

Bio-fencing as Promising Solution for Human-Elephant Conflict (HEC): Responses of Elephants and Underlying Leaf Chemistry of *Polyalthia longifolia*

A.A.L.C Perera

University of Sri Jayewardenepura

K.M.R.D Abhayapala (✉ ruvinidil@sjp.ac.lk)

University of Sri Jayewardenepura

N. Dharmarathne

R.N. Nugara

University of Sri Jayewardenepura

U. Kumarasinghe

University of Sri Jayewardenepura

Research Article

Keywords: Bio-fencing, human-elephant conflict, organic volatile compounds, palatability responses, *Polyalthia longifolia*, proximate analysis

Posted Date: May 17th, 2023

DOI: <https://doi.org/10.21203/rs.3.rs-2926225/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

1 **Bio-fencing as Promising Solution for Human-Elephant Conflict (HEC): Responses of Elephants and Underlying**
2 **Leaf Chemistry of *Polyalthia longifolia***

3 **Abstract**

4 Bio-fencing could be used as an effective tool for human-elephant conflict mitigation, yet the plant species currently used
5 need to be more viable. *Polyalthia longifolia* is reported to be having antifeedant properties against herbivores and is
6 repellent to them. Accordingly, two cases were studied to evaluate the antifeedant and repellency nature of the plant by
7 offering *P. longifolia*; (1) to wild elephants in 03 locations in Mahaweli System D, Sri Lanka and (2) to tamed elephants
8 of 03 age groups. The preference of tamed elephants were further evaluated giving leafy materials; coconut, fishtail palm,
9 grass mixture, and *P. longifolia* simultaneously. As a necessary consequence, this study was intended to (3) assess the
10 relative levels of moisture, ash, crude fat, crude fiber, crude protein and (4) organic volatile compounds responsible for the
11 odor of offered plant materials using a PEN3 electronic nose, and to (5) determine the relationship between leaf proximate
12 parameters with palatability responses and (6) organic volatile compounds. Results showed that the wild elephants prevent
13 their movement through their routes by placing bunches of *P. longifolia* leaf branches. Tamed elephants showed abnormal
14 responses against *P. longifolia* particularly movements of their body compared to the rest of feeding materials implying
15 that the leaves of *P. longifolia* are antifeedant and repellant to them, suggesting the greater potential as an effective bio-
16 fence against elephants. However, estimated differences in leaf proximate parameters and relative levels of organic volatile
17 compounds did not reveal the witnessed contrasting repellency of *P. longifolia*.

18 **Keywords:** Bio-fencing, human-elephant conflict, organic volatile compounds, palatability responses, *Polyalthia*
19 *longifolia*, proximate analysis

1. Introduction

Elephant habitat is being steadily declined as human population density rises and land-use patterns change and therefore induce conflicts with humans widely known as Human-Elephant Conflict (HEC). They are the heaviest existing land mammal and have attracted humans around the globe for millions of years (Riddle et al. 2010). They are extensively scattered in different parts of the world and possess a broad range of activities (Campos-Arceiz and Blake 2011), and have become an umbrella species due to their popularity by guaranteeing their conservation, while people indirectly safeguard other species living in the enormous ecosystems they inhabit (Hankinson and Nijman 2020). They may be found in 50 nations worldwide, including 13 countries in Asia (*Elephas maximus*) and 37 countries in Africa (*Loxodonta africana*) (Perera 2009). An extensive loss of elephant habitat was noticed across Asia and Africa since human settlements and agricultural fields have proliferated. This resulted in extensive, deteriorated fodder, diminished landscape connectivity, and a considerable drop in elephant populations compared to their historical size and overall range (Calabrese et al. 2017). As humans transform the landscape, pushing human and elephant populations to live in ever closer proximity, the likelihood of conflict increases with often fatal results. Since HEC is integrally associated to agriculture, elevated HEC occurrences are predicted during cultivation months. Thus, crop raiding on agricultural fields to satisfy food requirements is the most prevalent form of HEC in many regions of the world (Williams et al. 2001; Graham et al. 2010; Goswami et al. 2015; Liu et al. 2016). Consequently, it is anticipated to intensify the HEC in the next years due to the degree of habitat degradation in the few surviving refugees and elevated levels of conflict with humans (Sukumar 2003). The introduction of elephants onto human settlements and agricultural fields has had a significant impact on human fatalities, elephant deaths, and human injuries, bringing Sri Lanka to the forefront of HEC nations globally.

Elephant habitat offers a wide range of food such as grass, bark, wood, roots, and fruits (White et al. 1993). Being mega-herbivores, with a daily food requirement of about 10% of their body weight (Sukumar 1992), they have to find a large quantity of food, which means they cannot be specialized feeders selecting a narrow range of plants or the choicest plant parts. They have evolved to be generalist herbivores consuming a wide variety of vegetation over a hundred species (Vancuylenberg 1977; Sukumar 1990), and diverse plant components depending on the location, weather, and ecology where it lives (Dierenfeld 2006; Santosa and Thohari 2011). Furthermore, they are considered non-ruminants and have evolved a gastrointestinal tract that ingests a vast range of food than other herbivores. They enjoy a high dietary rate to satisfy their energy demands depending on their body size, age, and sex. They favor grasses as they grow abundantly, are easy to extract, and contain small amounts of secondary chemicals. However, grasses are only accessible seasonally in most Asian elephant habitats. Elephants consume shade-tolerant plant species as well, but only in modest numbers due to the problems that may encounter by secondary metabolite intake. The feeding preferences of wild elephants are diverse;

thus, they appear to consume the majority of the crops cultivated by farming communities. Although a plant is consumed frequently or in large quantities, it does not necessarily entail that elephants favor that plant. The availability of food influences food selection. It is also reported that elephants are quite selective in what they eat (Blake 2002 [Unpublished manuscript]), depending on the vegetation types (Tchamba 1996 [Unpublished manuscript]), their preference and palatability. It is also unknown whether elephants prefer damaged plants (Berliani et al. 2018). However, crops raided by elephants in HEC zones have yet to be identified.

Asian elephants (*Elephas maximus*) are one of the few endangered species (Prakash et al. 2020), and they can be further divided into three subspecies; *Elephas maximus maximus* from Sri Lanka, *Elephas maximus indicus* from mainland Asia, and *Elephas maximus sumatranus* from Sumatra (Shoshani 2005). The Asian elephant has currently been observed in only 13 nations, under extremely confined habitats, with population estimates ranging from 25,000 to 45,000 individuals (Blake and Hedges 2004), and poses a substantial level of conflict with humanity (Fernando 2015). Interestingly, Sri Lanka has the largest elephant density among their range countries (Leimgruber et al. 2003), and has the third highest human population density among the 13 Asian elephant range nations (Fernando and Pastorini 2011), which has become a severe conservation, socioeconomic, and political setback. Moreover, locals continue living in 69.4% of the elephant range in Sri Lanka (Fernando et al. 2021). Currently, they thrive in dry, evergreen and thorn-shrub forests in Sri Lanka, being mostly extirpated from wet zone rainforests by land-use changes during the previous century (Jayewardene 1994). The conflict between humans and elephants in Sri Lanka is not a recent event. It has been happening since man began agriculture in elephant-residing regions (Santiapillai et al. 2010). Thus, the issue is rather old, and it has become more severe in recent years with a significant threat to their conservation in Sri Lanka and across their range (Prakash et al. 2020).

In Sri Lanka, key efforts for HEC mitigation and elephant conservation include capturing and transporting elephants for relocation, encouraging elephant drives, distributing elephant thunder crackers, erecting electric fences, and enforcing laws, and HEC mitigation is almost entirely concerned with reducing the prevalence of elephant damage on humans (Fernando 2015). In addition, a number of traditional techniques are involved, such as noise, fire, shouting, elephant thunders, bamboo blasters, guarding the field, alarm system, bells, physical barriers such as trenches, covered trenches, sharp stones, vegetative barriers consisting of unpalatable crops, and buffer zones, to lessen the HEC. Though many methods were attempted to avoid crop destruction, the most of them were only momentary in nature, whereas elephants were only driven away for a limited period of time and were anticipated to return once the situation had relaxed a bit. Elephants are usually prevented from invading farms and human settlements employing physical exclusion means such as electric fences and trenches. Extensive construction and long-term upkeep costs make larger-scale implementation of these physical barriers difficult, particularly in shattered landscapes with high forest/farm exposure. Also, on many occasions,

the electric cables are fastened to concrete or wooden poles, and they are reliably wrecked by wild elephants. Electric fences are only effective if they are properly engineered to appropriate specifications and are frequently maintained. Most electric fences do not fulfill one or more of the criteria above and, as a consequence, have limited life spans ranging from a few months to a year. However, the effectiveness and sustainability of these mitigation approaches are yet to be explored. In advance, several studies have been conducted to identify crop damage issues, but relatively a few studies have been conducted to support the means and efficacy of currently used wildlife damage control practices (Sitati et al. 2005). As a result, an innovative and sustainable solution, such as bio-fencing, should be implemented to achieve long-term ecological, social and economic benefits.

Bio-fencing is one of the most sustainable approaches, which restricts crop raiding by wildlife while providing ecological benefits and even economic benefits. Some of these plants are grown as a permanent living fence or bio-fence around the field in remote areas, while others are cut and mounted as a temporary barrier to help minimize soil erosion and function as a wind break. Both homogeneous (01 plant species) and heterogeneous (02 or 03 plant species) fencing can be observed, but heterogeneous fences are the most common due to a scarcity of a single species that can be used as a barrier; the locals choose to use heterogeneous fencing. Plants with spines, thorns, or excessive branching are commonly used for bio-fencing (Bhattarai et al. 2007). The choice of plants could vary depending on the site conditions and availability. A variety of thorny plant species, including sisal, cactus, and bougainvillea, have been tested as biological fences. However, it is generally arduous to develop such barriers to the required length and width, with no gaps to prevent elephants from seeking to move across. However, elephants have been spotted comfortably passing these buffer crops on route to their favorite food crop, rendering them ineffectual (Bell 1894), and in some cases, elephants have been observed to be feeding on sisal (Hoare 1992), which was reported as an effective bio-fence. In Sri Lanka, a number of bio-fences have been tested, however none have consistently proven effective. This is not to claim that the concept is without worth; rather, it does not appear to function in isolation. For a number of reasons, elephants avoid specific plants. Some have offensive odors or enormous thorns, whereas others might be unpleasant to them.

Polyalthia longifolia cv. pendula is native to India's arid parts of the country and is widely planted in India, Pakistan, and Sri Lanka (Katkar et al. 2010) and belongs to the Annonaceae family (Lavanya et al. 2018). A tall, evergreen, pyramid-like, columnar tree with a straight, undivided main stem that can grow to a height of 12 m or more and is often employed as an avenue plant. It has weeping pendulous willowy branches and long thin leaves. Alternate, exstipulate leaves 7.5-23 by 1.5-3.8 cm, shiny, distichous, moderately aromatic glabrous, narrowly lanceolate, with a fine acuminate tip apex, undulate border, pinnate veining, leathery or sub-coriaceous, petiolate around 6 mm long (Katkar et al. 2010). Ripe fruits are ovoid, 1.8-2 cm long, many, stalked, glabrous, and have one seed; the stalk is 1.3 cm long, slender, and glabrous. Seeds

are smooth and gleaming. From February through June, the plant blooms and bears fruits (Yadav and Sardesai 2002). *P. longifolia* has been used in traditional medicine to treat fevers, skin disorders, diabetes, hypertension, and helminthiasis (Kirtikar and Basu 1995; Jothy et al. 2013) due to its antibacterial, antifungal, antitumor, anti-ulcer and antioxidant properties (Jothy et al. 2013). It was reported that *P. longifolia* primarily contains diterpenoids (Phadnis et al. 1988), alkaloids, tannins, and mucilages. The plant's primary chemical constituents are, O-methylbulbocapnine-N-oxide (Katkar et al. 2010), polyfothine (Bhagwati 2003), N-methylnandigerine-N-oxide (Harsha et al. 2002), oliveroline-N-oxide (Patwardhan et al. 2004), pendulamine A (Dahanukar et al. 2000), N-pendulamine B (Ashish 2003), 8-oxopolyalthiane (Sastri 1969), 16-oxo-5 (Faizi et al. 2008), 13-halimadien-15-oic acid (Rastogi and Mehrotra 1960), 16-Oxo-3, 13-clerodadien-15-oic acid (Raghunathan and Mitra 1982), 16-hydroxycleroda-3, 13-dien-16, 15-olide (Faizi et al. 2008). Excitingly, two clerodane-type diterpenoids, with antifeedant properties were isolated from *P. longifolia* and identified as 16 α -hydroxy-cleroda-3, 13(14) Z-dien-15,16-olide and 16-oxo-cleroda-3, 13 (14) E-dien-15-oic acid, on the basis of their spectral properties (Katkar et al. 2010). In fact these two chemical constituents can be found on leaves of the plant (Phadnis et al. 1988; Sashidara et al. 2010).

The plant trunk is covered by weeping pendulous branches, which elephants avoid approaching because the brushing of droopy branches causes irritation on their skin. Based on preliminary observations in Mahaweli System B, Sri Lanka, we hypothesized that elephants do not prefer to ingest the leaves of this plant and tend to avoid them. Due to its favorable morphological characteristics to grow as a bio-fence and repellency nature, this plant could be used as an effective bio-fence against wild elephants to mitigate HEC in Sri Lanka. With the intention of that this study was developed to (1) evaluate the palatability responses of *P. longifolia* against wild elephants, and to (2) evaluate the palatability and behavioral responses of *P. longifolia* and regular elephant feeding materials; coconut, fishtail palm, and a mixture of grasses against tamed elephants in order to verify that *P. longifolia* has a repellency nature to elephants that can be used as an effective bio-fence to mitigate HEC. In addition, *P. longifolia* and selected elephant feeding materials were further explored to (3) estimate relative levels (% by mass) of moisture, ash, crude fat, crude fiber, and crude protein, to (4) find out relative levels of chemical compounds responsible for odor of offered plant materials, to (5) find out the association between leaf proximate parameters and palatability/ behavioral responses of tamed elephants to *P. longifolia* and other elephant feeding materials, and to (6) find out the association between chemical compounds responsible for odor of offered plant materials and palatability/ behavioral responses of *P. longifolia* and other elephant feeding materials.

Instead, specific characteristics of this plant, such as greater stem strength and tendency, were focused on strengthening the electric fences currently being used in Sri Lanka to mitigate HEC. A strong live stem part of *P. longifolia* was introduced to the current electric fence as a preventative measure, since wooden or concrete poles in electric fences

140 are frequently damaged by wild elephants, Therefore, the combined effect of inherent repellency by leaf chemistry and the
141 ability to integrate into the existing electric fence could be a sustainable long-term mitigation tool against HEC in Sri
142 Lanka.

143 2. Materials and methods

144 2.1. Study sites selection and data collection

145 2.1.1 Experiment 01 - Elephant palatability and behavioral responses

146 Palatability responses of wild elephants were evaluated in Nebadawewa village managed under Bisopura Division,

147 administrated by the Mahaweli System D, Dhahamwewa, and Rotawewa dumpsite, Sri Lanka.



148 **Fig. 01** Location of the study site (a, b) in Nebadawewa managed under Bisopura Division, administrated by the Mahaweli

149 System D, Sri Lanka located 40 km away from Polonnaruwa city, North Eastern Province ($8^{\circ}15'13''N$, $80^{\circ}58'40''E$)

150 (Source: Google Earth Version 9.175.0.1)



151 **Fig. 02** Location of the study site (a, b) in Dhahamwewa, located 45 km away from Polonnaruwa city, North Eastern

152 Province ($8^{\circ}13'59''N$, $81^{\circ}01'00''E$) (Source: Google Earth Version 9.175.0.1)



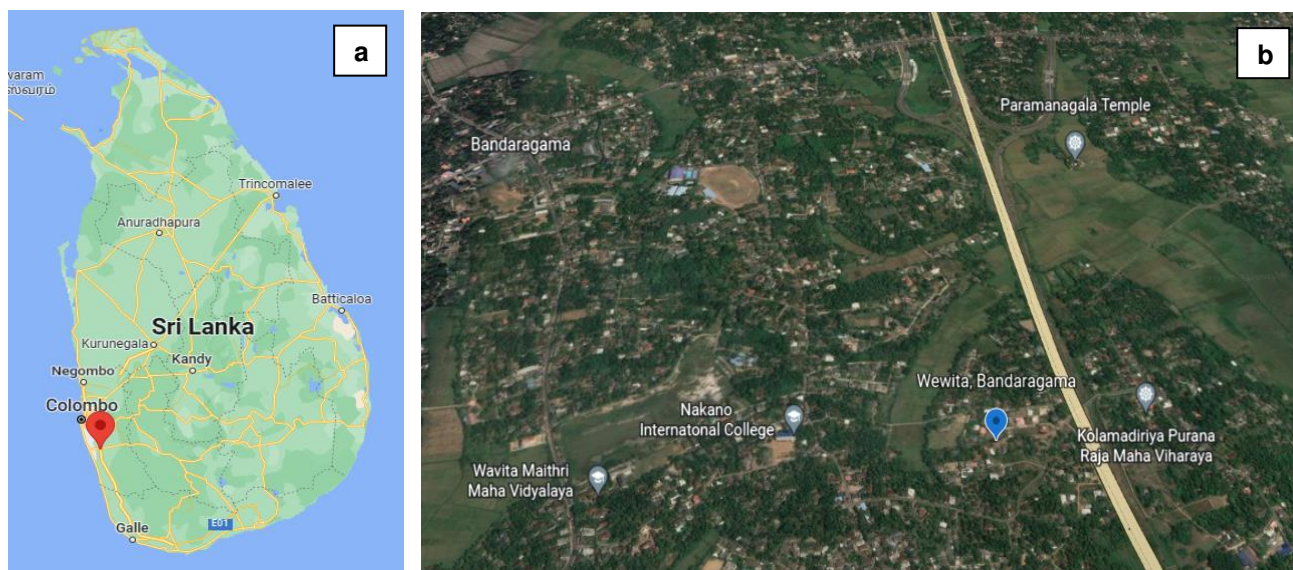
153 **Fig. 03** Location of the study site (a, b) in Rotawewa dumpsite, located 28 km away from Polonnaruwa city, North Eastern
 154 Province ($8^{\circ}05'12''\text{N}$, $80^{\circ}53'17''\text{E}$) (Source: Google Earth Version 9.175.0.1)

155 These 03 sites were selected for this study due to the greater abundance of elephants and the possibility of making
 156 safe observations. Bunches of *P. longifolia* leaf branches were placed across well-recognized elephant migratory routes.
 157 Elephant palatability responses were observed from late afternoon to midnight to test whether those leaf branches were
 158 ingested by the wild elephants. Data were collected for a period of 13 consecutive days followed by 02-months interval.
 159 This procedure was repeated 03 times, and the total duration of data collection was 06 months.



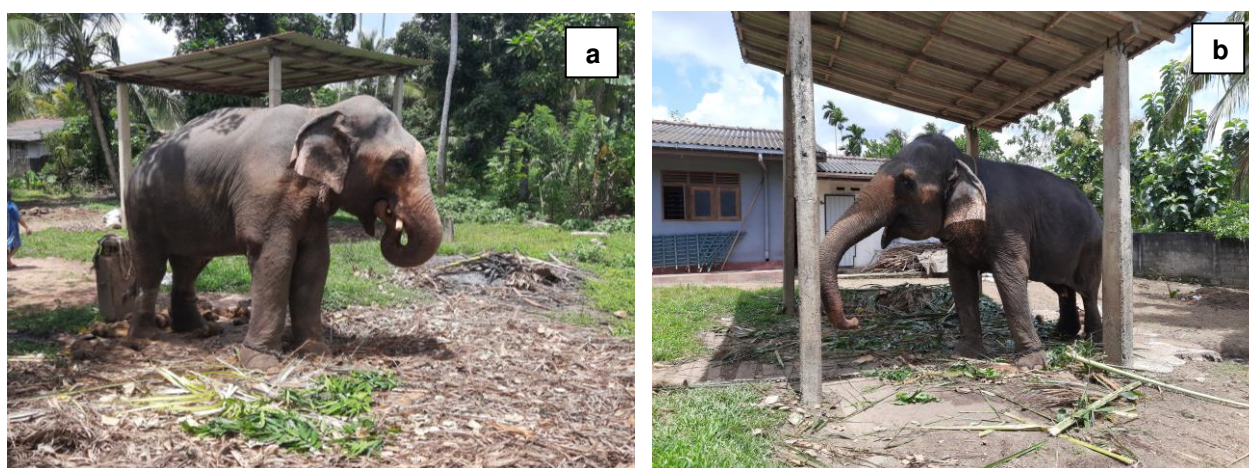
160 **Fig. 04** Well-recognized elephant drives at Nebadawewa (a), and Dhahamwewa (b); arrows showing the usual direction
 161 of elephant movement through elephant drives

162 Correspondingly, the palatability responses of tamed elephants were evaluated by using 03 tamed elephants of three
 163 distinct ages; ~12 years (male calf), ~25 years (mature male), and ~45 years (aged female) owned by an elephant keeper in
 164 Wewita, Bandaragama, Sri Lanka.



165 **Fig. 05** Location of the study site (a, b) in Wewita, located 1.7 km away from Bandaragama city, Western Province
 166 ($6^{\circ}42'18''N$, $79^{\circ}59'58''E$) (Source: Google Earth Version 9.175.0.1)

167 Subsequently, branches of *P. longifolia* and other feeding materials usually ingested by elephants, fishtail palm
 168 (*Caryota urens*), coconut fronds (*Cocos nucifera*), and a local grass mixture were offered. Each material was offered 03
 169 times per elephant per day for a period of 07 days at 01-day intervals. Accordingly, a total of 63 attempts were performed
 170 for a period of 01 month, and the responses of each elephant against *P. longifolia* leaves and other plant materials were
 171 evaluated. This procedure was replicated for 03 times at 02 months interval. Accordingly, the total duration of data
 172 collection was 07 months. Together, their body movements; trunk, head, body, legs, and tail were logged for all offered
 173 events. A particular observation was taken for 10 minutes after offering leaf materials.



174 **Fig. 06** *P. longifolia* leaf branches offered to a mature male elephant (a) and an aged female elephant (b)

175 2.1.2. Experiment 02 - Analysis of leaf proximate parameters and organic volatile compounds

176 For the leaf proximate analysis, leaf samples; *P. longifolia* and other elephant feeding materials; coconut, fishtail palm, and
 177 a mixture of grasses were collected from the site where the experiment on palatability responses of tamed elephants was

done in Wewita, Bandaragama, Sri Lanka. Leaf samples were carefully selected excluding damaged or deformed leaves and other residues and debris. Approximately, 700 g from each leaf material were packed in zip-lock covers by inserting wet tissues to reduce possible moisture losses until they were analyzed. Leaf samples were analyzed using standard analytical procedures (AOAC 17th Edition); moisture (AOAC 930.04), ash (AOAC 930.05), crude fat (AOAC 930.09), crude fiber (AOAC 930.10), and crude protein (N×6.25) (AOAC 930.04). A number of 03 replicates were done per each leaf proximate parameter.

Relative levels of organic volatile compounds were evaluated for leaf samples of 04 different species using a PEN3 Electronic Nose (Airsense Analytics GmbH, Schwerin, Germany). Technical specifications and the description of sensors used in PEN3 e-nose provided by Airsense Analytical are listed in table 01 and 02 respectively.

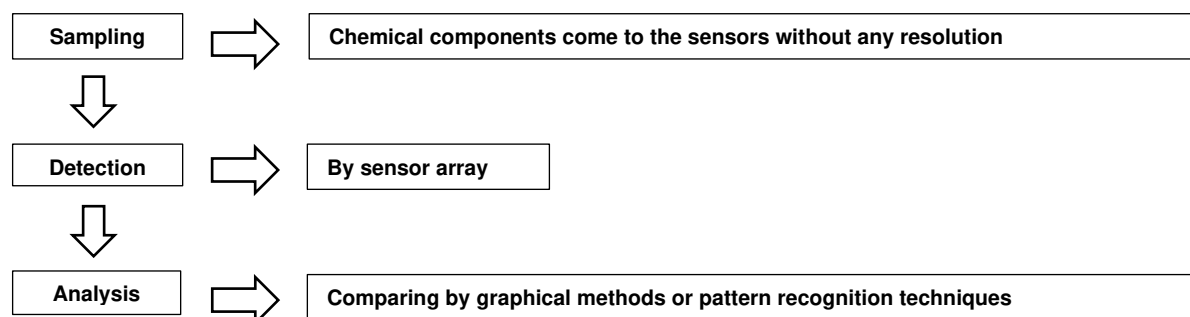
Table 01 Technical specifications of PEN3 e-nose provided by Airsense Analytical (Airsense Analytics handbook version 3.0 for PEN3 Electronic Nose)

Power, max. 40W	External power supply input: 100 – 240V output 12V 3.33A or 12VDC optional
Computer interface	USB port or serial RS – 232 (optional)
Electrical interface	TTL and relays digital signal port for communication with devices attached to the unit
Operating temperatures	Typical : 0°C ... 40°C
Operating humidity	5% ... 95% RH, non-condensing
Sapling flow	Adjustable : 10 ... 400ml/ min, built-in flow and sampling system
Inlet sampler	1/8" tube, special fluid connector
Sensor technology	Hot sensors, working temperature 200°C ... 500°C
Sensor array	10 different metal oxides thick film sensors
Sensor chamber	Volume 1.8ml, temperature 110°C, stainless steel
Sensor response time	Typical : less than 1 second
Sampling system	2 internal pumps (sampling and zero gas)
Zero gas	Air, charcoal filtered or zero gas generator
Measurement cycle time	Depending on the application, typical : 1min (20s measurement, 40s recovery time)
Pattern stability	e.g. 1 year for aromatic solvents
Sensitivity	LOD ca. 0.1 ...5 ppm for gases organic solvents (e.g. 0.1 ppm H ₂ S, 1ppm benzene)
Operating system	Device control software running on Win98SE, ME, 2000, XP
Operating mode	Single cycle or automatic cycling
Weight	2.3 kg
Dimensions	255 × 190 × 92 mm

Table 02 Description of the sensors used in PEN3 e-nose provided by Airsense Analytical (Baietto et al. 2013; Tyagi et al. 2021)

Sensor No.	Sensor	Substances for sensing
S1	W1C	Sensitive to aromatic compounds
S2	W5S	Sensitive to nitrogen oxides, with broad range
S3	W3C	Sensitive to aromatic compounds and ammonia
S4	W6S	Sensitive to hydrogen gas
S5	W5C	Sensitive to aromatic, alkanes, and aliphatic compounds
S6	W1S	Sensitive to methane in the environment, with broad range
S7	W1W	Sensitive to Sulphur and organic compounds
S8	W2S	Sensitive to alcohol and broad range
S9	W2W	Sensitive to aromatic compounds, inorganic Sulphur compounds
S10	W3S	Sensitive to methane and aliphatic compounds

191 For each species, 03 measurements were taken as fresh leaves, blended, and chopped by hand. For each
 192 measurement, 03 replicates were done. All the measurements were taken at their peak levels of output. Steps of obtaining
 193 electronic nose data are described as a flowchart below.



194 **Fig. 07** Steps of obtaining electronic nose data [Source: (Adak and Yumusak 2014)]

195 Elephant responses on preference for a particular leaf material, movements of the body, ears, head, legs, tail, and
 196 trunk were categorized in to several categories to find out the association between leaf proximate parameters and
 197 palatability responses as follows;

198 **Table 03** Categorized elephant responses for correlation analysis (each responses were categorized based on the
 199 experiences of mahouts in the study site at Wewita, Bandaragama, Sri Lanka)

Elephant responses	Response	Category
Preference for a particular leaf material	Accepted	Accepted
	Rejected	Rejected
Movements of the body	Naturally swung	Usual
	Triggered swing and Not moved	Unusual
Movements of the ears	Naturally wagged	Usual
	Stiffed, Not moved, and Triggered wagging	Unusual
Movements of the head	Naturally swung	Usual
	Moved away and Not moved	Unusual
Movements of the legs	Not moved	Usual
	Tried to move	Unusual
Movements of the tail	Naturally wagged	Usual
	Stiffed, Not moved, and Triggered wagging	Unusual
Movements of the trunk	Normal and Used to take feeds	Usual
	Moved away and Rolled	Unusual

200 Accordingly, all the natural behavioral movements were categorized as usual and the rest of non-natural behavioral
 201 movements were categorized as unusual. This classification was done based on experiences of mahouts. Accordingly,
 202 association between leaf proximate parameters and palatability responses were evaluated by considering proportion of non-
 203 natural (unusual) behavioral movements in particular body part and for preference for a particular leaf material, ‘rejected’
 204 response was considered for the analysis. Similarly, association between odor levels identified by the sensor array sensors
 205 of PEN3 Electronic Nose and palatability/ behavioral responses were evaluated.

206 **2.2. Data analysis**

207 **2.2.1. Experiment 01 – Elephant palatability and behavioral responses**

208 Palatability responses of wild elephants for *P. longifolia* leaf branches and the preference of tamed elephants for a particular
209 leaf material (%) were calculated as follows;

Preference for <i>P. longifolia</i> leaf branches = (Ingested events / Offered events) × 100

210 Correspondingly, differences in body movements among *P. longifolia* and other feeding materials, and each sort of
211 response in each body part (%) of tamed elephants were calculated as follows;

Response of a specific body part = (Response of the body part / Offered events) × 100
--

212 Collected data were analyzed via analysis of variance (ANOVA) by RStudio statistical software (2022.07.02 Build
213 576) and the bar plots were illustrated by Microsoft® Excel® 2016 MSO (Version 2211, Build 16.0.15831.20098).

214 **2.2.2. Experiment 02 - Analysis of leaf proximate parameters and organic volatile compounds**

215 Collected proximate analysis and responsible chemical compounds for odor of plant materials were analyzed via analysis
216 of variance (ANOVA). Correlation analyses between chemical compounds responsible for odor and palatability/ behavioral
217 responses, and leaf proximate parameters and palatability behavioral responses of tamed were done by Pearson correlation.
218 All data were analyzed by RStudio statistical software (2022.07.02 Build 576) and the bar plots were illustrated by
219 Microsoft® Excel® 2016 MSO (Version 2211, Build 16.0.15831.20098).

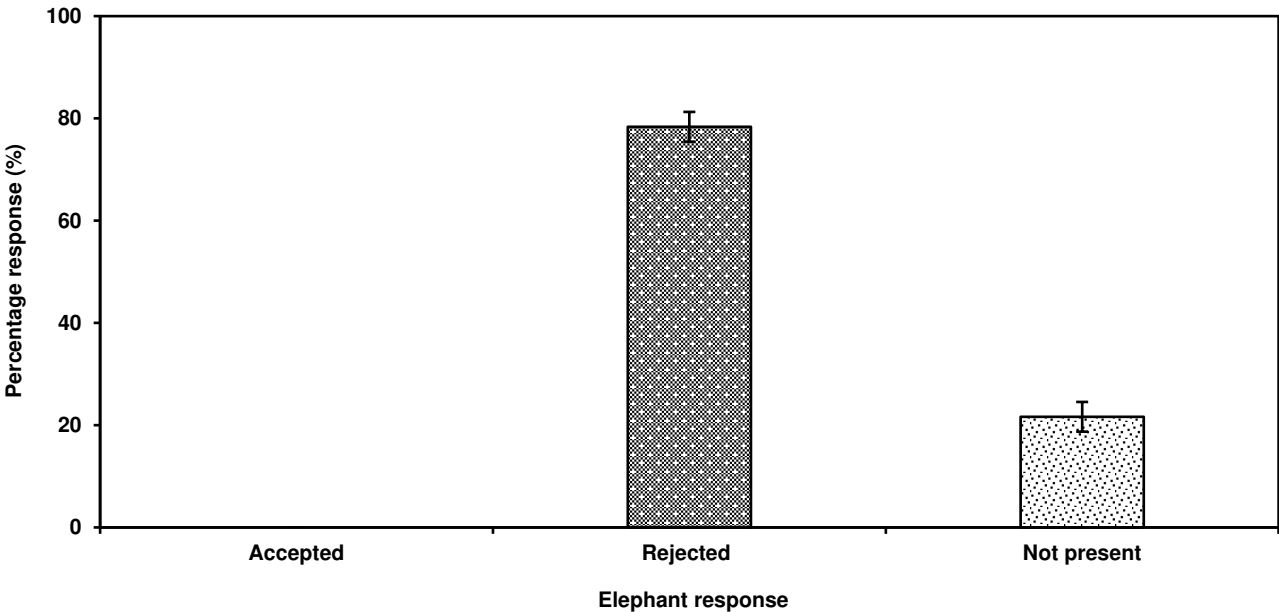
220 3. Results and discussion

221 3.1. Experiment 01 - Elephant palatability and behavioral responses

222 3.1.1. Case 01: Palatability responses of wild elephants



223 **Fig. 08** *P. longifolia* leaf branches placed across the well-recognized elephant drives in Dhahamwewa (a) and Rotawewa
224 dumpsite (b); circle showing the moving elephant in response to the *P. longifolia* leaves



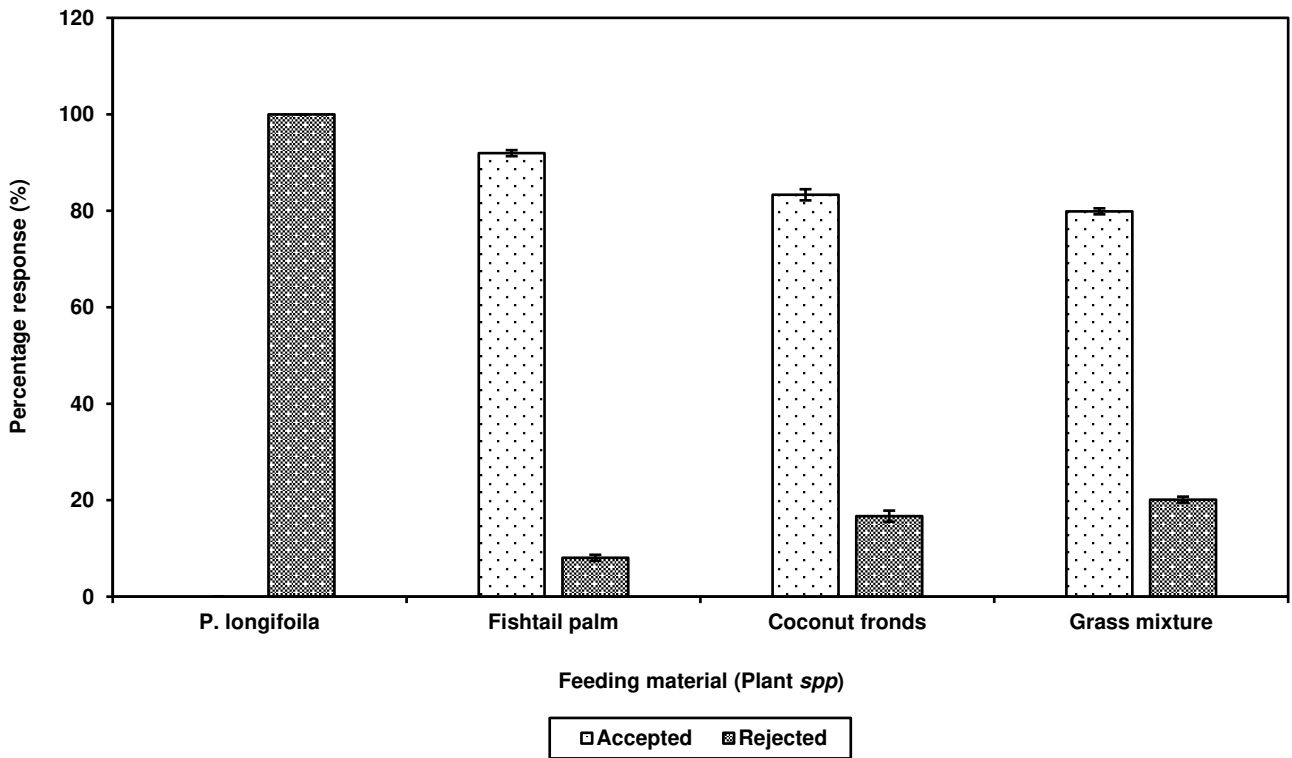
225 **Fig. 09** Palatability responses of wild elephants for *P. longifolia* as a % of the number of offerings

226 Since the experiment was done using wild elephants, there were some incidences that they were not present at the site of
227 observation. However, none of them preferred to ingest *P. longifolia* and tended to move away from the leaf branches
228 implying that *P. longifolia* bears a repellency characteristic that prevents elephant movements along their usual migratory
229 routes. In fact, rejected response showed a significantly higher level ($p < 0.05$, $R\text{-sq.} = 98.48\%$) among the rest of responses.
230 The possible reason could be due to an inherent distaste of the elephants for the leaf chemistry of the plant, which was
231 further investigated through the experiments that followed.

232 3.1.2. Case 02: Palatability and behavioral responses of tamed elephants

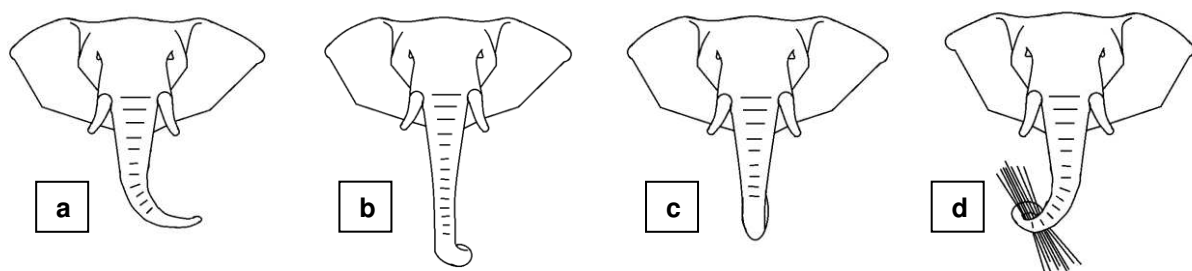


233 Fig. 10 Offering of *P. longifolia* leaf branches to the mature male elephant (a) and male calf (b)

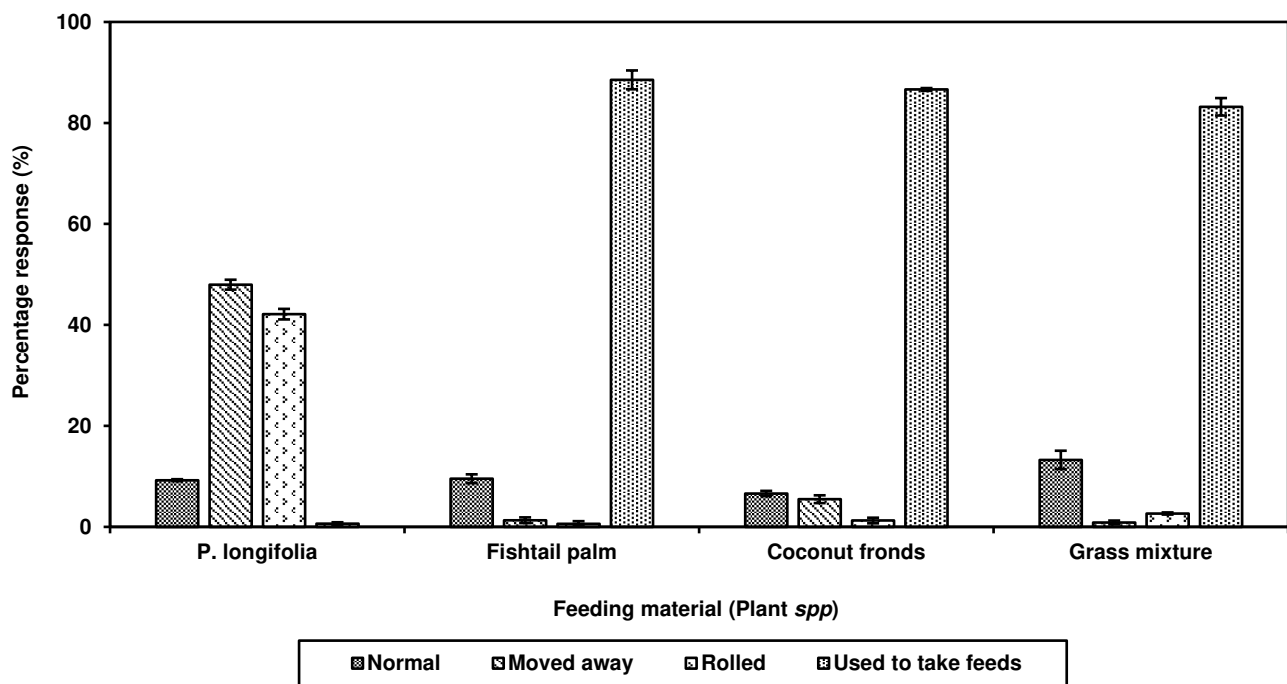


234 Fig. 11 Preference of tamed elephants [03 tamed elephants of three distinct ages; ~12 years (male calf), ~25 years (mature
235 male), and ~45 years (aged female)] for a particular leaf material as a % of the number of offerings

236 Resembling the results of the palatability test of wild elephants, tamed elephants showed a similar response to *P. longifolia*
237 while showing a regular response (accepted) to other feeding materials. Accordingly, rejected response was significantly
238 higher in *P. longifolia* and lowest in fishtail palm, no significant difference observed between the grass mixture and coconut
239 ($p < 0.05$, $R\text{-sq.} = 99.89\%$). Thus, it is evident that the leaf branches of *P. longifolia* were rejected, while the rest of the
240 materials were accepted in the majority of attempts. Therefore, it can be verified that *P. longifolia* is not consumed by
241 tamed elephants. Furthermore, the offering of *P. longifolia* showed several behavioral changes.

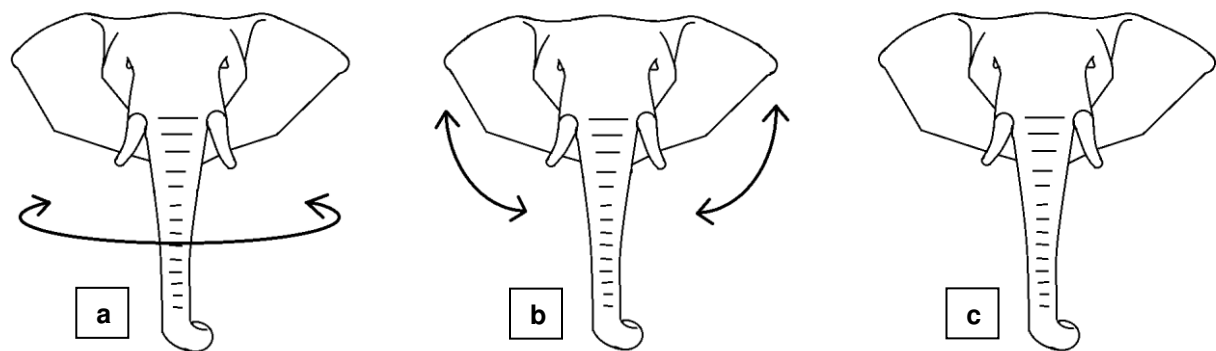


243 **Fig. 12** Schematic diagrams of movements of the trunk; Moved away (a), Normal (b), Rolled (c), and Used to take feeds
244 (d). Normal refers to the usual natural placement of the trunk

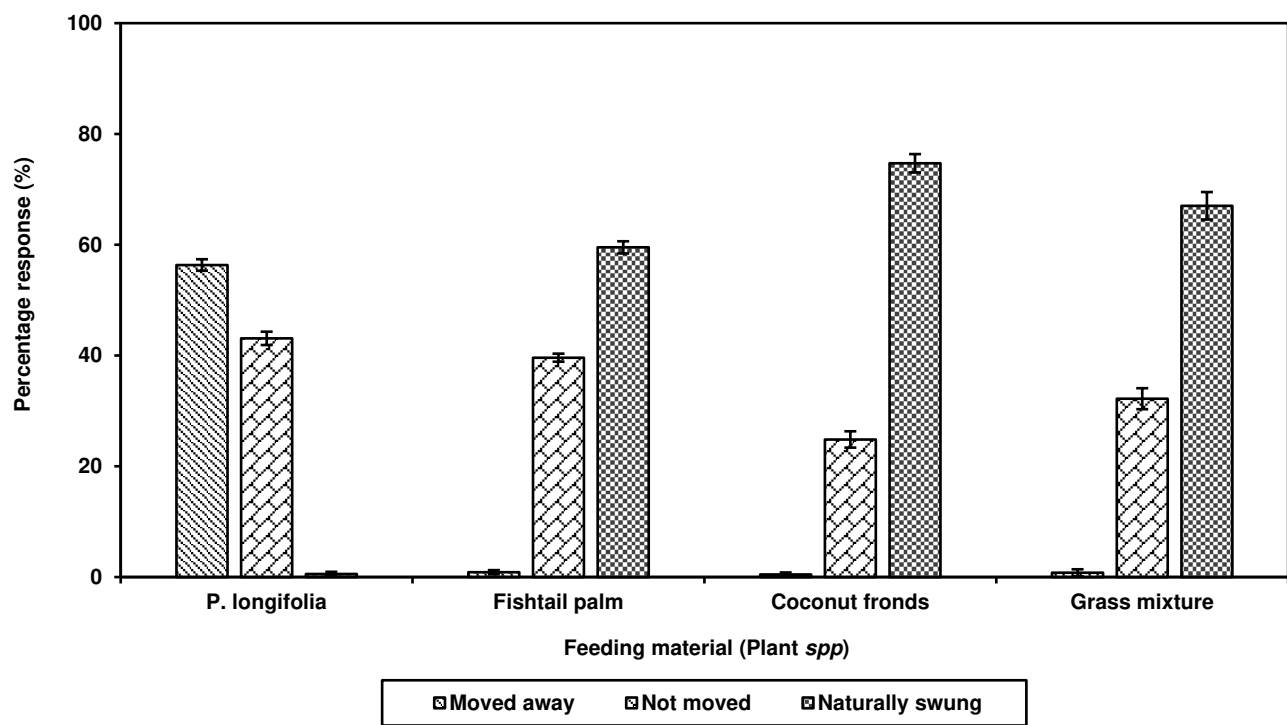


245 **Fig. 13** Movement of the trunk of tamed elephants [03 tamed elephants of three distinct ages; ~12 years (male calf), ~25
246 years (mature male), and ~45 years (aged female)] as a % of the number of offerings

247 For all other feeding materials, movements of the trunk have shown a similar response except for *P. longifolia*. Grass
248 mixture showed the highest level for normal response, but not significant while coconut was the lowest ($p < 0.05$, $R\text{-sq.} =$
249 63.07%). Interestingly, the behavior of rolling of the trunk (twisting the distal part of the trunk) could be predominantly
250 observed when *P. longifolia* was introduced to elephants and showed a significantly higher level among the rest of feeding
251 materials ($p < 0.05$, $R\text{-sq.} = 99.59\%$). In addition, a significantly higher of moved-away responses could also be observed
252 for *P. longifolia* ($p < 0.05$, $R\text{-sq.} = 99.61\%$). Moreover to the response of used to take feeds, *P. longifolia* showed a
253 significantly lower level among the rest of feeding materials ($p < 0.05$, $R\text{-sq.} = 99.64\%$). Thus, it can be assumed that the
254 movement of the trunk against *P. longifolia* did not support the usual response for their regular feeding materials.

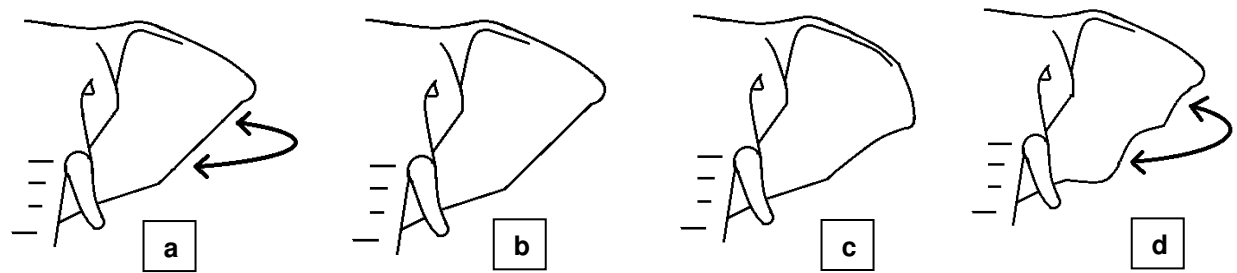


256 **Fig. 14** Schematic diagrams of movements of the head; Moved away (a), Naturally swung (b), and Not moved (c)



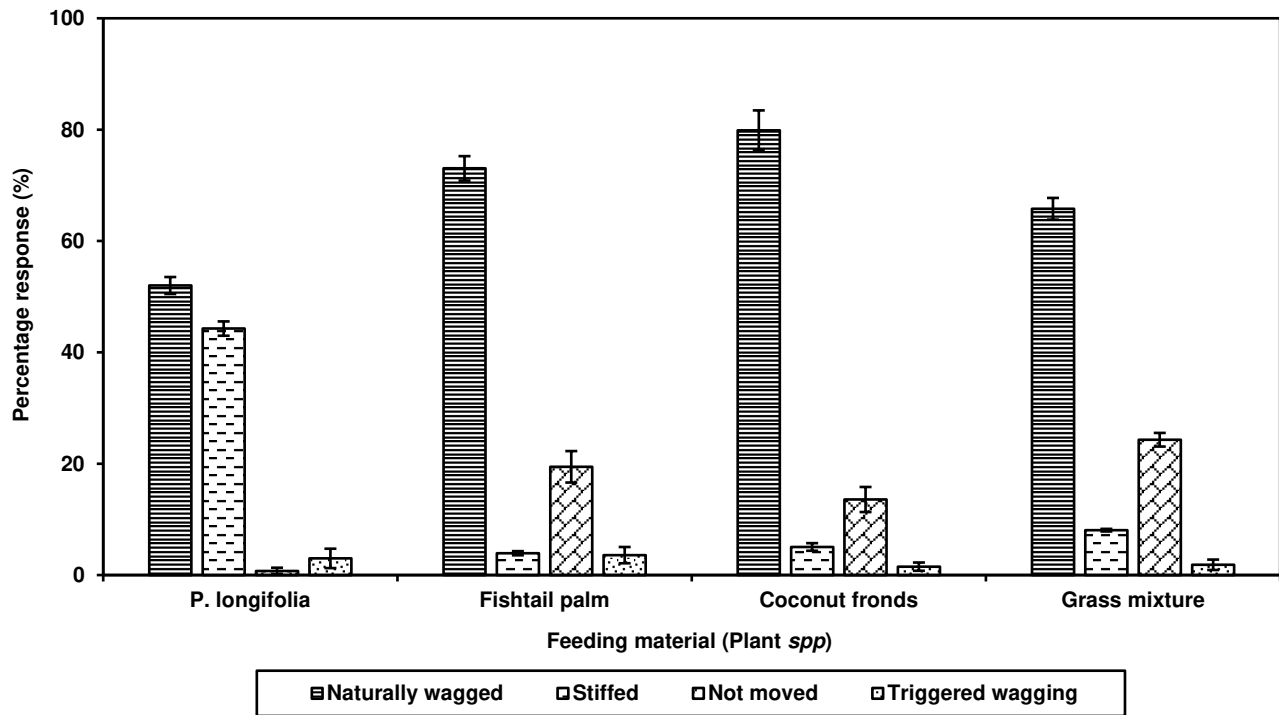
257 **Fig. 15** Movement of the head of tamed elephants [03 tamed elephants of three distinct ages; ~12 years (male calf), ~25
258 years (mature male), and ~45 years (aged female)] as a % of the number of offerings

259 Usually, elephants swing their head in most of incidences, which enables elephant keepers to recognize that the elephants
260 are indicating the gesture of gladness. This behavior is also could be observed in their feeding times. According to the
261 observations, elephants showed a significantly lowest level of naturally swung response to *P. longifolia* ($p<0.05$, $R\text{-sq.}$ -
262 99.11%). Moreover, a significantly higher level of moved away responses were observed for *P. longifolia* ($p<0.05$, $R\text{-sq.}$
263 - 99.77%) while no significant differences between the rests of feeding materials. Similarly, Not moved response was
264 significantly highest in *P. longifolia* and fishtail palm ($p<0.05$, $R\text{-sq.}$ - 89.49%) indicating that offering of *P. longifolia*
265 resulted non-natural behavioral responses of elephant trunks.



267 **Fig. 16** Schematic diagrams of movements of the ears; Naturally wagged (a), Not moved (b), Stiffed (c), and Triggered

268 wagging (d)



269 **Fig. 17** Movement of the ears of tamed elephants [03 tamed elephants of three distinct ages; ~12 years (male calf), ~25

270 years (mature male), and ~45 years (aged female)] as a % of the number of offerings

271 Natural wagging of ears could be observed for all plant materials but showed a lesser proportion for *P. longifolia*. In fact,

272 coconut fronds and fishtail palm showed the significantly highest level of response while *P. longifolia* showed the

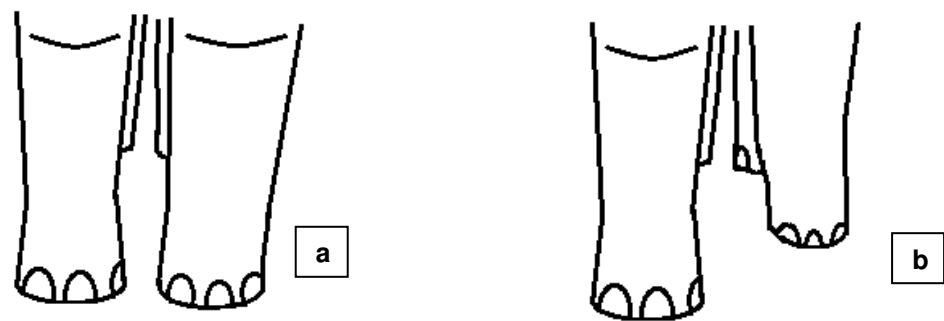
273 significantly lowest level of response ($p < 0.05$, $R\text{-sq.} = 85.62\%$). On the other hand, the response for *P. longifolia* showed

274 the significantly highest level of stiffing response and there were no significant difference between the rests of feeding

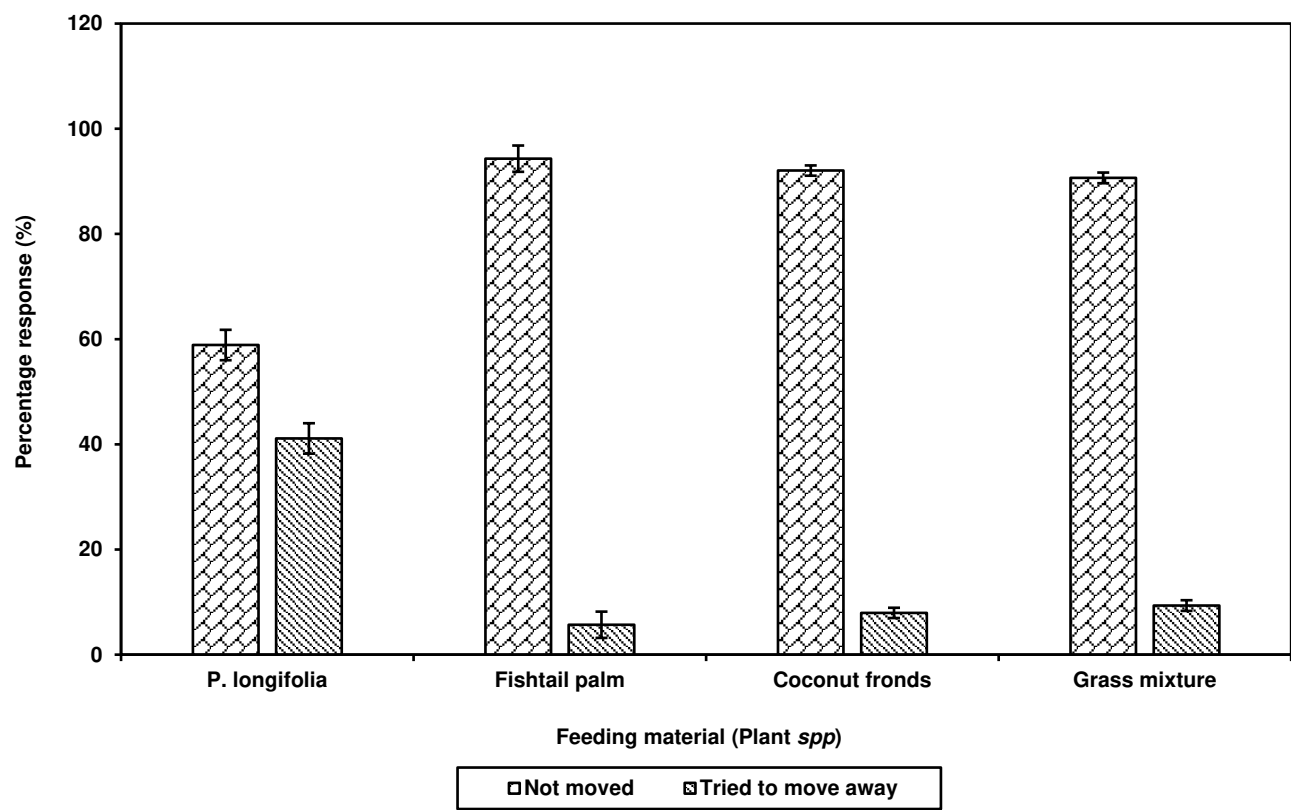
275 materials ($p < 0.05$, $R\text{-sq.} = 99.39\%$). Grass mixture and fishtail palm showed the significantly highest level of not moved

276 response while *P. longifolia* showed the significantly lowest level of response ($p < 0.05$, $R\text{-sq.} = 87.44\%$). However, no

277 significant differences among all the feeding materials could be observed for the response of triggered wagging ($p > 0.05$).



285 **Fig. 18** Schematic diagrams of movements of the legs; Not moved (a), and Tried to move (b)

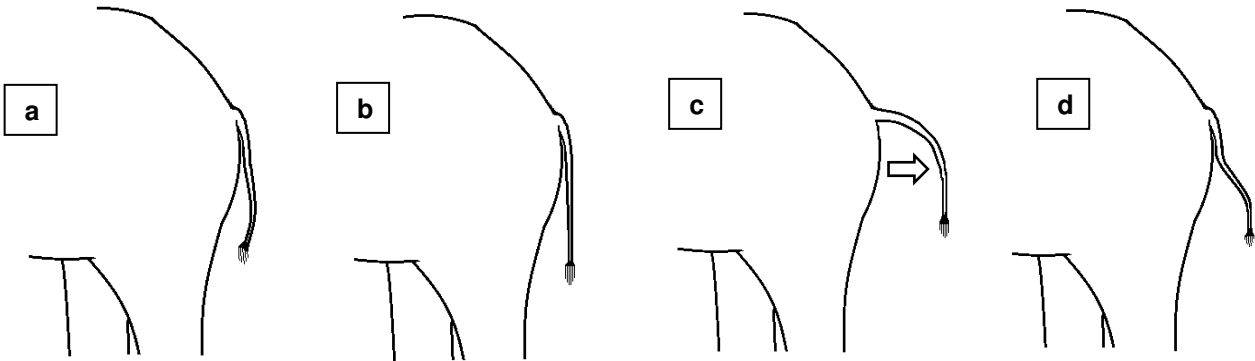


286 **Fig. 19** Movement of the legs of tamed elephants [03 tamed elephants of three distinct ages; ~12 years (male calf), ~25
287 years (mature male), and ~45 years (aged female)] as a % of the number of offerings

288 Since these elephants are tamed and privately managed, they are tied to nearby structures to restrict their movements
289 through metal chains. However, they are allowed to move over a certain area to maintain their good health. When the
290 elephants are fed with their daily feed, they do not try to move and begin to ingest them in almost all incidences.
291 Correspondingly response to all the feeding materials showed a not moved response in greater proportions. In contrast, *P.*
292 *longifolia* showed the significantly lowest level of response while there were no significant difference among the rests of
293 feeding materials ($p < 0.05$, $R\text{-sq.} = 94.45\%$). Similarly, elephants tried to move when offered the rest three feeding materials

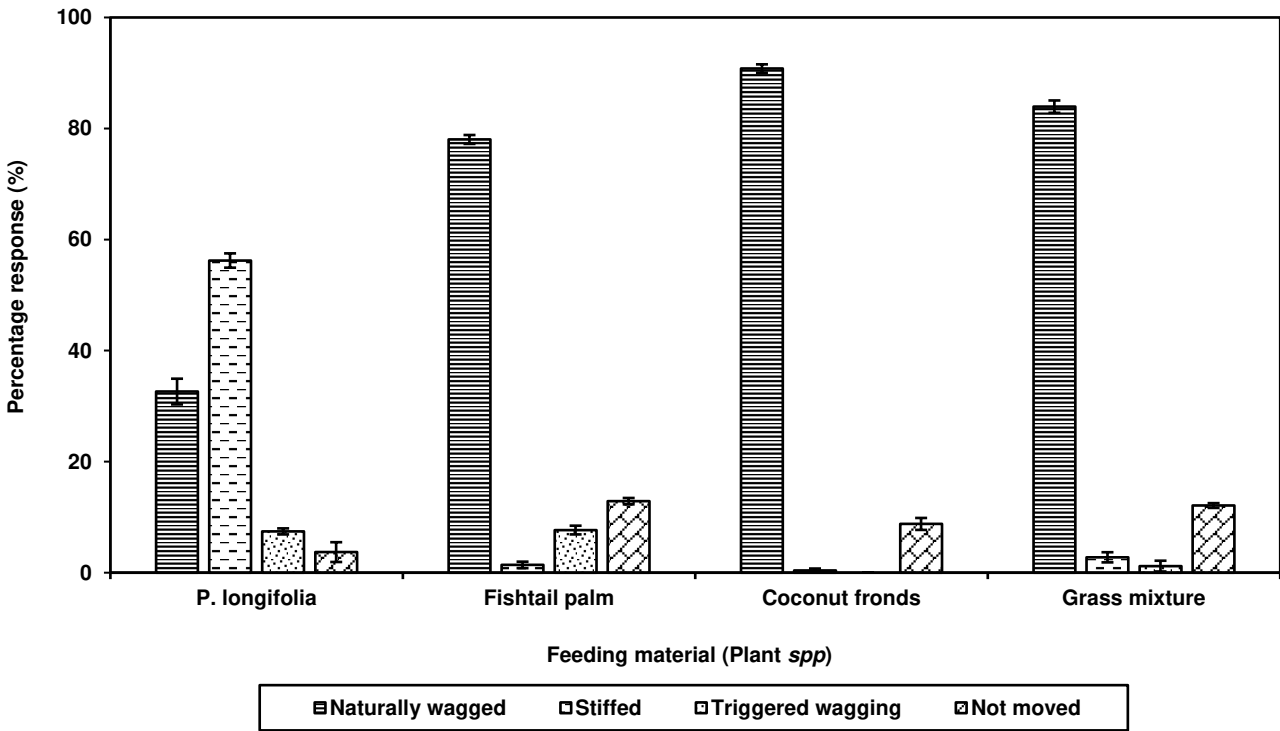
294 except fishtail palm. However, this response is notably greater for *P. longifolia* while there were no significant difference
 295 among the rests of feeding materials ($p < 0.05$, $R\text{-sq.} = 94.45\%$).

296 *Movement of the tail*



297

298 **Fig. 20** Schematic diagrams of movements of the tail; Naturally wagged (a), Not moved (b), Stiffed (c) (arrow showing
 299 the direction of tail erection), and Triggered wagging (d)

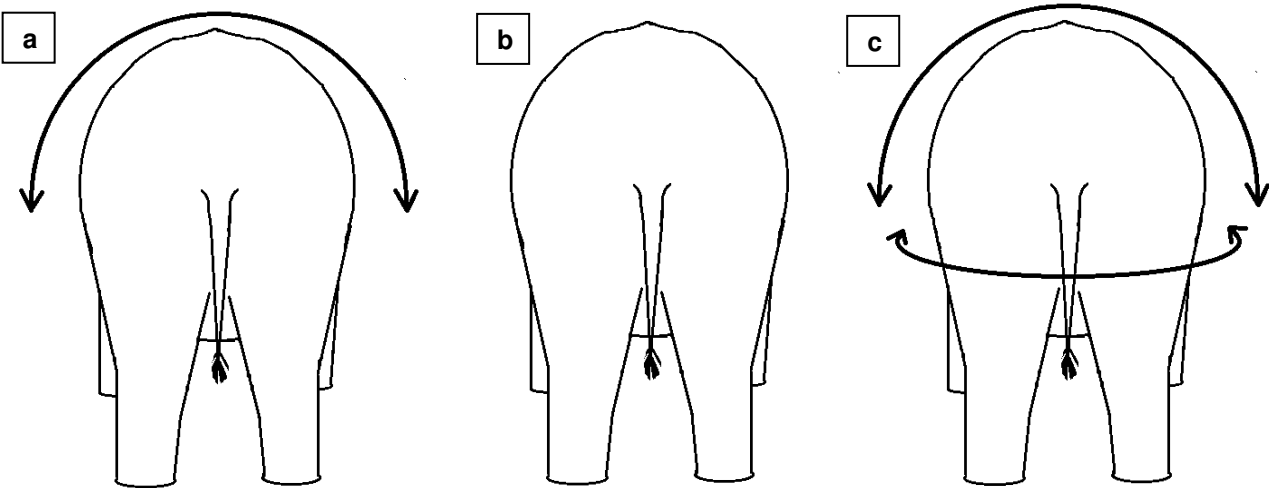


300 **Fig. 21** Movement of the tail of tamed elephants [03 tamed elephants of three distinct ages; ~12 years (male calf), ~25
 301 years (mature male), and ~45 years (aged female)] as a % of the number of offerings

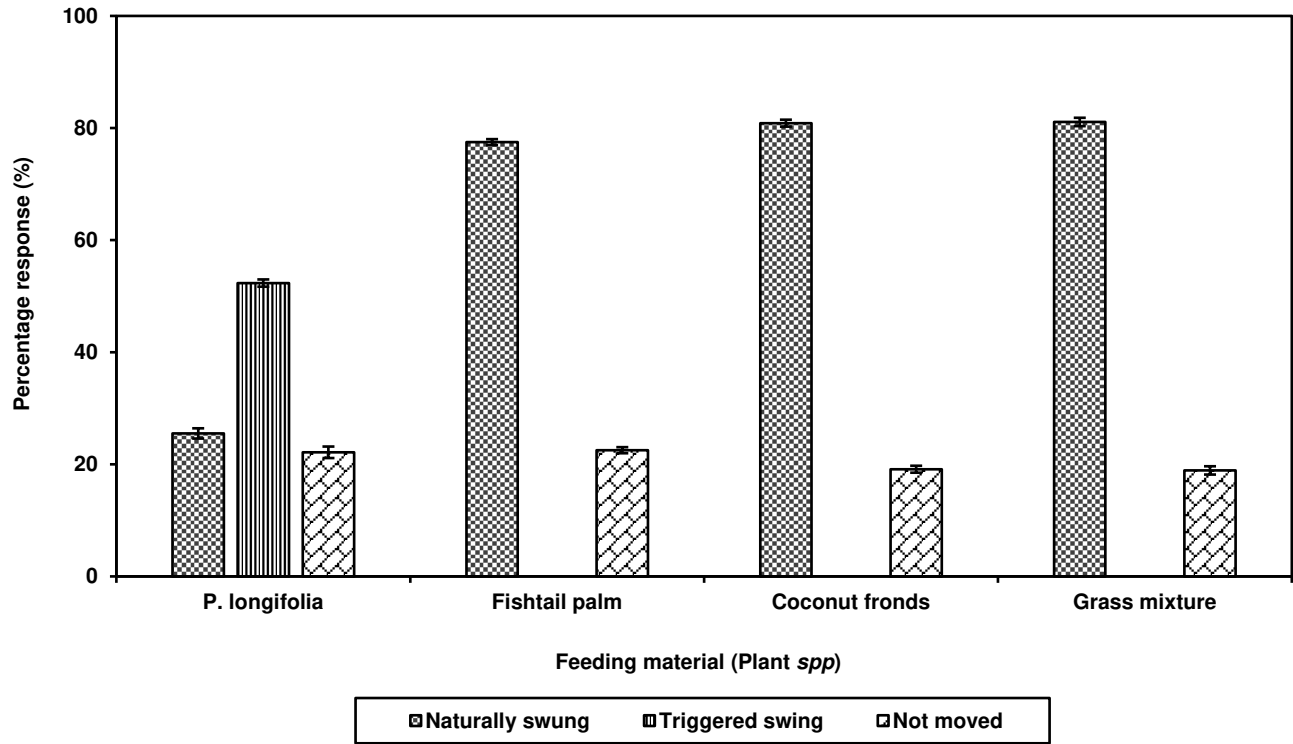
302 All the feeding materials except *P. longifolia* showed a mostly similar response in tail movement, and natural wagging of
 303 the tail could be observed in all four feeding materials. However, elephants showed an extraordinarily stiff response only
 304 for leaf branches of *P. longifolia*. Coconut fronds and grass mixture showed the significantly highest level of naturally
 305 wagged response while *P. longifolia* showed the lowest level of response ($p < 0.05$, $R\text{-sq.} = 98.88\%$). Also *P. longifolia*
 306 showed the highest level of stiffed response while there were no significant difference among the rests of feeding materials

307 ($p < 0.05$, $R\text{-sq.} = 99.61\%$). For the response of triggered wagging, *P. longifolia* and fishtail palm showed the highest level
 308 while grass mixture and coconut fronds showed the significantly lowest level of response ($p < 0.05$, $R\text{-sq.} = 89.89\%$).
 309 Furthermore, fishtail palm and the grass mixture showed a greater level of not moved response than the rest of feeding
 310 materials, but not statistically significant ($p > 0.05$) suggesting that offering *P. longifolia* resulted non-natural responses in
 311 elephant tails.

312 **Movement of the body**



313 **Fig. 22** Schematic diagrams of movements of the body; Naturally swung (a), Not moved (b), and Triggered swing (c)



314 **Fig. 23** Movement of the body of tamed elephants [03 tamed elephants of three distinct ages; ~12 years (male calf), ~25
 315 years (mature male), and ~45 years (aged female)] as a % of the number of offerings

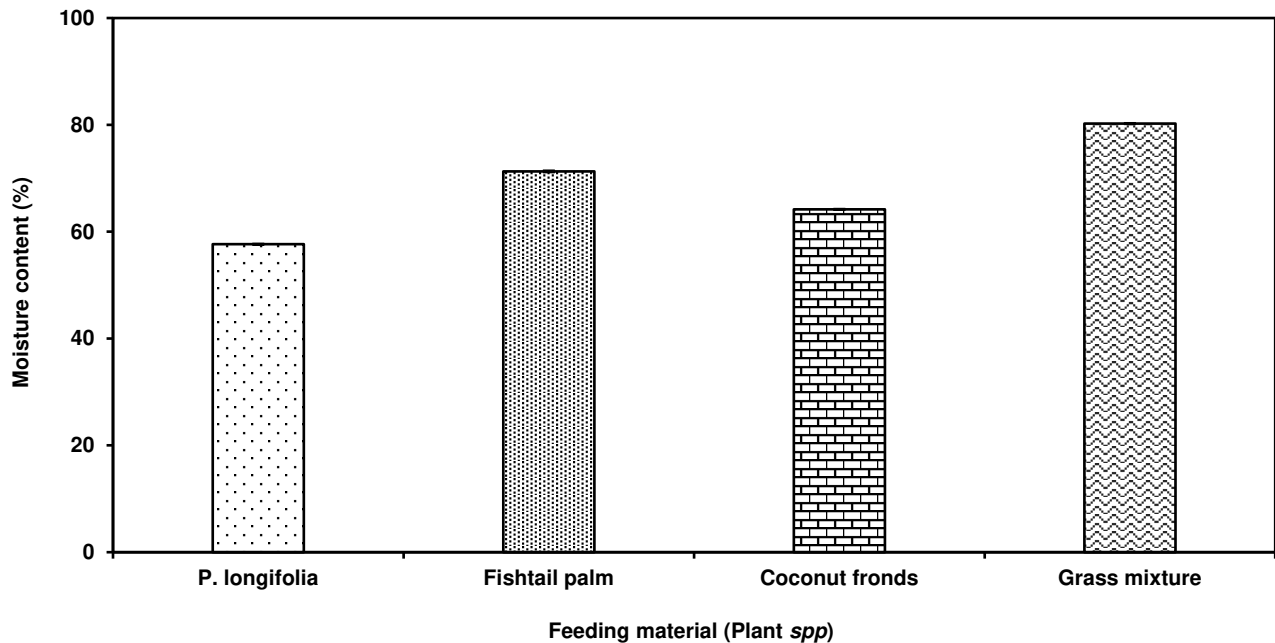
316 Similar to the head movement, elephants swing their body in most incidences, or otherwise, they remain stable. Movement
 317 of the body in response to feeding materials showed a similar behavior except for *P. longifolia*. In fact, naturally swung
 318 response showed the highest level for grass mixture, and lowest for *P. longifolia* ($p < 0.05$, $R\text{-sq.} = 99.72\%$). In addition, the
 319 response of triggered swing of their bodies could only be observed for *P. longifolia* ($p < 0.05$, $R\text{-sq.} = 99.94\%$). The response
 320 of not moved showed no significant difference ($p > 0.05$) among the feeding materials.

321 Based on the observations of both wild and tamed elephants, it could be suggested that *P. longifolia* was not
 322 preferred by elephants to consume despite of their age or sex. In addition, offering of leaf branches of *P. longifolia* showed
 323 non-natural responses compared to other offered leafy materials. Remarkably, chemical constituents having antifeedant
 324 properties reported by Phadnis et al. (1988), Katkar et al. (2010), and Sashidara et al. (2010) might be responsible for the
 325 repellent nature of *P. longifolia* by elephants which needs further experimentation.

326 3.2. Experiment 02 - Analysis of leaf proximate parameters and organic volatile compounds

327 3.2.1. Leaf proximate analysis

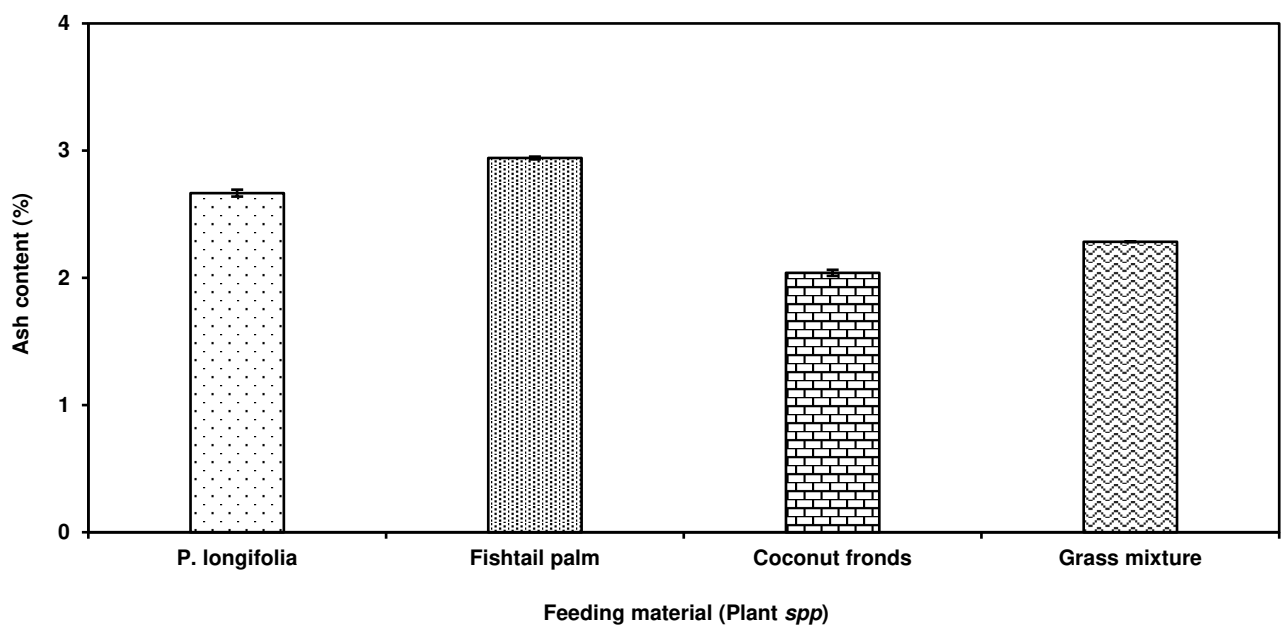
328 Leaf moisture content (%)



329 **Fig. 24** Moisture contents (%) of four different leaf materials; *P. longifolia*, fishtail palm, coconut fronds, and the grass
 330 mixture

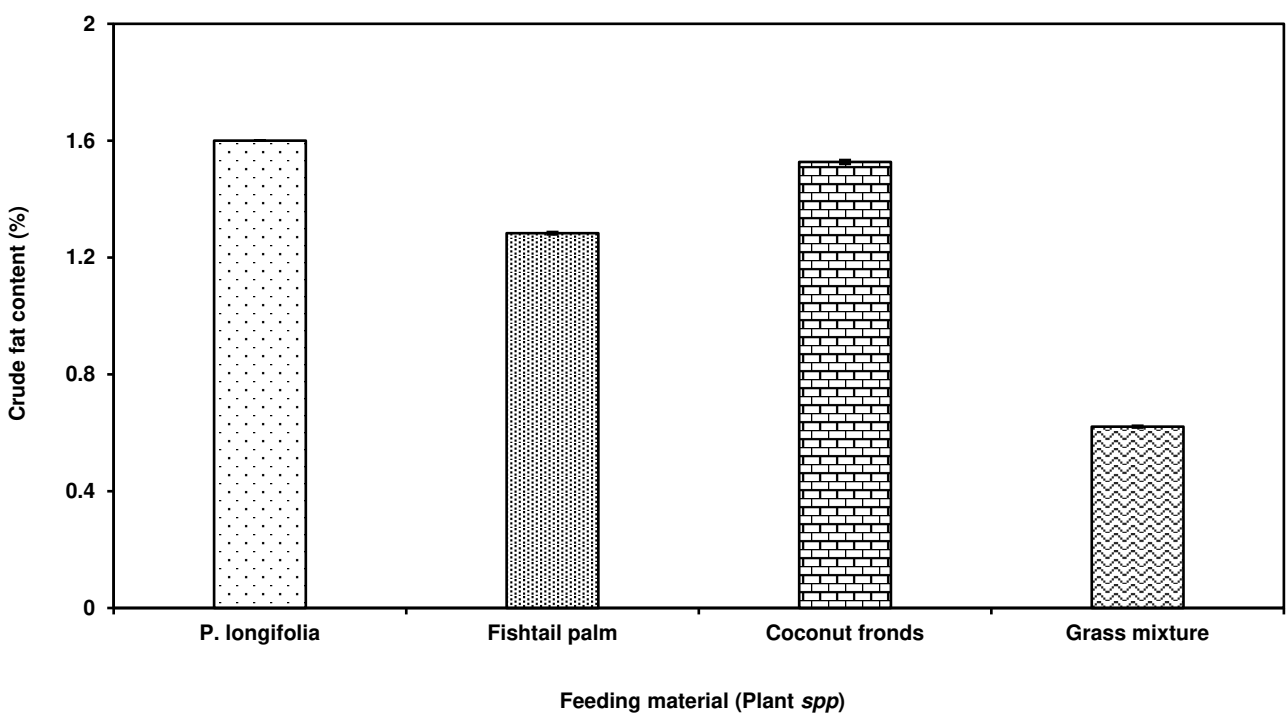
331 Moisture contents of four different leaf materials were significantly different from each other ($p < 0.05$, $R\text{-sq.} = 99.98\%$),
 332 and *P. longifolia* showed the least level of moisture content.

333 *Leaf ash content (%)*



334 **Fig. 25** Ash contents (%) of four different leaf materials; *P. longifolia*, fishtail palm, coconut fronds, and the grass mixture
335 Ash contents of four different leaf materials were significantly different from each other ($p < 0.05$, $R\text{-sq.} = 99.11\%$), and
336 fishtail palm showed the highest level of ash content followed by *P. longifolia*.

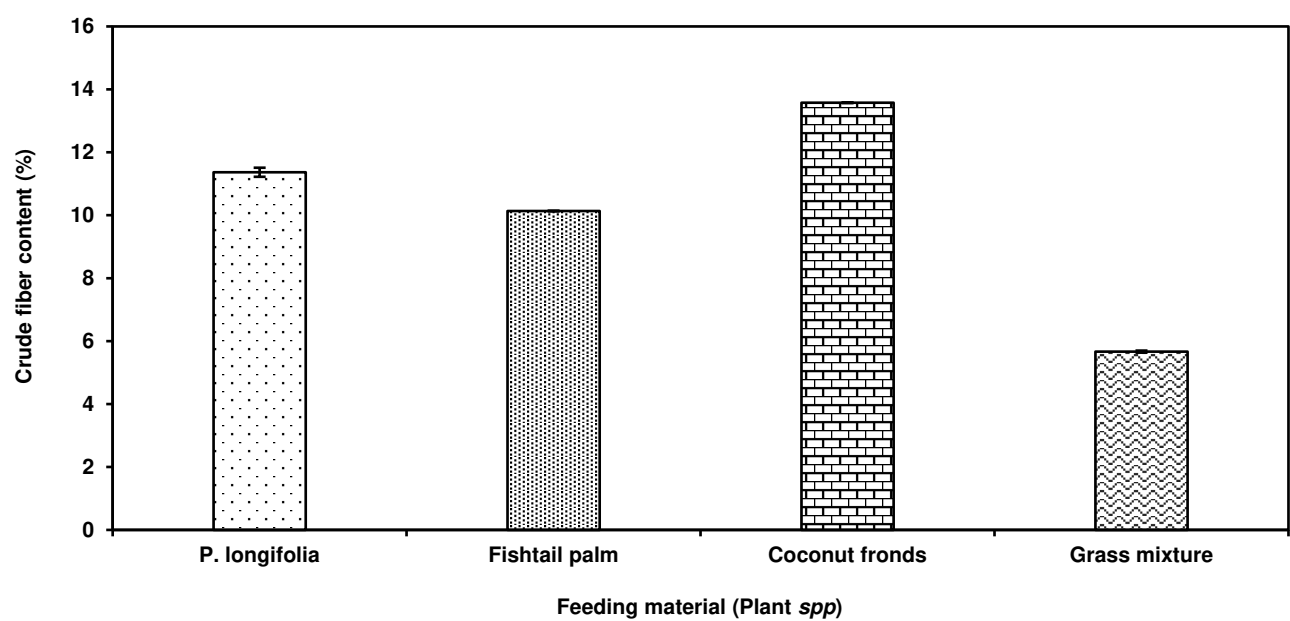
337 *Leaf crude fat content (%)*



338 **Fig. 26** Crude fat contents (%) of four different leaf materials; *P. longifolia*, fishtail palm, coconut fronds, and the grass
339 mixture

340 Crude fat contents of four different leaf materials were significantly different from each other ($p<0.05$, $R\text{-sq.} - 99.96\%$),
 341 and *P. longifolia* showed the highest level of crude fat content.

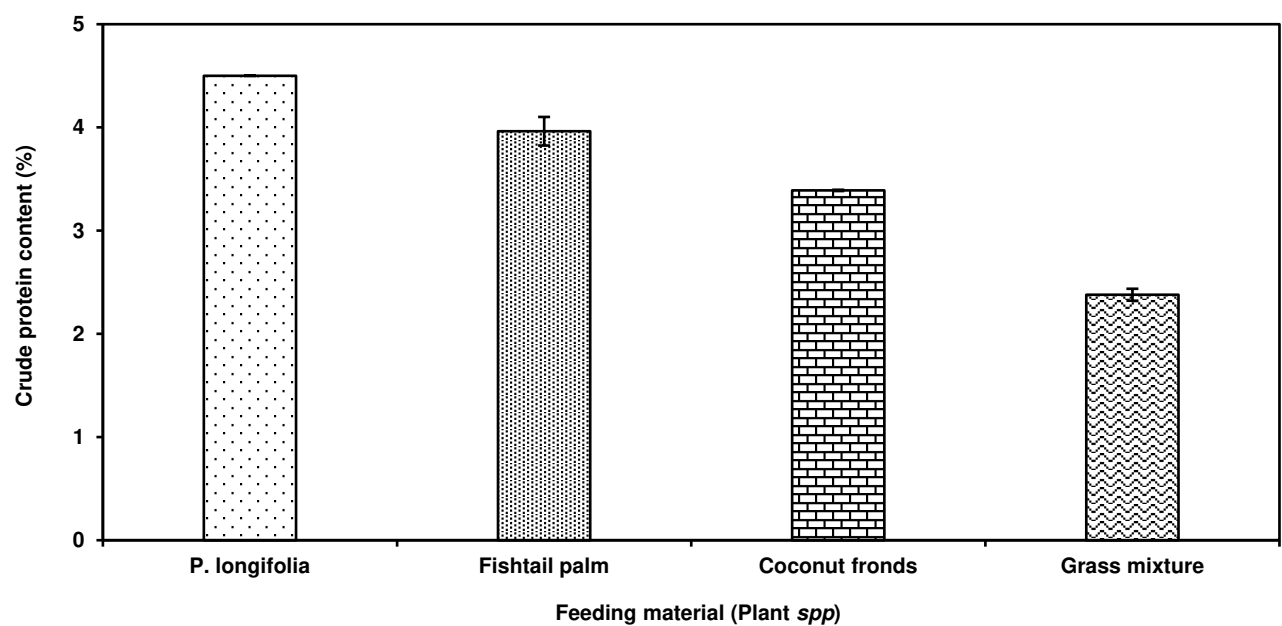
342 *Leaf crude fiber content (%)*



343 **Fig. 27** Crude fiber contents (%) of four different leaf materials; *P. longifolia*, fishtail palm, coconut fronds, and the grass
 344 mixture

345 Crude fiber contents of four different leaf materials were significantly different from each other ($p<0.05$, $R\text{-sq.} - 99.80\%$),
 346 and coconut fronds showed the highest level of crude fiber content followed by *P. longifolia*.

347 *Leaf crude protein content (%)*



348 **Fig. 28** Crude protein contents (%) of four different leaf materials; *P. longifolia*, fishtail palm, coconut fronds, and the
 349 grass mixture

Crude protein contents of four different leaf materials were significantly different from each other ($p < 0.05$, $R\text{-sq.} = 97.33\%$), and *P. longifolia* showed the highest level of crude protein content.

According to the obtained results, *P. longifolia* showed the significantly highest contents of crude fat and crude protein contents. Conversely, *P. longifolia* showed the least level of moisture content among four feeding materials. Variations in above-mentioned proximate parameters could be responsible for the variations in palatability responses of elephants against the four feeding materials. However, in relation to the ash and crude fiber contents, *P. longifolia* laid in between other three feeding materials. Correlation between leaf proximate parameters against elephant palatability and behavioral responses were assessed in the following analyses in order to find out the association between leaf proximate parameters and palatability responses of tamed elephants.

3.2.2. Responsible chemical compounds for odor of elephant feeding materials

The PEN3 e-nose consists of 10 gas sensors and the raw output of each sensors can be described as comparing by graphical methods or pattern recognition techniques. For exploratory analyses, bar charts are a simple and convenient way of visualizing the sensor response patterns that are produced by a sensor array (Scott *et al.*, 2006).

Relative levels of organic volatile compounds in fresh leaves

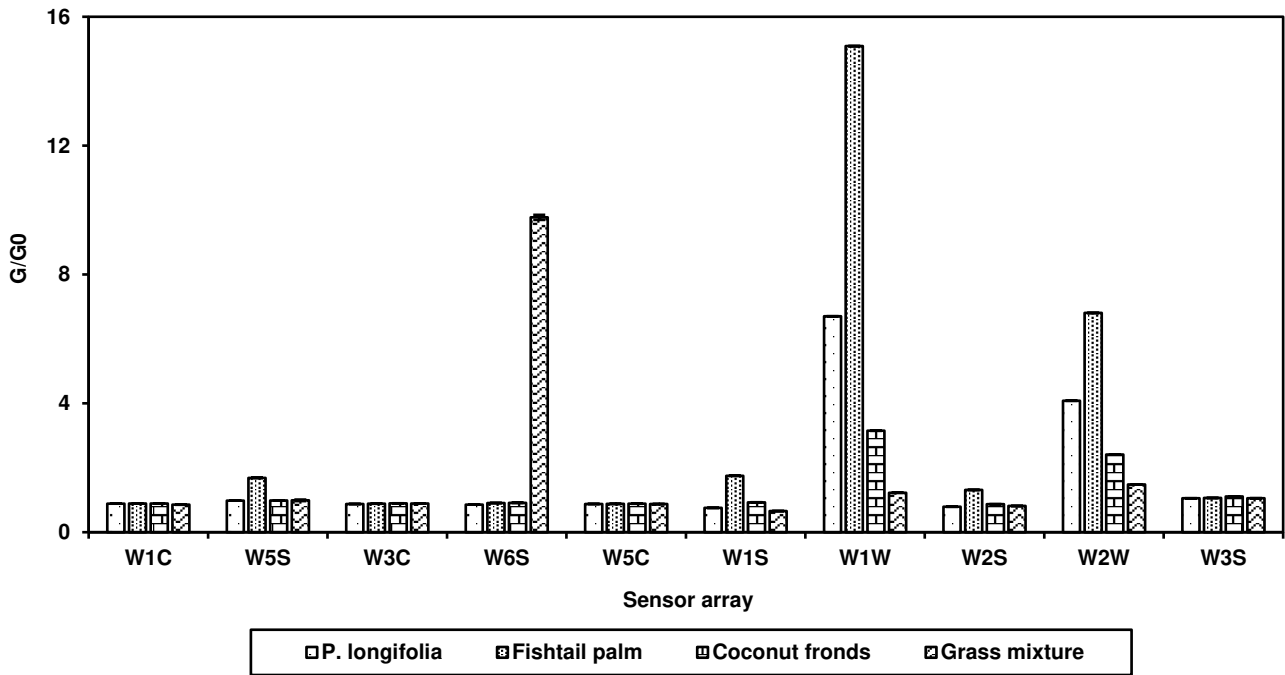


Fig. 29 Bar plot of the output features of the PEN3 to fresh leaves of elephant feeding materials. G/G0 is the ratio of the electrical conductivity response of the sensors to the sample gas (G) relative to the carrier gas (G0) over time

For the fresh leaf materials, coconut showed a significantly higher ($p < 0.05$, $R\text{-sq.} = 96.51\%$) level of methane and aliphatic compounds (W3S), while fishtail palm showed a significantly higher ($p < 0.05$, $R\text{-sq.} = 99.47\%$) level of nitrogen oxides, with broad range (W5S). Grass mixture showed a significantly lower ($p < 0.05$, $R\text{-sq.} = 91.97\%$) level of aromatic

compounds (W1C) and a significantly higher ($p < 0.05$, $R\text{-sq.} = 99.97\%$) level of hydrogen gas (W6S). In terms of methane in the environment, with broad range (W1S), sulphur and organic compounds (W1W), and aromatic and inorganic sulphur compounds (W2W), all species were significantly different from each other [$(p < 0.05, R\text{-sq.} = 99.99\%)$, $(p < 0.05, R\text{-sq.} = 100.00\%)$, $(p < 0.05, R\text{-sq.} = 100.00\%)$, respectively]. In fact fishtail palm showed the highest levels and the grass mixture showed the lowest for the above 03 sensor measurements. All species are significantly differ ($p < 0.05, R\text{-sq.} = 99.95\%$) from each other in terms of alcohol and broad range (W2S). Among them, fishtail palm showed the highest, while *P. longifolia* showed the lowest. For aromatic compounds and ammonia (W3C) and aromatic, alkanes, and aliphatic compounds (W5C), there were no significant differences ($p > 0.05$) among the 04 leafy materials. Incline to the objectives of this study, *P. longifolia* showed greater levels only for sulphur and organic compounds (W1W), and aromatic compounds, inorganic Sulphur compounds (W2W) but it was lower compared to the respective levels observed for fishtail palm. Therefore, observed results for the fresh leafy materials did not show any evidence for the contrasting repellency of *P. longifolia*, compared to other leafy materials.

Relative levels of organic volatile compounds in blended leaves

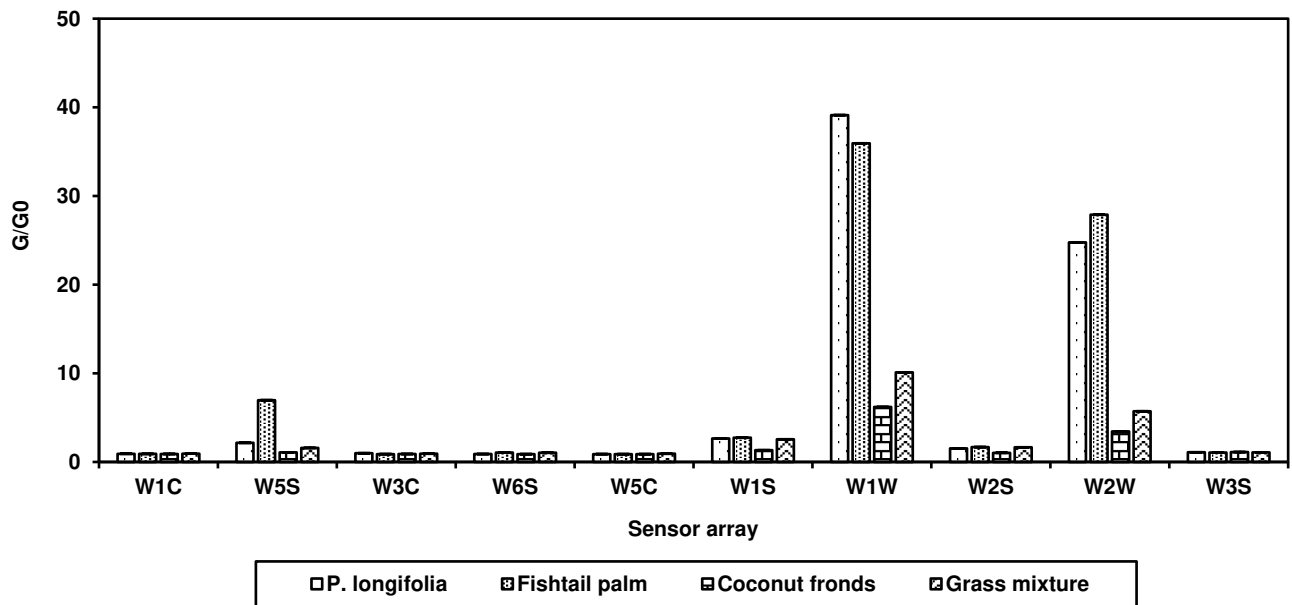


Fig. 30 Bar plot of the output features of the PEN3 to blended leaves of elephant feeding materials. G/G0 is the ratio of the electrical conductivity response of the sensors to the sample gas (G) relative to the carrier gas (G0) over time

For the blended leaf materials, coconut showed a significantly higher ($p < 0.05$, $R\text{-sq.} = 96.76\%$) level of methane and aliphatic compounds (W3S) followed by *P. longifolia*. Fishtail palm showed a significantly higher ($p < 0.05$, $R\text{-sq.} = 99.87\%$) level of hydrogen gas (W6S). Grass mixture showed significantly higher levels of aromatic compounds (W1C) and aromatic, alkanes, and aliphatic compounds (W5C) ($p < 0.05$, $R\text{-sq.} = 89.87\%$, $p < 0.05$, $R\text{-sq.} = 97.63\%$ respectively). Interestingly, *P. longifolia* showed a significantly higher ($p < 0.05$, $R\text{-sq.} = 95.26\%$) level of aromatic compounds and

ammonia (W3C). For sulphur and organic compounds (W1W), all species were significantly different ($p < 0.05$, $R\text{-sq.} - 100.00\%$) from each other while *P. longifolia* observed as the highest and coconut as the lowest). For nitrogen oxides, with broad range (W5S), methane in the environment, with broad range (W1S), alcohol and broad range (W2S), and aromatic compounds, inorganic Sulphur compounds (W2W), all species were significantly different from each other while fishtail palm observed as the highest, coconut as the lowest [$(p < 0.05, R\text{-sq.} - 99.95\%)$, $(p < 0.05, R\text{-sq.} - 99.99\%)$, $(p < 0.05, R\text{-sq.} - 99.97\%)$, $(p < 0.05, R\text{-sq.} - 100.00\%)$ respectively]. In terms of aromatic compounds and ammonia (W3C) and sulphur and organic compounds (W1W), *P. longifolia* showed a significantly higher levels than the rest of leafy materials in blended form. In addition, methane and aliphatic compounds (W3S) were comparatively higher than fishtail palm and the grass mixture. Therefore the greater levels of these substances could be involved in contrasting repellency of *P. longifolia*, compared to other leafy materials that will be further investigated in the correlation analysis.

Relative levels of organic volatile compounds in chopped leaves

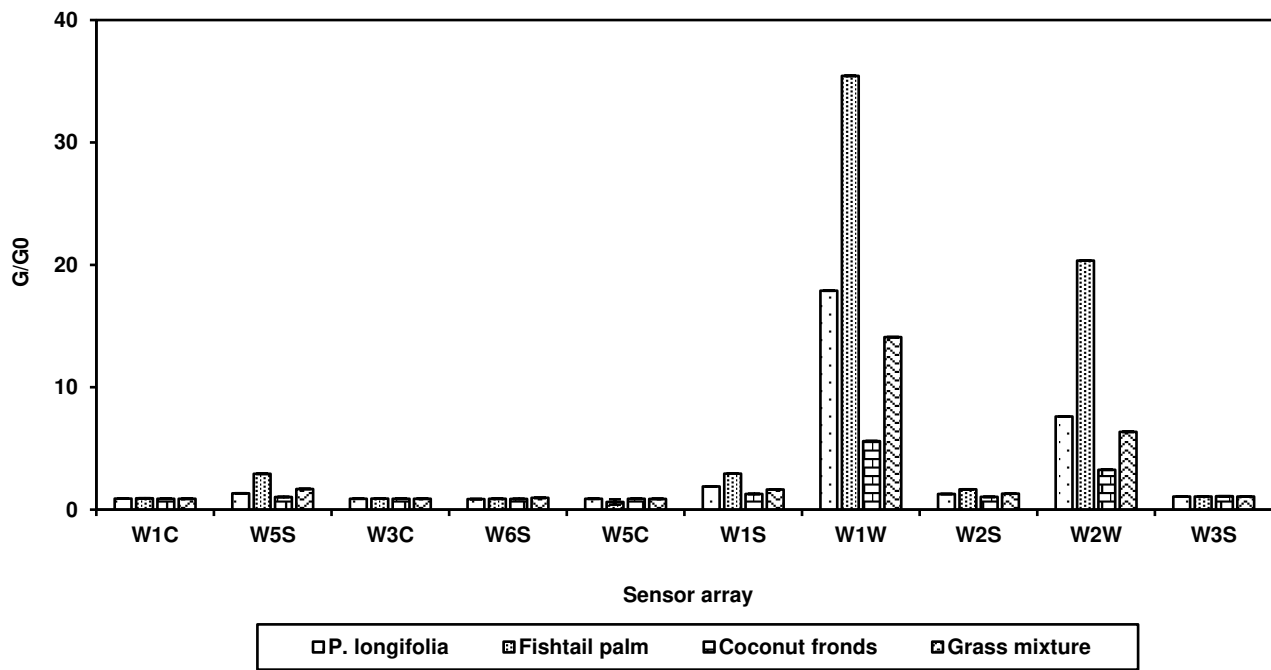


Fig. 31 Bar plot of the output features of the PEN3 to chopped leaves of elephant feeding materials. G/G0 is the ratio of the electrical conductivity response of the sensors to the sample gas (G) relative to the carrier gas (G0) over time

Coconut showed a significantly higher ($p < 0.05$, $R\text{-sq.} - 75.57\%$) level of methane and aliphatic compounds (W3S) than the rest of materials. Fishtail palm showed a significantly higher ($p < 0.05$, $R\text{-sq.} - 96.36\%$) level of aromatic compounds (W1C) while Grass mixture showed a significantly higher ($p < 0.05$, $R\text{-sq.} - 97.57\%$) level of hydrogen gas (W6S). For aromatic, alkanes, and aliphatic compounds (W5C), *P. longifolia* showed the highest level, but no significant difference observed ($p > 0.05$). For nitrogen oxides, with broad range (W5S), methane in the environment, with broad range (W1S), Sulphur and organic compounds (W1W), and alcohol and broad range (W2S), all species were significantly different from

each other [($p < 0.05$, $R\text{-sq.} = 100.00\%$), ($p < 0.05$, $R\text{-sq.} = 100.00\%$), ($p < 0.05$, $R\text{-sq.} = 100.00\%$), ($p < 0.05$, $R\text{-sq.} = 99.96\%$), respectively]. All species showed significantly different ($p < 0.05$, $R\text{-sq.} = 100.00\%$) levels of aromatic compounds, inorganic sulphur compounds (W2W) from each other while fishtail palm showed the highest level followed by *P. longifolia*, while coconut showed the lowest level. For aromatic compounds and ammonia (W3C), no significant difference ($p > 0.05$) observed among the chopped leafy materials. In focusing on the study objectives, *P. longifolia* showed the highest level, but no significant difference for aromatic, alkanes, and aliphatic compounds. Further, *P. longifolia* showed grater levels of aromatic compounds, inorganic sulphur compounds compared to coconut and the grass mixture. Therefore, resembling to the observed results of fresh leaves, chopped leafy materials did not show any evidence for the contrasting repellency of *P. longifolia*, compared to other leafy materials. According to the observed results for fresh, blended, and chopped leafy materials, sensor measurements of blended leaves possibly suggests contrasting repellency of *P. longifolia*, compared to the rest of leafy materials.

3.2.3. Association between leaf proximate parameters and palatability/ behavioral responses of tamed elephants

Obtained results of the association between leaf proximate parameters and palatability responses; particularly rejected and unusual responses are as follows;

Leaf moisture content against palatability/ behavioral responses

Table 04 Estimated correlation between unusual palatability and behavioral responses against leaf moisture content

Response	<i>p-value</i>	Correlation
1) Preference	0.2976	-0.7024
2) Body	0.2615	-0.7385
3) Ears	0.6827	-0.3173
4) Head	0.3331	-0.6669
5) Legs	0.2947	-0.7053
6) Tail	0.3441	-0.6559
7) Trunk	0.2468	-0.7532

Palatability and behavioral responses of tamed elephants showed a negative correlation with leaf moisture content, but none of them were statistically significant. Therefore it is evident that the leaf moisture content did not have an effect on elephant palatability and behavioral responses when they were exposed to selected leafy materials.

427 ***Leaf ash content against palatability/ behavioral responses***

428 **Table 05** Estimated correlation between unusual palatability and behavioral responses against leaf ash content

Response	<i>p-value</i>	Correlation
1) Preference	0.7936	0.2064
2) Body	0.6405	0.3595
3) Ears	0.6208	0.3792
4) Head	0.5317	0.4683
5) Legs	0.7639	0.2361
6) Tail	0.5208	0.4792
7) Trunk	0.7350	0.2650

429 Palatability and behavioral responses of tamed elephants showed a positive correlation with leaf ash content, but none of
 430 them were statistically significant, revealing that the leaf ash content did not have an effect on elephant palatability and
 431 behavioral responses when they were exposed to selected leafy materials.

432 ***Leaf crude fat content against palatability/ behavioral responses***

433 **Table 06** Estimated correlation between unusual palatability and behavioral responses against leaf crude fat content

Response	<i>p-value</i>	Correlation
1) Preference	0.5441	0.4559
2) Body	0.4729	0.5271
3) Ears	0.9535	0.0465
4) Head	0.5386	0.4614
5) Legs	0.5365	0.4634
6) Tail	0.5495	0.4505
7) Trunk	0.4710	0.5290

434 Palatability and behavioral responses of tamed elephants showed a positive correlation with leaf crude fat content, but none
 435 of them were statistically significant, showing that the leaf crude fat content did not have an effect on elephant palatability
 436 and behavioral responses when they were exposed to selected leafy materials.

437 ***Leaf crude fiber against palatability/ behavioral responses***

438 **Table 07** Estimated correlation between unusual palatability and behavioral responses against leaf crude fiber content

Response	<i>p-value</i>	Correlation
1) Preference	0.8056	0.1944
2) Body	0.7568	0.2432
3) Ears	0.7391	-0.2609
4) Head	0.8462	0.1538
5) Legs	0.8037	0.1963
6) Tail	0.8595	0.1405
7) Trunk	0.7371	0.2629

439 Almost all palatability and behavioral responses of tamed elephants, excluding movement of ears showed a positive
 440 correlation with leaf crude fiber content. Although none of them were statistically significant, indicating that the leaf crude
 441 fiber content did not have an effect on elephant palatability and behavioral responses when they were exposed to selected
 442 leafy materials.

443 ***Leaf crude protein against palatability/ behavioral responses***

444 **Table 08** Estimated correlation between unusual palatability and behavioral responses against leaf crude protein content

Response	<i>p-value</i>	Correlation
1) Preference	0.3914	0.6086
2) Body	0.2737	0.7263
3) Ears	0.6178	0.3822
4) Head	0.2731	0.7269
5) Legs	0.3725	0.6275
6) Tail	0.2763	0.7237
7) Trunk	0.3143	0.6857

445 Palatability and behavioral responses of tamed elephants showed a positive correlation with leaf crude protein content.
 446 Although none of them were statistically significant, indicating that the leaf crude protein content did not have an effect on
 447 elephant palatability and behavioral responses when they were exposed to selected leafy materials. Based on the results of
 448 the above correlation analysis, it can be suggested that palatability and behavioral responses of tamed elephants did not
 449 show any significant association with leaf moisture, ash crude fat, crude fiber, and crude protein contents of selected
 450 elephant feeding materials.

3.2.4. Association between chemical compounds responsible for odor and palatability/ behavioral responses

Only the blended leaves were used for following correlation analysis since sensor measurements of blended leaves possibly suggests contrasting repellency of *P. longifolia*, compared to the rest of leafy materials. Further, aromatic compounds and ammonia (W3C) and sulphur and organic compounds (W1W), were significantly greater in *P. longifolia* than the rest of blended leafy materials and methane and aliphatic compounds (W3S) were comparatively higher in *P. longifolia* than fishtail palm and the grass mixture in blended form. In addition, aromatic compounds, inorganic sulphur compounds (W2W) were comparatively higher in *P. longifolia* than coconut and the grass mixture. Accordingly, obtained results of the correlation analysis for selected sensor measurements are described below.

Aromatic compounds and ammonia (W3C) against palatability/ behavioral responses

Table 09 Estimated correlation between unusual palatability and behavioral responses against aromatic compounds and ammonia (W3C)

Response	<i>p-value</i>	Correlation
1) Preference	0.6920	-0.3080
2) Body	0.8517	-0.1483
3) Ears	0.5492	-0.4508
4) Head	0.8796	-0.1204
5) Legs	0.7158	-0.2842
6) Tail	0.8799	-0.1201
7) Trunk	0.7897	-0.2103

Aromatic compounds and ammonia (W3C) level showed a negative correlation with elephant palatability and behavioral responses, but none of them were statistically significant, showing that the aromatic compounds and ammonia did not have an effect on elephant palatability and behavioral responses when they were exposed to selected leafy materials.

465 ***Sulphur and organic compounds (W1W) against palatability/ behavioral responses***

466 **Table 10** Estimated correlation between unusual palatability and behavioral responses against sulphur and organic
467 compounds (W1W)

Response	<i>p-value</i>	Correlation
1) Preference	0.8801	-0.1199
2) Body	0.9622	0.0378
3) Ears	0.8925	0.1075
4) Head	0.8419	0.1581
5) Legs	0.9101	-0.0899
6) Tail	0.8292	0.1708
7) Trunk	0.9383	-0.0617

468 Level of sulphur and organic compounds (W1W) showed a negative or otherwise positive correlation with elephant
469 palatability and behavioral responses, but none of them were statistically significant, showing that the level of sulphur and
470 organic compounds did not effect on elephant palatability and behavioral responses when they were exposed to selected
471 leafy materials.

472 ***Methane and aliphatic compounds (W3S) against palatability/ behavioral responses***

473 **Table 11** Estimated correlation between unusual palatability and behavioral responses against methane and aliphatic
474 compounds (W3S)

Response	<i>p-value</i>	Correlation
1) Preference	0.6194	-0.3806
2) Body	0.5902	-0.4098
3) Ears	0.2452	-0.7548
4) Head	0.4816	-0.5184
5) Legs	0.6069	-0.3931
6) Tail	0.4679	-0.5321
7) Trunk	0.6450	-0.3550

475 Level of methane and aliphatic compounds (W3S) showed a negative correlation with elephant palatability and behavioral
476 responses except for movement of the body, but none of them were statistically significant, showing that the level of
477 methane and aliphatic compounds did not effect on elephant palatability and behavioral responses when they were exposed
478 to selected leafy materials.

479 *Aromatic compounds and inorganic sulphur compounds (W2W) against palatability/ behavioral responses*

480 **Table 12** Estimated correlation between unusual palatability and behavioral responses against aromatic compounds and
 481 inorganic Sulphur compounds (W2W)

Response	<i>p-value</i>	Correlation
8) Preference	0.7381	-0.2619
9) Body	0.9011	-0.0989
10) Ears	0.9343	-0.0657
11) Head	0.9857	0.0143
12) Legs	0.768	-0.2320
13) Tail	0.974	0.0260
14) Trunk	0.8033	-0.1967

482 Level of aromatic compounds and inorganic sulphur compounds (W2W) showed a negative correlation with elephant
 483 palatability and behavioral responses except for movement of the head and tail, but none of them were significant, showing
 484 that the level of aromatic compounds and inorganic sulphur compounds did not effect on elephant palatability and
 485 behavioral responses when they were exposed to selected leafy materials. Based on the results of the above correlation
 486 analysis, it can be stated that palatability and behavioral responses of tamed elephants did not show any significant
 487 association with organic volatile compounds measured by the sensor array of PEN3 e-nose.

4. Conclusions

Response of wild elephants to leaf branches of *P. longifolia* showed a repellency characteristic by preventing their movement through usual elephant drives. Similarly, the responses of tamed elephants showed non-natural behavioral responses against *P. longifolia* irrespective of their age and sex. Observed body movements of elephants against *P. longifolia* were differed compared with other feeding plant species. Furthermore, *P. longifolia* had the considerably higher crude fat and crude protein levels. *P. longifolia*, on the other hand, had the lowest moisture content of the four feeding materials tested and falls between the other 03 feeding materials in terms of ash and crude fiber content. However, correlation study revealed that palatability and behavioral responses of tamed elephants had no significant correlation with leaf moisture, ash crude fat, crude fiber, and crude protein levels. *P. longifolia* had significantly higher levels of aromatic compounds and ammonia (W3C) and sulphur and organic compounds (W1W) than the remaining blended leafy materials. Methane and aliphatic chemicals (W3S) were found in higher concentrations than fishtail palm and the grass mixture. Furthermore, aromatic compounds and inorganic Sulphur compounds (W2W) were indeed higher in *P. longifolia* than in coconut and the grass mixture. Following the results of correlation analysis, it is possible to conclude that the palatability and behavioral responses of tamed elephants have no significant correlation with organic volatile compounds measured by the sensor array of the PEN3 e-nose. Consequently, it can be argued that leaf proximate parameters and relative levels of organic volatile compounds differed between *P. longifolia* and other selected leafy materials, but therefore did not imply that why *P. longifolia* is more repellent than the rest of leafy materials. However, the results of this study can be concluded that *P. longifolia* could be used as an effective mean to establish a bio-fence to mitigate HEC in Sri Lanka. As an outcome, it is required to reveal the precise chemical compound(s) responsible for elephant repellency along with an acceptable method of assessing isolated repellency of that substance. Future experiments ought to be focused on the extraction of responsible chemical compounds for the repellency, impacts on the environment by the plant and the effectiveness of a *P. longifolia* when stands as a bio-fence under natural environmental conditions.

Declarations

Funding

This work was supported by University Research Grant of University of Sri Jayewardenepura, Gangodawila, Nugegoda, Sri Lanka (Grant number: ASP/01/RE/TEC/2021/77).

Competing interests

The authors declare no competing interests. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Financial and non-financial interests

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Ethics approval

This is an observational study. The Research Ethics Committee of University of Sri Jayewardenepura, Sri Lanka has confirmed that no ethical approval is required, since the study methodologies are not making any harm to any individual animal involved. In fact, *P. longifolia* is a natural plant species and only the fresh leaf bunches were offered to each elephant, and if rejected, elephants were not allowed to ingest *P. longifolia* leaves.

510 **Authors' contribution:** Conceptualization, K.M.R.D. Abhayapala, R.N. Nugara, U. Kumarasinghe and N.
511 Dharmarathne; Data curation, K.M.R.D. Abhayapala, R.N. Nugara and U. Kumarasinghe; Formal analysis,
512 A.A.L.C. Perera; Funding acquisition, K.M.R.D. Abhayapala; Investigation, A.A.L.C. Perera; Methodology,
513 K.M.R.D. Abhayapala, R.N. Nugara and U. Kumarasinghe; Project administration, K.M.R.D. Abhayapala;
514 Software, A.A.L.C. Perera; Supervision, K.M.R.D. Abhayapala, R.N. and U. Kumarasinghe; Validation,
515 K.M.R.D. Abhayapala, R.N. Nugara and U. Kumarasinghe; Visualization, A.A.L.C. Perera; Writing: original
516 draft, A.A.L.C. Perera; Writing: review & editing, K.M.R.D. Abhayapala, R.N. Nugara and U. Kumarasinghe
517 All authors have read and agreed to the published version of the manuscript.

518 **Acknowledgments:** We would like to acknowledge Mr. K.B. Kotagama, Director General, Mahaweli
519 Authority Sri Lanka, administrative officers of Mahaweli System D, and the villagers in Nabadawewa for
520 their enormous support in collecting palatability responses of wild elephants. In addition, we thank Mr. B.G.R.
521 Siriwardene, elephant owner and the mahouts in Wewita, Bandaragama for allowing us to perform this
522 experiment with tamed elephants in a secure environment.

References

- Adak MF, Yumusak N (2014) Electronic Noses that are used in Academic Studies. Proceedings of 2nd International Symposium on Innovative Technologies in Engineering and Science: 1-12
- Ashis G (2003) Herbal folk remedies of Bankura and Medinipur districts, West Bengal. Indian Journal of Traditional Knowledge 2: 393-396
- Bell RHV (1984) The man-animal interface: an assessment of crop damage and wildlife control. Conservation and wildlife management in Africa: 387-416
- Berliani K, Alikodra HS, Masy'Ud B, Kusri MD (2018) Food preference of Sumatran elephant (*Elephas maximus sumatranus*) to commodity crops in human-elephant conflict area of Aceh, Indonesia. Journal of Physics: Conference Series 1116: 052015. <https://doi.org/10.1088/1742-6596/1116/5/052015>
- Bhagwati U (2003) Utilization of medicinal plants by the rural women of Kulu, Himachal Pradesh. Indian Journal of Traditional Knowledge 2: 366-370
- Bhattarai S, Chaudhary RP, Taylor RSL (2007) Plants used as fence and fuelwood in Manang district, Central Nepal. Scientific World 5: 107-111
- Blake S, Hedges S (2004) Sinking the flagship: the case of forest elephants in Asia and Africa. Conservation Biology 18: 1191-1202
- Calabrese A, Calabrese JM, Songer M, Wegmann M, Hedges S, Rose R, Leimgruber P (2017) Conservation status of Asian elephants: the influence of habitat and governance. Biodiversity and Conservation 26: 2067-2081. <https://doi.org/10.1007/s10531-017-1345-5>
- Campos-Arceiz A, Blake S (2011) Mega gardeners of the forest – the role of elephants in seed dispersal. Acta Oecologica 37: 542-553. <https://doi.org/10.1016/j.actao.2011.01.014>
- Dahanukar SA, Kulkarni RA, Rege NN (2000) Pharmacology of medicinal plants and natural products. Indian journal of pharmacology 32: S81-S118
- Dierenfeld ES (2006) Nutrition. In: Fowler M, Mikota SK (ed) Biology, medicine, and surgery of elephants, 1st edn. Blackwell Publishing, Oxford, UK, pp 57-66
- Faizi S, Khan RA, Mughal NR, Malik MS, Sajjadi KES, Ahmad A (2008) Antimicrobial activity of various parts of *Polyalthia longifolia* var. pendula: isolation of active principles from the leaves and the berries. Phytotherapy Research 22: 907-912. <https://doi.org/10.1002/ptr.2414>
- Fernando P (2015) Managing elephants in Sri Lanka: where we are and where we need to be. Ceylon Journal of Science (Bio. Sci.) 44: 1-11. <http://dx.doi.org/10.4038/cjsbs.v44i1.7336>
- Fernando P, De Silva MCR, Jayasinghe LKA, Janaka HK, Pastorini J (2021) First country-wide survey of the Endangered Asian elephant: towards better conservation and management in Sri Lanka. Oryx 55: 46-55. <https://doi.org/10.1017/S0030605318001254>
- Fernando P, Pastorini J (2011) Range-wide status of Asian elephants. Gajah 35: 15-20
- Goswami VR, Medhi K, Nichols JD, Oli, MK (2015) Mechanistic understanding of human-wildlife conflict through a novel application of dynamic occupancy models. Conservation Biology 29: 1100-1110. <https://doi.org/10.1111/cobi.12475>
- Graham MD, Notter B, Adams WM, Lee PC, Ochieng TN (2010). Patterns of crop-raiding by elephants, *Loxodonta africana*, in Laikipia, Kenya, and the management of human-elephant conflict. Systematics and Biodiversity 8: 435-445. <https://doi.org/10.1080/14772000.2010.533716>
- Hankinson E, Nijman V (2020) Asian Elephants: 15 years of research and conservation. Journal of Physics: Conference Series 1460: 012055. <https://doi.org/10.1088/1742-6596/1460/1/012055>

- Harsha VH, Hebbar SS, Hegde GR, Shripathi V (2002). Ethnomedical knowledge of plants used by Kunabi Tribe of Karnataka in India. *Fitoterapia* 73: 281-287. [https://doi.org/10.1016/S0367-326X\(02\)00078-3](https://doi.org/10.1016/S0367-326X(02)00078-3)
- Hoare RE(1992). Present and future use of fencing in the management of larger African mammals. *Environmental conservation* 19: 160-164. <https://doi.org/10.1017/S0376892900030642>
- Jayewardene J (1994) Elephant drives in Sri Lanka. *Gajah* 13: 30-39
- Jothy SL, Choong YS, Saravanan D, Deivanai S, Latha LY, Vijayarathna S, Sasidharan S (2013) *Polyalthia longifolia* Sonn: An ancient remedy to explore for novel therapeutic agents. *Research Journal of Pharmaceutical, Biological and Chemical Sciences* 4: 714-730
- Katkar K, Suthar A, Chauhan V (2010) The chemistry, pharmacologic, and therapeutic applications of *Polyalthia longifolia*. *Pharmacognosy Reviews* 4: 62-68. <https://doi.org/10.4103/0973-7847.65329>
- Kirtikar KR, Basu BD (1995) Indian medicinal plants. International Book Distributors, Dehradun, India
- Krishnamurthi A, Manjunath BL, Sastri BN, Deshaprabhu SB, Chadha YR (1969) The wealth of India: raw materials. CSIR New Delhi, India 8: 396
- Lavanya C, Rao BG, Ramadevi D (2018) Phytochemical and pharmacological studies on *Polyalthia longifolia*. *Pharmaceutical Science and Research* 3: 1-7
- Leimgruber P, Gagnon JB, Wemmer C, Kelly DS, Songer MA, Selig ER (2003) Fragmentation of Asia's remaining wildlands: implications for Asian elephant conservation. *Animal conservation* 6: 347-359. <https://doi.org/10.1017/S1367943003003421>
- Liu P, Wen H, Lin L, Liu J, Zhang L (2016) Habitat evaluation for Asian elephants (*Elephas maximus*) in Lincang: Conservation planning for an extremely small population of elephants in China. *Biological Conservation* 198: 113-121. <https://doi.org/10.1016/j.biocon.2016.04.005>
- Patwardhan B, Vaidya AD, Chorghade M (2004) Ayurveda and natural products drug discovery. *Current science* 86: 789-799
- Perera BMAO (2009) The human-elephant conflict: A review of current status and mitigation methods. *Gajah* 30: 41-52
- Phadnis AP, Patwardhan SA, Dhaneshwar NN, Tavale SS, Row TNG (1988) Clerodane diterpenoids from *Polyalthia longifolia*. *Phytochemistry* 27: 2899-2901. [https://doi.org/10.1016/0031-9422\(88\)80684-8](https://doi.org/10.1016/0031-9422(88)80684-8)
- Prakash TGSL, Wijeratne AW, Fernando P (2020) Human-elephant conflict in Sri Lanka: patterns and extent. *Gajah* 51: 6-25
- Raghunathan K, Mitra, R (1982) Pharmacognosy of indigenous drugs. Central Council for Research in Ayurveda and Siddha, New Delhi, India
- Rastogi RP, Mehrotra BN (1960) Compendium of Indian Medicinal Plants. Council of Scientific and Industrial Research, New Delhi, India
- Riddle HS, Schulte BA, Desai AA, van der Meer L (2010) Elephants - a conservation overview. *Journal of Threatened Taxa* 2: 653-651
- Santiapillai C, Wijeyamohan S, Bandara G, Athurupana R, Dissanayake N, Read B (2010) An assessment of the human-elephant conflict in Sri Lanka. *Ceylon Journal of Science (Bio. Sci.)* 39: 21-33
- Santosa Y, Thohari M (2011). Preferences and estimation of natural feed productivity of Sumatran elephant population (*Elephas maximus sumatranus* temmick, 1847) in special production forest (hpkh) elephant training center (plg) sebelat, North Bengkulu. *Media Konservasi* 16: 149-155
- Sashidara KV, Singh SP, Sarkar J, Sinha S. (2010). Cytotoxic clerodane diterpenoids from the leaves of *Polyalthia longifolia*. *Natural Product Research* 24: 1687-1694. <https://doi.org/10.1080/10236240902765301>
- Shoshani J (2005) Order Proboscidea. In Wilson DE, Reeder DM (ed) *Mammal Species of the World: A taxonomic and Geographic Reference*, 3rd edn. John Hopkins University Press, Baltimore, USA, pp 90-91
- Sitati NW, Walpole MJ, Leader-Williams N (2005) Factors affecting susceptibility of farms to crop raiding by African elephants: using a predictive model to mitigate conflict. *Journal of Applied Ecology* 42: 1175-1182. <https://doi.org/10.1111/j.1365-2664.2005.01091.x>
- Sukumar R (1990) Ecology of the Asian elephant in southern India. II. Feeding habits and crop raiding patterns. *Journal of Tropical Ecology* 6: 33-53
- Sukumar R (1992) The Asian elephant: ecology and management. Cambridge University Press, UK
- Sukumar R (2003) The living elephants: evolutionary ecology, behaviour, and conservation. Oxford University Press, UK
- Vancuylenberg BWB (1977) Feeding behaviour of the Asiatic elephant in south-east Sri Lanka in relation to conservation. *Biological Conservation* 12: 33-54. [https://doi.org/10.1016/0006-3207\(77\)90056-8](https://doi.org/10.1016/0006-3207(77)90056-8)

- White LJ, Tutin CE, Fernandez M (1993) Group composition and diet of forest elephants, *Loxodonta africana cyclotis* Matschie 1900, in the Lopé Reserve, Gabon. African Journal of Ecology 31: 181-199. <https://doi.org/10.1111/j.1365-2028.1993.tb00532.x>
- Williams AC, Johnsingh AJ, Krausman PR (2001) Elephant-human conflicts in Rajaji National Park, northwestern India. Wildlife Society Bulletin 29: 1097-1104. <http://www.jstor.org/stable/3784132>
- Yadav SR, Sardesai MM (2002) Flora of Kolhapur district. Shivaji University, Kolhapur, India
- .