
**ISSN Print:** 2664-844X
**ISSN Online:** 2664-8458
NAAS Rating (2026): 4.97
IJAFS 2026; 8(4): 544-549
www.agriculturaljournals.com
Received: 05-03-2026
Accepted: 09-04-2026

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# Farmers' perception of arboreal vertebrate pests in mixed home-garden agroforestry systems and adoption of non-lethal deterrent practices

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**DOI:** https://www.doi.org/10.33545/2664844X.2026.v8.i4g.1735

**Abstract**
Across the East African highlands, mixed home-garden agroforestry systems that combine fruit trees, timber species and annual crops within a single landholding face persistent pressure from arboreal vertebrate pests, yet the farmers who manage these gardens have seldom been asked what they actually see, lose and do about the problem. This research documented farmers' perceptions of arboreal vertebrate pest damage, estimated yield losses attributed to four pest guilds, and assessed the adoption and perceived effectiveness of non-lethal deterrent practices in Embu County, central Kenya. A cross-sectional survey was administered to 186 smallholder farmers managing home gardens of 0.2–1.5 hectares between August 2022 and July 2023. Four arboreal pest guilds were identified by respondents: primates (mainly vervet monkeys, *Chlorocebus pygerythrus*), tree squirrels (*Paraxerus ochraceus*), straw-coloured fruit bats (*Eidolon helvum*) and large frugivorous birds (hornbills, turacos). Primates were ranked the most damaging guild by 64.5% of farmers, followed by fruit bats (18.8%), squirrels (10.2%) and birds (6.5%). Self-reported annual crop loss averaged 23.7% of total fruit harvest value. Eight non-lethal deterrent methods were in use; guard dogs (72.3% perceived effective) and chilli-grease fencing (68.1%) ranked highest, while traditional scarecrows (35.6%) and drumming (22.4%) ranked lowest. Adoption of newer methods netting, noise devices, reflective tape increased from 2018 to 2023, coinciding with extension-service outreach. The results inform targeted pest-management advisory by identifying which deterrents farmers trust, which they have abandoned, and which gaps remain for wildlife-friendly crop protection in agroforestry landscapes.

**Keywords:** Arboreal vertebrate pests, home-garden agroforestry, non-lethal deterrents, human-wildlife conflict, crop damage, farmers' perception, vervet monkeys, fruit bats, pest management, Kenya

## Introduction

Long before formal agroforestry science coined its terminology, smallholder farmers across Kenya's central highlands were planting fruit trees among their annual crops, combining avocado, mango and macadamia with maize, beans and banana in dense home-garden mosaics [1]. These multistrata gardens deliver nutrition, income, shade and soil protection on holdings often smaller than one hectare, and their tree component provides habitat for a range of arboreal wildlife that may be welcome (pollinators, seed dispersers) or unwelcome (crop raiders) depending on the species involved [2]. Managing the tension between the ecological services provided by resident vertebrates and the crop losses they inflict is a daily reality for home-garden farmers, yet it has received far less research attention than the more dramatic cases of elephant or buffalo crop raiding that dominate the East African human-wildlife conflict literature [3].

Arboreal vertebrate pests primates, squirrels, fruit bats and large frugivorous birds operate differently from ground-level crop raiders. They arrive from above, target ripe or ripening fruits, and can strip a tree canopy in a single night visit (in the case of bats) or over several mornings (in the case of monkeys) [4]. Because the damage occurs in the canopy rather than at ground level, conventional fencing is ineffective, and farmers must rely on deterrent strategies that work in three dimensions [5]. A mix of traditional practices (scarecrows, drumming, smoke) and newer techniques (reflective tape, bird netting, chilli-grease rope fences) are reported anecdotally, but systematic data on adoption rates, perceived effectiveness and farmer satisfaction are scarce for Kenyan agroforestry systems [6].

Perception-based surveys fill a gap that trap-based or camera-based wildlife monitoring cannot: they capture the farmer's lived experience of pest pressure, including damage that goes unrecorded by instruments, seasonal peaks that coincide with household labour cycles, and qualitative judgements about which deterrent methods are worth the effort and cost [7]. Earlier perception research in Uganda and Tanzania found that farmers ranked primates as the top pest guild by a wide margin but often overestimated absolute yield loss compared with measured values [8]. Whether the same pattern holds in Kenya's denser, more diversified home gardens where tree species richness may buffer or concentrate pest visits has not been tested.

Extension services in Embu County have promoted non-lethal deterrents since about 2019, partly in response to wildlife protection regulations that restrict lethal control of primates and bats [9]. Documenting whether these promoted methods are actually being adopted, and whether farmers trust them, is needed to evaluate extension impact and to redirect advisory effort toward the most effective and locally appropriate tools [10]. This research was therefore designed around three questions: (i) which arboreal vertebrate pest guilds do home-garden farmers perceive as most damaging, and how does perceived damage vary across the year? (ii) what non-lethal deterrent practices are currently in use, and how has adoption changed between 2018 and 2023? and (iii) which deterrent methods do farmers consider effective, partially effective or ineffective? Mukherjee and Mhangore [11] emphasised the value of documenting wildlife interactions in landscapes where data remain thin, and the same principle motivates this work in Kenyan home gardens.

## Material and Methods

### Research Area

The research was conducted in Embu County, situated on the south-eastern slopes of Mount Kenya in central Kenya (0°32′ S, 37°27′ E). The county spans an altitudinal gradient from about 500 m in the semi-arid lowlands to over 4,500 m on the mountain flanks. Survey sites were concentrated in the mid-altitude zone (1,200–1,600 m a.s.l.), where smallholder home-garden agroforestry is the dominant land-use type. This zone receives bimodal rainfall (long rains March–May, short rains October–December) totalling 1,200–1,500 mm annually, with mean temperatures of 19–22 °C. Soils are predominantly humic Nitisols of volcanic origin, supporting a diverse cropping system that typically includes banana, avocado, mango, macadamia, maize, beans and Grevillea robusta timber trees. Remnant gallery forest along stream corridors and small woodlots act as refugia for vervet monkeys, fruit bats and other arboreal vertebrates that move into adjacent gardens to feed.

### Material

Respondents were drawn from six sub-locations within three wards (Runyenjes, Manyatta, Nthawa) using a multi-stage sampling procedure. At the first stage, the three wards were selected purposively to capture the mid-altitude home-garden belt. At the second stage, two sub-locations per ward were selected randomly. At the third stage, 31 farmers per sub-location were selected using systematic random sampling from sub-location household registers. Inclusion criteria were: (a) the household managed a mixed home garden containing at least three fruit tree species, (b) the garden was between 0.2 and 1.5 hectares, and (c) the respondent was the principal farm decision-maker or their spouse. A pre-tested structured questionnaire was administered face-to-face in Kiembu or Kiswahili by trained enumerators.

### Survey Design and Data Collection

The questionnaire comprised four sections. Section A captured household demographics (age, gender, education, household size, farm size, years of farming experience). Section B asked respondents to identify, from a photo-aided species card, which arboreal vertebrate pest groups had raided their home garden in the past 12 months, rank them by perceived damage severity, and estimate the proportion of total fruit harvest lost to each guild (using a visual proportional piling exercise with 20 counters). Section C listed eight non-lethal deterrent methods scarecrows, noise devices (tin-can shakers, firecrackers), reflective tape, bird netting, chilli-grease rope fencing, guard dogs, smoke/fire, and drumming and asked for each whether the farmer had used it in any year from 2018 to 2023, and whether they considered it effective, partially effective or ineffective. Section D was an open-ended section inviting suggestions for improved pest management. Enumerators recorded monthly damage reports by asking farmers to recall which months in the preceding year they had experienced the heaviest raiding. The questionnaire was piloted with 15 farmers in a neighbouring sub-location not included in the main sample; minor wording revisions were made following the pilot.

### Methods

Perceived damage rankings were compared across pest guilds using the Friedman test, with Dunn-Bonferroni post-hoc comparisons. Association between deterrent adoption and farmer demographic variables was tested using binary logistic regression (adopted/not adopted as the dependent variable; age, education, farm size, livestock ownership and extension contact as predictors). Trends in deterrent adoption over the six-year recall period (2018–2023) were visualised and tested for linear trend using the Cochran-Armitage test. Perceived effectiveness ratings were summarised as proportions and compared across methods using the chi-squared test for independence. A significance threshold of $\alpha = 0.05$ was applied throughout. Ethical clearance was granted by the National Commission for Science, Technology and Innovation (NACOSTI/P/22/18947, issued 12 July 2022), and written informed consent was obtained from each respondent.

## Results

Of the 186 surveyed farmers, 178 (95.7%) reported experiencing arboreal vertebrate pest damage in their home gardens within the preceding 12 months. The remaining eight households attributed zero damage to arboreal pests, citing either very small gardens with no mature fruit trees (n = 5) or continuous guarding by household members (n = 3). Respondents identified four pest guilds. Primates predominantly vervet monkeys (*Chlorocebus pygerythrus*), with occasional mentions of Sykes' monkeys (Cercopithecus mitis) were ranked as the most damaging guild by 64.5% of respondents. Fruit bats (mainly *Eidolon helvum*) were ranked first by 18.8%, tree squirrels (*Paraxerus ochraceus*) by 10.2%, and large frugivorous birds (silvery-cheeked hornbills, Hartlaub's turacos) by 6.5%. The Friedman test confirmed a significant difference in perceived damage ranks among guilds ($\chi^2 = 187.4$, df = 3, $p<0.001$).

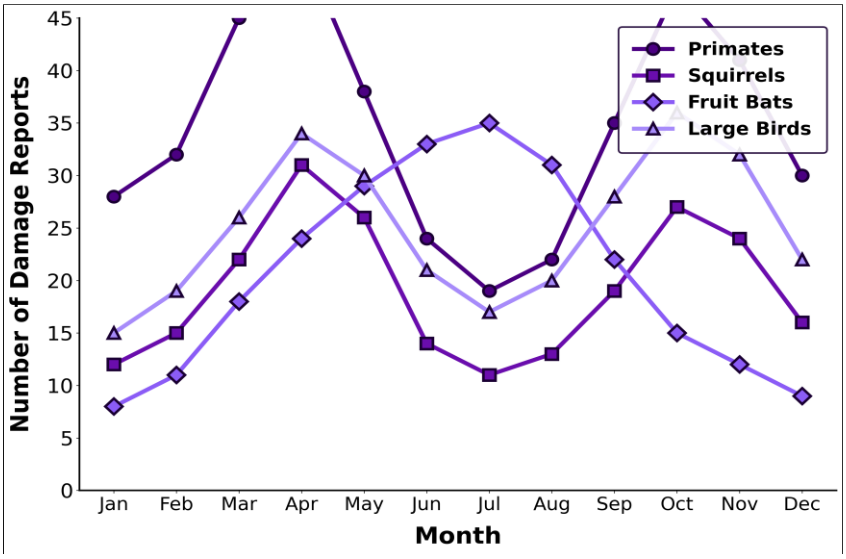


**Fig 1:** Monthly distribution of crop damage reports attributed to four arboreal vertebrate pest guilds in home-garden agroforestry systems, Embu County, Kenya (n = 178 respondents, August 2022 – July 2023)

**Table 1:** Perceived damage severity and estimated annual fruit harvest loss attributed to four arboreal vertebrate pest guilds by home-garden farmers in Embu County, Kenya (n = 178)

| Pest Guild | Ranked 1st (%) | Mean Rank ± SD | Est. Harvest Loss (%) | Peak Month(s) | Main Crop Targeted |
|---|---|---|---|---|---|
| Primates | 64.5 | 1.4 ± 0.7 | 12.8 ± 4.6 | Mar–May | Mango, Avocado |
| Fruit Bats | 18.8 | 2.3 ± 0.9 | 5.4 ± 3.1 | Jun–Aug | Mango, Macadamia |
| Tree Squirrels | 10.2 | 2.8 ± 0.8 | 3.1 ± 2.2 | Apr–May, Oct | Macadamia, Banana |
| Large Birds | 6.5 | 3.5 ± 0.6 | 2.4 ± 1.8 | Oct–Dec | Avocado, Papaya |
| All guilds combined | — | — | 23.7 ± 7.9 | Mar–May | — |

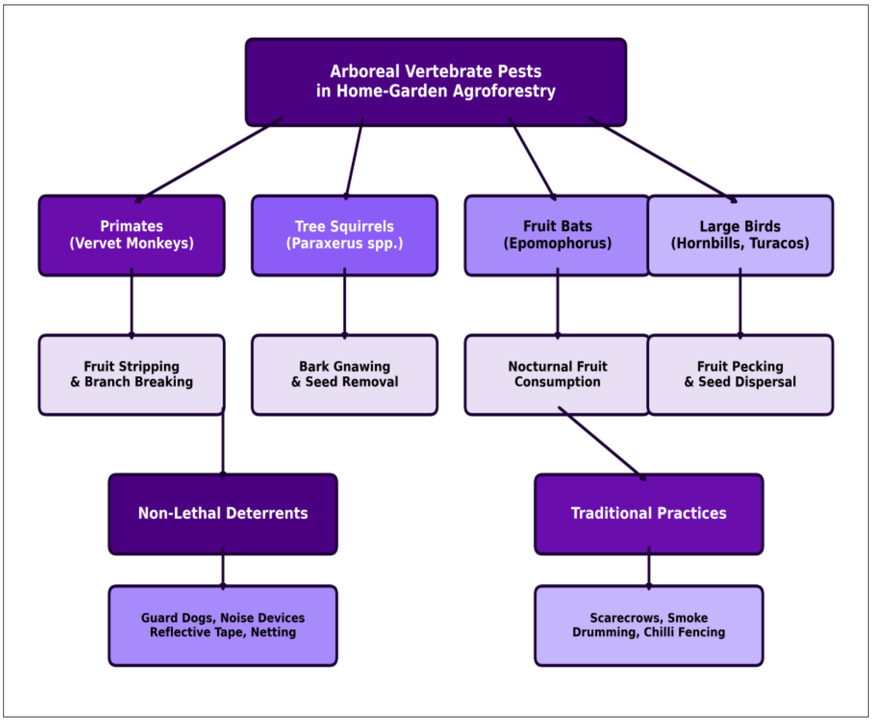


**Fig 2:** Schematic illustration of the four arboreal vertebrate pest guilds, their characteristic damage types and the two broad categories of non-lethal deterrent strategies reported by home-garden farmers in Embu County, Kenya

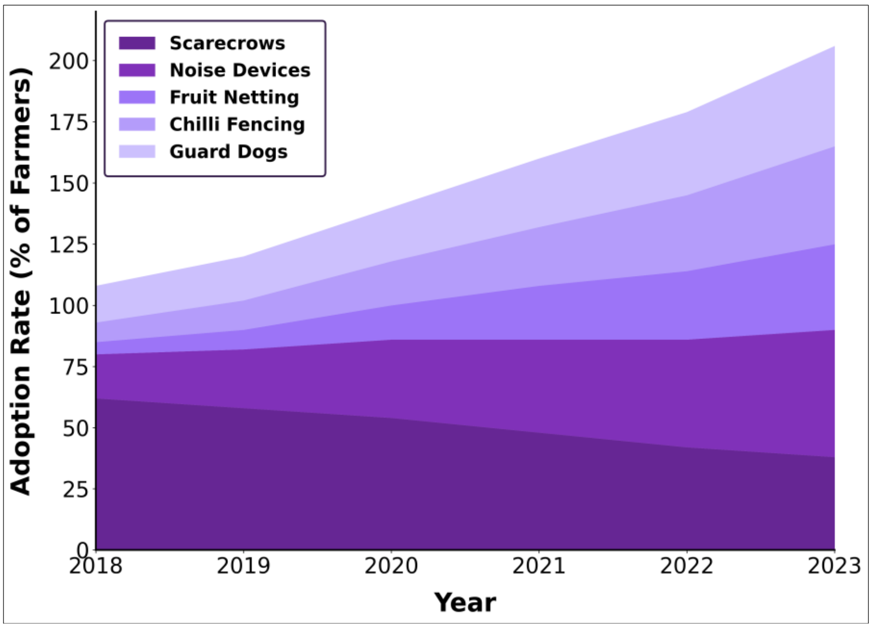


**Fig 3:** Stacked area chart showing temporal trends in adoption of five non-lethal deterrent methods by home-garden farmers in Embu County, Kenya, 2018–2023 (n = 178)

**Table 2:** Binary logistic regression results showing predictors of adoption of at least one modern non-lethal deterrent method (noise devices, netting, reflective tape or chilli fencing) among home-garden farmers, Embu County, Kenya (n = 178)

| Predictor | B | SE | Wald | OR (95% CI) | p-value |
|---|---|---|---|---|---|
| Age (years) | −0.034 | 0.018 | 3.57 | 0.97 (0.93–1.00) | 0.059 |
| Education (years) | 0.187 | 0.062 | 9.11 | 1.21 (1.07–1.36) | 0.003 |
| Farm size (ha) | 0.824 | 0.391 | 4.44 | 2.28 (1.06–4.91) | 0.035 |
| Livestock ownership | 0.412 | 0.318 | 1.68 | 1.51 (0.81–2.81) | 0.195 |
| Extension contact (past 2 yr) | 1.246 | 0.347 | 12.89 | 3.48 (1.76–6.86) | <0.001 |
| Constant | −2.318 | 1.124 | 4.25 | — | 0.039 |

Model $\chi^2$ = 38.7, df = 5, $p$<0.001; Nagelkerke $R^2$ = 0.29. OR = odds ratio; CI = confidence interval.

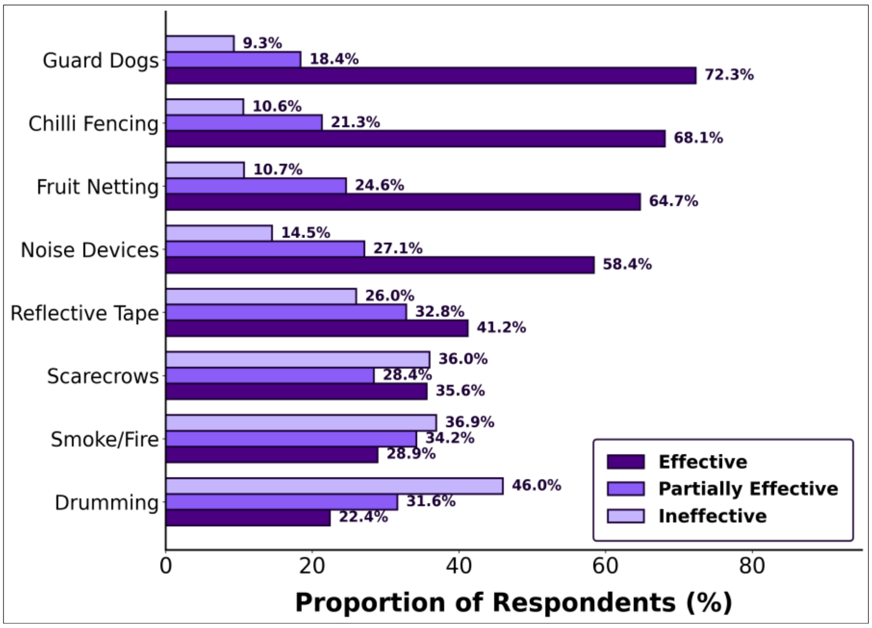


**Fig 4:** Perceived effectiveness of eight non-lethal deterrent methods as rated by home-garden farmers in Embu County, Kenya (n = 178), grouped into effective, partially effective and ineffective categories

The results reveal a pest-management landscape in transition. Traditional deterrents that cost nothing (scarecrows, drumming) are still widespread but are increasingly viewed as ineffective, particularly against primates. Newer methods that require modest investment netting, chilli fencing, noise devices are gaining adoption, and the logistic regression confirms that extension contact is the single strongest predictor of uptake (OR = 3.48, $p$<0.001). Education and farm size also reached significance, implying that resource-constrained and less-educated farmers may face adoption barriers that extension programmes need to address specifically. The combined self-reported harvest loss of 23.7% is economically meaningful on holdings that average less than one hectare and depend on fruit sales for 30–45% of cash income.

**Limitations**

Several constraints should be noted when interpreting these results. First, pest damage estimates were self-reported and relied on farmer recall over a 12-month window; recall bias may inflate or deflate actual losses. Second, the proportional-piling exercise used to estimate guild-level harvest loss, while intuitive and participatory, yields ordinal rather than ratio-scale data and cannot be compared directly with instrumental crop-loss measurements. Third, the six-year recall of deterrent adoption (2018–2023) is subject to telescoping bias, where events from earlier years may be remembered as more recent. Fourth, the research was confined to the mid-altitude zone of Embu County, and findings may not transfer to the drier lowland or cooler highland zones where fruit tree diversity and pest assemblage composition differ. Finally, the cross-sectional design precludes causal inference about the relationship between extension contact and deterrent adoption; a longitudinal or quasi-experimental design would be needed to establish causality.

## Discussion

Four arboreal vertebrate pest guilds were identified, with primates dominating perceived damage, a combined estimated harvest loss of 23.7%, and a clear shift from traditional toward modern non-lethal deterrents driven primarily by extension-service contact. Guard dogs and chilli fencing were rated most effective, while scarecrows and drumming were considered least effective.

The primacy of primates as the top-ranked pest guild aligns with findings from comparable smallholder landscapes in Uganda, Tanzania and Ethiopia. Naughton-Treves *et al.* (2011) documented vervet monkeys as the leading crop raider in Ugandan garden mosaics adjacent to forest reserves, and Hill (2015) reported similar rankings in western Tanzania [12, 13]. The seasonal damage peak during the long rains (March–May), when mango and avocado ripen simultaneously, matches the phenological overlap between fruit availability and primate ranging behaviour reported from Kenyan highland forests [14].

Where the present findings diverge from prior work is in the relatively high effectiveness rating for chilli-grease fencing (68.1%), which has received mixed evaluations elsewhere. In Mozambique, chilli-based deterrents against elephants showed strong initial efficacy that waned after two to three seasons as animals habituated [15]. However, the target taxon here monkeys appears more sensitive to capsaicin irritation than large pachyderms, and the home-garden scale (under 1.5 ha) means that perimeter lengths are manageable and fences can be maintained with modest labour. The finding that guard dogs were rated highest (72.3%) is consistent with South African research showing that free-ranging dogs significantly reduce baboon crop-raiding frequency near Cape Town [16], and it suggests that integrating dogs into primate management in Kenyan home gardens deserves more formal evaluation.

The logistic regression results carry practical implications for extension planning. Extension contact emerged as the strongest predictor of modern deterrent adoption (OR = 3.48), stronger than education or farm size. This is encouraging because it implies that the extension system is actually influencing behaviour, not merely reaching already-predisposed farmers [17]. At the same time, the non-significant effect of livestock ownership and the marginal effect of age suggest that adoption barriers are more informational than structural a finding that supports expanding outreach coverage rather than subsidising equipment [18].

From a conservation standpoint, the farmer preference for non-lethal methods is encouraging. Kenya's Wildlife Conservation and Management Act (2013) prohibits the killing of most wild primates and bats without a Kenya Wildlife Service permit, but enforcement in rural areas is weak. That most surveyed farmers were already using non-lethal deterrents even before knowing the legal framework in detail suggests a pragmatic rather than purely regulatory motivation: deterrents that work are cheaper and less socially contentious than lethal control [19]. Supporting this pragmatic alignment with conservation goals through subsidised netting and community guard-dog programmes could be a cost-effective strategy for reducing both crop loss and retaliatory wildlife killing in agroforestry landscapes [20].

## Conclusion

This research set out to document farmers' perceptions of arboreal vertebrate pest damage, measure deterrent adoption trends and evaluate perceived effectiveness across eight non-lethal methods in mixed home-garden agroforestry systems of central Kenya. Primates chiefly vervet monkeys were perceived as the most damaging guild, responsible for roughly half of the combined 23.7% estimated annual fruit harvest loss. Guard dogs and chilli-grease fencing were the deterrents farmers trusted most, while scarecrows and drumming were widely seen as ineffective. Modern deterrent adoption climbed steadily between 2018 and 2023, with extension-service contact serving as the strongest predictor of uptake. For agricultural advisory services, the practical message is clear: concentrate outreach on demonstrating guard-dog integration and chilli fencing rather than promoting traditional methods that farmers themselves have already judged inadequate. Future research should measure actual yield losses alongside farmer perceptions to calibrate the magnitude of self-reported estimates, trial community-level deterrent sharing schemes to lower per-household costs, and extend the geographic scope beyond the mid-altitude zone to capture variation across Kenya's diverse agroforestry landscapes.

**Acknowledgements**

The authors express their appreciation to the concerned authorities for the institutional support rendered during this research.

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