les pillages de cultures et de diversifier les sources de revenus dans la région du Lower Sagalla. Néanmoins, la réussite de cette approche en tant qu'outil de conservation et de renforcement des moyens de subsistance dépend de conditions climatiques favorables, et de contextes agricoles, économiques et culturels dynamiques et hautement intégrés. Un soutien institutionnel supplémentaire, sous la forme de services de vulgarisation agricole et de développement de marchés de distribution, est nécessaire pour une mise en œuvre efficace.

Introduction

Kenya's elephant (*Loxodonta africana*) population is approximately 36,280, with the Tsavo ecosystem hosting the country's largest population, approximately 14,964 elephants (Waweru et al. 2021). In 2017, aerial surveys by the Kenya Wildlife Service and the Tanzania Wildlife Research Institute revealed a 15.1% increase in the Tsavo ecosystem elephant population since 2014 (Ngene et al. 2017). While growing elephant populations are a conservation victory, the simultaneous fragmentation of habitat by human development has made human-elephant conflict (HEC) increasingly common (Thouless 1994). For farmers adjacent to protected areas, elephants can represent important challenges. For instance, elephants can cause extensive crop loss through trampling or directly feeding on crops (Vogel et al. 2020). These incursions also cause property damage, pose risks to human safety, and demand considerable time for guarding, often diverting labour from other livelihood activities. In some cases, students miss school to guard family farms or avoid elephant-prone routes, with measurable impacts on academic performance such as lower mean grades in schools located within elephant ranges (Mackenzie and Ahabyona 2012). The cumulative economic losses, persistent fear, and insecurity reinforce negative perceptions of elephants and exacerbate HEC (Nyumba et al. 2020).

The foraging ecology of elephants, characterized by high nutritional demands and selective feeding, often brings them into direct conflict with farmers, especially subsistence farmers living on the boundaries of protected areas (PAs). Historically, elephants met their nutritional needs within extensive habitats, but habitat loss and compression now limit access to natural forage, leading them to rely more on crops, which offer concentrated nutrients (Chama et al. 2025). Due to their large food requirements, a small herd of elephants can deplete the crops of a small-scale farm in one night. This is especially critical when it impacts subsistence farmers whose production matches their consumption with minimal surplus as it severely threatens their food security and income generation capacity (Sitati et al. 2005; Mackenzie and Ahabyona 2012). Such vulnerability to crop depletion has compelled subsistence farmers to devise and adopt a range of defensive measures to deter elephants from their fields. For instance, subsistence farmers have historically relied on basic, traditional elephant deterrent techniques such as shouting, banging objects, lighting fires, throwing stones, and using guard dogs to protect their farms (Graham and Ochieng 2008). However, these methods demand substantial labour and time investments from farmers and may lose their effectiveness over time as elephants habituate to them (Sitati et al. 2005).

The limitations of these traditional methods have spurred the development of a wider suite of advanced mitigation strategies. Among these are physical barriers, such as trenches, stone walls, and electric fences. Although farmers often identify electric fences as a highly effective elephant deterrent, their high cost makes them inaccessible for most subsistence farmers

(Thouless 1994). As a result, significant focus has shifted toward more affordable behavioural deterrents, such as the development of beehive fences that exploit elephants' natural avoidance of bees (King 2010), as well as chilli-based (Osborn and Parker 2002) and olfactory repellents (Tiller et al. 2022). Development has also progressed on broader management strategies, including coordinated community guarding (Osborn and Parker 2002), problem-animal translocation (Tiller et al. 2022), and land-use planning for wildlife corridors (Vasudev et al. 2023). These approaches are increasingly complemented by emerging technologies like GPS-based early-warning systems. Furthermore, proactive strategies such as the cultivation of less palatable and or non-palatable crops have gained traction, with evidence supporting their use to reduce crop raiding (Gross et al. 2015).

Elephant crop foraging behaviour is highly selective, driven by a preference for high-calorie crops and a consistent avoidance of those with lower nutritional returns or strong chemical defences. For instance, African elephants have consistently demonstrated a preference for energy-dense crops like maize, bananas, and beans, which offer high nutritional returns (Matsika et al. 2020). Conversely, they actively avoid plants with innate chemical defences, such as chillies, garlic, ginger, and onions (Gross et al. 2015). The empirical consequence of this selectivity is clearly demonstrated, for instance, in the Tsavo ecosystem, where maize accounted for 61% of all crop raiding incidents (Smith and Kasiki 1999). This foraging strategy has profound implications for HEC. For example, research on chillies demonstrated that growing non-palatable cash crops instead of maize can reduce crop loss and increase income per hectare (Parker and Osborn 2006).

Therefore, to mitigate crop raiding and foster human-elephant coexistence (HECx) among subsistence farmers, cultivating less palatable crops offers a targeted strategy to reduce field attractiveness and minimize conflict. This approach aligns with optimal foraging theory by lowering the nutritional incentive for elephants to raid farms, thereby directly supporting farmer livelihoods while advancing elephant conservation efforts. Although growing non-palatable crops depends on the soil, climate, economic factors, and people's traditions (Montero-Botey et al. 2021). There is still a knowledge gap concerning the evidence of palatability of many crops, including sunflowers (*Helianthus sp.*) and moringa (*Moringa oleifera*) to elephants, and how both elephant preference and crop utility jointly influence farmers' decisions. To address this, we employed a mixed-methods approach integrating on-farm experiments with farmer interviews to: i) compare elephant preference for maize, moringa, and sunflowers; ii) evaluate their agronomic suitability via germination and survival rates; and iii) understand factors influencing their adoption by farmers.

Study area

This study took place in two villages at the base of Sagalla Hill that are home to approximately 340 households and 1,300 residents and is referred to as Lower Sagalla (King et al. 2024) (Fig. 1). Lower Sagalla is within the Tsavo Conservation Area, approximately 3 km from Tsavo East National Park (NP) and has an elevation of ~600 m (King 2010). It borders the Park along the Nairobi–Mombasa Standard-Gauge Railway (SGR), which is fenced but includes two designated wildlife underpasses. Farms in Lower Sagalla have become a hotspot for HEC; elephants regularly access croplands via these underpasses and through adjoining communal and private lands to the west. Studies have found that, some underpasses can funnel elephants into community areas, increasing the likelihood of crop raids and HEC, highlighting the need for infrastructure designs that consider both wildlife movement and the protection of local communities (Okita-Ouma et al. 2021).

Subsistence farming is the primary or only income source for many in Lower Sagalla (Smith and Kasiki 1999). Farmers predominantly grow maize, cassava, watermelons, cowpeas, and mung beans as well as farm livestock (MoALF 2016). According to the Kenya Ministry of Agriculture, Livestock, and Fisheries (MoALF 2016), "between 61 and 80% of the population of Taita-Taveta County is engaged in maize production, mostly at a small scale". Despite high levels of agricultural activity, the region has low soil fertility, which limits crop production potential; the mean annual rainfall for the Tsavo Ecosystem is 550 mm (Smith and Kasiki 1999). The Tsavo Ecosystem has two rainy seasons: a long rainy season from March to May and a short rainy season from
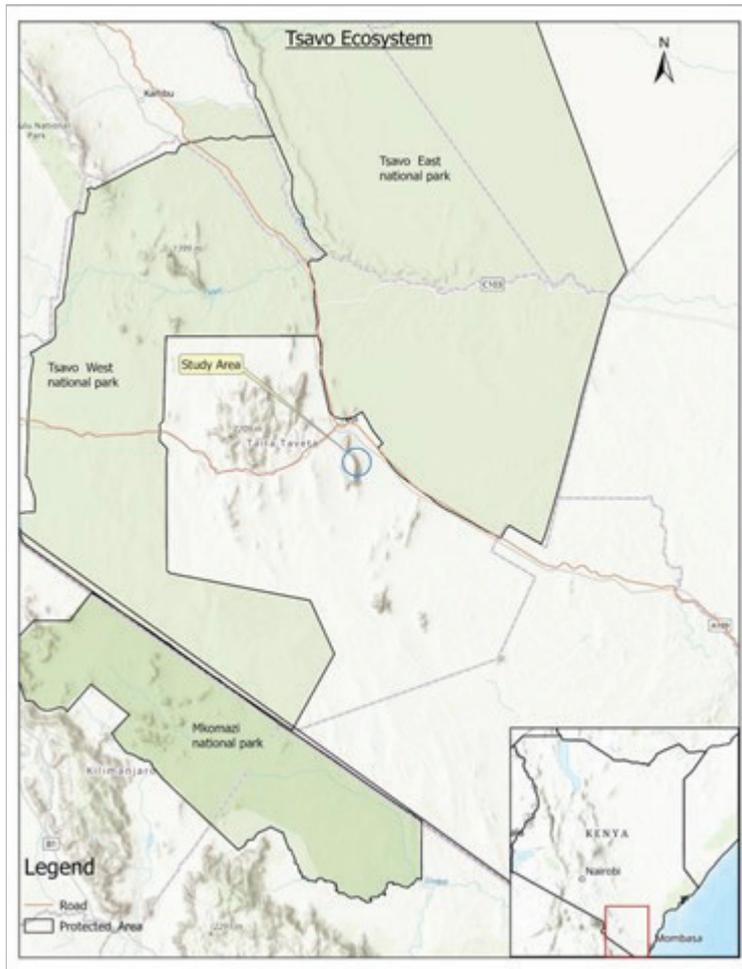
Figure 1. Study area in Lower Sagalla, Taita Taveta County, Kenya, which lies within the 42,000 km² Tsavo Conservation Area, 3 km from Tsavo East NP.

October to December (Smith and Kasiki 1999). This research was conducted during a peak period of elephant activity in Lower Sagalla, between August 2016 and July 2017.

Methodology

Crop experiments

We conducted on-farm experiments to assess whether two crops, sunflowers and moringa, are less palatable to elephants than maize, a local food staple, and if planting them can decrease elephant crop foraging. These crops were selected after informal conversations with 10 Lower Sagalla farmers about their farming experiences, which suggested that both crops may not be attractive to

elephants but were of interest to farmers.

Experimental sites were selected at 10 farms based on the farm's history of frequent elephant activity. Plots were placed where elephants had previously crop raided and far from homes to minimize deterrent effects from human presence. At each farm, three 5 m x 5 m plots (one per crop) were prepared and arranged linearly (Fig. 2). An 8.5 m buffer zone was established between the plots with a 1 m buffer around each experimental site. Treatment of the plot was assigned using a complete randomized block.

The plot size, plant spacing, seed number and depth, and planting date were determined in consultation with farmers. On each plot 50 moringa, 100 maize, or 100 sunflower seeds were planted; less moringa were planted due to moringa's larger size,
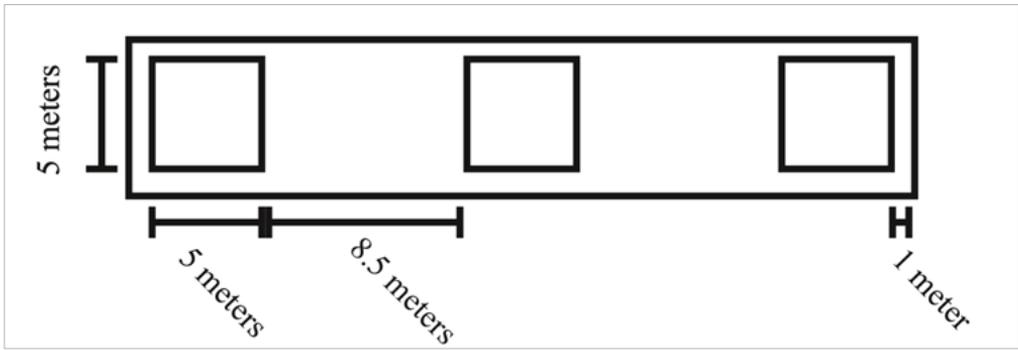
Figure 2. On-farm experimental plot arrangement. At each experimental farm, three 5 m x 5 m plots (one for each crop) were prepared and arranged linearly. An 8.5 m buffer was established between plots and a 1 m buffer around each farm's experimental area.

per farmers' recommendations. The maize and sunflower plots had 10 rows of 10 plants with a 0.5 m spacing between the plants and rows. Sunflower and maize seeds were planted 5–10 cm deep (4–5 maize seeds or 7–10 sunflower seeds) and covered with 2.5–5 cm of soil. Fifty moringa were cultivated per plot in five rows of 10 plants with a 1 m spacing between rows and a 0.5 m spacing between plants. Each plant was assigned a unique identifier.

Moringa seedlings (n = 420; 42 per plot) were sourced from a single nursery, with germination initiated in mid-September 2016. An additional eight seeds were directly sown per plot. The seed and sapling locations were determined by using a random number table. Moringa were planted in the experimental plots in the last two weeks of November, after the rainy season had begun. The maize and sunflower seeds were planted between mid-October and mid-November. None of the sunflowers germinated, and new seeds were planted in mid-December in the same plots.

Data collection

Throughout the experiment, we visited the experimental plots weekly and within 24 hours after farmers reported elephant activity. During visits, farmers described any crop raiding incident, including the number of elephants, where they entered and exited the farm, and any behavioural observations. The damage to the experimental plot was recorded using a standardised form (Fig. 3). The plants were classified as seedling (< 25 cm), intermediate (> 25 cm, but not flowering), or mature (exhibiting flowers or fruit). Plant health was classified into six statuses: good, alive (accidental elephant damage), alive (intentional elephant damage), dead (accidental elephant damage), dead (intentional elephant damage), and dead (other). Foraging and uprooting were considered intentional elephant damage; trampling was considered accidental elephant damage (Fig. 4). Other causes of damage included insects, environmental stress, trampling by livestock, and foraging by baboons and birds. Trail cameras were installed at each plot to support field observations and confirm the cause of damage.

Semi-structured interviews

To understand local perceptions of and experiences with sunflowers and moringa we conducted semi-structured interviews in June and July 2017. An interview guide was developed with a combination of closed-ended and open-ended questions. Thematic areas included: i) historical experiences with elephant crop raiding; ii) perceptions of crop palatability to elephants; and iii) primary factors influencing crop selection (e.g. market access, agronomic challenges). A university-educated interpreter fluent in English and Swahili translated the interview guide into Swahili and interpreted during interviews because English is the third language for many in Lower Sagalla. The guide was pre-tested through three practice interviews to refine questions for clarity, comprehension, and appropriate interview length.

Participants were initially selected purposefully based on their farming experience in Lower Sagalla and knowledge of HECx. Snowball sampling was then employed, whereby interviewees were asked to recommend other knowledgeable community members. This method ensured a representative

Figure 3. Crop status assessment form utilized to record individual plant health status following crop raiding events.
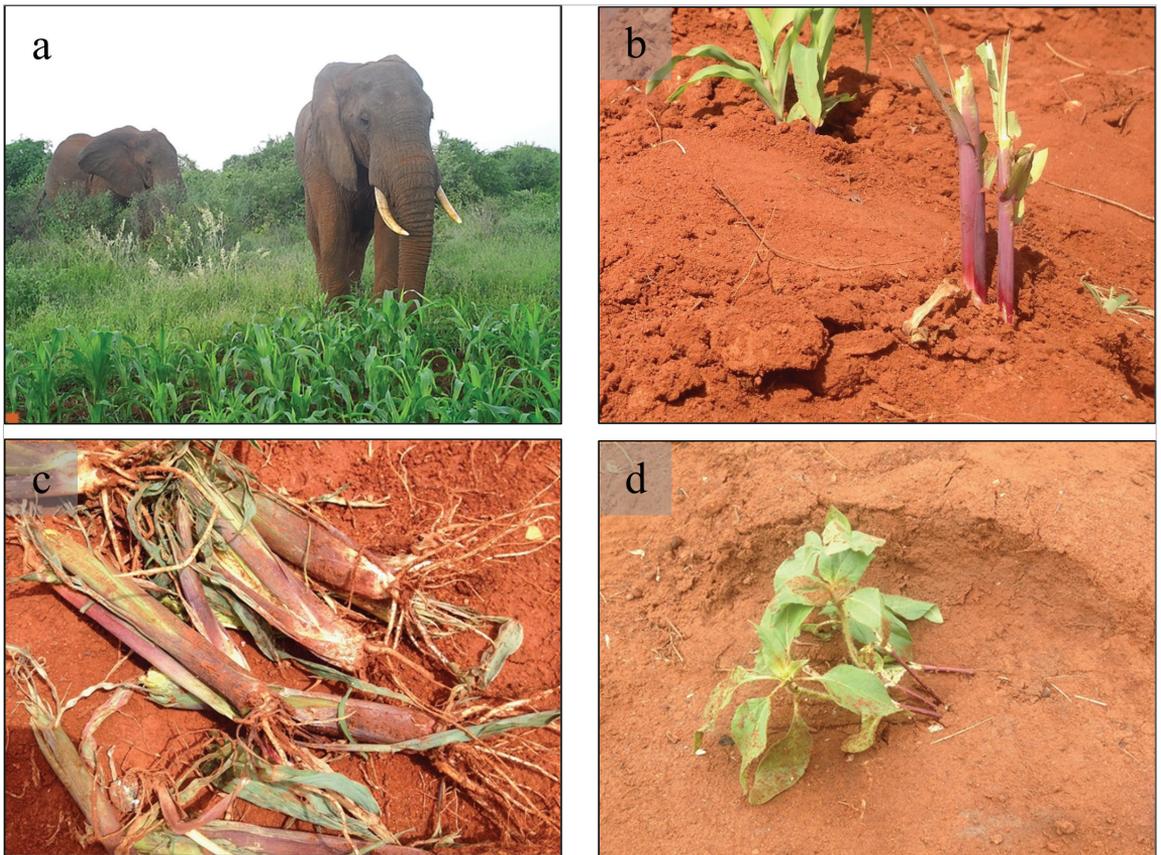

Figure 4. a) Elephants foraging at experimental farm plot. b) Intentional elephant damage (foraging) of maize. c) Intentional elephant damage (uprooting) of maize. d) Unintentional elephant damage (trampling) of a sunflower.

pool of participants, including farmers (n = 26), community leaders (n = 5), and local non-profit staff (n = 5). The total number of interviews conducted was 31; all community leaders were also farmers. Eighteen farmer interviews were with men, six were with women, and two involved couples. Farming experience was 10 to 56 years. Twelve farmers farmed 5–10 acres, seven farmed 10–20 acres, and one farmed 30 acres. Three people were not currently farming, and three did not know their farm size. Each interview lasted between 45 minutes and 3.5 hours. Verbal consent was obtained at the outset, with a clear outline of the interview topics and an emphasis on voluntary participation and confidentiality. Responses were audio-recorded and translated into English for analysis.

Crop experiment data analysis

Plant health was analysed twice during the study period, mid-January and late March 2017. Mid-January was selected because a large period of elephant crop raiding occurred between December 17 and January 20. Late March was the end of the growing season and showed what proportion of plants remained. These two timeframes answered four questions: 1) was there a difference in germination rates? (January); 2) was there a difference in the number of plants alive and healthy at the end of the growing season? (March); 3) was there a difference in intentional elephant damage mid-growing season? (January); and 4) was there a difference in intentional elephant-caused mortality at the end of the growing season? (March).

Data were analysed using SPSS and coded by crop type and farm. To account for variable germination rates among plots, the proportion of plants that germinated at a plot within each plant status was calculated instead of using the number of plants. Proportions were compared using Kruskal-Wallis and post-hoc pairwise comparisons.

Throughout the experiment, there was below-average rainfall. In 2017 only 2.2 mm of rain fell (King et al. *in prep*). To compensate for the lack of rainfall, we purchased water, and two farmers were hired to water each plot with 20 L of water three times a week. All crops were watered the same way. However, as the drought worsened, it was difficult to obtain sufficient water, which impacted plant growth.

Interview coding and analysis

All interviews were audio-recorded and supplemented with extensive field notes taken during and immediately after each session to capture contextual details and initial observations. Participants were assigned codes to maintain anonymity. For example, P1 indicates participant number 1. We reviewed and manually coded notes for overarching themes and created spreadsheets to organize interview topics: Sagalla history, land use, HEC, social and emotional impacts, economic impacts, elephant deterrents, beehive fences, and non-palatable crops. When an interviewee's response coincided with a topic, the participant code and the reference line number were recorded. In the interview notes, we highlighted references for each topic in a different colour. The topics most frequently discussed were identified and divided into themes, subthemes, and quantified. Responses to each closed-ended question were recorded and tables detailing the responses were created.

Results

Crop experiment

During the study period (December 2016 to March 2017), we documented 37 distinct crop raiding events; elephants raided in 9 out of 10 farms, and the frequency of raids per farm ranged from 2 to 8. The ecological suitability of the crops was compared using the germination rate and the percentage alive in March as proxies. The percentage of plants that germinated in mid-January 2017 (Kruskal-Wallis n = 30, df=2, p=0.41) and the post hoc pairwise analysis did not show statistically significant differences in the germination rates between the crop types. However, by the end of the season, significantly more sunflowers and moringa were alive than maize; this included plants that were damaged but still in good health (Kruskal-Wallis (n = 30, df=2, p=0.000). The pairwise analysis showed significant differences between maize and sunflowers (p=0.044) and maize and moringa (p=0.000).

To assess the relative palatability of each crop, the rates of intentional damage by elephants in January and March 2017 were compared. The January 2017 findings strongly suggest that sunflowers are less palatable to elephants than maize. Kruskal-Wallis (n=30, df=2) yielded a p-value of 0.002; pairwise comparison showed significant differences in intentional elephant damage between sunflowers and
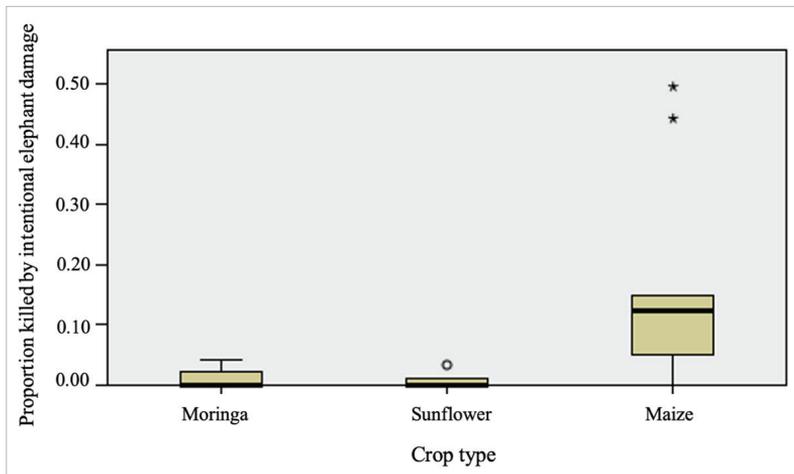
Figure 5. Proportion of plants intentionally damaged by elephants by crop type (March 2017) Kruskal-Wallis analysis of the proportion of each crop intentionally damaged by elephants (foraging and uprooting). Statistically significant differences were evident between sunflowers and maize (p=0.002) and moringa and maize (p=0.004).

maize (p=0.001) but not between moringa and maize (p=0.23). Similarly, the analysis in March 2017 showed that elephants intentionally foraged upon and/or damaged maize significantly more than sunflowers or moringa. Kruskal-Wallis (n=30, df=2, p=0.001), and pairwise comparisons showed significant forage damage differences between sunflowers and maize (p=0.002) and moringa and maize (p=0.004) (Fig. 5).

Interview results

Our interview results revealed three primary themes concerning the cultivation of alternative crops: 1) the critical trade-off between agronomic viability and economic security; 2) the perceived efficacy of crop palatability as an elephant deterrent; and 3) the significant structural barriers to adoption, namely market access and initial investment costs.

Farmers (n = 26) had strong crop preferences, with clear seasonal variation. For example, maize was favoured by 81% of farmers during the short rains (October–December 2015) but was only grown by 54% (of farmers) during the long rains (March–May 2016). In the latter period, legume cultivation became predominant, with 86% of farmers growing mung beans and 81% growing cowpeas.

Farmers considered many factors when selecting crops. For instance, 69% considered

rainfall and relied on the annual rains, growing different crops during the two rainy seasons. Other top factors considered were market value (27%) and food security (19%). Thirty-one per cent of farmers prioritized maize's cultural importance and role as a staple food; however growing maize is a challenge for coexistence with wildlife. Fifteen per cent considered crop attractiveness to elephants. A farmer noted, "I tried growing pigeon peas, but didn't harvest anything . . . Elephants raided. Elephants came when they were ready" (P2).

Farmer experiences with sunflowers

Fifty per cent of the 26 farmers interviewed had previously grown sunflowers. Regardless of cultivation experience, the majority (69%) believed that sunflowers were non-palatable to elephants.

Farmers reported numerous benefits of growing sunflowers: oil production (58%), bee fodder (46%), market value (38%), livestock fodder (15%), and food (15%). A farmer explained their versatility, "when it is used to make oil then the outer part you can give to livestock" (P2). Another farmer remarked, "sunflowers are food. Money when you sell it" (P16). However, there are significant agronomic and socio-economic challenges when cultivating sunflowers that may limit farmer adoption. For example, 38% mentioned drought and unreliable rainfall. A farmer noted, "I tried to plant sunflowers, but they did not do well because of drought" (P22). Fifteen per cent of farmers were
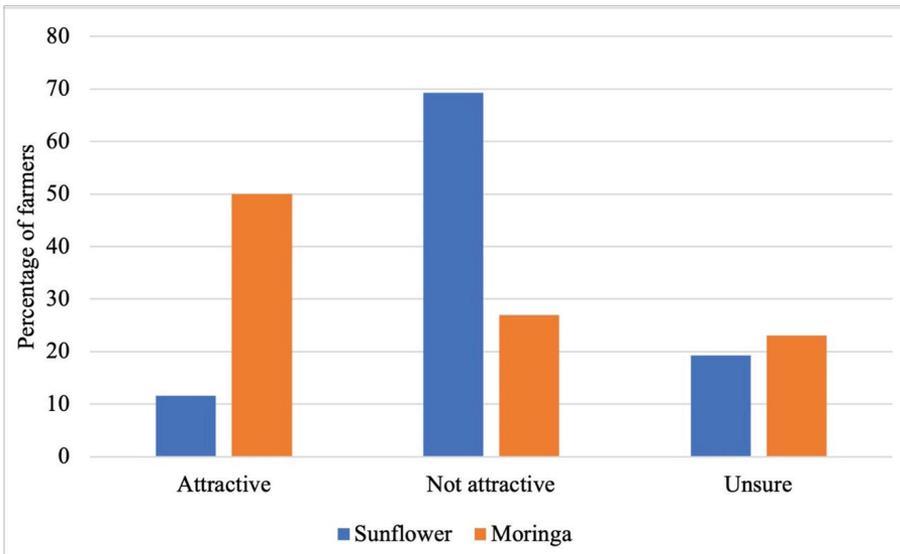
Figure 6. Farmers' perceptions of crop attraction to elephants (%) (n=26) as reported during interviews.

concerned about the impacts of wildlife, including rodent seed predation and damage by elephants and baboons. Twelve per cent of farmers cited lack of seeds as a challenge to growing sunflowers.

Fifty-four percent of farmers thought there was a local market for sunflowers. A farmer attested, "there is a market for sunflowers. You can sell it" (P20). During interviews, farmers cited local market prices of 50–140 KSH/kg (USD 40 cents to 1.20) for sunflower seeds. However, some mentioned they did not profit from growing sunflowers. A farmer explained, "there is an industry in Voi. But you see, when people grow sunflowers, they grow it in too small quantities, and the industry needs large quantities" (P21). Fifteen per cent of farmers thought there was no local market. The remaining 31% were unsure.

Farmer experiences with moringa

Of the 26 farmers interviewed, 42% had experience cultivating moringa. However, they expressed divergent views on its palatability, with 50% believing it to be attractive to elephants (Fig. 6). A farmer explained: "elephants love moringa. A close neighbour... is raided every time that her moringa plants are ready. Elephants trample and consume (the plants)" (P15). However, 27% of farmers believed that moringa is not attractive to elephants. A farmer remarked: "moringa? I think it is not attractive because there are some lands

[do these people farm areas where they don't have title deeds?] where they have grown moringa, but I have never seen elephants destroy them or eat them" (P19). However, as pointed out by one farmer and clear from other farmers' responses, moringa is a relatively new crop; therefore 23% of farmers were unsure about elephants' attraction to moringa.

The most reported benefits of moringa were its medical uses (73%) and role as a food source (46%). A farmer noted, "seed pods are a good vegetable . . . The leaves, when dried and taken with porridge, are good for my health" (P14). Other commonly reported benefits of moringa were market value (42%) and pressing for oil (12%). Two farmers noted its drought tolerance. Despite its benefits, 35% of farmers noted that drought and lack of rainfall were impediments to its adoption. Damage by elephants (27%) and pests (12%) were also reported as cultivation challenges. Fifteen per cent noted that a lack of awareness limits moringa cultivation. A farmer remarked, "moringa is, to us, a very new plant . . . We are being told it is a medicine, which cures a lot of sickness, but I don't know myself because I haven't used it. But now I'm planting this crop, maybe I'll learn more" (P18). Despite a lack of knowledge, they were eager to learn more about moringa.

Sixty-nine percent of farmers believed there is a local market for moringa. One farmer remarked, "everything about moringa means money. You sell the flower for money. You sell the seeds for money"

(P22). Several cited local moringa market prices of 200-300 KSH/ kg of seeds, 800 KSH/ kg of leaves, and 1,000 KSH/kg (USD 7) of flowers. Two farmers thought there was no local moringa market; the remaining 23% were unsure.

Discussion

In this interdisciplinary study, combining elephant crop-palatability trials, agronomic assessments, and qualitative socio-economic analysis, we aimed to assess the role of non-palatable crops in mitigating HEC. In Lower Sagalla, an area affected by recurrent HEC, while maize, the staple food and a culturally important crop is widely cultivated (MoALF 2016), elephant foraging heavily impacts its cultivation; farmers invest their money and time in growing maize but often reap minimal harvest (Smith and Kasiki 1999). A local farmer summarized, "if I continue fighting with the animals, trying to grow the maize and fighting with them, I won't end up anywhere" (P21). Non-palatable crops like sunflowers and moringa hold potential to support agricultural diversification and, consequently, household livelihood resiliency, in the face of increasing climatic uncertainty and elephant crop raiding pressure. Understanding the palatability and adoption potential of these crops, particularly among subsistence farmers living at the edge of PAs is important to develop locally grounded strategies for coexistence.

Crop palatability to elephants

We found that sunflowers are a climatically viable, non-palatable crop that suits the sandy, iron-rich soil conditions of the community lands and that could provide multiple benefits for Lower Sagalla farmers. At both the mid-growing season (January 2017) and end of the growing season (March 2017), elephants had intentionally foraged upon or damaged significantly more maize than sunflowers (Fig. 5). This suggests that sunflowers are much less palatable to elephants than maize and that incorporating sunflowers into farms may decrease intentional elephant damage and increase the harvest income for these at-risk farmers.

The evidence for moringa's non-palatability compared to maize was less definitive in the initial stages of the study. Specifically, at the mid-growing season (January 2017), the incidence of intentional elephant damage did not differ significantly between the two crops. At the end of the growing season (March 2017), significantly less crop death was attributed to intentional elephant activity in moringa than in maize. However, this may be due to differences in life stage; maize grows faster and fruits within one growing season while moringa reaches maturity in two years. This may have led elephants to preferentially forage maize instead of early stage moringa and suggests that a longer time window is needed to fully assess the palatability of moringa to elephants across all life stages before conclusions are drawn.

Based on our findings, we propose that dedicating a portion of farmland to cultivating sunflowers and moringa instead of known elephant preferred crops like maize may reduce the attraction for elephants to enter farms. Previous research by Matsika et al. (2023) showed that greater crop diversity reduced crop raiding vulnerability. Furthermore, non-palatable crops could be coupled with effective elephant deterrent methods to increase farm profitability. For example, farmers could strategically plant high-value elephant favourites inside beehive or electric fences while planting less palatable crops outside, reducing the time and money needed to protect crops. Additionally, effective land-use planning can promote human-elephant coexistence (Buchholtz et al. 2019). For example, "frontline" farms could grow non-palatable crops, thus creating buffer zones in front of individual farms or farm clusters for farmers growing maize "behind' in the rest of the community (Matsika et al. 2020). This benefit of effectively protecting second or third layer farmers by mitigating the indirect consequences of elephant movement and foraging could be an attractive strategy for village land use plans.

Climatic suitability

Most Kenyan farmers, including those in Lower Sagalla, rely on rainfall for their agriculture, so considering crop resiliency is essential as climate change makes rainfall less predictable and drought more common in eastern Kenya (Marigi 2017). Two ways farmers across sub-Saharan Africa are adapting to climate change are crop diversification and adopting drought-tolerant crops (Magesa et al. 2023). In Taita Taveta County, MoALF (2016) reported that climate change has diminished maize yields and recommended cultivating drought-tolerant crops. We found that both sunflowers and moringa grew better than maize in Lower Sagalla

despite low rainfall. In mid-January 2017 there were no significant differences in germination rates among crops; all germinated equally well. However, at the end of the growing season (March 2017), significantly more sunflowers and moringa remained than maize. Both crops better withstood the cultivation challenges in Lower Sagalla including soil conditions, slope, elephant crop raiding, drought, and insect damage; they germinated well and persisted throughout the growing season. An agriculture expert highlighted moringa's climate resiliency: "[moringa] are drought tolerant . . . it is also good for agroforestry if someone is rotating crops and growing other plants. It is also a nitrogen fixer" (P27). Growing both rapidly maturing non-palatable crops like sunflowers and chillies as well as slow-maturing non-palatable trees, including moringa could provide farmers with both short-term harvests and long-term agroecological benefits that withstand the challenges of elephant foraging and climate change.

Challenges to crop diversification and household livelihood resiliency

While elephant crop raiding has undermined the economic viability of small-scale agriculture in Lower Sagalla, crop diversification, a potential strategy for reducing losses, is itself hindered by challenges, including the superior market value and cultural significance of staple crops, alongside the perceived risk and agronomic uncertainty of cultivating alternatives. As one farmer (P5), in our study explained, that they would be in a better position economically if the elephants in the area did not crop raid. The threat of crop damage necessitates vigilant field guarding to deter marauding elephants, which reduces farmers' abilities to pursue off-farm income-generating activities. Farmers become exhausted and hopeless as they lose crops to elephant foraging and struggle to transition to alternative livelihoods, which often fosters animosity towards elephants and protected areas and creates resistance to elephant conservation initiatives (Sitati et al. 2005).

Despite the cultivation challenges of growing and protecting maize from elephants, it is still widely grown and highly valued. A farmer explained the local importance of maize, "farmers plant maize because they say that you

cannot prepare porridge from green grams or cowpeas. Even when you tell that person to change, it will take a lot of time to change" (P15). Therefore, increasing non-palatable crop cultivation to replace maize needs to be better understood before being promoted as a simplistic solution to HEC especially understanding the trade-offs that farmers would make based on their historic diets, farming, and broader livelihood strategies. Although planting non-palatable crops may be a useful strategy to reduce elephant foraging, our findings demonstrate that it must be understood within farmers' broader agricultural, socio-economic, and cultural contexts. Furthermore, our findings underscore the necessity of evaluating the opportunity and labour costs of reducing, let alone replacing, known crops such as maize or legumes with less known crops such as sunflowers or moringa (Lukanu et al. 2024).

Although sunflower seeds can be eaten directly, they are not a staple food and are commonly consumed (or sold) as oil. This requires the cost of a grinding machine to convert the seeds into sunflower oil (a staple need for households as well as a valuable commodity). Grinding can be done at a village level through a shared grinder, potentially providing frontline farmers needing to plant non-palatable crops with a highly valued oil product that can be sold in local markets. Similarly, moringa can benefit farmers as both a food source and a marketable crop. Moringa leaves can be eaten fresh as a vegetable or dried and crushed by farmers into a nutritious powder that can be consumed by the household or sold at market. Importantly, dual-purpose crops may hold greater potential for adoption than "purely cash crops" (Lukanu et al. 2004).

While Lower Sagalla farmers already grow and sell sunflowers and moringa, it is predominantly on a small-scale. The agriculture expert noted, "people have not gone full out to exploit the potential of moringa here, which is huge" (P27). This highlights key adoption barriers, including the relative newness of the crop in the region, a consequent lack of technical knowledge and processing capacity, and a strong cultural preference for established staples like maize. Therefore, overcoming these barriers will likely require targeted support from government extension services or non-profit organizations to provide training, market linkages, and initial resources (Lukanu et al. 2004; Ogunjinmi et al. 2024). An agriculture expert recommended, "there is a market for sunflowers, but the problem is when the community sells it raw. There is exploitation. So, we would have to find a market

and try to negotiate prices for the community or encourage people to invest in factories" (P27). There is also concern if too much supply comes on the market simultaneously. Issues of future supply, demand, and price are critical components of whether or not new cropping systems serve their initial objectives (Lukanu et al. 2004).

Although farmers would want to diversify their incomes and grow non-palatable crops, challenging farming conditions, including saving the necessary capital, have made it difficult for them to do so. For example, one farmer explained, "I'm not planting [sunflowers] because of lack of finance, though I am hoping to plant" (P11). Similarly, Mackenzie and Ahabyona (2012) found that small-scale farmers who take out loans to pay for farming supplies at the beginning of the season and suffer crop raiding often find themselves in further debt. Therefore, without reliable harvests or outside assistance, farmers cannot accumulate enough surplus to invest in alternative livelihood activities.

An important factor regarding challenges to raising financial capital is that Lower Sagalla farmers cannot leverage their land to gain capital to invest in other economic activities because it is titled at the community level. Instead of purchasing individual land parcels, community members pay a one-time fee authorizing them to use community land. Thus, they can claim land for farming or grazing but cannot sell claims or use it as loan collateral. In Taita Taveta County, only 40% of farmers have title deeds (MoALF 2016); so many have few options except to engage in low productivity farming where the land is free, but production unreliable, risky and invariably limited.

Despite the challenges of adopting moringa and sunflowers, these crops hold potential for households to diversify from sole reliance on maize cultivation and to increase resilience in the Lower Sagalla conflict zone. In sub-Saharan Africa, greater household livelihood diversity is associated with higher total household income, increased food security, and improved future economic opportunities (Alobo Loison 2015) and is a principal strategy to adapt to a changing climate (Magesa et al. 2023). Thus, growing sunflowers, moringa, or other non-palatable crops has the potential to improve resiliency of farmer livelihoods. It can help by reducing the amount of time farm household members spend guarding fields, producing both unprocessed and value-added products for market sale, and diversifying livelihood sources. Since the conclusion of our study in 2017, sunflowers continue to demonstrate non-palatability to elephants, and their adoption is increasing (LE King, pers comm., 2025).

While this study offers valuable insights from interviews and experimental plots into HECx challenges in Lower Sagalla, we acknowledge the small sample size, short temporal scale, and impacts of drought limit its generalizability to other communities. Therefore, additional research on sunflowers and moringa in additional sites, focusing on palatability to elephants, socio-economic implications of changing a livelihood resource, planting strategies, climatic vulnerabilities, and opportunities, is necessary to assess our findings' significance. To increase the robustness of future studies, we recommend including greater replication over multiple growing seasons, especially for moringa to fully assess its palatability to elephants at all life stages.

Conclusions

The unfenced boundary of Tsavo East NP is essential for ecological connectivity and genetic flow for elephants, yet it consistently generates HEC, resulting in food insecurity and economic hardship for adjacent communities. Our study demonstrates that cultivating non-palatable, drought-resistant crops such as sunflowers can reduce the attractiveness of farmlands to elephants, offering an ecologically grounded foraging deterrent. However, the integrated approach employed here, combining palatability trials, agronomic evaluation, and socio-economic analysis, shows that crop adoption is constrained less by agronomic potential than by profound socio-economic and cultural factors, most, notably, the irreplaceable role of maize as both a dietary staple and a culturally significant crop.

Based on these findings, we propose the following recommendations:

For policy: Conservation and agricultural policies should integrate market-based interventions, such as developing stable value chains and providing economic incentives for alternative crops, to enhance their financial viability and reduce smallholder reliance on high-risk staples. 2) For extension services: Training

programs should address knowledge gaps related to the cultivation, processing, and commercial use of non-palatable crops while acknowledging and working within cultural preferences for maize. This should include an assessment of the differences in labour demands between maize and non-palatable crops. Finally, for future research, studies should prioritize the evaluation of landscape-level planting schemes such as sunflowers as perimeter buffers and longitudinal assessments of how alternative crops affect both elephant movement and household income resilience.

Sustainable HECx will require strategies that are not only ecologically functional but also economically compelling and culturally sensitive. Interventions must be co-developed with local communities to ensure they support both conservation goals and livelihood security, thereby bridging the gap between ecological theory and on-the-ground applicability.

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