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Insects Associated with *Terminalia brownii* Growing in Kitui, Baringo and Homa Bay Counties, Kenya: Implications on Tree Species Domestication

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Abstract: *Terminalia brownii* Fresen (Combretaceae) is widely grown as an agroforestry tree species in dry lowlands of Eastern-Africa. A study aimed to identify insects that interact with *T. brownii* in Kitui, Baringo and Homa Bay Counties of Kenya was carried to highlight the implication of these insects on domestication of *T. brownii* in the drylands of Kenya. Ninety *T. brownii* trees were randomly selected; thirty from each of the three counties and their GPS locations recorded. Baited insect traps were erected on branches of selected trees to capture visiting insects. Sweep nets and pan traps were used to capture flying insects on site at the time of trap inspection during day time. A cutting test on randomly selected immature and mature fruits was carried out. Collected data was analyzed using GENSTAT version 18 and descriptive charts were used to inform the differences in insect interactions with *T. brownii.* The beneficial insects encountered included Diptera (*Helina spp., Musca spp. and Orthellia spp.)*. Gall formation was frequent in Kitui region (70%) associated with Gall Wasps attack. Defoliation in Kitui County was higher, associated with Lepidoptera attack (60%). Cerambycidae and Curculionadae larvae were found in 58% of probed mature fruits in Kitui. Of the probed seeds, 12.8% had empty endosperms implying poor pollination levels. Baringo and Homa Bay had more full seeds (73% and 77% respectively) compared to Kitui (32%). This study informs on *T. brownii*-insect-interactions as one of the factors that influence successful tree domestication.

Keywords: *Terminalia brownii*, agroforestry, domestication and insects.

1. Introduction

Terminalia brownii Fresen is a deciduous, multipurpose tree on which livelihoods of communities in semi-arid regions of Kenya are dependent. The generic name comes from the Latin 'terminalis' (ending), and refers to the habit of the leaves being crowded at the ends of the shoots (Orwa et al. 2009).

1.1. Distribution of Terminalia spp.

Terminalia (Combretaceae) species, distributed in the tropics and sub-tropic regions, are famous for their usefulness in traditional medicine (Liu et al. 2009; Machumi et al. 2013). Terminalia brownii is among the major indigenous tree species which are widely distributed in drylands of East, Central and West Africa as they are drought tolerant (Beentje, 1994; Mosango, 2013; Orwa et al. 2009).

1.2. Service functions of T. brownii

Terminalia brownii has the potential of restoring woodland regeneration on degraded areas because it stabilizes soils and accelerates development of diverse flora and fauna where they have been planted (Loo et al. 2014; Jamala et al. 2013). Other service functions of *T. brownii* to communities include reduction of wind speed, weed control and the heavy leaf fall makes excellent mulch and soil enrichment. According to Orwa et al., 2009, leaves are suitable fodder for livestock. It's wood is used in a wide range of products such as timber, wood carving and hand tools among others (Beentje, 1994; Gibreel et al. 2013; Orwa et al. 2009). Decoctions and macerations of the stem bark and roots of *T. brownii* are used in traditional medicine for fungal infections and as fungicides on field crops and in traditional granaries in Sudan. *Terminalia brownii* is traditionally used in parts of Eastern and Central Africa (Mbwambo et al. 2007; Machumi et al. 2013;) as a remedy for malaria, yellow fever, diarrhea, ulcers, cough, hepatitis, stomach ache and sexually transmitted diseases (Plant Resources of Tropical Africa, Salih et al. 2017; Salih et al. 2018).

1.3. The Arid and Semi-Arid Lands of Kenya and indigenous trees planting

The Arid and Semi-Arid Lands (ASALs) of Kenya are characterized by naturally occurring woods/bushes with a few patches of plantations and trees growing on farm. However, population growth, expansion for agriculture and pasture/ grazing area and establishment of infrastructure is a major threat to Forestry/agroforestry in ASALS. Overexploitation of indigenous trees for their vast medicinal uses has also been found to hinder establishment of natural forests and trees on-farm. Forestry/agroforestry is a means of increasing food production and wood availability, hence playing a key role in alleviating poverty and livelihood improvement in dry lands. Indigenous trees in Kenya have gained much attention driven by a strong desire to restore the glory of forests in Kenya. A community forest association has begun planting indigenous trees in Elgeyo Forest in Kenya which has been depleted at an alarming rate. Excessive logging prompted the desire of local actors and farmers to rehabilitate a large section of Kapchemutwa forest with indigenous trees. They have so far planted 10 acres of indigenous trees with plans to eliminate exotic trees in the long run (https://www.the-star.co.ke/news/2018/06/11/indigenous-tree-planting-saves-face-of-depleted-elgeyo-forest_c1765182).

1.4. Interaction between insects and trees in different ecosystems

Organisms in a forest ecosystem interact in various ways. Insects and trees, being examples of the components of such an ecosystem also interact with one another both positively when they pollinate the flowers, and negatively, as in the case of feeding on the reproductive organs which are the flowers and seeds, interfering with its reproduction. Other positive ways include when they play the roles in nutrient recycling, eliminating sick or weakened trees and feeding on some of the more serious forest insect pests thus keeping their populations in check (Sebukyu and Mosango, 2012). Negative ways on the other hand include damage in stages of tree development that affect the ability of both natural forests and plantations to meet their management objectives (FAO, 2001; Nair, 2007). Insect pests that interact with *T. brownii* thrive well under warm, dry conditions and may also be harbored by other flowering plants apart from the desired crop (Hamba et al. 2014). According to Begoude Boyogueno (2009) many insect species are associated with *Terminalia* spp. but no widespread pest problems have been recorded. Previous studies have shown that not many insect pests are associated with *Terminalia* species; however, *Nanophyes Terminaliae* and *Carella rotundipennis* weevils have been reported feeding on flowers and developing fruits of *T. paniculata* in Kerala forest, India (Pillai and Chandrashekara, 2011). Recently in Kenya, outbreaks of defoliation in *T. brownii* have been recorded. Bulbs on young shoots, twigs and fruits of *T. brownii* are frequently reported in the drier parts of Kenya. Further, there is poor germination of *T. brownii* seeds even after pre-sowing treatments known to break seed dormancy. Poor germination of *T. brownii* seed has partly been attributed to infestation by insect pests (Mosango, 2013; Orwa et al. 2009); however, the authors did not attempt to identify them. Therefore, there is need for more studies to identify insect pests that infest *T. brownii* phenophases and their impact on seed viability. Some seeds have been reported to have holes on the surface others are too small in size while others are full but fail to germinate. Scanty research has been carried out to inform the interaction between insects and *T. brownii* which has become a tree of economic importance to Kenya especially in the drier parts.

1.5. Seeds of T. brownii

Terminalia brownii fruits are winged, smooth, greenish when young, purplish-red to brown when mature, broadly elliptic to ovate, apex obtuse to rounded, pedicel 0.5-0.7 cm long; endocarp woody, containing long and delicate seeds. The seed handling unit is the samara, which is very hard making the morphological seed difficult to extract.

1.6. Study justification

Previous studies have not highlighted the different insects associated with *T. brownii* which would recommend conservation of the insects involved, which by extension would affect production of food crops for improved livelihood of communities that heavily depend on *T. brownii.* Early detection of pest infestations and practices that promote predatory populations are important to minimize the impact of serious woodland tree pests; in agroforestry and also in natural plantations. Informing farmers on the need for conservation of the key pollinators will in return promote food crops production. Highlighting the issue of bulbing which hinders production of viable seeds will enable policy makers to come up with the best method of promoting resistant varieties of *T. brownii* in different regions of Kenya for increased fecundity of *T. brownii.* This will lead to improved production of *T. brownii* for livelihood improvement in the communities of drier parts of Kenya dependent on the tree. To minimize damage to fruits and seeds, it is important therefore to identify such pests and ensure Integrated Pest Management and conservation of pollinators for efficient domestication of *T. brownii* which will therefore ameliorate degradation state and increase tree cover in the drylands through on-farm tree growing.

1.7. Objective

To identify insects associated with *T. brownii* growing in Kitui, Baringo and Homa Bay Counties, Kenya and inform their implications on tree species domestication.

2. Materials and Methods

2.1. Study area

The study area was in three Counties (Kitui, Homa Bay and Baringo) which are in the drier parts of Kenya where *T. brownii* grows naturally onfarm and in natural forests.

Kitui County has a low-lying topography with arid and semi-arid climate (Government of Kenya, 2014) and is located between latitudes 0°10' and 3°0' South and longitudes 37°50' and 39°0' East. Falling between 400 m and 1800 m above sea level, annual temperatures range from 14°C to 34°C with the hot months between September - October and January-March. Rainfall distribution is erratic and unreliable with annual rainfall ranging between 250 mm and 1050 mm per annum. In the highlands of Kitui, farmers are involved in subsistence agriculture - mainly growing cotton, tobacco, sisal, mangoes, maize, beans, cassava, sorghum, millet and pigeon peas and also keep livestock (http://www.kenya-information-guide.com/kitui-county.html).

Homa Bay County is in the now defunct Nyanza Province between Latitude: 0° 40' 60.00" N and longitude: 34° 27' 0.00" E and 1166 meters elevation above the sea level. It has semi-arid climatic conditions with daily temperatures ranging between 26°C during the coldest months (April and November) and 34°C during the hottest months (January to March). The county receives between 250 mm and 1200 mm of rainfall annually, with the average annual rainfall estimated at 1,100 mm. It has two rainy seasons; March-April-May (long rains) and September to November (short rains) (http://www.kenya-information-guide.com/homa-bay-county.html).

Baringo County falls between longitudes 35°30' and 36°30' East and between latitudes 0°10' and 1°40' South in the former Rift Valley County (County Annual Development Plan, 2015/2016). It has two distinct weather patterns with temperatures in the southern part ranging between 25°C during the cold months (June and July) and 30°C during the hot months (January and February) while in the northern parts, temperatures range between 30°C to 35°C. The county receives between 1000 mm and 1500 mm of rainfall annually in the highlands and 600 mm in the lowlands. Baringo experiences two rainy seasons, namely; March to June (long rains) and November (short rains) (http://www.kenya-information-guide.com/baringo-county.html).

2.2. Selection of experimental trees

A total of 90 *T. brownii* experimental trees were used for this study. Thirty trees were randomly selected from the study sites in Homa Bay , Kitui and Baringo Counties and their GPS locations recorded during flowering stages.

Onsite visits were made from the flowering period through fruit maturation to second fruiting to document different activities by different insects at varying phenophases on the *T. brownii* canopies (flowers, leaves, branches, twigs, mature and immature fruits) and recorded. Trees with a height of between 7 m and 9 m and 4 m to 7 m crown width at the emergence of inflorescence were randomly selected in all field sites. Observations were carried out early in the morning and late evening to note visiting insects. Seasonality of insect visits onsite were noted based on the rainfall patterns of areas of study. Difference in phenophases in different sites was noted.

2.3. Data collection

Baited insect traps were installed on branches of marked trees. Inspections were done daily to collect the captured visiting crawlers, and other insects while noting the type of activity they were associated with, at two months interval. The baited traps composed of two plastic plates fitted with a thin muslin cloth and a supporting plate on top to shelter the collecting plate below and to suspend the trap vertically from the middle canopy. Sweep nets were used to capture flying insects on site at the time of trap inspection. Insect capturing was done between 6.00 am and 10.00 am and evening between 4.00 pm and 7.00 pm. Blue, red, yellow and green Pan plates were filled with water and detergent solution and placed in different positions around *T. brownii* trees to attract insects. Insects collected in sweep nets, baited traps and pan traps were preserved in 75% ethanol apart from Lepidoptera which were put in special insect envelopes to prevent deformation of important morphological structures like antennae which are of importance during morphological characterization. Containers with collected insect samples were well labeled and transported in cooler boxes to KEFRI entomology laboratories for morphological identification.

2.3.1. Assessment of insects in fruits using cutting test

A total of 300 fruits i.e. 10 fruits from each of 10 randomly selected trees per site; were selected at random, labeled and transported to entomology labs and stored through the Orthodox method for assessment. A hand lens was used to scan the surface of fruits and classify them as either probed or non-probed. The fruits were dewinged to allow for easy dehiscing using secateurs. A cutting test was conducted on all probed and non-probed fruits from each County. Presence or absence of an endosperm, presence of larvae or adult insect and other observations in the fruit were recorded in datasheets. Adults of encountered insects were curated for identification and storage at KEFRI-IRC. Live larvae were reared through incubation under temperatures of 24°C, humidity of 45% and fed with endosperms from mature seeds of *T. brownii* until eclosion into adults for identification. Dead larvae were identified, preserved in 75% ethanol, labeled and kept in the IRC. Data on the number of insects in the fruits, stages of infestation and type of damage caused in the cases of those found in the seeds was collected.

2.3.2. Morphological characterization of insects

Phenotypic characteristics of insects were used to place insects in different orders, families and genus and sometimes a specific name accorded different insects. This was with the aid of a collection of morphologically identified and preserved insect samples in the KEFRI Insect Reference Collection (IRC). Insects whose identity could not be verifiable at KEFRI were taken to the National Museums of Kenya (NMK) and British National History Museums (BNHM) for identification. Small sized insects were microscopically observed while a hand lens was used on larger insects. Lepidoptera were mounted on mounting boards to spread their wings for definite identification while forceps were used to hold other insects during identification.

2.4. Data analysis

Collected data was analyzed using GENSTAT version 18 and Microsoft Office Excel (Version 2010) computer software programs. Results were summarized in tables and graphs.

3. Results

3.1. Insects activities on T. brownii and their classification

3.1.1. Pollinators of T. brownii

Pollinators that dominated in the trees were Diptera which included: Muscidae (*Helina sp., Musca domestica, Musca lusori* and *Orthellia sp.*), Sarcophagidae (*Sarcophaga aethiopica, S. hirtipes* and *S. inaequalis*) and Syrphidae (*Eristalinus quinqielineators, Phytomia natalensis, Phytomia incise*) (Figure 1).

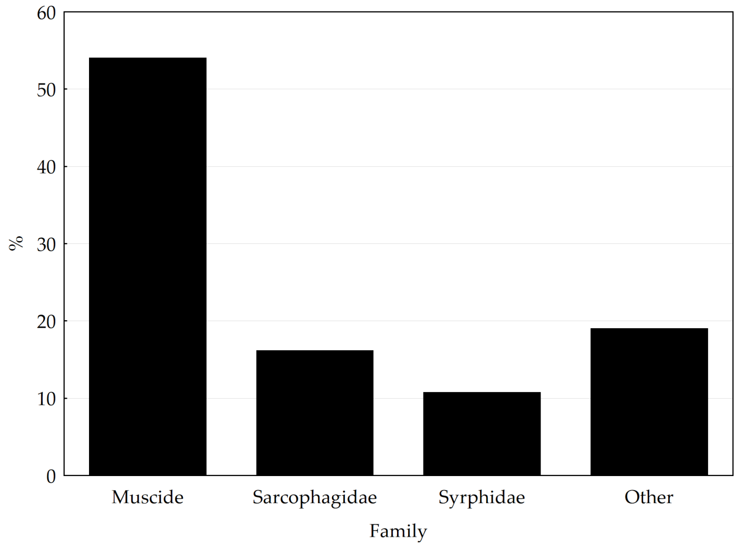

Figure 1. Diptera families found interacting with *T. brownii* in Kitui, Baringo and Homa Bay Counties.

Other Diptera families found interracting with *T. brownii* include; Therevidae, Tephritidae (*Campiglossa* sp.), Tachinidae (*Palexorista* sp.) and Calliphoridae (blow flies) (*Chysomya* sp. and *Stegosoma* sp.). Members of Apidae (honey bees) family captured onsite were *Anthophara* sp. and *Apis mellifera.*

3.1.2. Defoliators of T. brownii

Defoliation of *T. brownii* was more pronounced in Baringo compared to Kitui and Homa Bay Counties. Lepidoptera were the major defoliators (70%) represented by members of the Noctunidae (66%), Pieridae (13.2%), Nyphalidae (5.66%) families. Noctuidae family comprised of *Amyna octo, Amyna puctum, Erebus walker, Grammodes stolida, Archephia basilinea, Sphingomorpha chlorea* and *Spodoptera* spp. *Junonia hierta* and *Vanessa cardui cardui* represented the Nyphalidae family while *Eurema Brigitta* was the only Pieridae. Other families of Lepidoptera found onsite were Arctiidae, Crambidae (*Pyrausta incoloratii*), Cternichidae and Hesperiidae which constituted 15.1%. The other causes of defoliation in *T. brownii* were not identified in this study. Crambidae and some Noctunidae (*Amyna octo*) were collected on flowers (Figure 2).

3.1.3. Gall formers found attacking T. brownii

Galls were found at the tip of twigs and on immature fruits represented by bumpy swellings on the surface during the early stages of fruit formation. The condition was more severe in the Kitui region (70%) compared to other regions. Galls were induced by Hymenoptera of families Halictidae (*Lasioglossum sp* and *Lipotrichessp*), Scoliidae (*Hemipepsis isoptera* and *Scolia* *morio*), Sphecidae (*Ammophila bonae spei* and *Gastrosericus sp.*) and Formicidae which were in equal proportions (25%).

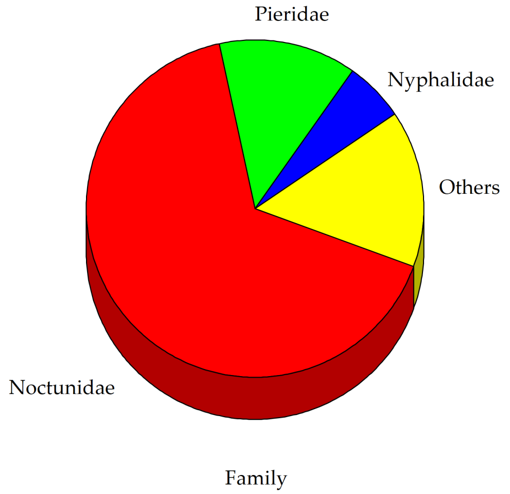

Figure 2. Defoliators that interact with *T. brownii* in Kitui, Baringo and Homa Bay Counties of Kenya.

3.1.4. Sap sucking insects that interact with T. brownii

The dominant (60%) sap sucking insects were the Agonoscelis versicolor (Hemiptera: Heteroptera: Penatatomidae) (Sunflower seed bug) while other families identified included the Cicadellidae, Fulgoridae, Lygaeidae and Miridae families.

3.2. Seasonality of the insects in T. brownii

Activities of Gall formers, sap-suckers, pollinators and defoliators were highest during the wet in the months of long and short rains. Fruit development takes about 5-6 months (Orwa et al. 2009). Results from this study showed that in Kitui; flowering, fruit formation and fruit maturation takes place in the months of November/December to August/September; while April/May to November/December applied for Homa Bay County. In Baringo County the respective phenophases takes place in the months of April to May, June to August, and September to November.

3.3. Fruits/seed borers in T. brownii

Full seeds were identified most (60.7%), followed by those that were unclear (17.1%). Probing of fruits was due to Cerambycidae and Curculionadae (seed feeding Scolytinae - Ambrosia beetles) families of Order Coleoptera attack; whose larvae were found in 58% of probed mature fruits in Kitui. Out of the probed seeds from the three counties of study, 12.8 % had empty endosperms with no signs of insect infestation as shown in table 1.

In the three study sites seeds that were empty, full and rotten were more rampant in seed batches studied. In Baringo those that were full were more (73.0 %), in Homa bay (77.0 %), while in Kitui (32.0 %) as shown in table 2.

Table 1. Different categories of seeds from cutting test results.

Cutting test	Number	Percentage of number tested
Full	182	60.7
Empty	32	12.8
Rotten	45	15.0
Larvae	11	11.0
Unclear	30	17.1

Table 2. Cutting test results per County.

Site	Cutting test	Sum of Count of Cutting test	Percentage of number tested
Baringo	Full	73	73
	Empty	12	12
	Rotten	14	14
	Unclear	1	1
Homa Bay	Full	77	77
	Empty	4	4
	Rotten	16	16
	Unclear	3	3
Kitui	Full	32	32
	Empty	16	16
	Rotten	15	15
	Larvae	11	11
	Unclear	26	26

4. Discussion

Pollination in *T. brownii* was majorly by flies in all the Counties in question which was in tandem with other studies whose results highlight that flowering is generally at the latter part of the dry season extending into the rainy season, in the seasonal East Africa from March-April – June with subsequent fruiting from October to November with pollination by insects, mainly flies (Schmidt, 2010). Pollination has a great effect on the yield of fruit trees with Blow flies considered as an effective pollinator (Saeed et al. 2016) in *T. brownii*. Galls are a reaction of cambium and other meristematic tissues to stimuli produced by the organisms are subsequently used by the organisms as shelter and food source and gives protection from parasites and predators (Muraghendra, 2014). In this study, insets found in the galls were dominated by Hymenoptera and these galls were found at the terminus of shoots during fruiting season. Sap-sucking insects feed on the sugary sap produced in foliage and transported in the soft phloem tissue beneath the bark and some insects' feeding affects plant growth hormones, causing distinctive foliage or shoot deformities called galls (US Forest Health Protection, 2011) which could have been the case in this study. Previous studies have shown that the majority of plant galls harm the host plant only by diverting plant resources and thus have little economic impact (Schick et al. 2009). *Sap*-sucking insects were dominated by members of order Hemiptera, which are known to vector certain plant diseases (US Forest Health Protection, 2011). Defoliation was subjugated by Lepidoptera, and moths being the frequent defoliators. Results showed that damage by native defoliators is frequently inflicted whenever native tree species have been used for plantations, often outside of their natural range which was in tandem with other studies. Native defoliating insects have been considered a threat to the forests since ancient time because of their periodic demographic explosions that have worried generations of forest managers and the public in general (Andrea et al. 2016).

Most of the *Terminalia brownii* fruits contained seeds without endosperms which suggested low pollination rates. Most of the probed fruits had no endosperms and most of those without endosperms had larval stages of Cerambycidae and Curculionadae larvae found to have bored the fruits and infested them. Cutting test results suggested that seeds from Homa Bay are more viable compared to seeds from other regions studied since most of seeds collected from this region had their endosperms intact. Results from this study highlighted poor pollination of flowers in Kitui County compared to other Counties since more seeds collected from Kitui region had empty and rotten endosperms.

5. Conclusion

1. Major observation made onsite was galling and bulb formation on younger twigs and on surfaces of immature fruits in Kitui region.
2. Low levels of pollination was highlighted which was marked by a higher number of empty endosperms in seeds collected from Kitui County compared to seeds from other Counties of study.
3. Seeds from HomaBay County followed by those collected from Baringo County were bigger morphologically and had more full seeds compared to seeds collected from Kitui County.
4. *Terminalia brownii* generally flower and seed in different seasonality in the three Counties of study.

6. Recommendations

1. More studies are required to know how these galled tissues are formed and what are the ecological factors affecting the galls formation and whether it is an adaptation strategy for the *T. brownii* trees mostly in Kitui County.
2. Conservation of biodiversity especially pollinators of *T. brownii* is paramount. This will lead to improved production of *T. brownii* for livelihood improvement in the communities of drier parts of Kenya dependent on the tree.
3. More studies are recommended to highlight the pollination services of *T. brownii* to food crops in an agroforestry setting and monitoring and evaluating degradation of the biodiversity in the regions planted with indigenous trees.
4. Research on other indigenous tree species morphology, phenology, propagation, utilization and sustainability for rehabilitation of the drier parts of Kenya which will enable achievement of the 10% forest cover by 2020.

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