Pollination of Strawberry in Kenya, by Stingless Bees *(*Hymenoptera:Meliponini*)* and Honey Bee *(*Hymenoptera:Apini*)* for Improved Fruit Quality

By

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DECLARATION

This thesis is my original work and has not been submitted to any other University for Award of a degree. All sources of information have been acknowledged.

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Signature

Date 29 July 2011

This thesis has been submitted for examination with our approval as University of Nairobi supervisors:

1. Dr. Gedion H.N Nyamasyo, Sign Date 02/08/2011

2. Dr. Wanja Kinuthia, Sign Date 29 July 2011

Dedication

To Nelly Junior, also known as Prince

You reminded us to water the plants and not to pluck the flower

You were, instead plucked from our midst before you plummeted

'Inspiration is aspiration, it starts early'

GA Asiko

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List of abbreviations/Acronyms

ANSTI	African Network of Scientific and Technological Institutions
ASAL	Arid and Semi Arid Lands
ADB-ALLPRO	ASAL- based Livestock and Rural Livelihoods Support Project
GIS	Geographic Information System
ICIPE	International Centre of Insect Physiology and Ecology
ILRI	International Livestock Research Institute
KARI	Kenya Agricultural Research Institute
MOLD	Ministry of Livestock Development
MOA & RD	Ministry of Agriculture and Rural Development
NALEP	National Agriculture and Livestock Extension Project
NEMA	National Environment Management Authority
NBS	National Beekeeping Station
NMK	National Museums of Kenya
NRC	National Research Centre, South Africa
POP	Provisioning and oviposion process
TON/HA/YR	Tonnes per Hectare per Year
UON	University of Nairobi
UNESCO	United Nations Educational, Social and Cultural Organization

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Abstract

The essence of pollination in crop and fruit production, for increased food production, in quantity and quality, is undisputed. A wide range of agricultural crops rely on pollinators, particularly bees for their pollination requirement. Strawberry, for instance, is self-pollinated, wind and bee-pollinated. The production of strawberry fruits is heavily dependant on efficient and effective pollination, such that when properly pollinated, the fruits become heart-shaped, suitable for market at premium prices. Besides pollination by honey bees, stingless bees and solidary bees are suitable alternative pollinators, in the wake of declining honey bee colonies, due to anthropogenic factors, hence declines in food production. Pollination studies in Africa have, in the past been initiated but abandoned due to prioritization challenges. The study aimed at testing the pollination efficiency of three stingless bee species (*Hypotrigona sp*., *Meliponula sp. Plebeina sp.*) and the honey bee, *Apis mellifera scutellata*, on two strawberry varieties, rotunda and chandler, in enclosures, in order to recommend their utilization by commercial farmers to increase horticultural production and for improved fruit quality. Specific objectives were: a) To determine the pollination efficiency of the selected stingless bee species and the honey bee, *Apis mellifera scutellata*, on strawberry plants in net enclosures, cages. b) To determine the quality and quantity of strawberry fruit production through stingless and honey bee pollination. c) To establish strawberry fruit variation due to: ecological zone, stem age, season, bee species, strawberry variety and crop husbandry. Experiments were set up in three ecological zones of Kenya, with differing Agricultural land productivity: Kakamega, high potential; Nairobi, medium potential and Kima, low potential. Using a randomized split block design, five stingless bee species, *Hypotrigona gribodoi*, *Hypotrigona ruspolii*, *Meliponula ferruginea*, *M. bocandei*, *Plebeina hildebrandti* and the honey bee, *Apis mellifera scutellata*, were tested for their suitability in the pollination of two strawberry varieties, rotunda and chandler. This was done on 6 x 11 Metre split plots. The study incorporated two control strategies: In the first control, strawberry cultivars were planted in the open with free pollination and could therefore be pollinated by self, wind or any other pollinator in the viscinity. In the second control, the study plots were enclosed by an insect net, to keep off would be pollinators, hence, no external pollinator was used such that only self pollination occurred. The total number of fruits harvested per day, their weight, size and quality classification, were used as the response variables, whereas bee species, strawberry variety and location, were the main explanatory variables. Rainfall and daily temperature data were recorded. Regression analysis revealed significant association between rotunda strawberry variety and bee species (d.f=6; $P<0.001$, 505). Similarly, between chandler variety and bee species (d.f =9; $P<0.001$, 2055). A chi-square test to establish association between fruit quality and stingless bee species, and fruit quality and strawberry variety, were both highly significant (d.f=21; $X^2 =62.95$; $P<0.001$ and d.f=7; $X^2 =2909$; $P<0.001$ respectively). Pearson chi-square test for association between strawberry variety and bee species was highly significant (d.f=7; $X^2=2909$; $p<0.001$). The mean number of fruits picked per day for chandler strawberry variety was 4, whereas that of rotunda was 2 (d.f 424; $P<0.001$). The study showed that strawberry variety and quality of fruits for, Kima and Nairobi sites were significant (d.f 3; $P=0.05$). There was high significant association between strawberry variety and quality of fruits for, Kakamega and Nairobi sites (d.f=3, $X^2=46.79$, $P<0.001$). The honey bee pollination improved fruit yield and quality. The Pearson Chi-square test showed significant association between strawberry variety and fruit class (d.f=3; P=0.05, 9.24). It further revealed significant association between quality of fruits and ecological zones (d.f= 3; X^2 =7.83; p< 0.050). There was significant seasonal effect on productivity of strawberry varieties (d.f=3; P<0.001,709). There was significant interaction between season and strawberry variety (d.f= 3; F<0.001, 3.82). Some bee species responded differently with change of environment, from endemic site to an introduced site (*Plebeina hildebrandti*, from Kima to Nairobi site). There was positive correlation between the number of fruits picked per day and the warm temperature (coefficient 7.5 with a p-value 0.04). Season and location were found to be important factors that influence the number of fruits picked per day. In conclusion, the two strawberry varieties, rotunda and chandler, require differrent stingless bee species for optimal pollination. *Hypotrigona species* were more efficient pollinators of strawberries than *meliponula* and *plebeina species.* It was recommended that farmers in Kakamega be advised to cultivate chandler strawberry variety for increased food and nutrition security, whereas those in Kima should cultivate rotunda, since it is capable of withstanding stress conditions, to some extend, as opposed to chandler variety. Farmers in Nairobi may cultivate both, rotunda and chandler, and use the bee species best adapted to the climatic condition for their pollination requirement.

CHAPTER ONE

1.0 GENERAL INTRODUCTION

Pollination is a vital biological process for improved quantity and quality crop and fruit yields (Connor, 1970; Crane, 1985; Bradbear, 2009). Many pollinating agents are involved in the process of pollen transfer from the anther to the stigma, especially insects (Roubik, 1995). Insect pollinators play a complementary role in obtaining maximum fruit-set (Free, 1968; Thomson, 1971; Connor, 1972; Pion *et al.,* 1980). A large number of fruits and vegetables such as: apples (*Malus domestica* Linneaus), cherries (*Prunus avium* Linneaus), pears (*Pyrus communis* Linneaus), plums (*Prunus* spp.) strawberries (*Fragaria x ananassa* sp.*)*, cucumbers (*Cucumis sativa* Linneaus.*)*, sweet pepper (*Capsicum annum* Linneaus*)*, egg plant (*Solanum melongena* Linneaus), kales (*Brassica spp.* Linneaus*)*, tomatoes (*Lycopersicon esculentum* Linneaus), pumpkin (*Cucurbita pepo* Linneaus*)*, avocado (*Persea Americana* Linneaus*)*, pawpaw (*Carica papaya* Linneaus*)*, onions (*Allium cepa* Linneaus), garden peas (*Pisum sativum* Linneaus*)*, french beans (*Phaseolus vulgaris* Linneaus) and water melons (*Citrulus lanatus* Thunb. Mansf.), are bee pollinated, of which honey bees are the most studied. Stingless bees and solitary bees are equally becoming recognized as essential and specialized pollinators, other than the honey bee (Jaycox, 1979; Sellers, 2007).

1.1 Worldwide valuation of honey bee pollination services

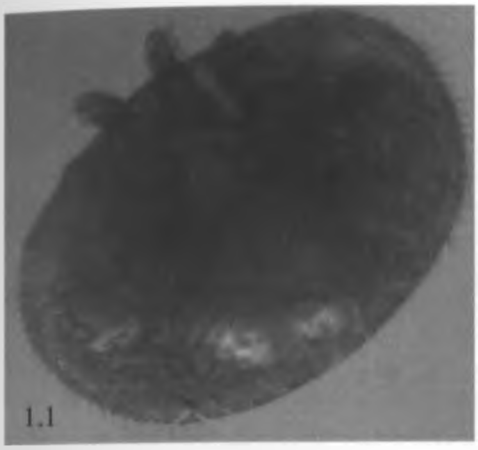
Valuation of honey bee pollination to crop yields reveal: $US 238.9 Billion worldwide (Gallai *et al.*, 2009). Earlier valuation had revealed: $US 312 Million in the United Kingdom, in 1998, $US 0.78 Billion in Canada, in 1998, $ US 14.6 Billion in USA, in the year 2000 and $US 2.4 Billion in Australia, in 2001 (Kevan *et al.*, 2006). The question of the value of honey bees in pollination is however complex (Southwick and Southwick, 1992; Kevan and Phillips, 2001; Rucker *et al.*, 2003 and NRC, 2006).

More than 80% of all angiosperms rely on insect pollination, most of which is done by bees. There are an estimated 30,000 bee species in the world. The honey bee, *Apis mellifera* Linnaeus, is an efficient and effective pollinator. Evidence from cage experiments showed that honey bee pollination increase yields and reduce the proportion of malformed fruits (Sannino and Priore, 1979; Moeller and Koval, 1973; Nye and Anderson, 1974; Goodman and Oldroyd, 1988). Moore (1969), found that caging strawberries to exclude insects reduced yields, 32 to 71 % in 4 years of tests. About 48% of the berries in the cages were deformed compared with only 15% on plants in the open. Free (1968), demonstrated that pollination by bees increased the percentage of flowers that set fruit, the weight of the individual berries, and the percentage of well-formed berries (quality). Connor and Martin (1973) observed that 53% of strawberry fruit set was due to selfing alone, 67% selfing plus wind and 91% all factors, including insects. Honey bees improved yields by 19-22% (Connor, 1970). Bees are essential for the best strawberry pollination in the field (Darrow, 1966), particularly on the primary bloom. Experience however has shown that using honey bees to pollinate early flowering crops in greenhouses is particularly likely to harm the colonies. Consequently, efforts are made to use colonies whose destruction will be of no great loss (Sommeijer and Ruijter, 2000).

1.2 Use of honey bee as a pollinator in enclosures

There are limitations in the use of honey bees, *Apis mellifera,* for greenhouse pollination. Honey bees in greenhouses attempt to forage outside, through open windows, when the crop inside is less attractive compared to the plants outside the greenhouse (Dag and Eisikowitch, 1999, Delaplane and Mayer, 2000). They are maintained in large colonies which restricts their use at small scale and under conditions with low food reward. Because of their relatively large body size, only a certain number of flowers are accessible to them without actual damage. Honey bees also have a tendency to transfer, during the flower visiting flight, the pollen collected in the hairs on the body quickly to the pollen baskets on the hind-legs. In temperate regions, honey bees have a definite seasonal cycle with a long inactive period, which makes them less suitable for the pollination of off-season crops and they have a swarming period during which about half the colony leaves the nest. At present, the management of beehives is world wide handicapped by: (a) Varroa mites, *Varroa destructor*, which is an important vector for many viral honey bee diseases (b) American Foul Brood, caused by the bacterium, *Paenibacillus larvae* (c) Chalk brood, *Ascosphaera apis*, and other serious brood diseases (d) Anthropogenic factors, such as bee habitat loss, as a result of environmental destruction and innappropriate use of Agricultural chemicals, toxic to beneficial insects, honey bees inclusive, leading to the current 'colony collapse disorder,' (Johansen and Mayer, 1996, Slaa *et al.*, 2006; Bradbear, 2009).

Varroa mites are external honey bee parasites which attack both adult bees and brood, with a distinct preference for drone brood. They suck the haemolymph of adult bees, thus weakening the colony, with the subsequent death, if left untreated. Emerging brood may be deformed, with missing legs or wings (Bessin, 2001).



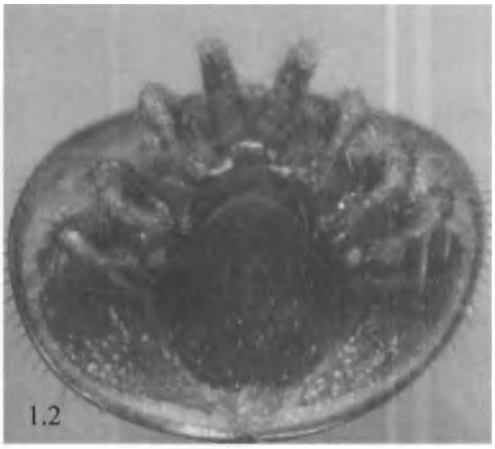


Plate1: 1.1 and 1.2: *Varroa destructor* x16 – Dorsal and Ventral view, respectively, revealing the appendages and sucking Parts. Photo: Asiko G.A, July 2010

Varroa destructor was first detected in experimental hives in Kenya in the year 2007. Field surveys, jointly conducted by ICIPE, Pennislyvania State University, USA and the Ministry of Livestock Development, in the year 2009, confirmed the presence of the mites in the following parts of Kenya: Mwingi, Makueni, Machakos, Meru, Isiolo, Kakamega, Taita hills, Kwale and Kilifi (Muchoki *et al.*, 2011). The phenomenon has attracted Veterinary attention and multi-disciplinary teams, including the National Beekeeping Station, have been set up to develop possible strategies to help curb the spread of the mite.

Figure1 shows the declining honey production trend in Kenya, which is a clear indication of reduced bee population (Beekeeping annual report, 2009). Production from the year 2005-2006 depicts a normal fluctuation. The trend from the year 2007-2008, however, shows the 'Colony Collapse Disorder,' caused by factors extrinsic or

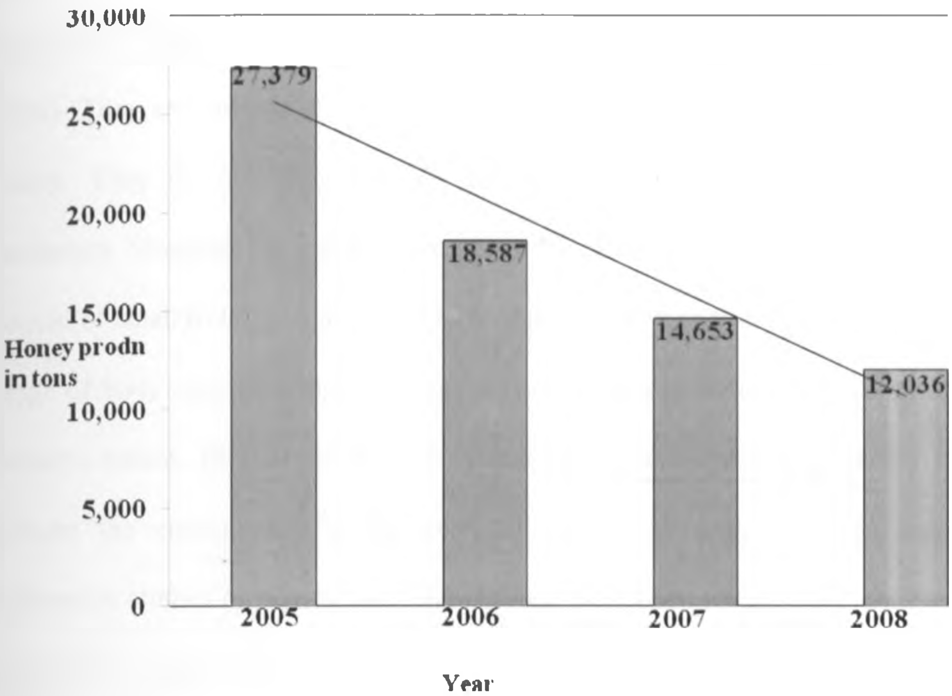


Figure 1: Declining honey production trend in Kenya between 2005-2008. Ref: Beekeeping Annual report, 2009

intrinsic to the colony (Sommeijer & Ruijter, 2000; Sellers, 2007). The escalating management and rental costs for honey bee pollinating colonies calls for conservation of wild native pollinators, adapted to local conditions, as alternative pollinators to the outstretched honeybee.

1.3 Stingless bee pollination prospects

Stingless bees (*Melipona sp. and Trigona sp.*) are suitable alternative pollinators to the honey bee, in enclosures, with high economic prospects (Michener, 1974; Roubik, 1989; Kakutani, 1993; Heard, 1999; Sommeijer and Ruijter, 2000; Mumbi, 2001; Asiko, 2004; Asiko *et al.*, 2007). Stingless bees orientate quickly and forage efficiently in enclosures (cages), at a flight range of 0.5-1.5 Km for *Hypotrigona spp.* and 1.5-2.5 Km for *Melliponula spp*, compared to the flight range of 5 Km radius for honey bees (Roubik and Aluja, 1983). They are resistant to the known diseases and parasites of the honey bee, though they are very susceptible to pesticides (Slaa *et al.*, 2006). They are easy to manage through artificial feeding on pollen substitute and honey. They do not sting humans and animals, hence easily accepted by the beekeeper. Stingless bee colonies are perennial, lasting for more than one year. They consist of small to large numbers of individuals, according to the species, with a wide range of body size. Although they are poly-lectic, the individual worker tends to be flower constant. This means that one species can be used for a large variety of crops without the consequence of reduced pollination efficiency. A large number of pollination studies of Agricultural significance have been initiated but not completed in Africa. A survey and some work on stingless bees in Kenya had been conducted, mainly in dry areas (Gikungu 2006; Gikungu and Njoroge, 2006; Kioko *et al.*, 2006). Local studies approved stingless bee domestication (Meliponiculture) and conservation as being able to make significant contribution to food security and household income (Martins *et al.*, 2003; Kinuthia, 2007). With the growing need to increase horticultural production within and outside greenhouses and in enclosures, there is need to identify and utilize appropriate stingless bee pollinators in their required densities, for efficient and effective pollination in Kenya.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Bee classification and global distribution

2.1.1 Classification

Bees are grouped under the Phylum Arthropoda, Class Insecta, Order Hymenoptera. They belong to the Super-family Apoidae and Family Apidae (Borror *et al.*, 1976, Michener, 1990, 2000, 2007).

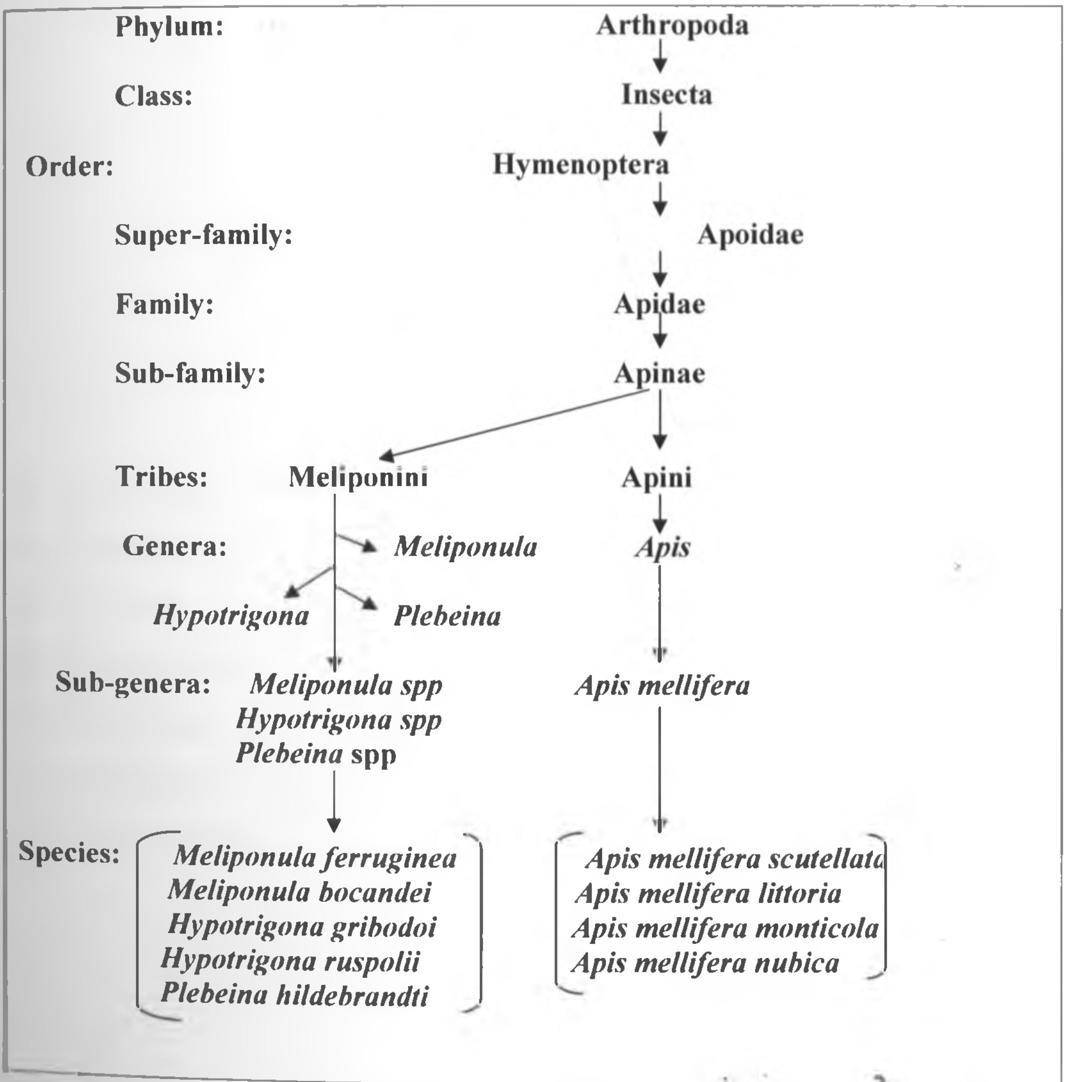


Figure 2: Classification of the study bee genera and species. Michener, 2000

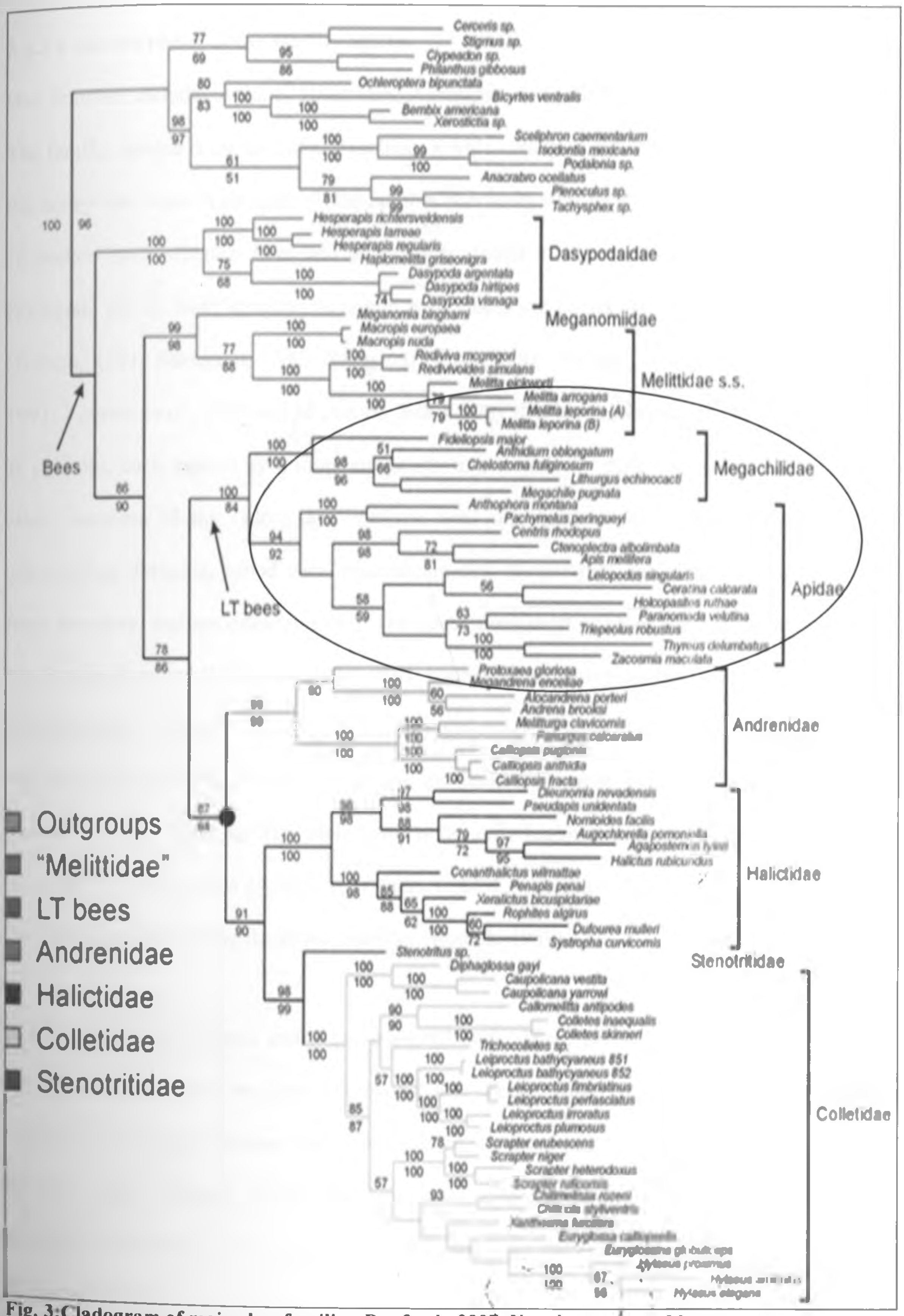


Fig. 3:Cladogram of major bee families. Danforth, 2007. Note long tongued bees

2.1.2 Characteristics of the family, Apidae

Bee families include: Apidae, Halictidae, Adrenidae, Megachilidae and Colletidae. The family, Apidae is the largest and includes a wide variety of native bee species and the honey bee, Apis. It includes all the bumble bees, carpenter bees and some species of cuckoo bees, stingless bees and orchid bees, found in the tropics (Moisset and Buchman, 2011). Both stingless bees and honey bees are social and honey making (Wilson, 1971; Sakagami, 1982; Sakagami *et al.*, 1983; Velthuis, 1990; Winston, 1991; Yamane *et al.*, 1995 and Michener, 2000). They live in social cohesions known as colonies, each headed by a morphologically and trophically different queen. The other members of the colony are workers, who do most or all the work (nest construction, foraging, brood care, maintaining nest temperature, guarding the nest from intruders) and are often unmated. The queen does most or all of the egg laying and is usually mated (Michener, 2007). Both honeybees and stingless bees, belong to the Sub-family, Apinae. The differences between stingless bees (Tribe, Meliponini) and honey bees (Tribe, Apini), are notable, particularly in caste differentiation and manner of comb building. The Meliponini is the only highly social bee tribe other than the true honey bees (Apini). It is characterized by multiple layers of cerumen (involucrum) surrounding the brood chamber (Roubik, 1989).

Apini (Apis) has corbicula and 3 sub-marginal cells. There is only one species in Africa and Europe, *Apis mellifera* Linneaus. Other species, *Apis cerana, Apis dorsata* Fabricius, *Apis florea* Fabricius, *Apis laboriosa,* occur in the east (Borror *et al.*, 1976; Roubik, 1989; Kraemer, 2010). The honey bee races found in Kenya are: *Apis mellifera scutellata*, *Apis mellifera littoria*, *Apis mellifera monticola* and *Apis mellifera nubica.*

Meliponini (stingless bees) have corbicula and less than 3 sub-marginal cells. There are 6 genera of stingless bees: *Cleptotrigona* (corbicula and antennal sockets below middle of face), *Dactylurina* (slender bee with convex corbicula and 2 sub-marginal cells), *Hypotrigona* (corbicula, 1 sub-marginal cell and long propodeum), plate 11-13 and 25; *Liotrigona* (corbicula, I sub-marginal cell and short propodeum), *Meliponula* (spoon-shaped corbicula and 2 sub-marginal cells, Plate 9-10, 13-12, 25-28) and *Plebeina* (flat corbicula and 2 sub-marginal cells), Plate 8, 12, 25 and 29.

2.2 Stingless and honey bee biology

Among the social bees, the Meliponini, or stingless bees, form an important group, rich in species and in the variation in which their sociality is expressed (Wilson, 1971, Velthuis, 1990). Stingless bees, like Honey bees, attain the highest level of social evolution. They live in colonies and multiply through localized swarming, where by bees move to and occupy a neighbouring hive, unlike in the honey bee, where swarming is not necessarily localized, plate 2 and 4.

In stingless bees and honey bees, queens and workers are diverged in their morphology and specialized in their tasks (Winston, 1991, Michener, 2007). Bee species can be distinguished according to morphological characters (wing venation, hind leg structure and presence of hairs) and social behaviour characteristics (the way brood cells are arranged, how queens are reared, how bees communicate).

Stingless bees use mass provisioning and are characterized by 'provisioning and oviposition process, the 'POP.' to distinguish them from progressive provisioning exhibited by honey bees and bumblebees (Velthuis, 1997). In the stingless bees, there is no contact between the adult population and the developing larvae. The production of a new individual begins with cell construction. New brood cells are added at the margin of the comb, or, in case of having cell clusters, at the margin of the brood nest. In *Plebeian* species, many cells are constructed and provisioned simultaneously. The brood cells, like in most stingless bees, are arranged in horizontal combs, surrounded by several layers of waxy sheets, the involucrum, which provide insulation.

In the tiny African stingless bee, *Hypotrigona gribodoi* species, brood cells are arranged in clusters (Plate 21). Adjacent are the large storage pots for nectar and pollen. Other African stingless bees include: *Meliponula* species where a mass of involucrum separate brood area, pollen and honey pots, *Plebeina* species, which is characterized by extensive connectives and involucrum, covering brood area. There are isolated storage pots for pollen and honey. Colony loss in stingless bees due to migration as it happens in Honey bee swarms is not possible. Thus, stingless bees' movement is localized hence an advantage to colony multiplication.

2.2.1 Honey bee behaviour

The behavioural characteristics displayed by honey bees include: Migration, absconding and swarming. The latter is the natural way of reproduction in honey bees through which colonies multiply, Plate 4. Honey bees too may drift from one colony to another, where they are attacked and mauled out of the hive. In some instances, particularly when loaded with food resource, they are accepted (Kigatiira, 1986). Supercedure, the art of replacing a queen in an existing honey bee colony when the old queen's fecundity rate reduces or when she gets injured, is a common phenomenon, occuring widely in honeybee colonies.

Plate 2: Bee dances. The bee at the centre, bd, is dancing ferociously after spotting food resource. Photo: Asiko G.A, 2008

2.2.1.1 Honey bee behaviour in the net enclosure

Plate 3: Ethological observations. The honey bee struggles to move out of the enclosure through any possible opening. Photo: Asiko G.A, 2008

2.2.1.2 Swarming in honey bees

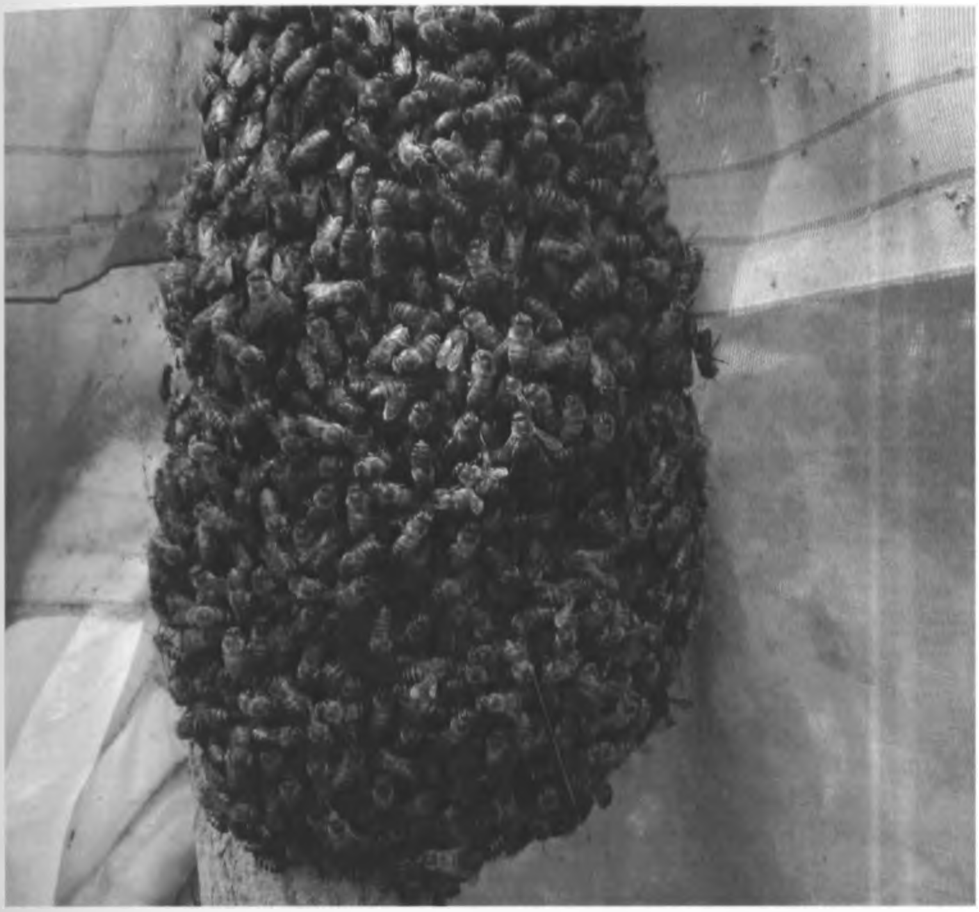


Plate 4: A swarm of bees, Apis mellifera scutellata. Foraging, particularly of nectar, continues, despite the clustering. Photo: Asiko G.A, 2008

Most honey bee colonies are kept in man-made hives. The colony composition comprises of: The queen, the progenitor and perpetuator of the colony, with her prolific egg laying ability; drones for mating with queens from other colonies; workers, best known for their altruism and literary performing all tasks of cleaning, feeding the queen, drones and brood, building combs, foraging, guarding the hive and maintaining the hive temperature. Escaped swarms, Plate 4, usually nest in hollows of trees, Plate 7.3 and 7.4. The colony continues to function normally. The scout bees are defensive. The foragers source for nectar and pollen, mainly, Plate 2 and 4. The queen is super-guarded. When there is no leakage for escape, the swarm finally returns to the previous hive, within the enclosure. Swarming is the natural way of reproduction in honey bees. It usually takes place when conditions for brood rearing are ideal, leading to an increase in hive population. The resultant congestion triggers the swarming impulse, whereby swarm cells are produced. Incase of two queens, one, usually the older, leaves the hive with a group of workers, almost half the bee population in the hive, to build a nest elsewhere (Borror et al., 1976).

2.2.2 Stingless bee species in Kenya

Major Meliponini genera in Kenya include: *Hypotrigona*, *Meliponula* and *Plebeina*, with focus species, *Hypotrigona gribodoi*, *Hypotrigona ruspolii*, *Meliponula ferruginea*, *Meliponula bocandei* and *Plebeina hildebrandti* (Raina *et al.*, 2010).

Stingless bee nests are abundant in Kenya, especially in undisturbed areas with natural habitation such as forests, grass and tree savannah. The stingless bee species are largely identified by tunnel length and nest entrance shape (funnel-shaped for *Hypotrigona spp* and oval-shaped for *Meliponula spp*. Plate 12, besides habitation locality, Plates 7: 7.1-7.6. The stingless bee species in Kakamega forest, an area with high stingless bee nest abundance include: *Meliponula ferruginea*, medium in size with body length 8-9 mm; black or black with a red metasoma, appearing grey because of the white vestiture, when viewed with the naked eye; the black *Meliponula bocandei*, biggest with body length 6.5-8 mm and 2.6 mm head length, with orange vestiture, a largely black face, yellowish-orange scutellum and spoon-shaped hind tibia; *Hypotrigona gribodoi*, the smallest stingless bee with 2-3 mm body length; *Hypotrigona ruspolii*, small with 4 mm body length and *Plebeina hildebrandti*, smaller than than meliponula ferruginea (Michener 2000, 2007). In Makueni area, also rich in stingless bee nest abundance, the most common stingless bee species is: *Plebeina hildebrandti* (yellow in colour) and *Hypotrigona* species (Asiko et al.,2007). Other recently identified species are: *Meliponula lendliana* Moure (with a spectacular, upper level, nest entrance, body size, 4.5-7.0 mm) and *Dactylurina* species. Elsewhere, in other areas, the species are replicated.

2.2.3 Other bee species

There are numerous other wild solitary bees which are excellent crop pollinators, besides honeybees, which nest individually in the soil and elsewhere (Jaycox, 1979). A solidary mining bee, *Andrena melanochroa*, for instance, is a highly effective strawberry pollinator, visiting only strawberries (Jaycox, 1970). Most bumble bees (Bombini), many sweat bees (Halictinae) and carpenter bees (Xylocopinae) may live in small colonies, mostly started by single females working as solitary individuals, performing all necessary functions of nest construction, foraging, provisioning cells or feeding larvae progressively and laying eggs. Colonial life may arise later, including division of labour between the queen and workers. These are primitively eusocial colonies. Queens and workers are essentially alike morphologically, although often differing in size. They differ more distinctly in physiology and behaviour. Such colonies usually break down with production of reproductives. The colonies are thus obligately temporary rather than potentially permanent, like those of highly eusocial bees (Michener, 2007).

2.2.4 Global distribution of stingless bees

Stingless bee distribution extend from 32°S to 38°S in South America and Australia, respectively; 28°S in Africa and a little beyond the tropic of Cancer, in the Northern hemisphere. These include: South and Central America, including Mexico; Sub-Saharan Africa; India; Southern China and Australia. Today, over 600 species in 56 named genera live in tropical and sub-tropical areas of the world and 400 known species exist in the Neo-tropical region. It is estimated that there are more than 100 species yet to be described (Cortopassi-Laurino, 2006). There are 128 Sub-Saharan bee genera, of which 83 have been revised and 24 under review (Eardley, 2002).

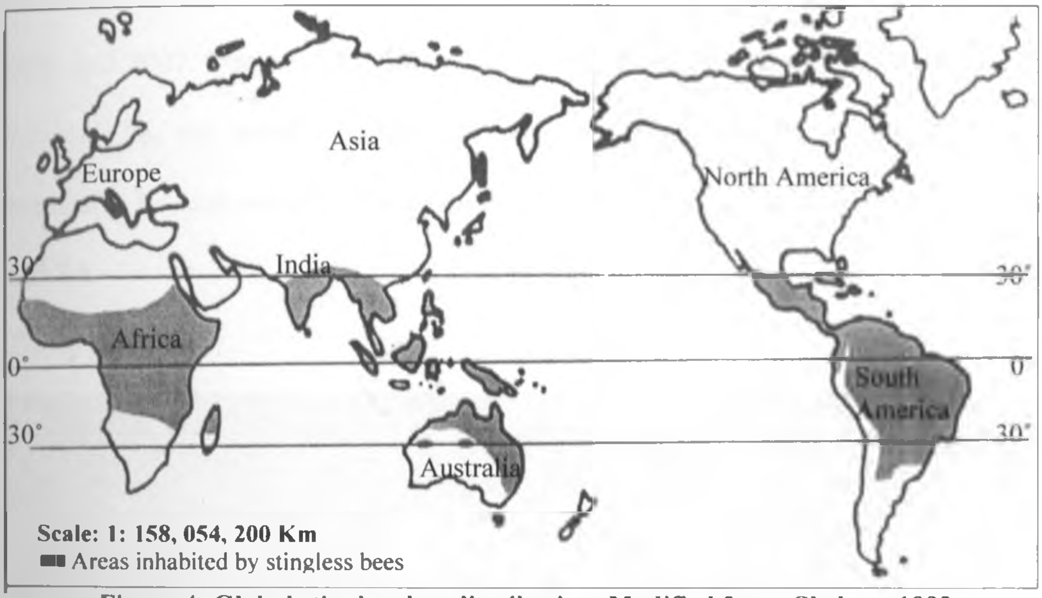


Figure 4: Global stingless bee distribution. Modified from, Skelton, 1993

2.3 Bee habitation

Some members of the larger families, Apidae, Adrenidae, Halictidae, Megachilidae and Colletidae, are ground nesters, Plate 5 and 7.6. They excavate a long tunnel, slightly wider than their own bodies (Moisset and Buchmann, 2010), Plates 7.6 and 12. Most bee species occupy existing holes and cavities, made by beetles or other insects in dead wood, Plate 7: 7.4 and 7.5. The bees may limit the nest space by walling off unused areas. Such walls are part of the batumen that typically surrounds the nest, Plate 8: 8.2, and are called, "batumen plates" (Roubik, 1989). Feral colonies of both stingless and honey bees live in hollow crevices in the soil (fossilial and subterranean, Plate 5, 7: 7.1 and 7.6, or in the trees (arboreal and aerial), Plate 7: 7.2-7.5). At times, nests are found in rock crevices and hollow walls of buildings (Velthuis, 1997; Michener, 2007). Honey bees have long been domesticated in well designed hives to maximize on honey production, though there are still abundant colonies in undisturbed habitats. Nests of most Melipona species, particularly *M. bocandei*, are found in tree cavities, Plate 7: 7.3 and 7.4, and in the ground (Michener, 2000 and 2007, Muthuraman, 2002). Abandoned terrestrial termite mounds, Plate 7: 7.1 and 7.6, are suitable habitats for most of the ground-nesting stingless bees, especially *P. hildebrandti*. *Hypotrigona species* are mostly tree nesting, Plate 7: 7.2 and 7.5.

Plate 5. Undisturbed nest entrace, ne, actual size, in Kima area of Makueni, Eastern Kenya. Photo: Asiko G.A, 2007

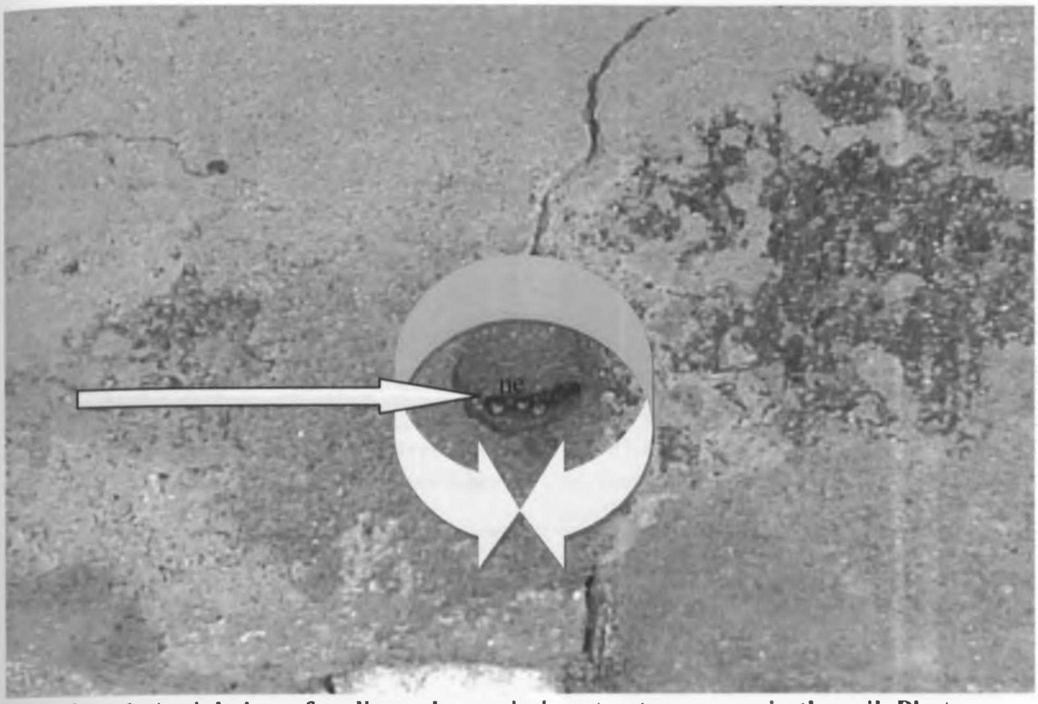


Plate 6. Aerial view of meliponula species' nest entrance, ne, in the soil. Photo: Muthuraman M, 2002

In search for wild bee colonies, whole trees are chopped when harvesting feral colonies of the tree nesting bee species (Plates 7: 7.3 and 7.4), and chunks of soil are truncated and dug as far as 7-15 metres, Plate 6, to secure honey from the ground-nesting (subterranean bee species).

Plate7.1: Abandoned termite mound, a suitable habitat for *P. hildebrandti*

Plate7.2: Hollows in a living tree, suitable for *M. bocandei* and *H. gribodoi*

Plate7.3: Cavity in a dried up tree trunk, suitable for *M. bocandei, Hypotrigona* species and *Apis mellifera scutellata*

Plate7.4: Cavity in a rotting log, suitable for *M. bocandei, Hypotrigona* species and *Apis mellifera scutellata*

Plate 7.5: Tunnel from a roof pole, suitable for *Hypotrigona* species

Plate 7.6: Tunnel from the soil, typical of *P. hildebrandti*

Plate 7: 7.1-7.6, stingless and honey bee habitats. Photos: Asiko G.A, 2008

2.4 Floral needs and suitable ecologies for honey bees and stingless bees

The first flowering plants evolved 125 Million years ago. Each flowering plant species has a small guild of bees and other pollinators which co-evolved with them to ensure their pollination (Moisset and Buchman, 2010). Typically, bees collect nectar from a wider range of blossoms than they will for pollen. Some bees, such as bumble bees, are generalists in foraging habits, and use pollen from a wide variety of flowering plants. Other bees have some degree of specialization in foraging. They utilize pollen from only one or two families of flowering plants. Squash bees are efficient visitors and pollinators of cucurbit plants. Apidae is the largest bee family and includes a wide variety of native bee species including the honey bee, *Apis mellifera*.

2.5 Stingless bee variability and hive architecture

2.5.1 Hive architecture: *P. hildebrandti*

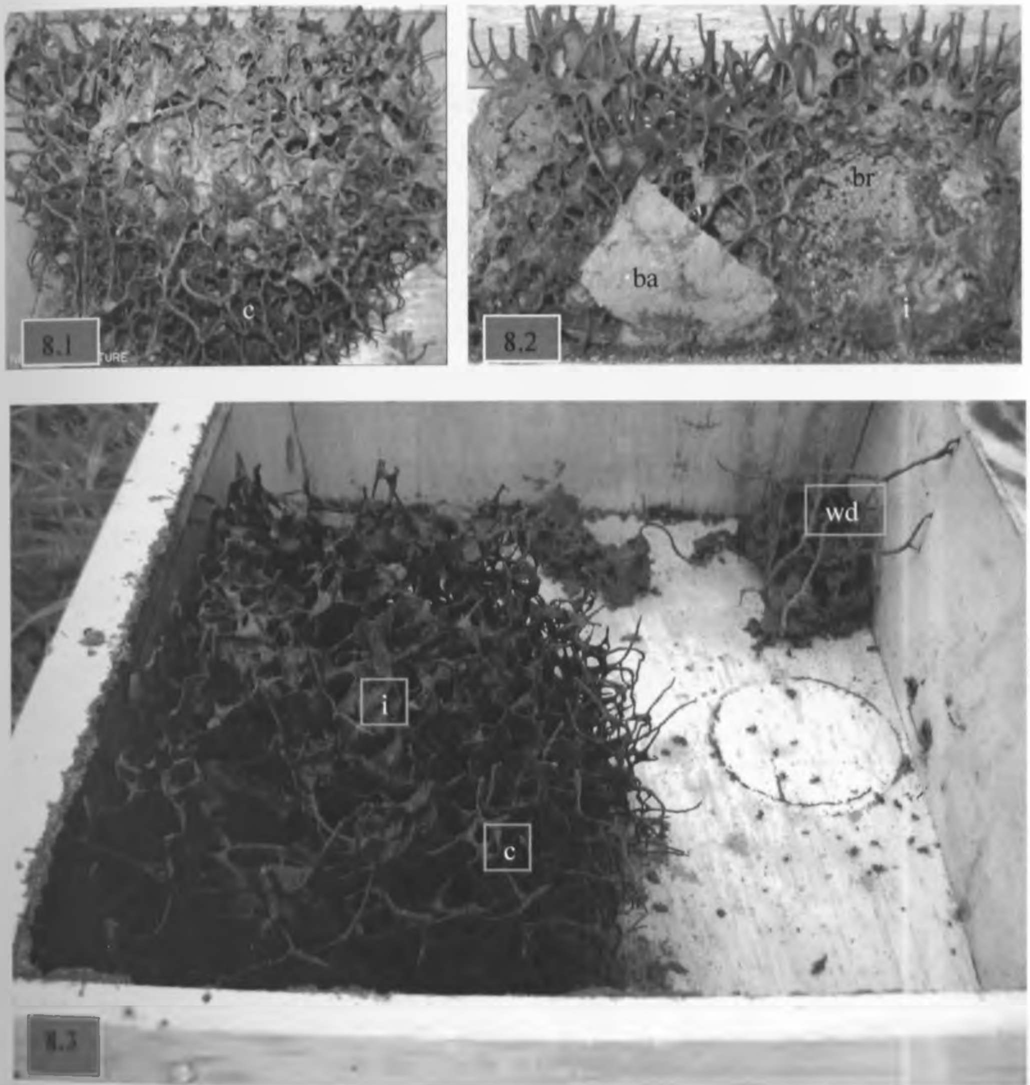


Plate 8: 8.1, *P. hildebrandti* natural nest, a, characterized by intensive connectives, c; 8.2, involucrum, i, removed to reveal brood cells, br, remnants of batumen plates, ba; 8.3, A hive innovation for domestication of *P. hildebrandti*, modified from Delaplane and Mayer, 2000, revealing connectives, c, involucrum, i, and waste dump, wd. Photo: Asiko G.A, 2007

The hive modification, plate 8: 8.3, though suitable for the bee species, was found to be bigger than was desired, hence the need for further improvement.

2.5.2 Hive architecture: *Meliponula bocandei*

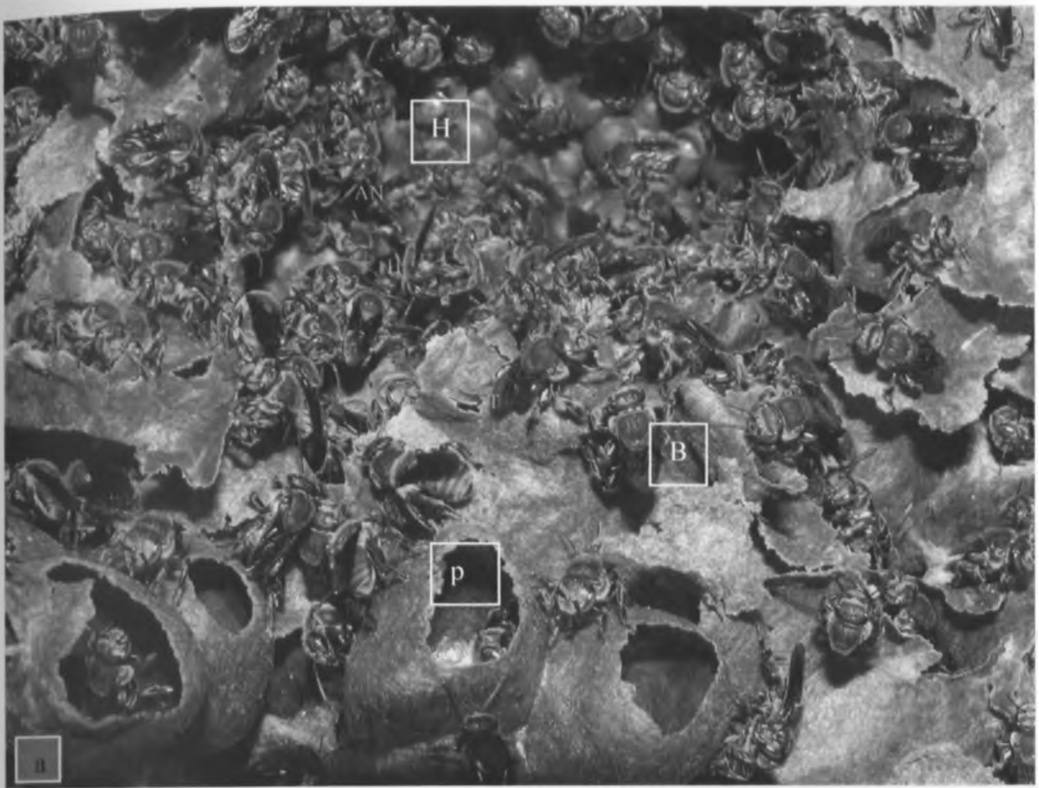


Plate 9: Hive architecture of M. bocandei Spinola, 5, at Kakamega forest (p=Pollen pots; h=Honey pots; B=M. bocandei). Photo: Asiko G.A 2007

2.5.3 Hive architecture: *Meliponula ferruginea*

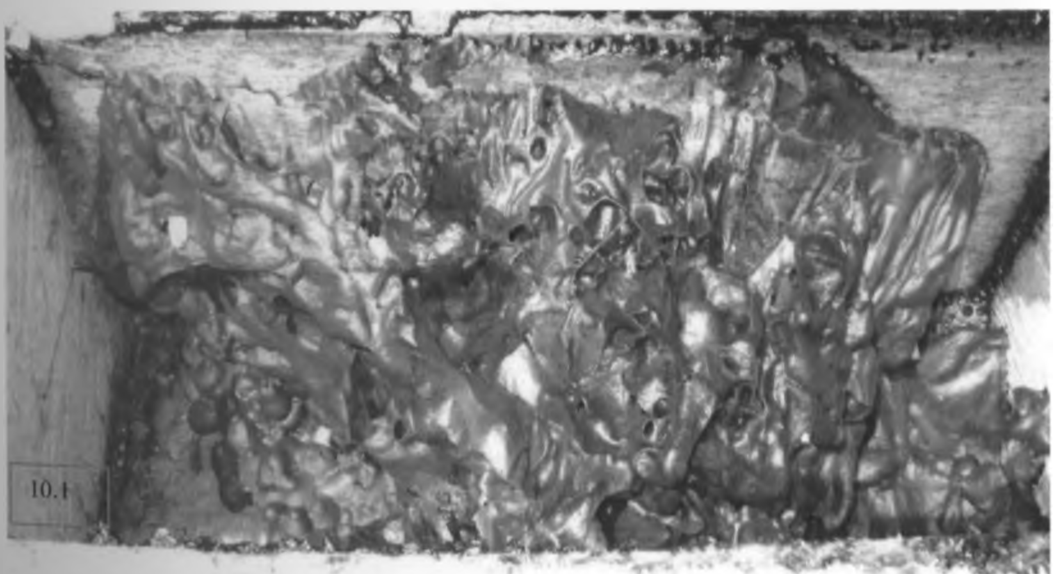


Plate 10: Nest structure of domesticated *M. ferruginea*, 10.1, characterized by intensive involucrum, i, and honey & pollen pots, h,and p. Photo: Asiko G.A, 2007

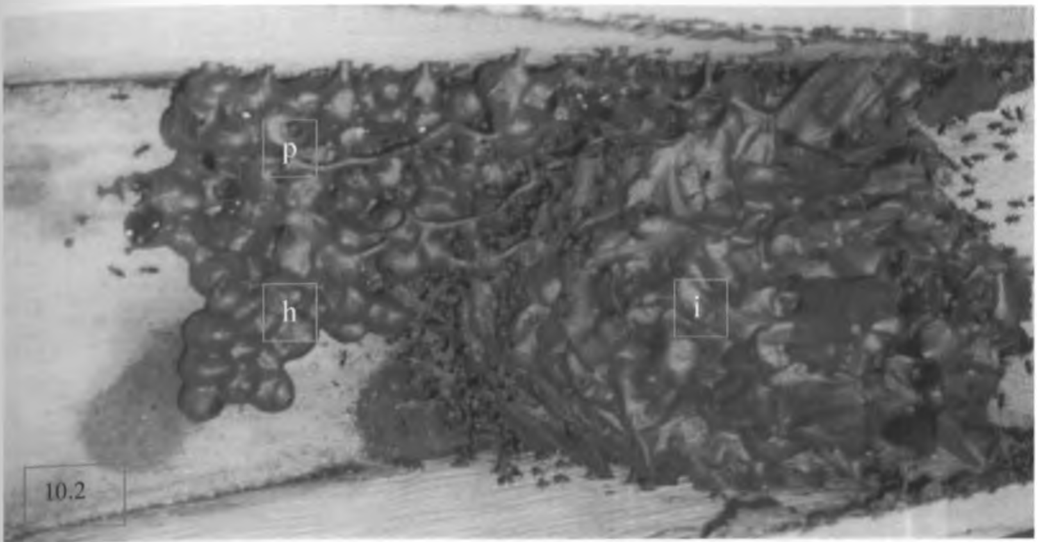


Plate 10.2: ***Meliponula ferruginea*** **colony x4, 10.2, showing involucrum,i, covering the brood. See the location of honey, h, and pollen, p, pots. Photo: Asiko G.A, 2007**

2.5.4 Hive architecture: *Hypotrigona gribodoi*

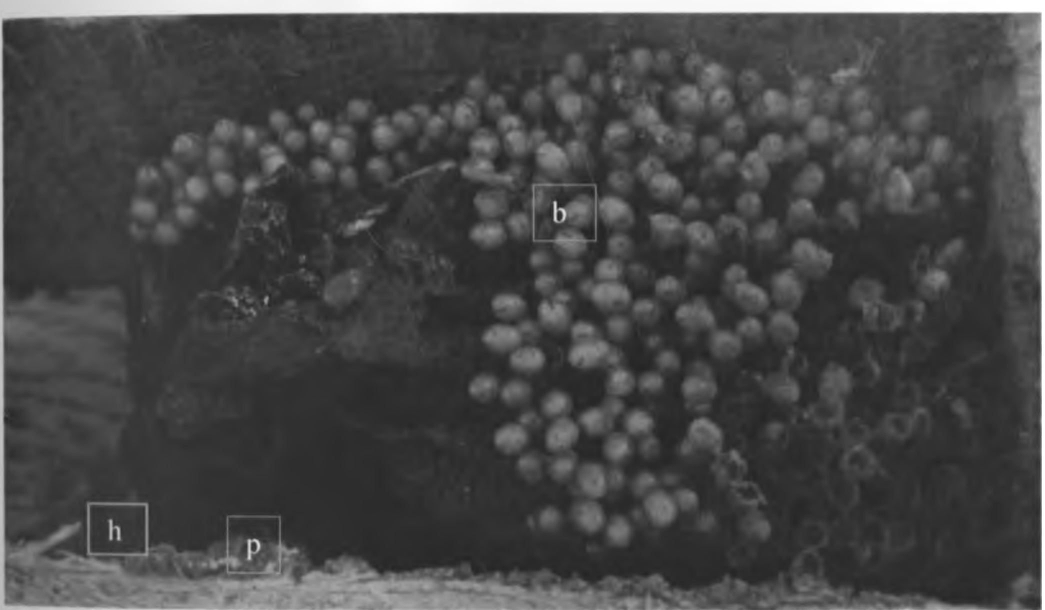


Plate 11: Hive architecture: Hypotrigona species, x150. See the location of brood, b, and pots (p=pollen, and h=honey). Photo: Asiko, G.A, 2008

2.6 Stingless bee body size and nest entrance as a distinquishing feature between species

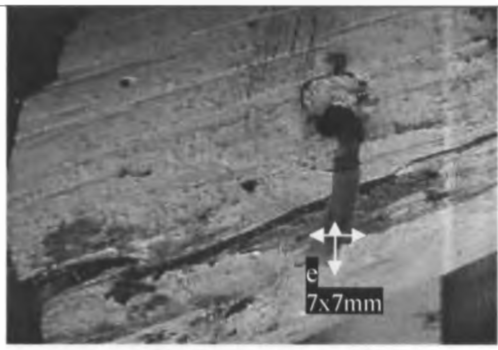
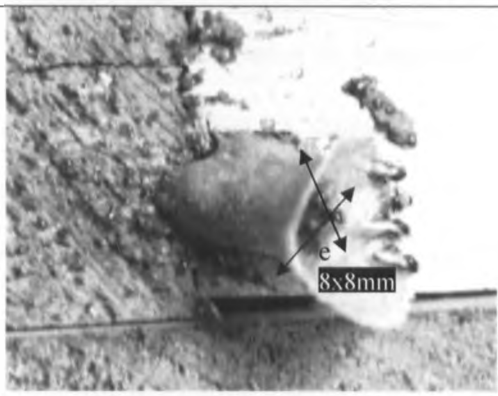
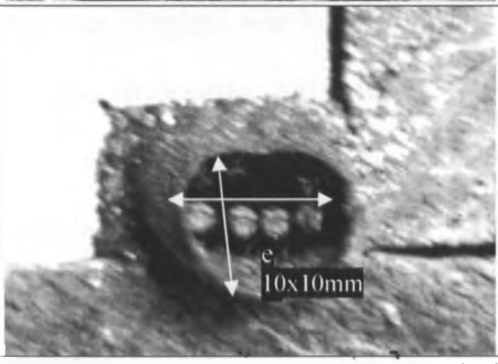
Bee species	Hive entrance
 3mm *Hypotrigona gribodoi*	
 4mm *Hypotrigona ruspolii*	
 5mm *Plebeina hildebrandti*	
 *Meliponula ferruginea*	

Plate 12: Stingless bee body size and shape of hive entrance, as major distinquishing factors between species. Photo: Asiko, G.A, 2007

2.7 Stingless bee and honey bee domestication

2.7.1 Stingless bee domestication

Stingless bees play an important role in the ethnobiology of traditional households in many countries. The realization of stingless bee honey's medicinal value, due to their foraging habits has brought to the fore the need for their domestication. Most communities, particularly in Africa, have in the past, practiced destructive honey collection (Kinuthia, 2007). Domestication efforts worldwide have been noted and intensified among, for instance, the 'Kayapo' people in Brazil (Posey and Carmago, 1985; Carmago and Posey, 1990), where semi-domestication in horizontal hives is practiced (Cortopassi-Laurino *et al.*, 2006). The species domesticated include: *Tetragonisca angustula*; *Trigona cilipes* and *Trigona dallatorreana*, which are semi-domesticated in banana leaf baskets. The Mayan people of Yucatan, in Mexico, too, domesticate *Melipona beecheii.* Other known stingless bee species which are exploited for honey and other products are: *Melipona seminigra pernigra*, *Melipona melanoventer*, *Melipona rufiventris flavolineata*, *Scaptotrigona nigrohirta* and *Scaptotrigona polysticta.* In Australia, stingless beekeeping has been practiced since 1997, in specially designed boxes, to facilitate access to honey stores without damaging the rest of the nest structure (Heard, 2006).

In Africa, there is indication of indigenous stingless bee knowledge among the Abayandas in Bwindi forest reserve in Uganda (Byarugaba, 2003), Batwa, Bakiga and Bafumbira people. The main stingless bee species is *Meliponula ferruginea* Lepeletier. Currently, there is limited stingless bee keeping in fabricated hives by a few innovative farmers in Kenya and Tanzania. Around Kakamega forest, stingless bees are kept in a fabricated hive, popularly known as 'Mukhaya hive,' Plate 13, developed by the farmer, Stanley Imbusi Mukhaya (Pers. comn.). The stingless bee species in Kakamega forest include: *Meliponula ferruginea* Lepeletier, 1841 as described by Eardley, 2004, *Meliponula bocandei* Spinola, 1853, *Hypotrigona gribodoi* Magretti, 1884, and *Hypotrigona ruspolii* Magretti, 1898. In Kima area, the most common stingless bee species is: *Plebeina hildebrandti* Friese, 1900 as described by Smith, 1954 and Eardley, 2004, besides *Hypotrigona* species, Plate 11.

Plate 13: Meliponiculture in 'Mukhaya hives' at the National Beekeeping Station (size of the hive corresponds to bee species, b, g, f, l, r = *M. bocandei, H. gribodoi, M. ferruginea, M. lendliana & H. ruspolii.* Photo: Asiko G.A. 2008

2.7.2 Honey bee domestication

The honey bee, *Apis mellifera,* has long been domesticated for honey and beeswax. The Three major hive types used for honey bee management in Kenya are: The traditional Log Hive, The Kenya Top Bar Hive and the Langstroth Hive. Bee management pose a great challenge due to prevalent of pests and predators, such as ants (*Dorylus molestans* and *Componotus consobrinus)* and apes, *Papiocynocephalus anubis*, besides wax moth, mites and emerging bee diseases.

2.8 Strawberry (Fragaria chiloensis x Ananassa duchense)

2.8.1 Description and distribution

Strawberries are perennial stoloniferous herbs, rooting at the nodes and forming new plants. Stipules are red-brown and papery. The leaves are petiolate and trifoliolate, densely clustered from a basal rosette. Leaflets are ovate, oblong or oblong-ovate, 3-4 x 2-3 cm, obtuse, basally cuneate to more or less truncate, sharply serrated with rather few acute and large teeth. They are green above, with a few appressed hairs or glabrous, whitish below with silky appressed hairs. Flowers are pentamerous, protogynous (12-18 cm diameter). Petals and epicalyx are present. The petiole is densely covered with spreading, silky hairs, commonly 3-6 (but up to 25) cm long. The petioles are very short. The leaflets are often sub-sessile. The inflorescence is an erect, leafless cyme, bearing about 5 flowers; flowering stems grow up to 15 cm tall and are hairy, as the petioles. The calyx is covered externally with appressed silky hairs and the calyx-lobes are ovate, acuminate and about 2.75 mm long. The epicalyx-lobes are oblong, acute, nearly equaling the calyx-lobes. The petals are white obovate, more or less 4 mm long. The fruit is red or reddish, when ripe and consists of many small, one-seeded achenes, covering the accrescent, juicy succulent receptacle. It may be ovoid or spherical, nodding.

Strawberry is a delicious, edible fruit of economic importance. It is rich in vitamin C and is utilized for domestic use and also industrially, in the preparation of salads, pastries and juices (Ohio State University Bulletin, 2006). Strawberry is a temperate fruit, though, with the introduction of hybrids, its cultivation has spread to tropical regions. The fruit is red or reddish when ripe and consists of many small, one-seeded achenes, covering the excrescent succulent receptacle.

Fragaria vesca Linneaus, is a temperate and sub-tropical genus, of which some species and hybrids are widely cultivated and popularly eaten as strawberries. It is a native of Europe, Temperate Asia, North America, Madeira and Azores. It inhabits upland grassland and forest edges (2400-2850 M). In Kenya, current varieties under production include: Chandler, Rotunda, Douglas and Aiko (Ministry of Agriculture and Rural Development, MOA&RD, 2003).

2.8.2 Growth habits and general requirements

The strawberry plant is a low perennial herb, growing above the ground, with a short crown and shallow roots which arise from the short underground part of the stem (rhizome). It grows at an altitude of 1500-2200 M East of the Rift Valley and 1800-2200 M West of the Rift Valley. Temperature requirements range from temperate to warm temperate (12°C-24°C). Strawberries require well distributed rainfall of about 1200 mm. Where rainfall is less, irrigation is necessary at 25mm/week. The crop does not tolerate drought. It grows on a wide range of soils (MOA&RD, 2003). However, deep, sandy loams, which are well drained and rich in humus, are ideal. The pH of between 5.5-6.5 is preferred. Cultivation in saline soils should be avoided.

2.8.3 Propagation and growth

Splitting is the commonest method used to propagate strawberries. Runners are also used, to start the crop. The soil should be worked before planting to attain a deep and reasonably loose planting bed. Spacing is 45x30cm between and within rows, giving a plant population of 74,000 plants/hectare. Vigorous varieties, like rotunda, are spaced at 90x30cm (55,000 plants/ha). The crown is very short and does not require deep planting (MOA&RD, 2003). Roots should not dry out and must be spread out in the planting hole. High soil organic matter increased yields, hence manure was applied during land preparation.

2.8.4 Management of strawberry plants

Straw, black polythene and rice husks may be used as mulch. The mulch reduces weeds, conserves moisture and keeps fruits clean. However, some mulch may serve as a source of contamination, in terms of disease, if not well cleaned. De-flowering is necessary to control pre-mature cropping which is induced by short day conditions occurring in Kenya. Plants start flowering before they are established. De-flowering should be carried out for a few weeks until the crop establishes itself. This reduces early exhaustion of the plant. During rest period, all old and diseased leaves are removed to reduce disease and infection sources, including pests, to allow re-growth of foliage. Removed leaves should be collected and burned outside the field. Runners should be regularly cut off except for those required for re-planting. One or two runners from the runner types can be rooted for next planting. Diseases include: Leaf spot (*Mycosphaerella sp.*) observed as grey spots, with purple margins on leaves; *Verticillium* wilt; manifested in yellow appearance, wilted leaves and stunted growth; Grey mould, appearing as soft rot of fruit and grey mould on infected plants.

Red spider mites *(Tetranychus sp.*), observed as greyish brown mites, may be found on the lower surface of leaves. Predators include: Birds, *Hadada ibis* and Apes, *Papiocynocephalus anubis*, together *with other Homo sapiens.*

Through observation, the maturity of strawberry is a function of the prevailing temperatures during growth period. Maturity period ranges from 18 to 40 days of flowering but the optimum period is 30 days from flowering. Berries should be picked when they are completely or nearly red. Over-ripe berries soon become rotten. Harvested berries should be taken to the packaging shelter as quickly as possible to avoid dehydration and deterioration. Strawberry loose quality rapidly and continuously after harvest (MOA&RD, 2003). This is due to chemical changes in the berries and of growth decay causing organisms hence the need to store in a cool place (4°C). The expected fruit yields in the first year is approximately 10,000 kg/acre of strawberries, 7,500 kg and 5,000 kg in the second and third year, respectively (Free, 1993). The plants should be renewed with disease-free plants by the end of the third year. The fruits are eaten fresh or canned. They are also used in cake baking, ice creams and in jams. The fruit is rich in vitamin C.

2.9 Pollination

Pollination is the transfer of pollen from the male parts (anthers) of a flower to the female part (stigma) of the same or different plant species. It is only in Angiosperms that pollination is typically developed in its three phases of: pollen release from the male part of the flower and transfer from the paternal to the maternal part, successfully placing the pollen on the recipient surface of the latter, followed by germination of the pollen grain (Feagri and Van der Pijl, 1971). Pollination is an obligatory step for fruit-set in most of the cultivated crops.

Normally, Angiosperms exhibit two kinds of pollination modes: self-pollination and cross-pollination. When pollination takes place within a flower, it is called self-pollination. When pollen from one flower is carried to the stigma of another flower, it is called cross-pollination. When crossing is between flowers of two different plants, this is true out-crossing (Roubik, 1995). Pollen is a non-mobile spore. It must be transferred from the anther to the stigma by a vector (Roubik, 1995). Transfer of pollen from the stamens to the stigma of another flower depends on the pattern of movement of the visitor as it enters and leaves the flower (Proctor *et al.*, 1996). Behavioural traits, such as frequent movement between flowers of different plants, and body contact with a flower's reproductive organs, are indicators of cross-pollination efficiency. The more the time a pollinator spends on the flower, the greater the efficiency.

2.9.1 General pollination considerations

The size of the flower in comparison to pollinator species is considered together with flower morphology and physiology. The receptiveness of the stigma and flower opening times in nectar/pollen collection trips are particularly important. Flower attractiveness in terms of reward (pollen and nectar), is of prime importance, including pollen structure, for dispersal purposes. Abundance of other flowers in the study plot viscinity, as well as pollinator density, are vital determinants to successful flower visit by insects (Delaplane and Mayer, 2000; Amots *et al.*, 2005). Generally, increased bee activity translates to high fruit-set. It is advisable to optimize on bee cross pollination by inter-planting compatible types of cultivars in the same row. The pollination process is drastically hampered by extreme weather conditions as bee activity is reduced (Jaycox, 1970, 1979, Chagnon *et al.*, 1989).

2.9.2 Stratification and structure of strawberry flowers

The first flower is the primary (1°) flower. The next two are the secondary (2°) flowers whereas the next four are the tertiary (3°) flowers. Primary flowers produce the largest fruit (Darrow, 1966; Jaycox, Chagnon et al., 1989). The flowers are perfect, with both male and female parts, in most commercial varieties. However, some varieties have exclusively female flowers, exclusively male flowers, flowers with only a few stamens or flowers with non-functioning stamens (Feagri and Van der

Pijl, 1971). Strawberry is an aggregate fruit like raspberry, which means that each flower has many pistils that develop together as a single mass.

The structure of the flower differs between strawberry cultivars and between primary and the later ones. Some cultivars have short stamens and tall receptacles. These benefit most from insects. Cultivars with tall stamens in relation to receptacle height are largely self pollinated and receive less benefit from insect visits (Connor and Martin, 1973). The difference between the floral parts is greatest in the primary blossoms but becomes smaller with successive bloom. Strawberry flowers are thus, self-pollinated readily if the pollen is released above or even with the stigmas. Wind and the resulting movement of the flower also assist in pollination. However, when the anthers are lower than the receptacle, not enough pollen reaches the stigmas to set a well-formed fruit without the help of insect visitors, usually bees.

Strawberry, *Fragaria chiloensis* x A*nanassa duchense*, belong to the family *Rosaceae* and genus *Fragaria*. The flowers are hermaphroditic and self-compatible to a certain extent, although a few varieties have pistillate flowers only, flowers with few stamens, stamens that fail to produce pollen hence practically self sterile (Eaton and Smith, 1962; Hyams, 1962; Hughes, 1951; Shoemaker, 1955).

The strawberry flower is white and 2.5-3.8 cm across. Each perfect flower has 5 petals, although some have 7, many pistils and styles, and 24-36 stamens, Plate 14.

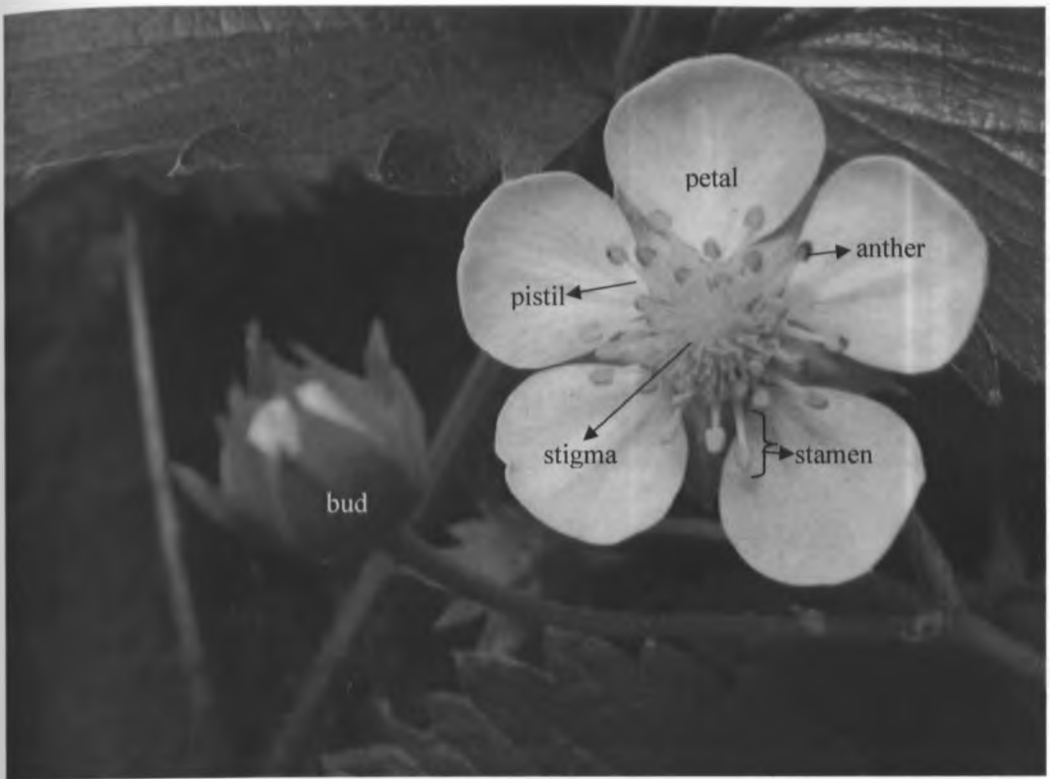


Plate 14: Strawberry flower and bud, revealing 5 petals, many pistils and stylesand 29 stamens, deep yellow. Photo: Asiko G.A, 2008

Plate 15: Strawberry flower, revealing petals, many pistils and styles and 26 stamens. Photo: Asiko G.A, 2008

Autogamy occurs in strawberry. This depends on the number of flowers open on a plant at the same time, on the pollinator behaviour, and on the level of pollen carryover. Often less than 20% of an insect's pollen load is deposited on each flower it visits, so a mass floral display may be less than it seems at first sight (Robertson, 1992).

The stigmas of the strawberry flower are receptive a few hours, second day of bud opening, before the anthers dehisce, protogynous, favouring cross-pollination by insects (Crane and Walker, 1984; Free, 1993). Free anthesis of strawberry does not occur below 14°C (Percival, 1955; Jaycox, 1979). The conical receptacle of a strawberry flower contains numerous pistils, each with one carpel from which the true fruits or achenes of the strawberry are formed. Achenes containing fertilized ovules release a hormone that stimulates growth of the receptacle. When an achene does not contain a fertilized seed, it remains small and the receptacle in its area fails to grow (Robbins, 1931; Nitsch, 1952). Berries are deformed in parts in which achenes are not fertilized. Pollination of all stigmas of a flower is therefore necessary for maximum berry size and perfect shape (McGregor, 1976; Crane and Walker, 1984).

Primary flowers have about 350 stigmas. Secondary flowers have about 260 and tertiary flowers have about 180 (Darrow, 1966). Stamens become deep yellow when they have viable pollen, Plate 16. Nectar forms a pool at the base of the outermost pistils. Pollen is not released until the flower has been open for a while and the anthers have begun to dry. When the drying anthers finally open, pollen bursts from them under tension and scatters across the numerous stigmas. Once released, pollen stays viable for several days. Pollination is most likely to take place during the first 4 days after the flower opens (McGregor, 1976) but some flowers start to dry by the second day (Connor, 1970). Fertilized ovules stimulate the surrounding tissue to begin growing. Non-fertilized ovules do not grow and if there are many of them, the berry will be mis-shapen (Free, 1968; McGregor, 1980), if it develops at all. Berry deformity is a severe problem in commercial cultivation of strawberries in greenhouses (Kakutani *et al.*, 1993). The plants are good for research since a well-shaped fruit indicates that all the stigmas on the flower have been efficiently pollinated to induce fruit-set. Strawberry flowers produce nectar and pollen, but they are not always attractive to honey bees (Delaplane and Mayer, 2000).

2.9.3 Evidence of completeness of pollination

Fruit-set is the ultimate result of successful pollination. If the pistils were pollinated, they will appear dark and shrunken in size, Plate17.1 . If they were not pollinated, they will appear yellow-green and fresh in appearance, Plate17.2 . A partially pollinated strawberry flower will have a mottled appearance (Connor and Martin, 1973; Jaycox 1979).

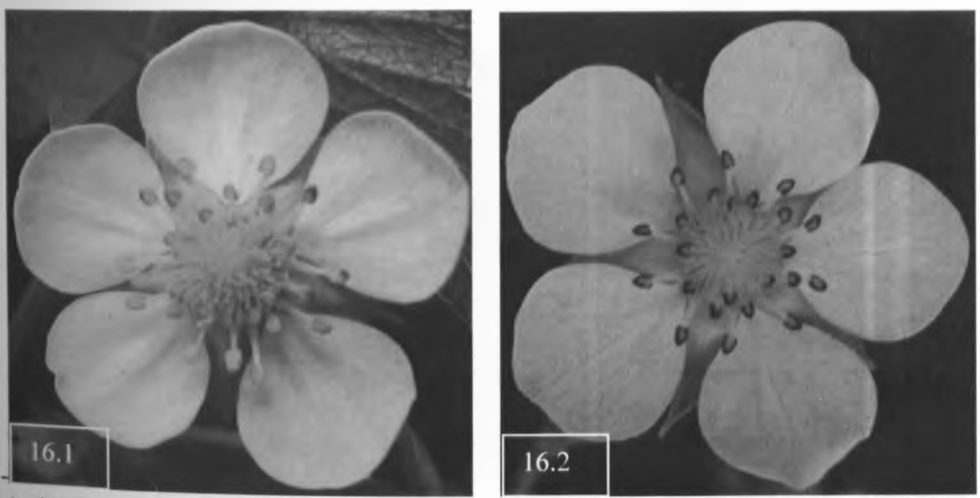


Plate 16: Fresh, newly opened flower, yet to be pollinated, 16.1, and fully pollinated strawberry flower, 16.2, actual size. Note the browning of pistils in, 16.2. Photo: Asiko, G.A, 2008

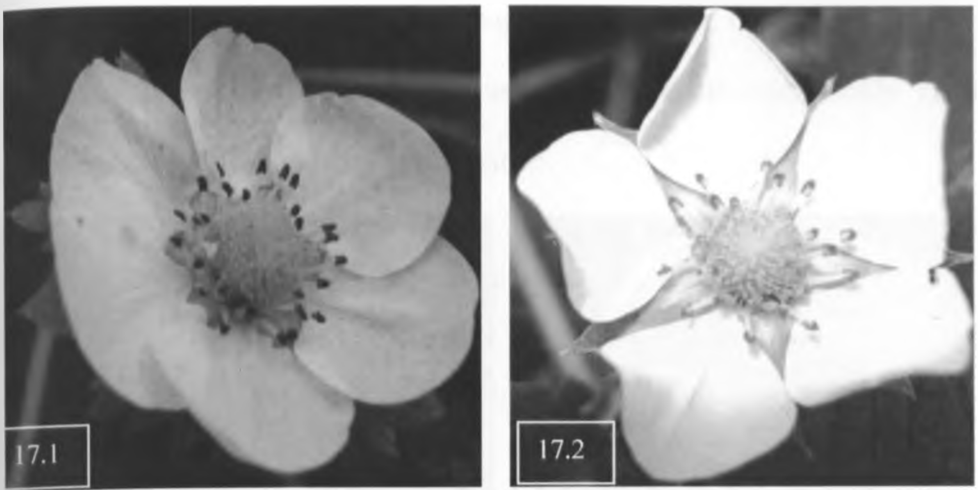


Plate 17: Pollinated dark and shrunken pistils, 17.1. Unpollinated, yellow-green, fresh appearance,17.2. Photo: Asiko G.A, 2008

2.9.4 Use of bees as pollinators

The dependency of commercial yields of various crops on honey bee pollination is enormous (Regev and Dag, 2000). When pollinators visit flowers for nectar collection, they in turn pollinate them. Bees, about 30,000 species in the world (Michener, 2000), make more visits to flowers, than do other insects, enhancing their effectiveness as pollinators because they rely on nectar and pollen for their survival (Proctor *et al.*, 1996). The most efficient pollinators, such as the honey bee, have universal attributes that enable them fulfil the task of a pollinator under a large sphere of circumstances (Free, 1993). They carry plenty of pollen, brush against stigmata, hence transferring pollen, visit several flowers of the same species and move frequently from flower to flower and plant to plant, in quick succession (Roubik, 1995).

2.9.5 Strawberry pollination requirements

Most commercial varieties are self-fertile, and the pollen-scattering action of the anthers promotes self-pollination (Jaycox, 1979). However, every pistil in the aggregate flower must be pollinated in order to form a perfect berry, and self-pollination cannot service every pistil. Thus, wind, causing flower movement, and bees, are important supplement pollinators. Varieties differ considerably in their responsiveness to different modes of pollination.

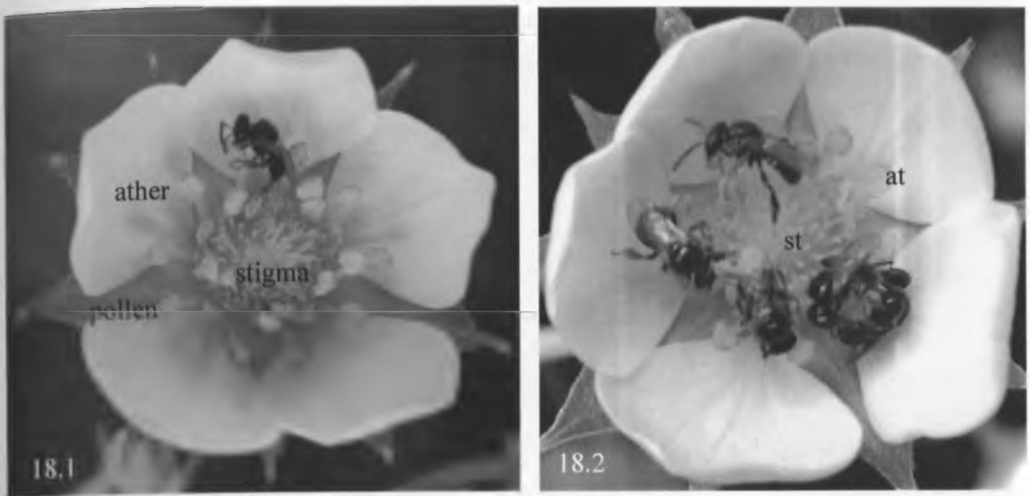


Plate 18: Stingless bees, Hypotrigona gribodoi, x40, on strawberry flower. All are collecting pollen. Note the gleaning technique in '18.1' whereby a bee drags the hind basitarsus on which pollen is passed on to the middle tarsus and then onto the orbiculae, and group foraging by recruitment of individual bees in '18.2'. Photo: Asiko G.A, 2008

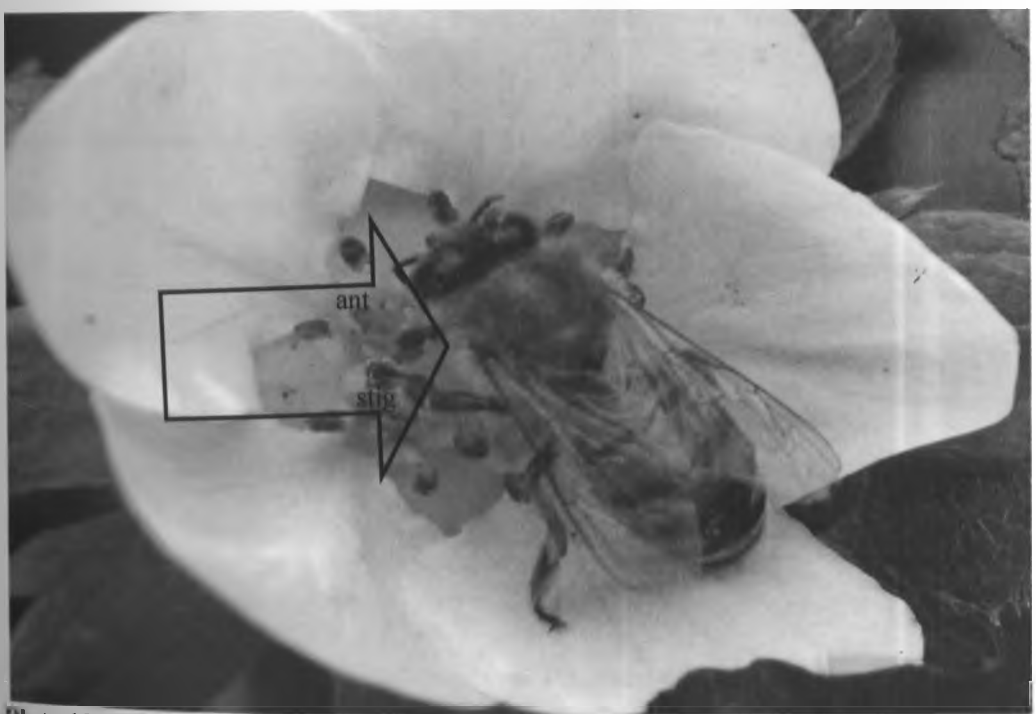


Plate 19: The honey bee, x40, on strawberry flower. In the pollen collection trip, the bee may step on the stigma and anthers, thereby facilitating pollen transfer. Photo: Asiko, G.A, 2007

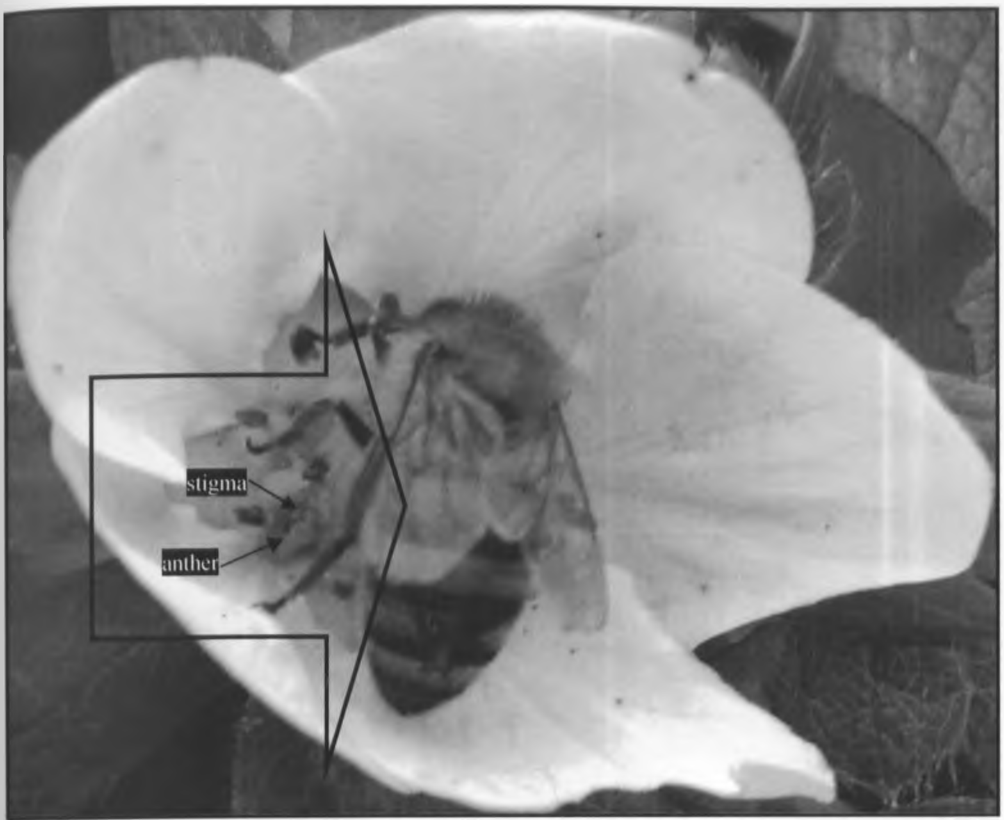


Plate 20: Honey bee foraging behaviour on the strawberry flower. The anther and the stigma are carefully avoided on a nectar collecting visit. Photo: Asiko, G.A 2007

The behaviour elicited by the bee may evoke a pollen/nectar collection response, or both. Honey bees forage as individuals, Plate 19-21 whereas *Hypotrigona* and *Plebeina* species forage in cohorts, with the recruitment principle, Plate 18: 18.2. Their characteristic hovering style may constitute additional bee flower visits, making the two species effective pollinators, in terms of number of visits to the flower.

Strawberry is pollinated by self, wind and bees. The relative contribution of each varies by variety, weather and bee population size (Delaplane and Mayer, 2000). According to Connor and Martin, 1973, self-pollination accounts for 53% of fruit development; wind an additional 14% (=67%) and bees add another 24% (=91%). Self-pollination is more difficult in varieties with short stamens making pollination by bees crucial. Honey bee visitation improves fruit yield and quality in strawberry, in-

Plate 21: Honey bee behavioural observations on the strawberry flower. On a pollen trip, the bee may contact the anther surface, 'at' and collect pollen. Other specialized movements may accompany pollen capture. The bee's body is slightly raised, avoiding stigma contact, clearly demonstrating efficiency in cross pollination. Photo: Asiko G.A, 2008

spite of the self-pollinating habit (Free, 1993; Antonelli *et al.*, 1988). Almost every honey bee visiting a strawberry flower contacts the stigmas and anthers (Free, 1968b), thus bees help distribute pollen to all pistils, promoting a well-shaped fruit, Plate 14 and 21. Earlier work on effectiveness of Honey bees as pollinators of strawberry revealed 25% fruit-set increase, 36.7% increase in yields, 13.5% decrease in malformed fruit, 49% decrease in culled fruit and 6.4% increase in fruit size (Free, 1993).

Research in strawberry pollination revealed that many large commercial fields were nearly devoid of bees; a number of varieties benefited substantially from bee pollination and some varieties were not attractive to bees because of low nectar and /or pollen production (Connor and Martin, 1973; Delaplane and Mayer, 2000). The European Honey bee, *Apis mellifera mellifera*, has been practically used as a pollinator in greenhouses. However, due to the foraging habits of the honey bee, foraging at a range of up to 5 Km radius from the hive, and immediately flying upward to a height of several dozen meters, a large number of bees get trapped in the greenhouse ceiling and die, hence the resultant low foraging efficiency in greenhouses. The stingless bee, with about 600 species and a colony size of 300–180,000 bees, depending on the species (Michener, 2000; Cortopassi-Laurino, 2006) is closely related to the Honey bee (11 species). In many species of the stingless bee, foraging range is smaller (0.5–1 Km for *Trigona sp.* and 1.5–2 Km for *Melipona sp.*) than that of the honey bee and foragers perform hovering flights near the nest entrance, not showing upward flights as in the latter (Visscher and Seeley, 1982; Seeley, 1985; Katayama, 1987; Kakutani *et al.*, 1993).

2.10 Ethological observations

Forager behavior as it encounters a flower in the process of pollination is of immense importance since it can be deduced as to whether it is collecting nectar or pollen. The most efficient pollinators carry plenty of pollen, brush against the stigmata hence transferring pollen, visit several flowers of the same species in succession and move from flower to flower and plant to plant (Roubik, 1995). Free (1968b) observed that on nearly every flower visit, honey bee nectar-gatherers touched both stigmas and anthers, Plate 19, although bees sometimes alighted on the petals of a flower and approached the nectary from the side, they nearly always proceeded to walk over the stigmas. Some bees that were collecting nectar also had pollen loads, Plate 18.2, and so were collecting pollen incidentally. However, some bees also collected pollen deliberately, Plate 23.1 and 4. Such bees either walked round the ring of anthers and scrabbled for pollen while doing so, or stood on the central stigmas and pivoted their heads and fore-parts of their thoraces over the ring of anthers, Plate 23.1 and 23.2. Some bees scrabbling for pollen also collected nectar. Goodman and Oldroyd (1988) observed that some nectar-gatherers worked the flowers from the side and made little or no contact with the stigmas. Antonelli *et al.*, (1988) reported that 80% of Honey bees visiting strawberry flowers carried pollen loads. It has been observed that bees spend about 7 seconds (Petkov, 1965) or 10 seconds (Free, 1968b) per flower visit, although those collecting pollen worked slightly faster than those collecting nectar. In honey bees, the first visit to the flower is usually the longest (Chagnon *et al.*, 1989).

Plate 22: Stingless bee, Hypotrigona gribodoi. Behavioural observations on the strawberry before, '22.1' and after, '22.2' pollination. Notice the immature and mature pollen, p, respectively. Photo: Asiko G.A, 2008

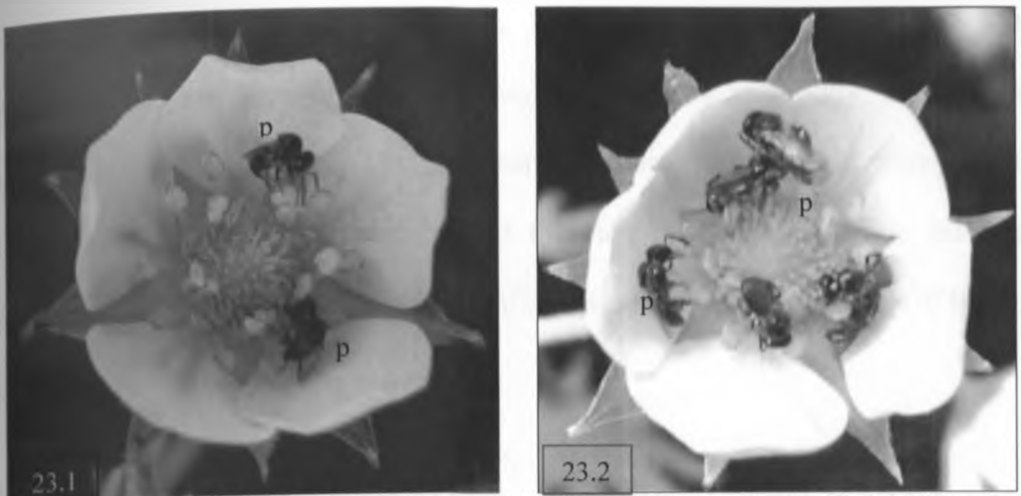


Plate 23: Stingless bee, Hypotrigona gribodoi, x16, c & d, are all pollen trips, where bees pivot their heads & fore parts on their thoraces over the ring of anthers. Photo: Asiko G.A, 2008

Plate 24: Stingless bee, Hypotrigona gribodoi, 24.1, x16 & 24.2, x40 are collecting both nectar and pollen simultaneously. The two bees in 24.2, are about to fly away, after successful foraging trips. Photo: Asiko G.A, 2008

Ordinarily, bees can collect pollen by contacting the surfaces of anthers and then grooming pollen adhering to hairs and, especially for relatively sticky pollen, elsewhere on their body. Bees usually collect pollen by combined working of the forelegs and mouth parts, even shredding or destroying anthers in the process, and by movement of the body over the anthers and flower parts. Subtle behavioural or anatomical features may come into play even during relatively passive pollen capture. Many bees press strongly downward on a flower while collecting pollen as they grasp its edges with their claws. Their bodies deflect petals and stamens with what appears to be specialized and rapid movements. Weak buzzing and rocking motions by *Melipona sp.* has been observed as they visit flowers with fully exposed and accessible pollen (Roubik, 1989). Other bees are known to display similar combinations of gathering behaviour, as they use methods particularly suited to harvesting poricidally dehiscent pollen while visiting anthers of other types of flowers (Buchmann, 1985).

Loading of pollen in the apid corbiculae, among all but the meliponinae, occurs through the motion of the basitarsus and its distinctive basal pollen press (Michener *et al.*,1978; Wille, 1979a), as in *Trigona*, sub-genus, *Scaura*, *Plebeia* and *Trigonisca*, and even *Apis mellifera mellifera*, employ the gleaning technique, Plate 18.1, of dragging the hind basitarsus across flower parts on which pollen has fallen, after which it is passed on to the middle tarsus and then onto the corbiculae, (Laroca and Lauer, 1973; Michener *et al.,* 1978). Hovering is energetically costly, and is associated with grooming pollen and packing it into corbiculae.

In preliminary experiments on caged strawberry cultivar to exclude insects, Hughes (1961 and 1962) found that yield was decreased and fruits were malformed. The weight of the berry produced depended on the stage of development of the flower when it was visited, and visits to flowers at times other than when the maximum number of their stigmas were receptive resulted in fruits of less than maximum size being produced. The same principle applied when flowers were hand-pollinated. Nitsch (1950) had shown that the weight of the berry was directly proportional to the number of fertilized achenes.

2.11 Problem statement

Currently, the Honey bee has suffered major declines due to Varroa mites, disease, habitat loss and increased use of chemicals (Sommeijer and Ruijter, 2000; Slaa *et al.*, 2000; Moisset and Buchman, 2010). In the Western world, and elsewhere, rental costs for pollinating honey bee colonies are escalating. Consequently, wild indigenous pollinators, stingless bees, which are adapted to the local conditions should be domesticated and conserved as alternative pollinators to the honey bee.

The need for insect pollination of plants in enclosures and green houses arises either because the plants must be isolated to produce uncontaminated seed, or because attempts are being made to find out whether the visits of the pollinator species in question contribute positively to increased seed or fruit yield in quality and quantity or because the crop is being produced under artificial conditions for off season production. Several pollination studies of agricultural significance have been initiated but not completed in Africa. With the rising need to increase horticultural production within and outside greenhouses and in enclosures, there is need to identify and utilize appropriate stingless bee pollinators in their required densities, for efficient and effective pollination.

2.12 Objective of the research

2.12.1 Overall objective

The study aimed at testing the pollination efficiency of three stingless bee species (*Hypotrigona sp., Meliponula sp. Plebeina sp.*) and the Honey bee, *Apis mellifera scutellata*, on two strawberry varieties, rotunda and chandler, in enclosures, in order to recommend their utilization by commercial farmers to increase horticultural production and for improved fruit quality.

2.12.2 Specific objectives

a) To determine the pollination efficiency of different endemic stingless bee species (*Hypotrigona, Meliponula, Plebeina*) and the honey bee, *Apis mellifera scutellata*, best suited for strawberry pollination in enclosures.

b) To establish the quality and quantity of strawberry fruit production through stingless and honey bee pollination.

c) To determine strawberry fruit variation due to: Ecological zone, season, location, bee species, strawberry variety and crop husbandry (shading, mixed cropping, fertilizer application).

2.13 Study sites

The study was carried out in three different localities: A) Lenana (National Beekeeping Station and Show ground) in Nairobi; B) Kakamega (Ivyhiga in Kakamega forest and Bushibo in Bukura) in Western Kenya and C) Makueni/Kibwezi (Kima) in Eastern Kenya. The three sites are found in different ecological zones. The

National Beekeeping Station (NBS) was used as the baseline location, where all the bee species used in the study were tested.

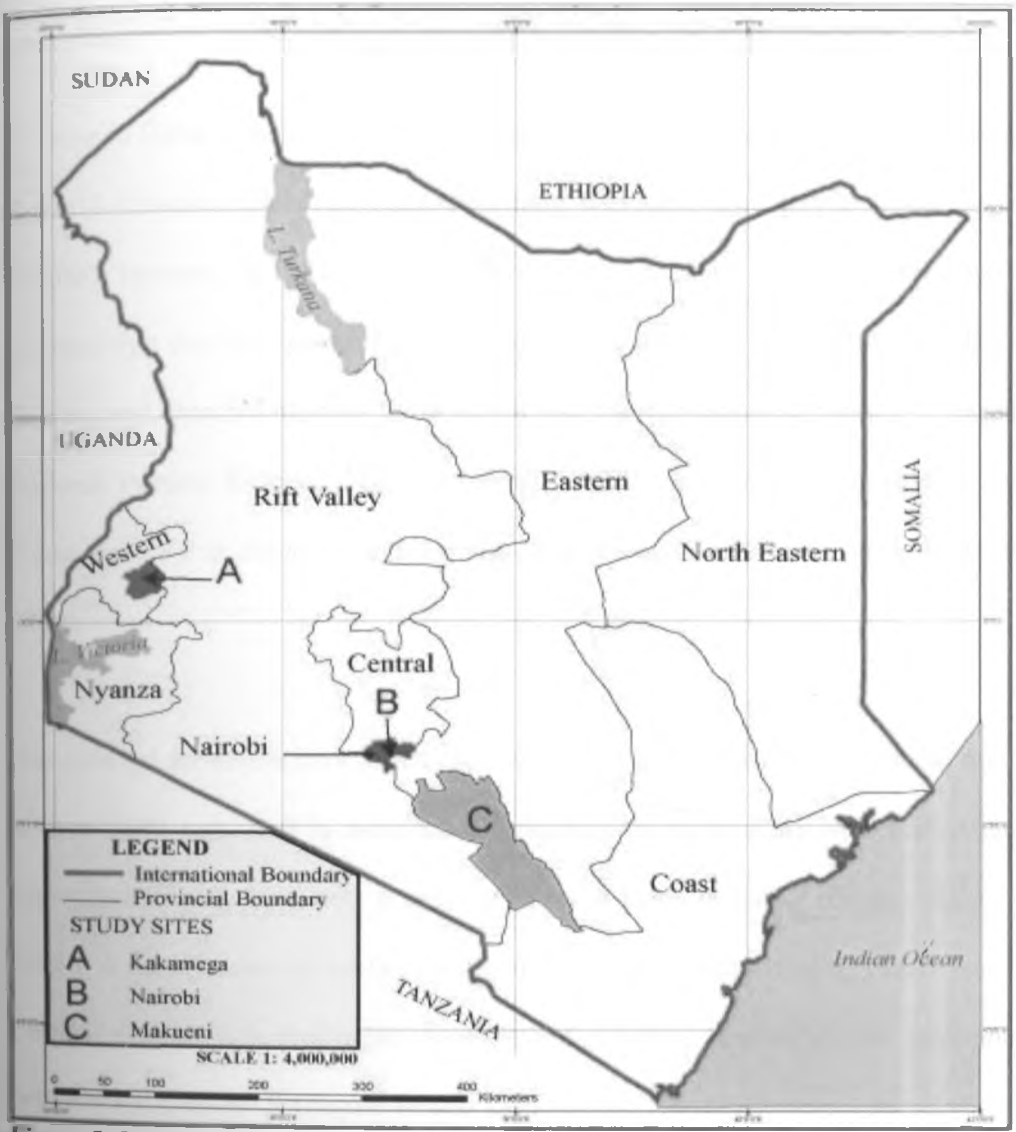


Figure 5: Map of Kenya, showing Provincial boundaries. Drawing: Chyuma R, 2007

2.13.1 Kakamega forest

The Geographical Information System (GIS) Coordinates: UTM 36M 0713997, 0028262 and UTM 36M 0679998, 0021237, for Kakamega forest (Ivyhiga) and Bukura, in Western Kenya, respectively.

Kakamega forest is the only relic of the unique Guinea-Congolian forest ecosystem. It is a mid-altitude tropical rainforest, stretching West, through Uganda. It was initially 240,000 hectares in 1820 but is now 23,000 hectares, a clear indication of deforestation due to population pressure and unemployment, leading to clearance for farming and charcoal burning for domestic use and for sale. The forest is a gazetted National Primate Reserve. The vegetation is mostly indigenous, with trees such as Elgon teak, *Ficus thoningii* and the age-old *Mysopsis eminee*, due to conservation efforts.

The soils are ferralsols, dark to red clay, with a pH of less than 6. The annual rainfall is over 2000 mm, and is bimodal, experienced between April-May and August-September (Figure 1.1), with a short dry season from January-February. Rain falls mostly in the afternoon or early evening and is often accompanied by thunderstorms. Climate change is a challenge. Average temperatures remain similar throughout, between 15° C to 28° C (Figure 14 and 15).

Figure 6: Study site A, Kakamega. Drawing: Chyuma R, 2007

2.13.2 National Beekeeping Station, Lenana

This is located at GIS Coordinates: UTM 37M 0257490, 9858862 and UTM 37M 0247395, 9855834 for Lenana National Beekeeping Station and Jamhuri Show ground, in Nairobi, respectively.

The National Beekeeping Station is situated approximately 6 Km from Nairobi's Central Business District. It borders Ngong forest, the only indigenous forest located within the confines of a capital city, Nairobi. The forest harbours rare animal and plant species, and is characterized by indigenous trees like *Croton mecalocarpus* and tree plantations. It is interspersed with patches of grass. The area experiences long rainfall seasons from March-May and short rainy seasons from October-December (Figure 12). The average rainfall is 1000 mm whereas the mean temperature is 23°C (Figure 16 and 18).

Common animals found within the Ngong forest include: Duiker, African Hare, Black-faced vervet monkey, black and white Colombus Monkey, baboon and Bushbuck. Forest resources include: honey, firewood, construction poles, medicinal herbs and shrubs. The human activity, settlement and grazing, threaten forest conservation efforts (personal observation).

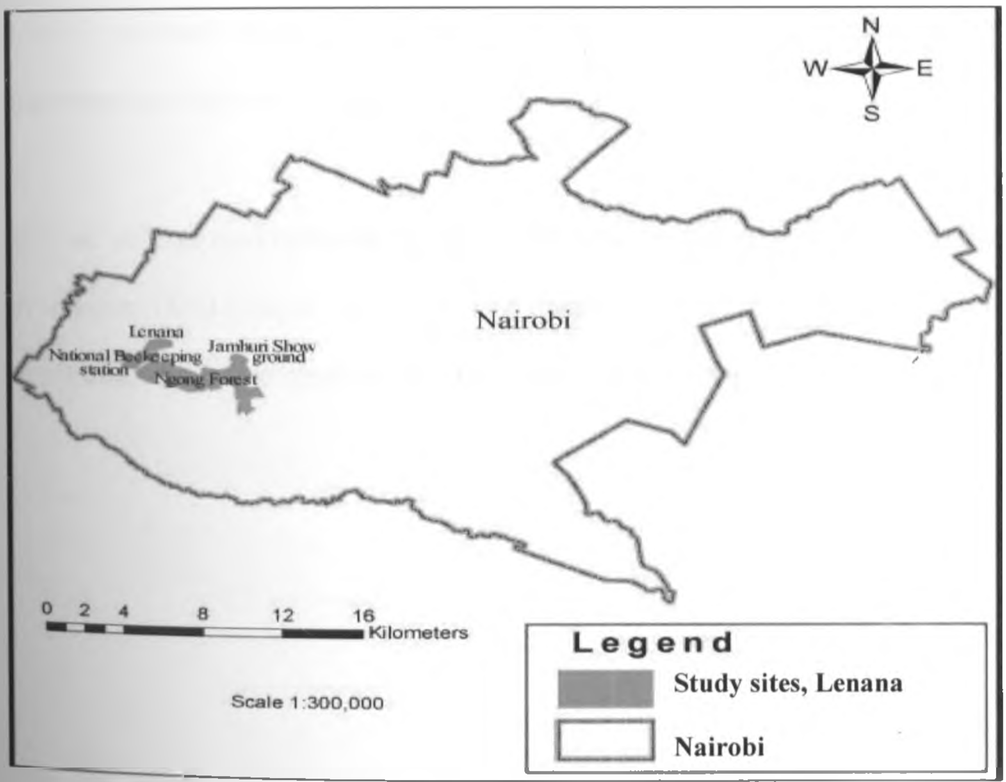


Figure 7: Study site B, Nairobi. Drawing: Chyuma R, 2007

2.13.3 Kima area

This is located at GIS Coordinates: UTM 37M 0308336, 9789486 in Makueni, in Eastern Kenya. The locality is classified as Arid and Semi-Arid area (ASAL), which form the larger proportion of Kenya (70%). It is situated 95 Kilometres Southwest of Nairobi and borders Machakos and greater Makueni Districts. It fringes sub-divided ranches, Konza and Malili. Communities keep livestock, particularly the small stock (goats) for food security. Wild animals include: Cheetah, leopard, hyena, buffalo giraffe, and zebra.

The area occasionally experiences wildlife-livestock conflicts due to resource sharing. Sub-division of land, which to a great extend is ranch area, into smaller parcels for subsistence farming, is a threat to the environmental conservation effort. The annual rainfall is minimal, averaging less than 800 mm (Figure 13). High diurnal and low temperatures at night are the norm (Figure 17 and 18).

There are several environmental groups in the area, including Kenya Initiatives for Development (KID Kenya), with a focus on conservation of the environment through tree planting, awareness creation and beekeeping, among others.

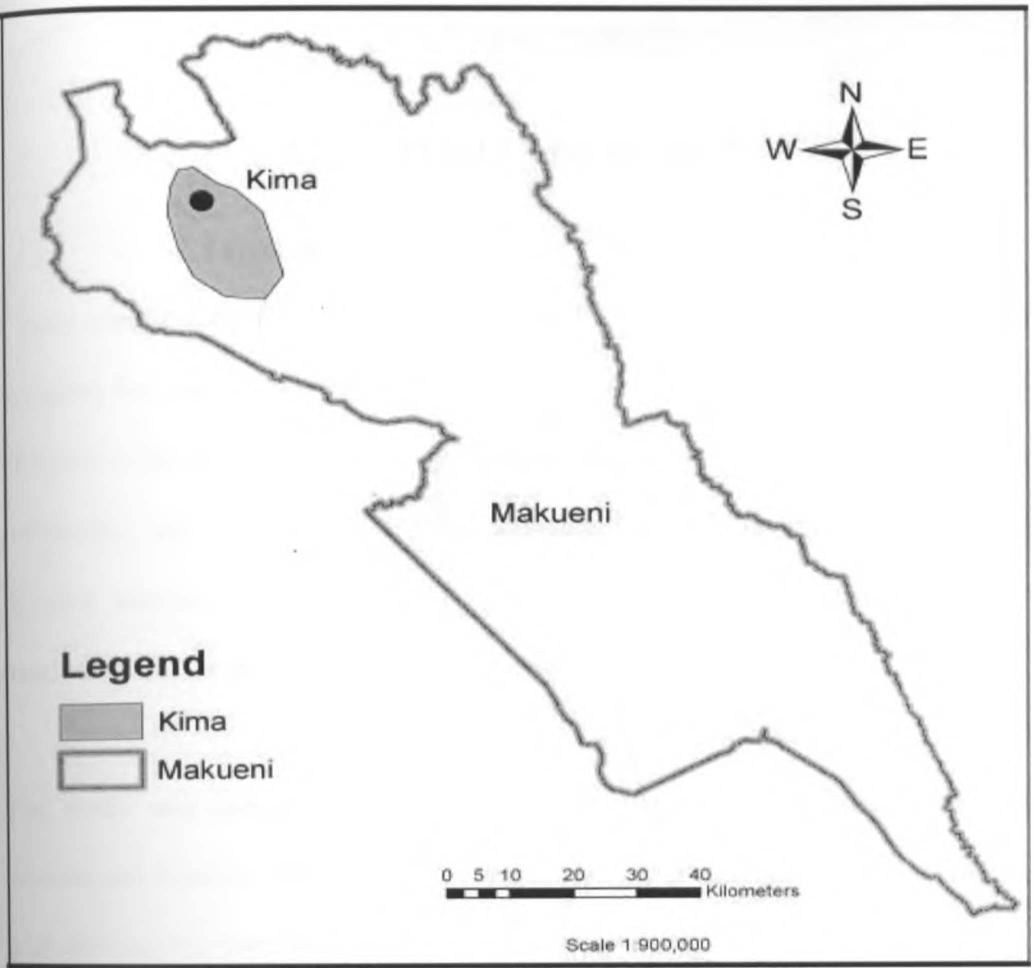


Figure 8: Study site C, Makueni. Chyuma R, 2007

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 General Methods

Caged experiments were designed to examine the impact of three naturally occuring stingless bee species on pollination of the local strawberry varieties, rotunda and chandler, with respect to fruit quality. Strawberry plants in the open environment (free pollination) and in cages (enclosed in a net) were used. Selected stingless bee species, in their colonies, were introduced interchangeably into the caged plants for a maximum of three months for each bee species.

The study was carried out in three ecologically different localities (Kakamega, Nairobi and Kima in Makueni), with two replications at each study site. *Hypotrigona gribodoi* was the main species used in Kakamega, whereas *Plebeina hildebrandti* was used in Kibwezi. The two species were finally used in Nairobi for comparison purposes under the same environmental conditions. Additional bee species used under Nairobi conditions were: *Hypotrigona ruspolii*, *Meliponula ferruginea* and *Apis Mellifera scutellata*, Plate 25. *Meliponula bocandei*, Plate 26 and 27, was introduced but absconded after two weeks hence its study was discontinued. It was, however, assessed in Kakamega forest plot, where it is endemic.

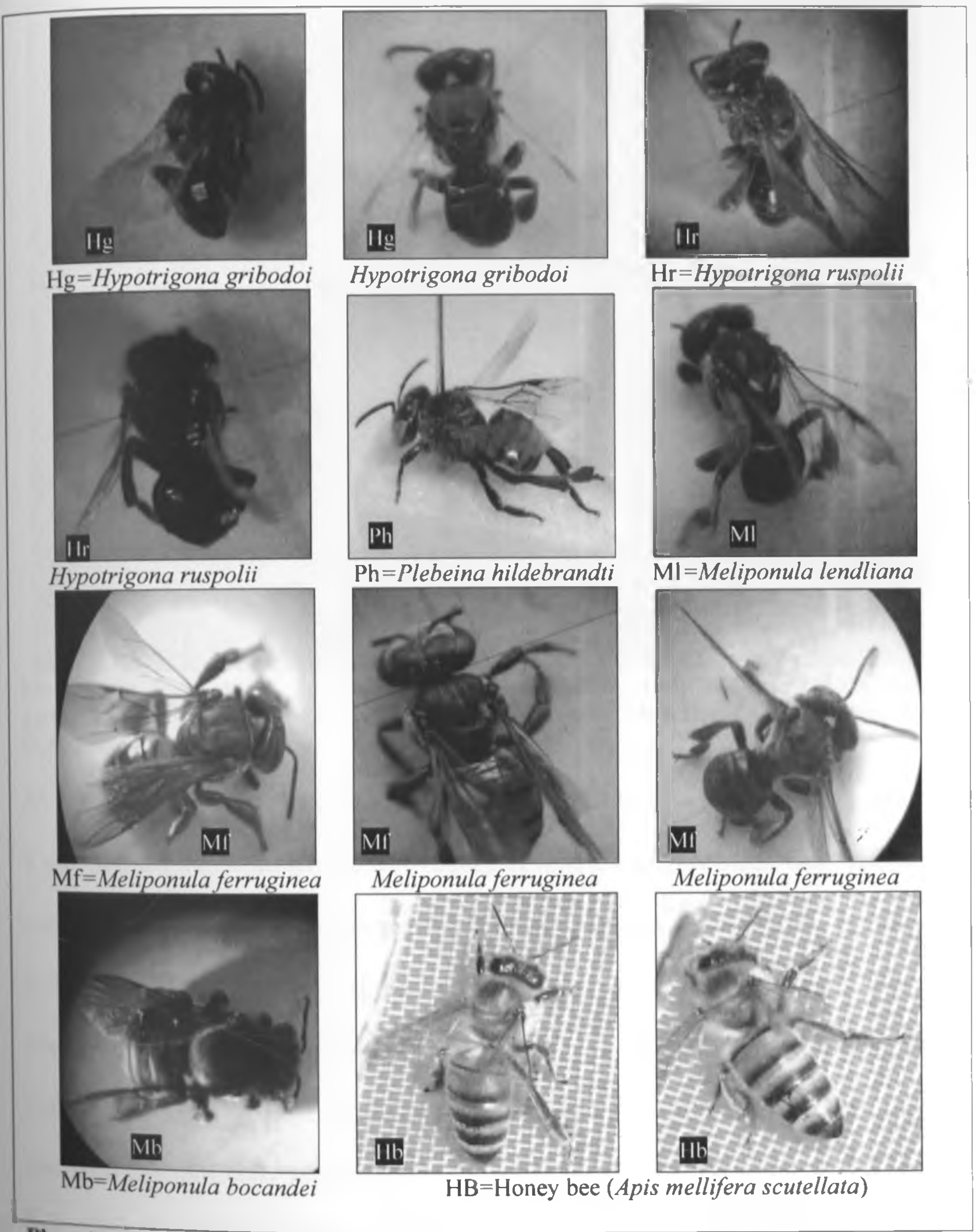
The study included two control strategies: a) Strawberry plants were planted in the open and could therefore be pollinated by self, wind or any other pollinator in the area b) The study plots were enclosed in the ordinary insect net to keep off would be pollinators, hence, no external pollinator was used such that only self-pollination occurred. Crop husbandry methods such as mixed cropping of strawberry varieties, fertilizer application and shading were tested. Of great importance were the ecological effect, seasonal effect and stem age. The watering regime was uniform across the study plots. The total number of fruits picked from each plot were recorded, weighed and classified according to the internationally recognized standard for strawberries, 'Greenery International Quality Description.' Fruit size was measured in millimetres (mm) whereas weight was measured in grammes (gm).

The total number of fruits harvested per day, their weight, size and classification, were used as the response variables while bee species, strawberry variety and location were the main explanatory variables. Rainfall and average daily temperatures were used to adjust for weather changes.

3.2 Materials

3.2.1 Bee species

The stingless bee species, *Hypotrigona sp., Meliponula sp. and Plebeina sp.*, were identified and used as the experimental colonies, H_1 One colony of each at a time, *Hypotrigona gribodoi, Hypotrigona ruspolii, Plebeina hildebrandti, Meliponula ferruginea* and *Meliponula bocandei,* Plate12 and 25-29. The process involved digging them from their natural habitats and acclimatizing them at the experimental site or obtaining them from known stingless bee farmers and setting them up, for experimental purposes, preferably in the same ecological zone, as per the National Environment Management Authority (NEMA) specification. The Honey bee species, *Apis mellifera scutellata* Linneaus, constituted the experimental colony, H_2 which was used, for comparison. The strawberry varieties used were: Chandler and rotunda, obtained locally from the same commercial farm. Propagation was done from a central point and established potted plants distributed simultaneously to the three selected study sites.



Hg=*Hypotrigona gribodoi* | *Hypotrigona gribodoi* | Hr=*Hypotrigona ruspolii*

Hypotrigona ruspolii | Ph=*Plebeina hildebrandti* | Ml=*Meliponula lendliana*

Mf=*Meliponula ferruginea* | *Meliponula ferruginea* | *Meliponula ferruginea*

Mb=*Meliponula bocandei* | HB=Honey bee (*Apis mellifera scutellata*)

Plate 25: Morphological features of bees used in the study, body size, wing venation, number of sub-marginal cells and presence of cobiculae. Photo: Asiko G.A, 2007

3.2.1.1 Identifying endemic stingless bee species best suited for strawberry pollination in efficiency and effectiveness.

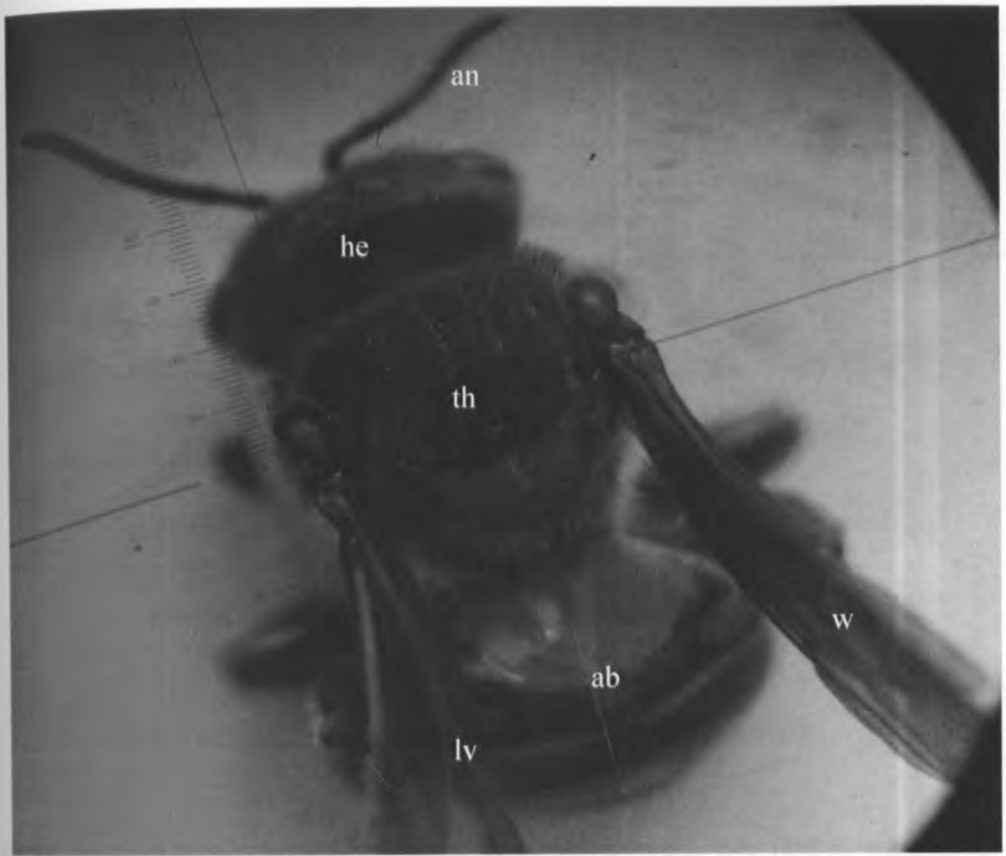


Plate 26.1: Meliponula bocandei Spinola x16. Body size, 7-8 mm (150% zoom). an=antena, he=head, th=thorax, ab=abdomen, w=wing, lv=lateral vein. Photo: Asiko G.A, 2007

Meliponula bocandei (Plate 26-27), is the biggest stingless bee, with body length 6.5-8 mm and 2.6 mm head length, with orange vestiture, a largely black face, yellowish-orange scutellum and spoon-shaped hind tibia (Michener 2000, 2007). *Meliponula ferruginea* (Plate 28.1-28.4), is medium in size with body length 8-9 mm; black or black with a red metasoma, appearing grey because of the white vestiture, when viewed with the naked eye. *Hypotrigona gribodoi,* Plate 25) is the smallest stingless bee with 2-3 mm body length; *Hypotrigona ruspolii,* Plate 25) is small with 4 mm body length and *Plebeina hildebrandti,* Plate 25 and 29), is smaller than *meliponula ferruginea* (Michener 2000, 2007). It is yellow in colour (Asiko *et al.*, 2007).

Plate 26.2: Morphology, side view, *M. bocandei* Spinola, x16 (150% zoom)(h=head, th=thorax, ab=abdomen, ce=compound eye, oc=ocelli, bv=basal vein, sm=2 sub-marginal cells). Photo: Asiko G.A 2007

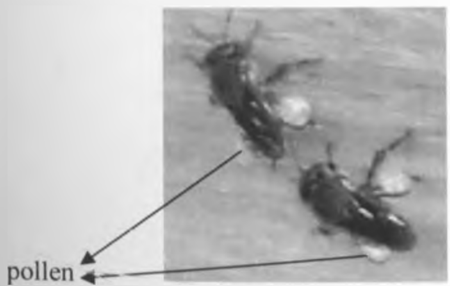


Plate 27: *Meliponula bocandei* , x4, loaded with pollen. Photo: Asiko G.A, 2009

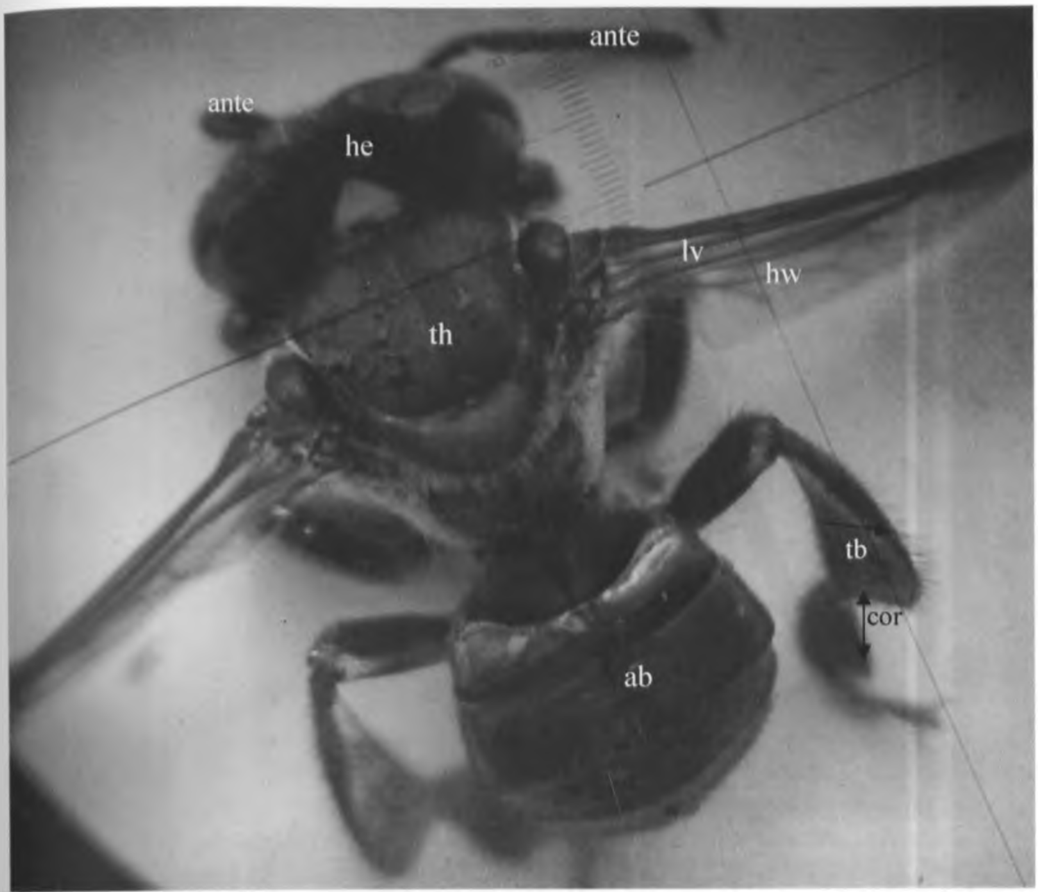


Plate 28.1: Microscopic view of *M. ferruginea* x16 (150% zoom), c, showing head, he. Thorax, th, and Abdomen, ab. See the location of hind wing, hw, and lateral vein, lv. Note the spoon-shaped corbiculae, *cor* on the hind leg, adapted to pollen collection and storage and the blade-shaped hind tibia, tb. G.A, 2007

Plate 28.2 : Dorsal view of *M. Ferruginea*, x16. Note corbiculae and wing venation with 2 sub-marginal cells, sm. Photo: Asiko G.A, 2008

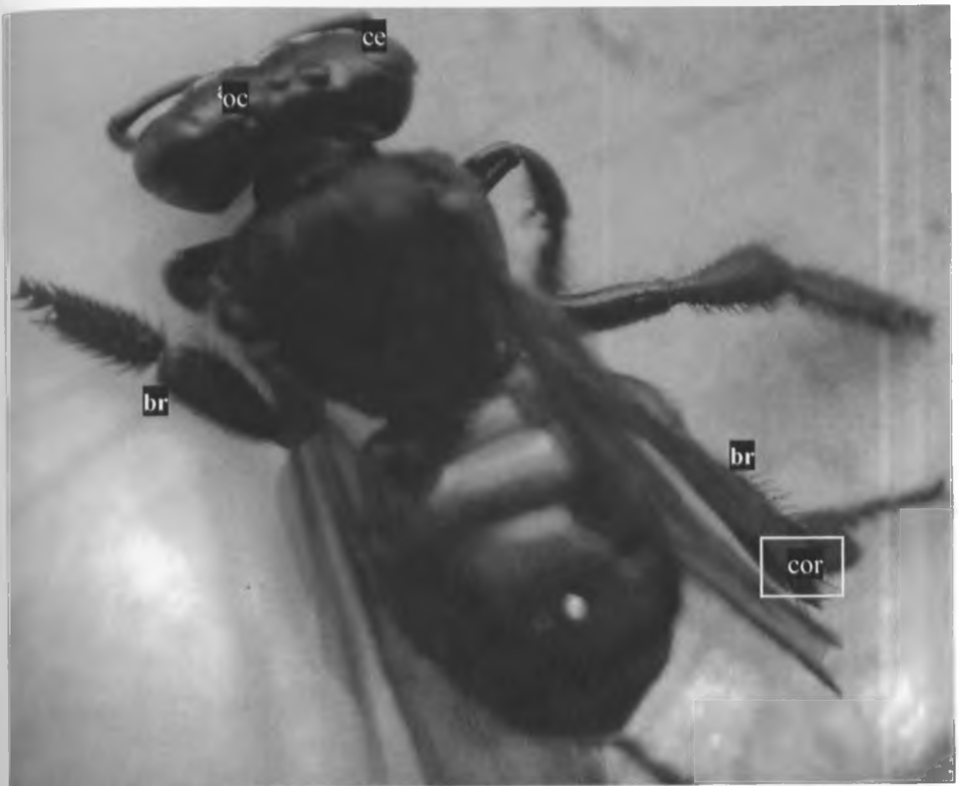


Plate 28.3: Meliponula Ferruginea, x16 (150% zoom). Note corbiculae, *cor*, ocelli, *oc*, and compound eye, *ce* and the bristles on the legs, *br*. Photo: Asiko G.A 2007

Plate 28.4: Microscopic view, *M. ferruginea* x16. Depending on the angle of view, it may exhibit various forms and size, typical of the species. Photo: Asiko G.A, 2007

Plate 29: ***Plebeina hildebrandti*, x16 (150% zoom). Note the wing venation, wv, flat corbicula and 2 sub-marginal cells, *sm*. Photo: Asiko G.A, 2008**

3.2.2 Strawberry varieties used in the research

The strawberry varieties used in the study were: Chandler (potential yields 300-500 Ton/Ha/Yr) and Rotunda (potential yields 200-250 Ton/Ha/Yr), Plates 30 and 31, respectively. The two varieties differ from each other in morphology, growth habits and fruit shape. Rotunda variety is leafy, prolific with runners and mostly round fruits whereas rotunda is less robust with no elaborate tendrils in early stages. The fruits are oblong in shape.

Potted plants, strawberry (SB), were asexually propagated from rooted strawberry runners or splits from old plant tuft. The plants were uniformly watered daily at a specified time, once every evening.

Plate 30: Open strawberries, chandler variety. Photo: Asiko G.A, 2007

Plate 31: Open strawberries, rotunda variety. Photo: Asiko G.A, 2007

3.3 Research design

150 freshly propagated strawberry plants (chandler/rotunda varieties, in flower) were transferred to freshly prepared split randomized block experimental plots measuring 6 x 11Meters. The strawberry varieties, chandler and rotunda were planted at a 30 x 30 Centimetre spacing. In the mixed cropping design, rotunda and chandler strawberry varieties were planted in alternate lines. The plots were caged in an ordinary white insect net, obtained from a popular research and innovation support Company, Amiran Kenya Limited. Each bee species for pollination was introduced inside the caged strawberry varieties, ensuring that insect pollination was predominantly done by the selected bee species.

Preliminary data was taken simultaneously at all the study sites (two replications at each study site, Kakamega and Makueni) before centralizing the research at the Lenana site, in Nairobi (with three replications). Physical observation of the pollinating bee species served as prove of which pollinator species was predominant. Two controls: Caged without pollinators and not caged (open), with the honey bee being the predominant pollinator species, were instituted. Shading, using 50% light filtration black shade-net and mixed cropping (chandler and rotunda), were other aspects of the study, introduced later into the research design. Similar experiments were set up at Kakamega and Makueni sites.

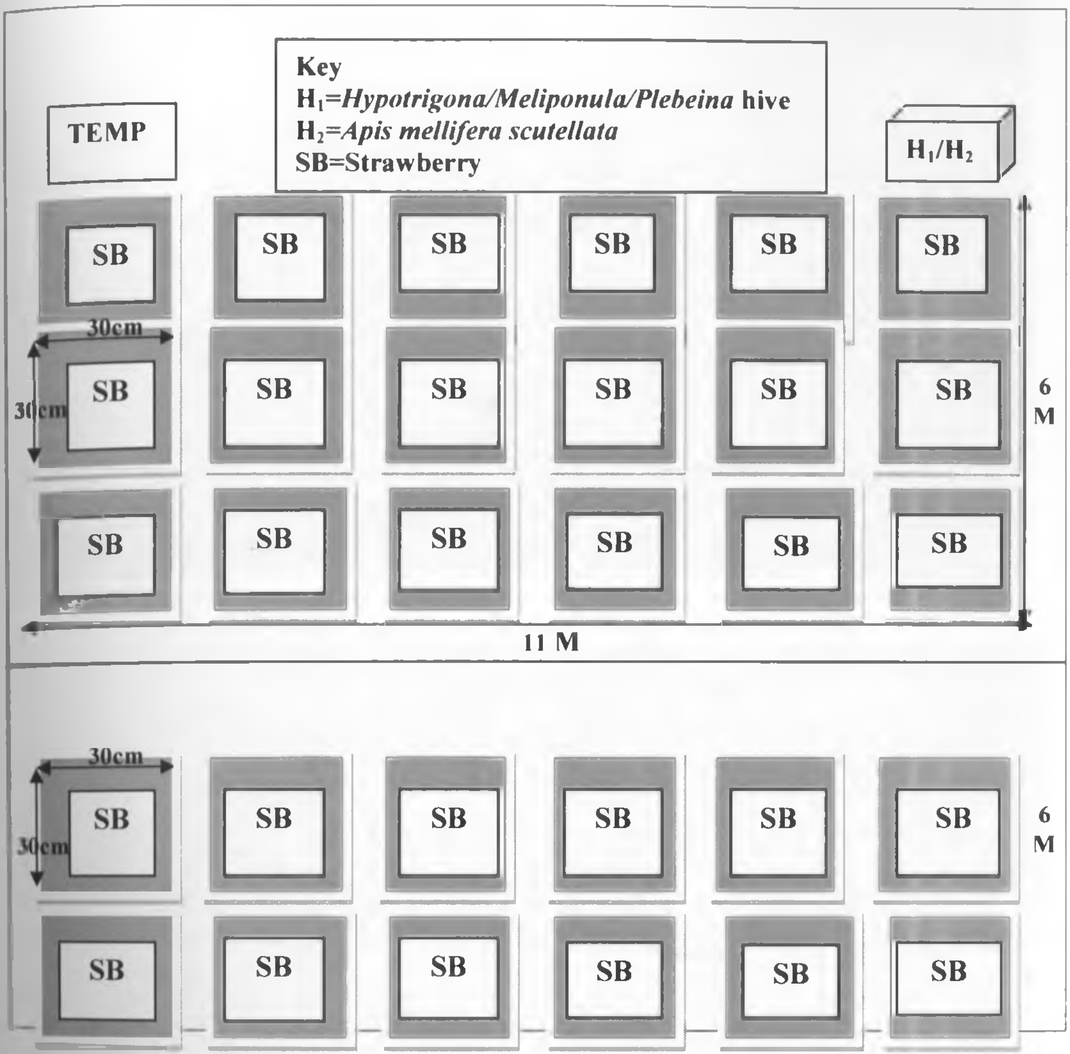


Figure 9: Experimental set-up of strawberry plants and the pollinator hive. A randomized split-block design was used, whereby some plants were inside the net cage, pollinated by the selected bee pollinator species, H_1 or H_2, Plate 32, whereas some were in the open, not caged, hence exposed to all possible pollinators, Plate 33.

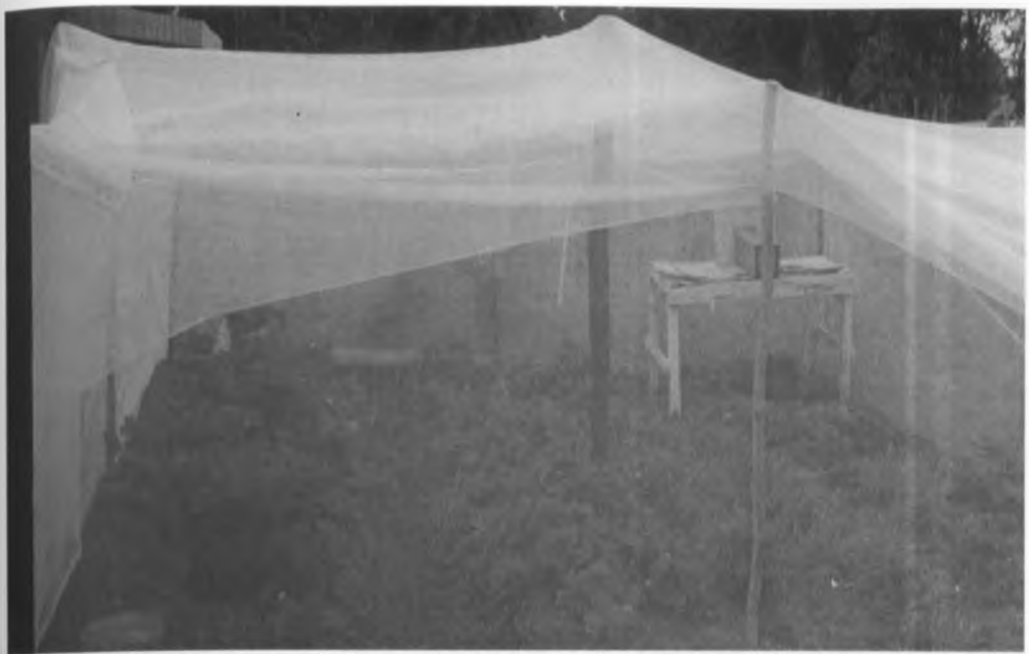


Plate 32: The Experimental set-up of strawberry plants in an ordinary insect net cage and the bee pollinator hive, *Hypotrigona ruspolii*. Photo: Asiko G.A , 2007

Plate 33. Split-block design

3.4 Study plots

3.4.1 Plot 1 and Plot 2 (Lenana, Nairobi)

The initial strawberry cultivars were purchased from a renowned strawberry farm in Limuru and asexually propagated by splits. It took 21 days for the splits to get established and another 21 days for the actual flowering process to commense, although false flowering does occur. In this case, it is advisable to de-flower before experimental use.

Plate 34: Freshly propagated strawberry plants, ready for transplant. Photo, Asiko, G.A, 2007

Plate 35: Strawberry plants in the open, free pollination, and caged, at NBS1. Photo: Asiko, G.A 2007

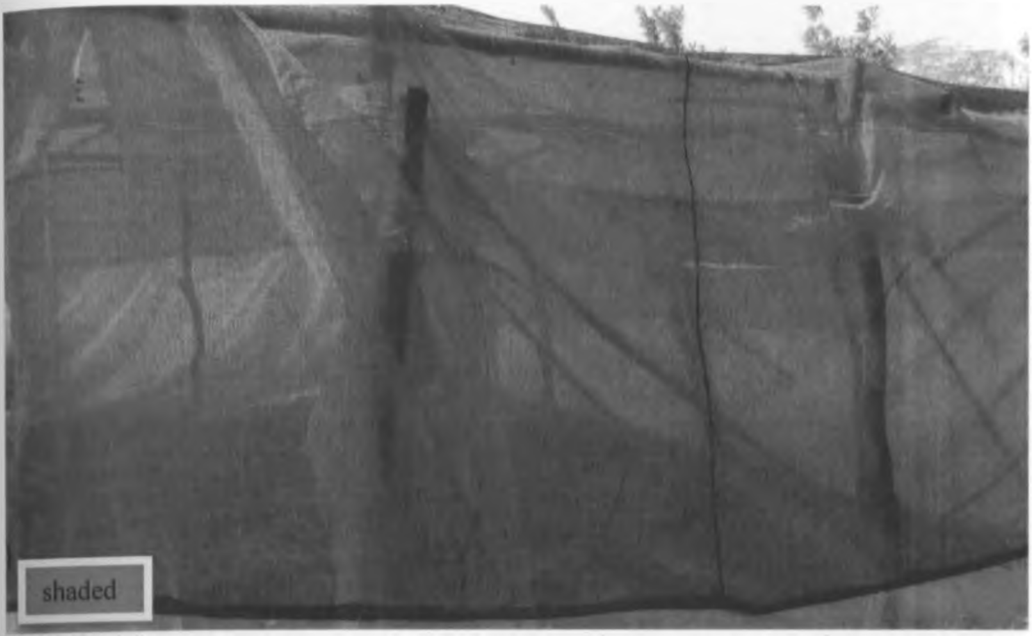


Plate 36: Strawberry plants, shaded, NBS1: Photo: Asiko, G.A 2008

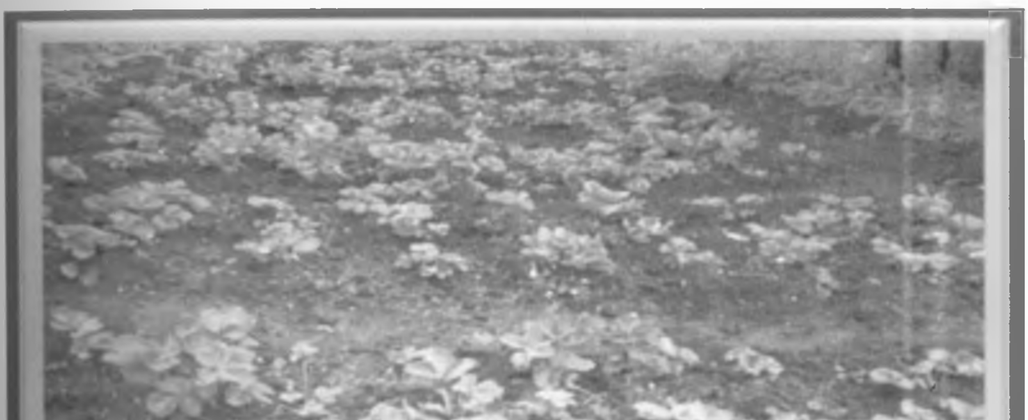


Plate 37: Strawberry plants in the open, free pollination, at NBS2. Photo: Asiko, G.A, 2007

Plate 38: Strawberry plants under a natural shade of bananas, at NBS2. Photo: Asiko, G.A, 2008

3.4.2 Plot 3 and plot 4 (Kakamega) - Kakamega forest (Ivyhiga) and Bukura) in Western Kenya.

Plate 39: Open and caged strawberry plants at Ivihiga in Kakamega forest. Photo: Asiko, G.A, 2007

Plate 40: Caged and open strawberry plants, Bukura. Photo: Asiko, G.A, 2007

Plate 41: Caged strawberry plants, showing a stingless bee hive, Bukura, 2007

3.4.3 Plot 5 (Kibwezi) - Kima area in Eastern Province. Gis Coordinates: UTM 37M 0308336, 9789486.

The plants were caged and later shaded as in the set up in Plates 2.11-2.13.

3.5 Sampling

Sampling was random, focused on red or near red fruit harvesting for productivity in terms of numbers, Figure 13. The strawberry fruit was weighed to establish the actual weight. Size was measured and quality ascertained. Data was taken daily and simultaneously at all the study sites, by site assistants, after an initial training on data collection. Ethological aspects for efficiency and effectiveness of pollination, were observed in the mornings, at the set times, with recording, where applicable, whereas weighing, measuring and determination of quality, were done in the afternoons, for convenience. Data was also taken on weather (Jaycox, 1979), season, shading, fertiliser application, with regard to Jamhuri Show ground. The bee species and strawberry variety were put into consideration (Jaycox, 1979).

3.6 Pollination success

This was measured by the quantity of strawberries that produced well-shaped fruits, Plates 42, 43-44. Fruit deformity is as a result of inadequate pollination (Free, 1968). The presence of bees is important to attain high pollination rates in strawberries. Pollination rate, according to Chagnon (1989), is calculated as the number of fertilized achenes divided by the total number of achenes per berry.

3.7 Fruit quality

Fruit-set, with the resultant fruit quantity and quality, was subjected to measurable parameters like the fruit malformity level, according to "The Greenery International" fruit quality description into: Industry, Class2, Class1 and Super classes (established and accepted, for strawberry cultivaters, throughout Europe), Plate 42. Well shaped fruits were an indicative measure of successful pollination and fertilization.

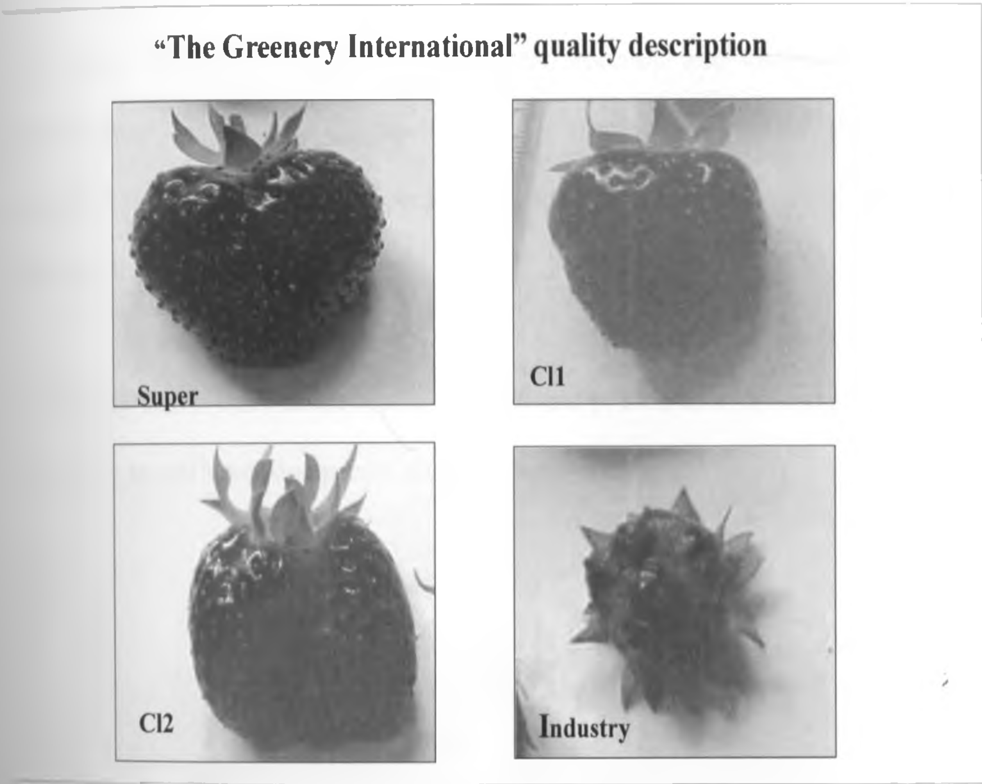


Plate 42: "The Greenery International" quality description of Super, Class1, Class2 and Industry, categories. Actual size.

The super quality is flawless, heart-shaped, and could fetch premium prices. Class one is symmetrical in shape and readily marketable. Class two is asymmetrical and has a cleft, popularly known as 'cut-nose' appearance (unsuitable for market). Industry is totally malformed and would only qualify for juice making, Plate 42.

3.8 Pollination efficiency and effectiveness of stingless versus honey bees

The behaviour of the bee on the flower is critical in determining efficiency and effectiveness. The bee may contact the anther/stigma or both, walk/fly to or from flower to flower, hover or fly away. This translates into pollination efficiency, measured by the percentage of flowers which turned into berries (quantity) and percentage of well-formed berries (quality), Plates 45, 44 and 43.

3.8.1 Strawberry quantity

The yield of the two strawberry varieties, rotunda and chandler, was tested in experimental plots using the controls and different bee species. Each variety was subjected to similar pollinator species and their effect on productivity and fruit quality measured.

Strawberry fruits were numerically counted and presented as average number of fruits according to variety, bee species and locality, Plates 43.

Plate 43: Strawberry. Chandler variety, a, is oblong in shape. Photo: Muthuraman M, 2002

Plate 44: Strawberry. Rotunda variety, b (150% zoom), is round in shape. Photo: Asiko G.A, 2007

Plate 45: Strawberry. Chandler and Rotunda variety, mixed. Photo: Asiko G.A, 2007

3.8.2 Strawberry fruit size

The size of ripe strawberries was measured using a measuring scale calibrated in Millimetres (mm). The size of the largest diameter point was taken, Plate 46.

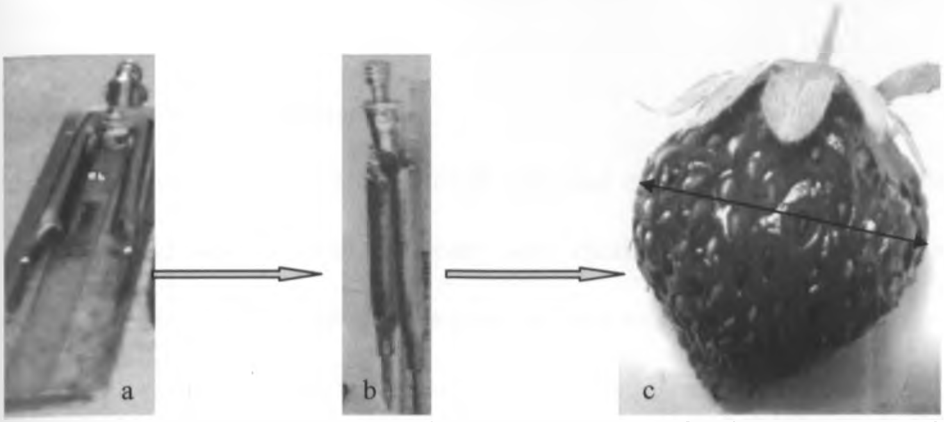


Plate 46: determination of strawberry size, a and & b=Pair of calipers and measuring scale; c

3.8.3 Strawberry weight

The weight of ripe strawberries was measured using a sensitive weighing scale (Salter Max. 500g x 5gms). Each fruit to be measured was placed on a sensitive kitchen scale for immediate readings, Fig. 10.

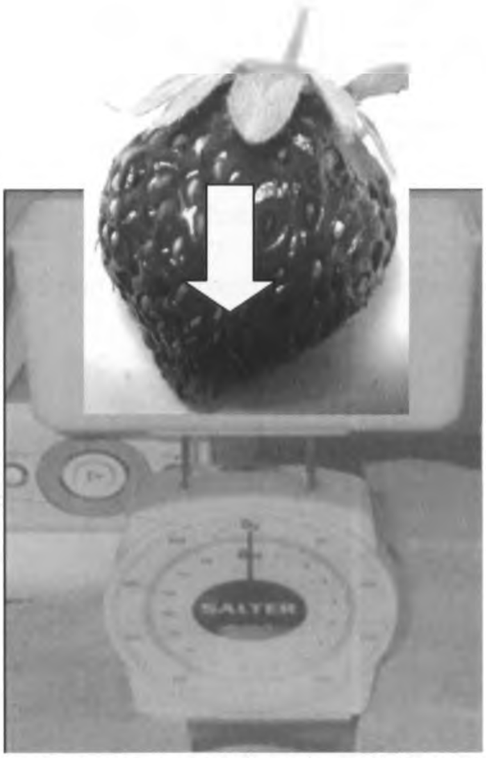


Figure 10: Measurement of strawberry weight using a Salter weighing scale. Photo: Asiko, G.A

3.9 Data collection

Data was collected and recorded through physical observations, supplemented by photography and video. Strawberry fruits were picked when red ripe, counted for numbers, measured and weighed for size (mm) and weight (gm), respectively. This constituted strawberry productivity. Data from the controls was treated likewise. Ethological data was captured using photos and videos.

3.10 Statistical methods

Genstat statistical software, Release 12 (VSN International Ltd, 2009) and SPSS statistical package for social scientists, Version17 (2009) were used for Analysis. The statistical methods of Analysis included: Pearson Chi-square test was used to test for association between the bee pollinators, strawberry variety & study location. Regression and Analysis of Variance, ANOVA was used to show variation due to strawberry variety, bee pollinator species, stem age, fruit quality, ecological zone and seasons. Student's t-test was used to compare differences in yield between strawberry varieties. Effect of shading, use of fertilizer and inter-cropping of rotunda and chandler strawberry varieties, were observed and inferences extrapolated from the results.

Econometric Regression model with multiple dummy variables, was used to determine the effect of bee species on yield (Myoung, 2002). A dummy variable is a binary variable that has either 1 or zero value. It is commonly used to examine group and time effects in regression. Panel data analysis estimates the fixed effect and/or random effect models using dummy variables. The fixed effect model examines difference in intercept among groups, assuming the same slopes. By contrast, the random effect model estimates error variances of groups, assuming the same intercept and slopes. An example of the random effect model is the groupwise heteroscesasticity model that assumes each group has different variances (Greene 2000).

Dummy variables were defined for the five species of stingless bees, *Meliponula ferruginea*, *Hypotrigona ruspolii*, *Hypotrigona gribodoi*, *Meliponula bocandei* and *Plebeina hildebrandti*. The honey bee, *Apis mellifera scutellata*, was used as the baseline bee pollinator species. The analysis followed three basic equations as follows:

(i) $\mathbf{y = x_i + e_i}$

where y=fruits harvested per day, weight, size and count; x_i=bee species, location, year, season and rainfall.

The Dummy regression equation for continous variables is:

(ii) $\mathbf{yield = \beta_o + \beta_i x_i + \delta_i d_i + \alpha_i g_i + \varepsilon_i}$

Where:

$\mathbf{x_i}$ =Rainfall and temperature; $\mathbf{d_i}$=Bee species (omitted, *Apis mellifera scutellata*); $\mathbf{g_i}$=Location (omitted, Lenana site); ($\mathbf{d_i}$ and $\mathbf{g_i}$ are dummy variables); $\boldsymbol{\beta}$, $\boldsymbol{\delta}$ and $\boldsymbol{\alpha}$ are the intercepts and coefficients; $\boldsymbol{\varepsilon}$=error term. The omitted bee species and location were used as baselines for statistical comparison.

CHAPTER FOUR

4.0 RESULTS AND DATA ANALYSIS

4.1 Weather conditions

4.1.1 Rainfall

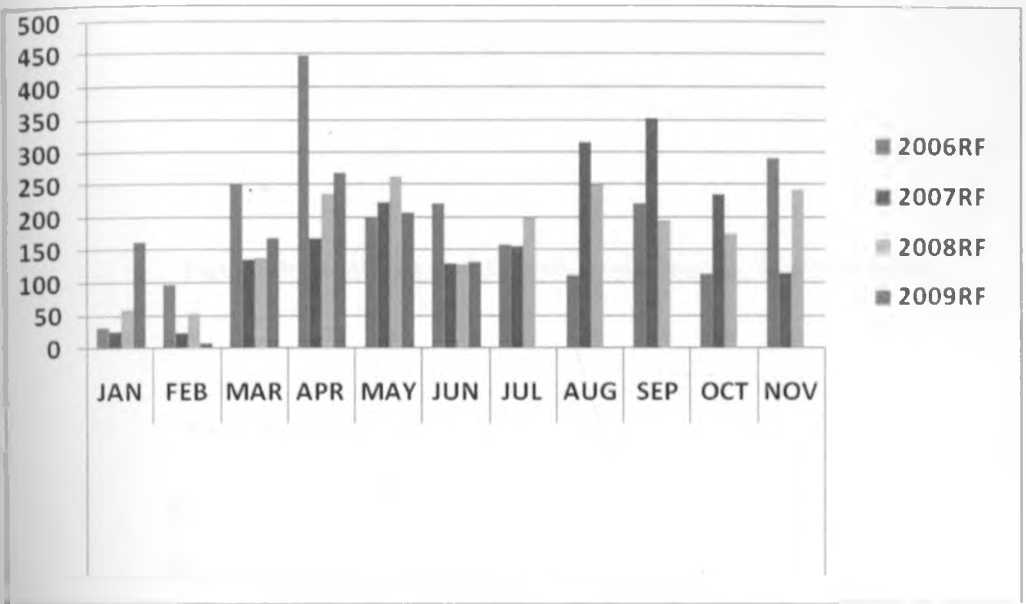


Figure11: Monthly rainfall totals in millimetres, Kakamega Station

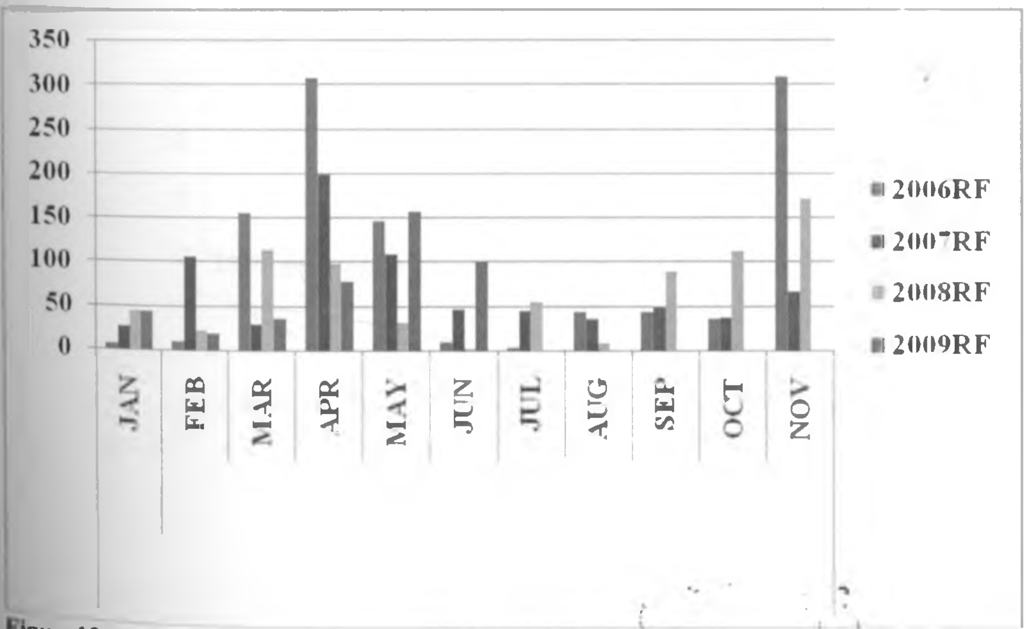


Figure12: Monthly rainfall totals in millimetres, Dagoretti=Lenana Station

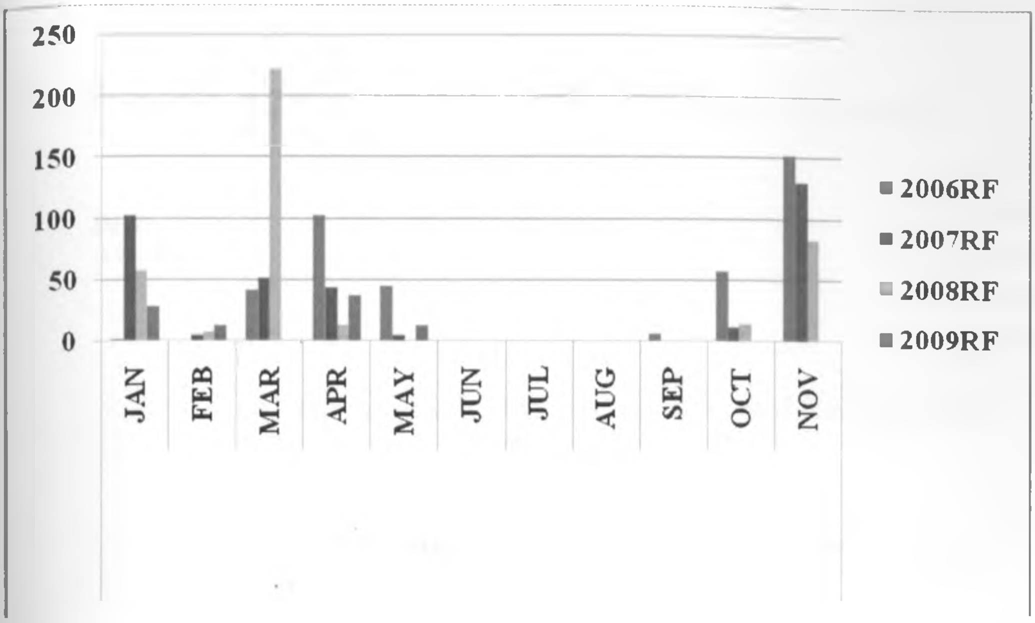


Figure13: Monthly rainfall totals in millimetres, Makindu=Kima

4.1.2 Temperature

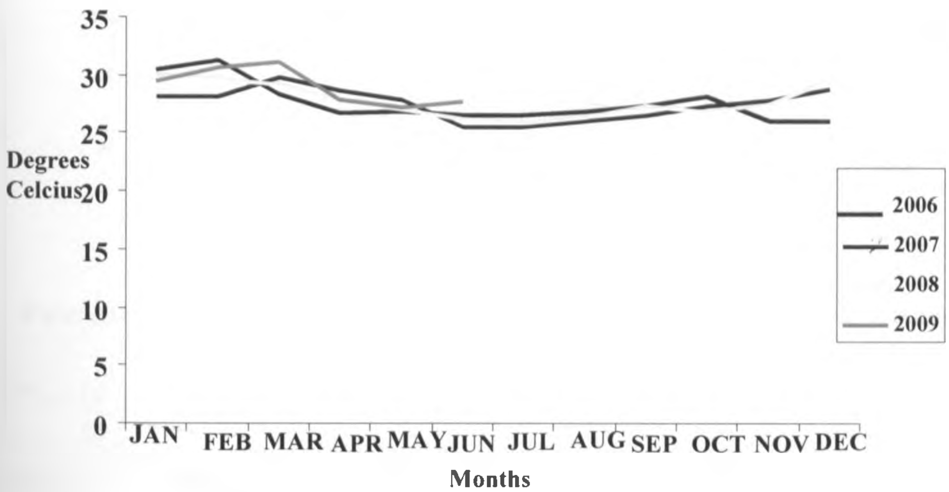


Figure 14: Monthly mean maximum temperatures, Kakamega Station

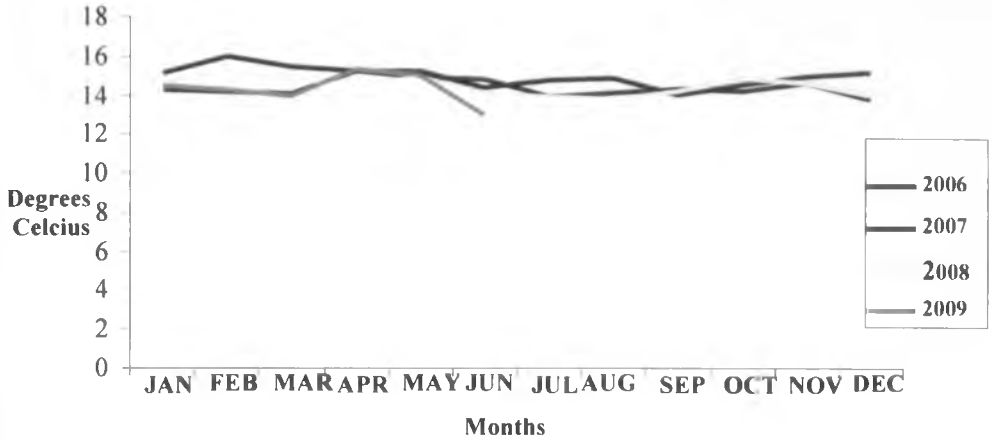


Figure 15: Monthly mean minimum temperatures, Kakamega Station

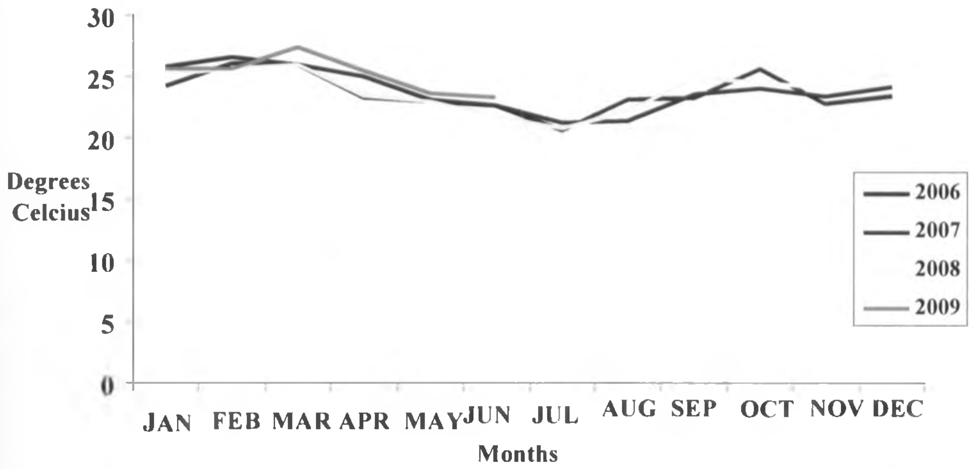


Figure 16: Monthly mean maximum temperatures, Dagoretti =Lenana Station

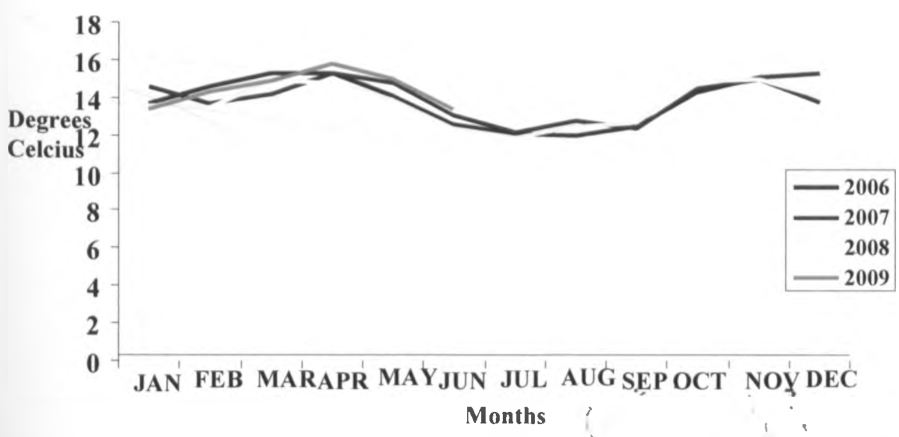


Figure 17: Monthly mean minimum temperatures, Dagoretti =Lenana Station

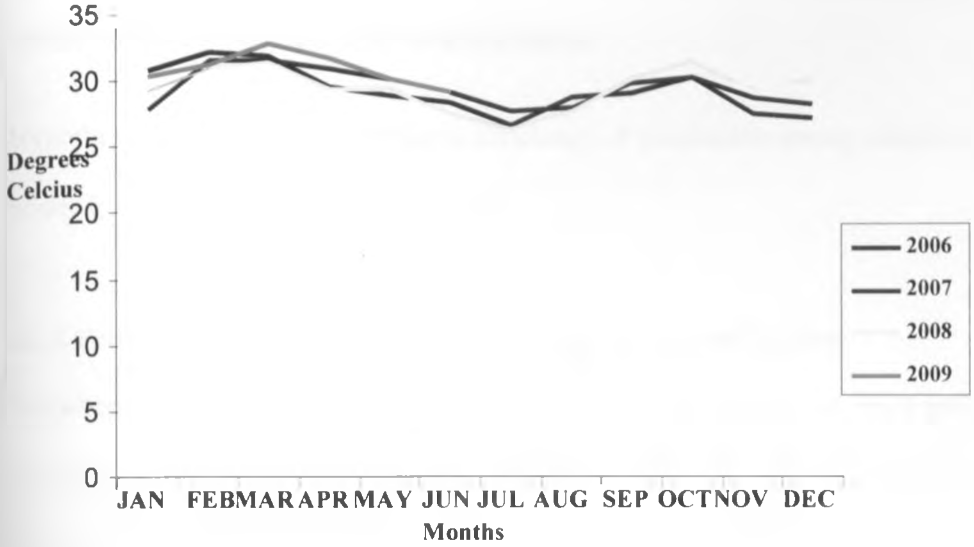


Figure18: Monthly mean maximum temperatures, Makindu=Kima

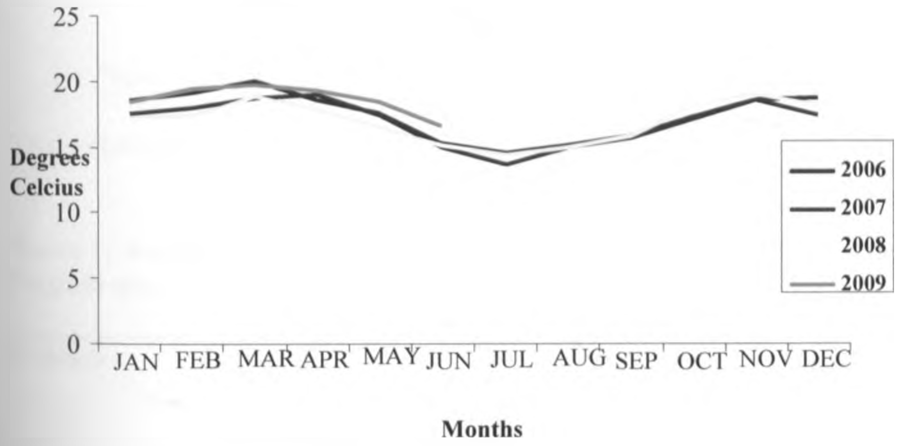


Figure 19: Monthly mean minimum temperatures, Makindu=Kima

4.2 Pollination efficiency of the stingless bees (Plebeina sp., Hypotrigona sp., Meliponula sp.) and Apis mellifera scutellata.

Hypothesis: 'There is no difference in efficiency of pollination among stingless and honey bees, in all study ecological zones.'

4.2.1 Productivity by strawberry variety, bee species and locality

Strawberry productivity by variety was measured using number of fruits picked per day from a 6M x 11M plot, weight, quality or class of fruit. Using Nairobi as a baseline ecological zone, to correct for the seasonal and climatic conditions, Table 2 and Figure 2a, a Chi-square test for association between bee species and locality was applied. The first analysis compared Nairobi and Kima and the second analysis, Nairobi and Kakamega.

i) Nairobi and Kima

The performance of *Plebeina hildebrandti* was studied in both Kima and Nairobi

Table 1: Average size, weight, fruit numbers and fruit quality at Kima and Nairobi sites

Pollinator	Location	Average size	Average weight	Average number of fruits picked per day	Proportion of super class picked
Controlnetted	Kima	24.0	5.08	7	0.60
	Nairobi	21.6	4.73	14	0.62
Plebeina hildebrandti	Kima	22.0	4.78	10	0.60
	Nairobi	24.6	5.88	12	0.61

Plebeina hildebrandti responded differently with change of environment, from endemic site (Kima) to an introduced site (Nairobi). Nairobi site appeared favourable, with increased strawberry productivity in terms of size, weight and numbers, than at Kima site, Table 1.

There was marginal significance in the number of fruits picked from Nairobi and Kima localities (df=1, p=0.042). The predicted means for Kima was 9 while that of Nairobi was 14 fruits per day. The Chi-square test showed that there was a marginal significant association between quality of fruits and ecological zones (d.f=3; X^2 =7.83; p< 0.050). A further analysis was carried out to test for association between variety and quality for Kima ecological zone. The Pearson Chi-square test showed a significant association between strawberry variety and fruit class (d.f=3;P=0.05, 9.24). This marginal association was not, however, significant at 0.01 significance level.

ii) Nairobi and Kakamega

Table 2: Mean size, weight and fruit numbers at Nairobi and Kakamega, Bukura, sites

Bee species	*Locality*	*Mean number ±SD*	*Mean size ±SD*	*Mean weight ±SD*
Controlnetted	Kakamega	5.386±6.574	18.410±4.659	4.903±2.701
Controlnetted	Nairobi	4.339±5.719	22.334±6.331	4.347±2.276
H. ruspoli	Kakamega	7.713±8.782	20.726±6.009	7.364±3.449
H. ruspoli	Nairobi	2.467±2.201	19.841±4.001	3.008±1.652

Hypotrigona ruspolii had lower means in Nairobi than in Kakamega. There was high significant association between quality of fruits and ecological zones, Kakamega and

Nairobi, on application of the Chi-square test (d.f =3; X^2 =46.79; $p< 0.001$), Table 4.10.

Table 3: Mean size, weight, fruit numbers and fruit quality at Nairobi and Kakamega forest, sites

Bee species	Locality	Mean number ±SD	Mean size ±SD	Mean weight ±SD	Proportion of super class fruits
Controlnetted	Kakamega	7.056±6.960	19.128±4.559	5.023±2.701	0.789
Controlnetted	Nairobi	12.297±11.727	20.782±6.021	3.877±2.365	0.632
H. gribodoi	Kakamega	10.671±11.608	20.575±3.835	7.271±2.267	0.849
H. gribodoi	Nairobi	5.464±4.320	19.718±4.966	3.000±2.222	0.712

Hypotrigona gribodoi pollinated strawberries in Kakamega, its endemic environment, better than in Nairobi, in all aspects, including the quality of fruits, Table 3.

Table 4. Mean number of fruit yields per strawberry variety by various stingless bee species, in Nairobi, for one growing season, three Months

Variety	control	controlnetted	H. ruspolii	H. gribodoi	M. ferruginea	P. hildebrandti
Chandler	3837±7.3	2148±11.0	671±4.7	112±1.6	334±10.1	336±6.1
Rotunda	1865±4.7	1502±7.37	1373±13.8	1059±7.5	107±3.4	51±1.3

Rotunda strawberry yields in the open control are almost double the chandler yields, in one growing season. *Hypotrigona species* favoured rotunda strawberry variety for pollination, whereas *Meliponula ferruginea* and *Plebeina hildebrandtii* pollinated chandler variety.

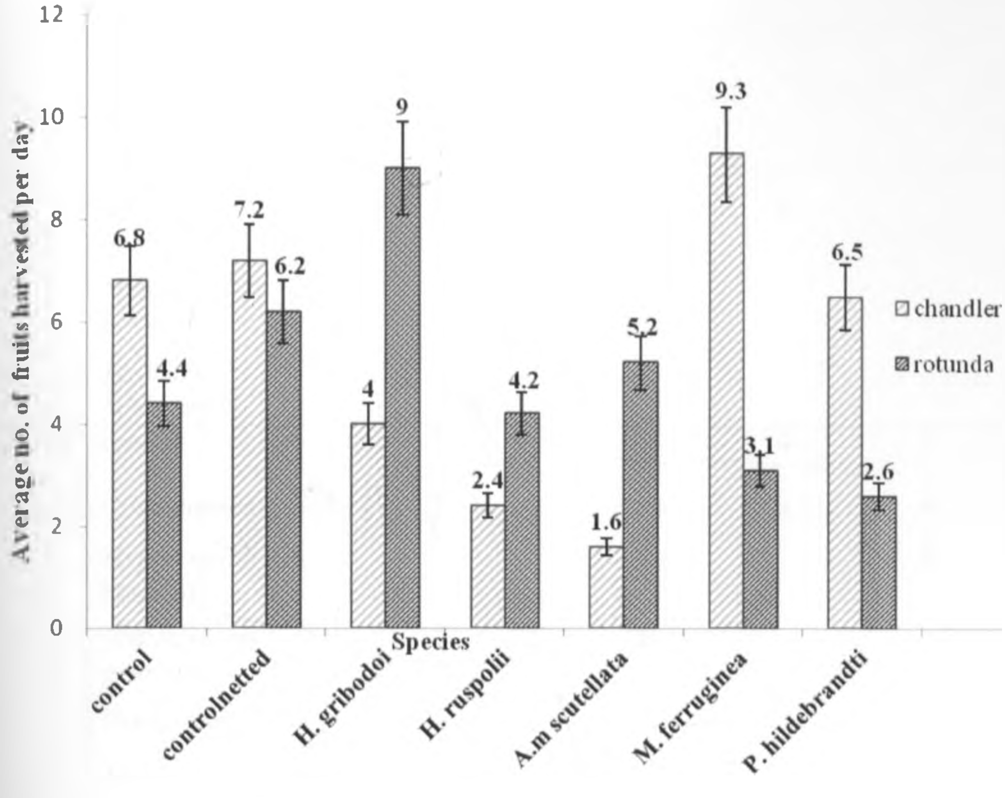


Fig 20: Mean number of fruits harvested per day as a result of pollination by different pollinator species, in Nairobi plots, during the year 2007

Hypotrigona species pollinated rotunda strawberry variety (mean=9 fruits per day, for *Hypotrigona gribodoi*) whereas *Meliponula ferruginea* and *Plebeina hildebrandti* pollinated chandler strawberry variety (mean=9 and 6 fruits per day, respectively). Chandler strawberry variety yielded most fruits in the open control, Table 6.

Table 5. Mean number of fruits picked per day, showing yield variation due to strawberry variety, bee species, location and ecological differences

Variety	Bee species	National B/keeping Station 1	Bukura	Kima	National B/keeping Station 2	Kakamega	Jamhuri Show ground
chandler	control	2	1	2	4	3	4
	controlnetted	2	1	3	5	3	8

	Hypotrigona ruspolii	2			3		3
	Hypotrigona gribodoi		1		2		
	Honey bee	1					
	Meliponula bocandei					3	
	Meliponula ferruginea	2			6		
	Plebeina hildebrandti			4	5		
Rotunda	control	4	2		2	4	3
	Controlnetted	4	7		3	3	4
	Hypotrigona ruspolii	8			3		2
	Hypotrigona gribodoi		8		3		
	Honey bee	4					
	Meliponula bocandei					2	
	Meliponula ferruginea	1			2		
	Plebeina hildebrandti			2	2		

The National Beekeeping Station and Jamhuri Show ground were used as comparative plots within the same site, Lenana, and also selectively as a comparative site for stingless bee species from other endemic sites, Table 5. Although *Hypotrigona ruspolii* was introduced in all the three sites in Nairobi, it pollinated better at the National bee keeping Station 2 and Jamhuri Show ground, both registering a mean of 3 fruits per day, than at the National Bee Keeping Station 1, which had a mean of 2 fruits per day, for chandler variety. On the other hand, *Hypotrigona ruspolii* had a higher mean number of strawberry fruits on rotunda, 8 fruits per day, compared to 3 and 2 at the National Bee Keeping Station 2 and Jamhuri Show ground, respectively.

The mean number of fruits harvested as a result of pollination by *Hypotrigona gribodoi,* was 2, in Nairobi and 1, in Bukura, on chandler strawberry variety, but much higher on rotunda than chandler at Bukura. The mean number of strawberry fruits harvested as a result of pollination by *Meliponula bocandei* was 3 fruits on chandler and 2 on rotunda strawberry varieties, at Kakamega forest, but similar strawberry fruit means for both controls. The mean strawberry fruit production as a result of pollination by *Meliponula ferruginea* was 6 fruits per day, on chandler strawberry variety, but 2 on rotunda strawberry variety. The mean number of fruits per day as a result of chandler strawberry pollination by *Plebeina hildebrandti* was 2, both in Nairobi and Kima, though the difference in strawberry variety was noticeable, 5 fruits per day for chandler and 2 for rotunda, in Nairobi. A similar pattern was repeated for Kima, with a mean number of 4 fruits for chandler variety and 2 for rotunda.

The Strawberry mean fruit production on rotunda as a result of honey bee pollination was higher than that of chandler variety, with a daily mean production of 4 and 1 fruits on the two strawberry varieties respectively, Table 5. No measurements were taken as a result of *Meliponula bocandei pollination,* at the centralized station, Lenana, because it absconded almost immediately after introduction to the experimental plot.

Table 6: Mean fruit Productivity for chandler and rotunda in Nairobi, Lenana, in the open control and enclosed conditions

Variety	Bee species	Mean no. of fruits	Mean size	Mean weight
Chandler	Control	3.885±3.56	22.894±5.62	5.537±2.60
Chandler	Controlnetted	5.083±4.39	21.780±7.11	4.828±2.30

Chandler	*H. gribodoi*	2.879±3.19	23.081±5.12	4.765±2.43
Chandler	*H. ruspoli*	1.750±1.14	21.036±4.77	4.204±1.92
Chandler	*A. m scutellata*	1.455±0.69	17.227±4.64	2.909±2.27
Chandler	*M. bocandei*	3.246±3.12	20.955±4.42	6.603±2.72
Chandler	*M. ferruginea*	5.653±4.28	24.249±4.30	5.964±2.36
Chandler	*P. hildebrandti*	4.048±3.45	23.456±5.97	5.221±2.52
Rotunda	Control	2.852±2.87	20.293±5.07	3.670±2.17
Rotunda	Controlnetted	3.729±4.05	19.933±4.79	3.227±2.11
Rotunda	*H. gribodoi*	5.623±6.11	21.094±4.62	2.998±1.59
Rotunda	*H. ruspoli*	5.033±6.61	19.873±4.78	4.593±3.48
Rotunda	*A. m scutellata*	3.864±3.77	17.752±3.50	2.132±0.88
Rotunda	*M. bocandei*	2.085±1.06	19.822±3.58	5.414±2.48
Rotunda	*M. ferruginea*	2.184±2.56	22.009±4.12	3.578±1.31
rotunda	*M. hildebrandti*	1.700±0.88	22.128±5.96	3.956±3.04

It was apparent from observation in the field that the honey bee, *A. m. scutellata* was the predominant bee species in the open control at the Nairobi plots. This observation is also indicated by the near similar mean number of fruits per day between the control and honey bee results in Tables 6 and 9. *Hypotrigona species* effectively pollinated rotunda strawberry variety with a mean daily fruit productivity of 5-6 fruits whereas *Plebeina hildebrandti* and *Melliponula ferruginea,* effectively pollinated chandler strawberry variety, with a mean daily fruit productivity of 4-6 fruits, respectively.

4.2.2 Productivity of strawberry varieties pollinated by different bee species under similar climatic conditions.

Table 7: Mean number of chandler fruits harvested per day in Kima

Bee species	Yield	Super class	Industry class
Control	3.33±1.873	4.330±0.752	2.313±0.894
Control netted	4.400±2.375	6.000±2.756	2.000±0.000
P. hildebrandti	5.343±3.423	7.952±3.676	1.429±0.629

Plebeina hildebrandti pollination yielded a higher daily fruit mean, compared to fruit means from the open control and controlnetted (caged). The same pattern was repeated for quality as shown in Table 7.

4.2.3 Productivity of strawberry varieties, chandler and rotunda, pollinated by *Apis mellifera scutellata* (control), under similar climatic conditions, Lenana, Nairobi.

Table 8: Mean number of fruits, size and weight, for chandler and rotunda strawberry varieties in Nairobi (Lenana) plots

Variety	Mean No. of fruits	Mean size	Mean weight
chandler	4.11759±3.2	22.8463±5.2	5.41445±2.5
rotunda	3.75748±2.4	20.4667±4.7	3.70265±2.4

Chandler was a superior fruit to rotunda, as indicated by the mean size and weight in Table 6. The honey bee was the major pollinator species in the open, at Lenana and Jamhuri showground plots due to the presence of many bee hives in the viscinity.

4.2.4 Strawberry variety and bee species

4.2.4.1 Regression analysis revealed significant association between rotunda strawberry variety and bee species (d.f=6; P<0.001, 505).

Table 9: Estimates of parameters for rotunda strawberry variety

Parameter	estimate	s.e.	t(*)	t pr.	antilog of estimate
Constant	1.6173	0.0727	22.26	<.001	5.040
controlnetted	-0.332	0.105	-3.17	0.002	0.7175
H. gribodoi	0.622	0.118	5.29	<.001	1.863
H. ruspolii	0.235	0.176	1.34	0.181	1.266
A. m scutellata	1.689	0.412	4.10	<.001	5.416
M. bocandei	0	*	*	*	1.000
M. ferruginea	-1.184	0.229	-5.17	<.001	0.3061
P. hildebrandti	-0.924	0.347	-2.66	0.008	0.3969

NB: The analysis used the control as the reference species

The honey bee, *Apis mellifera scutellata*, *Hypotrigona gribodoi* and *Hypotrigona ruspolii*, had a significant positive association that was higher than the controls, whereas *Meliponula ferruginea* and *Plebeina hildebrandti* had a significant negative association which was lower than the controls. Pearson chi-square test for association between strawberry variety and bee species was highly significant (d.f=7; X^2=2909; p < 0.001).

4.2.4.2 Regression analysis revealed significant association between chandler strawberry variety and bee species (d.f =9; P<0.001, 2055).

Table 10: Estimates of parameters for chandler strawberry variety

Parameter	estimate	s.e.	t(2046)	t pr.
Constant	-20.59	3.27	-6.29	<.001
Stingless bees (controlnetted)	0.195	0.285	0.68	0.494
Honey bee(freely pollinated)	-1.765	0.825	-2.14	0.033
Kima	-5.14	1.03	-5.00	<.001
Nairobi	0.615	0.530	1.16	0.246
Rainfall	-0.01102	0.00222	-4.96	<.001
Stemage	-0.00094	0.00139	-0.68	0.497
Temperature	0.904	0.185	4.88	<.001

The yield of the two strawberry varieties, rotunda and chandler, was tested in Kakamega and Nairobi, using the controls and different bee species. The mean number of fruits picked per day, mean weight and mean size were measured and classified, Table 6.

Table 11: The mean number of fruits harvested per day in Kakamega according to variety, class and pollinator species

		Super class		Industry class	
Pollinator	Variety	N	Mean	N	Mean
control	chandler	22	4	11	3
	rotunda	54	5	27	2
controlnetted	chandler	15	3	8	1
	rotunda	36	8	12	2
H. ruspolii	chandler	0		3	1
	rotunda	58	12	12	1
M. bocandei	chandler	34	5	16	3
	rotunda	24	3	15	2

The yield of rotunda strawberry variety in the caged control was more than twice that of chandler (8 and 3, respectively) implying a higher rate of self-pollination in rotunda than in chandler. *Hypotrigona ruspolii* pollination yielded a higher mean for rotunda strawberry variety, 58, than chandler, whereas *Meliponula bocandei* pollination yielded a higher mean for chandler variety, 34, than rotunda, 24, Table 11.

The analysis of variance results showed that strawberry variety and bee species were significant in determining fruit size and weight, Tables 13, 14 and Figure 21.

Table 12: The average number of fruits harvested in Nairobi (Jamhuri show ground) by variety, class and pollinator species

		Super class		Industry class	
	Strawberry Variety	N	Mean	N	Mean
control	Chandler	31	8.839±5.6	26	2.346±1.9
	rotunda	23	5.348±3.4	12	2.000±1.2
controlnetted	chandler	25	17.360±	17	6.353±6.3
	rotunda	15	7.067±8.2	9	4.222±3.2
H. gribodoi	chandler	23	6.913±5.0	20	2.400±1.3
	rotunda	8	3.250±3.0	3	1.667±1.2

4.3 Average fruit size and fruit weight

4.3.1 Average fruit size

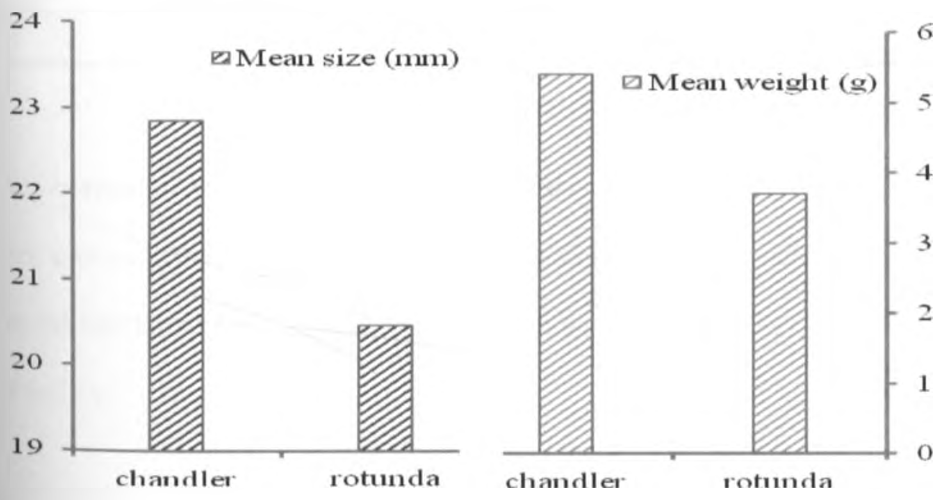


Figure 21 : Mean size and weight for chandler and rotunda strawberry varieties pollinated by stingless bee species. Size and weight follows a similar trend

An analysis of variance was carried out to test for the effect of pollination by stingless bee pollinator species on fruit size. Prior to ANOVA, a test of normality was carried out to test if the fruit size variable was normally distributed. Bee species's effect was highly significant on fruit size (d.f= 7; P<0.001; 3562).

4.3.2 Average fruit weight

An analysis of variance was carried out to test for the effect of pollination by stingless bee pollinator species on fruit weight. Bee species effect was highly significant on fruit weight (d.f= 7; P<0.001; 3562).

Table 13: Mean fruit numbers per bee pollinator species in relation to strawberry variety, for three months

Variety	*control*	*control netted*	*H. gribodoi*	*H. ruspolii*	*hb*	*M. bocandei*	*M. ferruginea*	*P. Hildebrandti*
Chandler	3356	1526	464	109	16	0	1334	149
Rotunda	1381	1055	1342	335	170	0	107	46

It was apparent from observation in the field that *A.m scutellata* was the predominant bee species in the open control at the Nairobi plots. This observation was supported by the similar number of mean fruits between the control and *A.m scutellata,* Table 6 9 and 14.

Table 14: Mean number of strawberry fruits by size, weight, strawberry variety and bee species

Variety	Bee species	Mean number of fruits	Mean size	Mean weight
Chandler	Control	3.728±3.56	22.894±5.62	5.537±2.60
Chandler	Controlnetted	4.860±6.39	21.780±7.11	4.828±2.29
Chandler	*H. gribodoi*	2.868±3.19	23.081±5.12	4.765±2.43
Chandler	*H. ruspolii*	1.750±1.14	21.036±4.77	4.204±1.92
Chandler	*A.m scutellata*	1.455±0.69	17.227±4.64	2.909±2.27
Chandler	*M. bocandei*	3.782±3.77	20.955±4.42	6.603±2.72
Chandler	*M. ferruginea*	5.633±5.28	24.249±4.30	5.964±2.36
Chandler	*P. hildebrandti*	3.581±3.45	23.456±5.97	5.221±2.52
Rotunda	Control	2.795±2.87	20.293±5.07	3.670±2.17
Rotunda	Controlnetted	3.793±5.05	19.933±4.79	3.227±2.11
Rotunda	*H. gribodoi*	5.559±9.11	21.094±4.62	2.998±1.59
Rotunda	*H. ruspolii*	5.033±6.61	19.873±4.78	4.593±3.48
Rotunda	*A.m scutellata*	3.864±3.77	17.752±3.50	2.132±0.88
Rotunda	*M. bocandei*	2.085±1.06	19.822±3.58	5.414±2.48
Rotunda	*M. ferruginea*	2.184±2.56	22.009±4.12	3.578±1.31
Rotunda	*P. hildebrandti*	1.700±0.88	22.128±5.96	3.956±3.04

4.4 Improvement of quality and quantity of strawberry fruit production through stingless bees pollination

Hypothesis: 'The quantity and quality of strawberry fruits is the same for all stingless bees species.'

4.4.1 Quality determination by strawberry variety

Although the introduction of the bee pollinator species changed the production in terms of quantity and quality of fruits per day, its effect was not the same on the two strawberry varieties, chandler and rotunda, and for the different bee species. *Hypotrigona gribodoi* and *H. ruspolii* performed poorly on chandler but increased the amount of quality fruits for rotunda from 6 to 12 and 6 respectively. On the other hand, *M. ferruginea* and *P. Hildebrandti*, performed better on chandler by increasing the amount of quality fruits from an average of 9 to 14 and 9 respectively, Tables 9, 15 and Figure 20.

Under ideal conditions, both chandler and rotunda strawberry varieties have an equal chance of becoming either of the classes: Super, class1, class2 or industry, Figure 22. The proportion of rotunda strawberry variety was about 60% for all fruit quality categories as compared to chandler at 40%, Figure 24. A breakdown of the above figure by pollinator species showed that the honey bee made a higher contribution to the super class strawberry quality through pollination, compared to stingless bee species, Figure 23.

4.4.2 Quality determination as a result of pollination by various bee species

The honey bee pollination yielded a higher percentage of super class strawberry fruits, over 60 percent, compared to the stingless bee species, Figures 23 and 24. The stingless bee pollination, *Meliponula ferruginea* and *Hypotrigona ruspolii* yielded similarly with the controls in the net, with regard to super class quality of strawberry fruits. *Hypotrigona gribodoi* pollination yielded most of class one fruits. *Plebeina hildebrandti* pollination was equated to nil pollination by a pollinator, and resulted in the most deformed fruits, industry. The results from the analysis showed that fruit quality and bee species were significantly associated (d.f= 21; X^2 = 62.95; P<0.001).

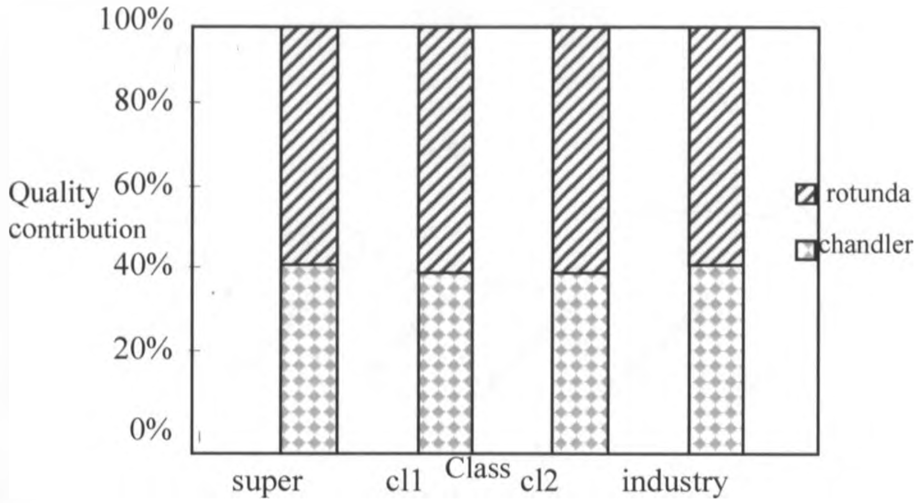


Figure 22: Proportion of rotunda and chandler strawberry varieties in each fruit class category

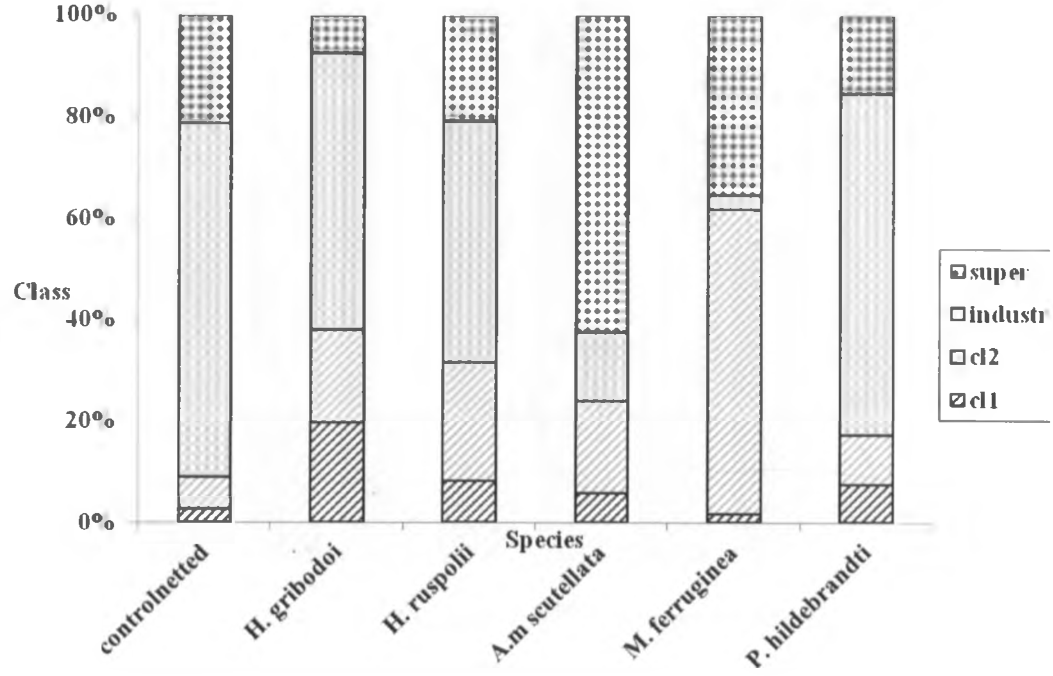


Figure 23: Contribution to each quality class of strawberry by pollinator species

4.4.3 Proportion of super class fruits harvested as a result of strawberry pollination by various bee species

The honey bee pollination yielded most fruits in super class (100% for chandler and 96% for rotunda). Pollination by *Hypotrigona* species yielded 85-90%, for both chandler and rotunda varieties. *Meliponula ferruginea* pollination yielded similarly with *Plebeina hildebrandti,* 85% for chandler variety and less than 60% for rotunda. *Hypotrigona ruspolii* pollination yielded similarly to control open, 85% for both chandler and rotunda strawberry varieties, figure 24.

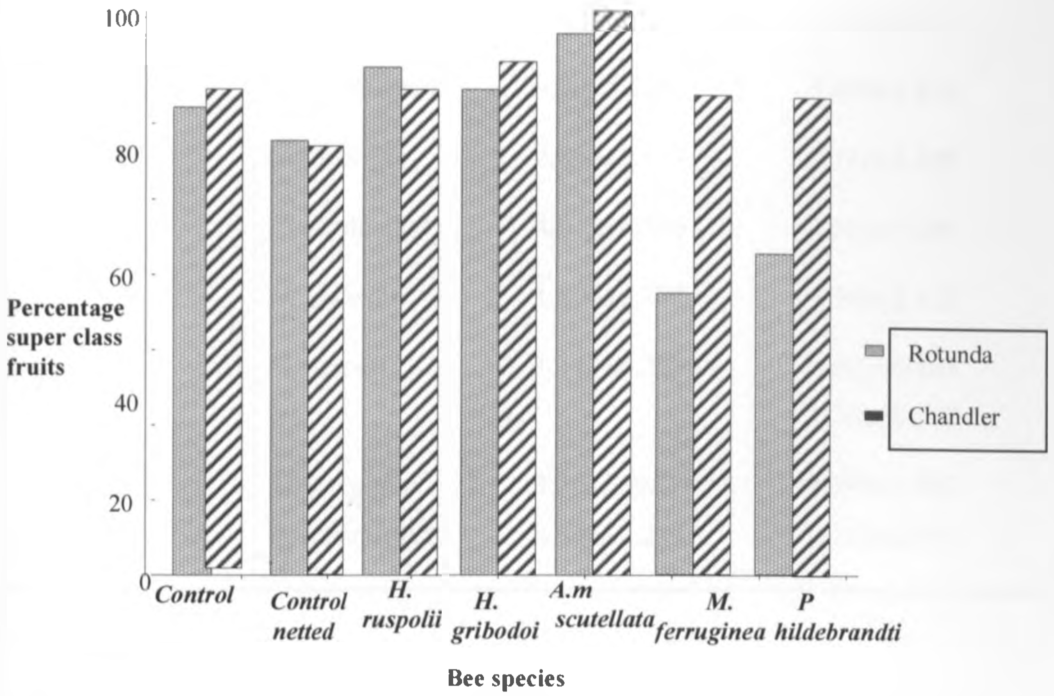


Figure 24: Proportion of super class fruits harvested per day from the Lenana plots showing variation occassioned by bee species and strawberry variety

Strawberry pollination by the honey bee, *Apis scutellata*, *H. gribodoi* and *H. ruspolii*, on rotunda strawberry variety, resulted in better strawberry fruits than the controls, hence had a positive impact, whereas pollination *by M. ferruginea* and *P. hildebrandti* resulted in significantly inferior strawberry fruits than the controls, with a negative impact, Table 9 and Figure 24.

Table 15: Mean number of fruits harvested per day by variety, pollinator species and quality

Class	Pollinator	Chandler	Rotunda
Super	Control	8.931±6.72	5.663±5.083
	Controlnetted	9.098±11.381	7.864±7.651
	H. gribodoi	4.926±5.121	12.357±13.118
	H. ruspoli	2.676±1.843	5.740±6.844

	A. m scutellata	1.600±0.966	5.655±4.412
	M. ferruginea	13.963±10.940	3.600±2.611
	P. hildebrandti	9.00±6.589	2.889±1.854
Industry	Control	2.843±2.427	2.116±1.498
	Controlnetted	4.622±4.544	3.603±3.293
	H. gribodoi	1.806±1.228	2.569±2.178
	H. ruspoli	1.111±0.289	1.655±0.805
	Hb		1.500±0.577
	M. ferruginea	3.22±2.466	2.789±1.653
	P. hildebrandti	2.556±1.217	2.222±0.971

4.5 Strawberry fruit variation due to ecological zone, season, location, strawberry variety, crop stem-age and crop husbandry

Hypothesis: 'There is no seasonal, ecological, locational, varietal, bee species, and husbandry effects on strawberry production.'

4.5.1 Strawberry fruit variation due to season

Prior to model application, the effect of season was tested separately. The total number of fruits harvested per day was transformed using the log transformation before a one-way anova was applied, to test the seasonal effect. Season was fitted as treatment and variety as block. There was significant seasonal effect on productivity of strawberry varieties (d.f=3; P<0.001,709).

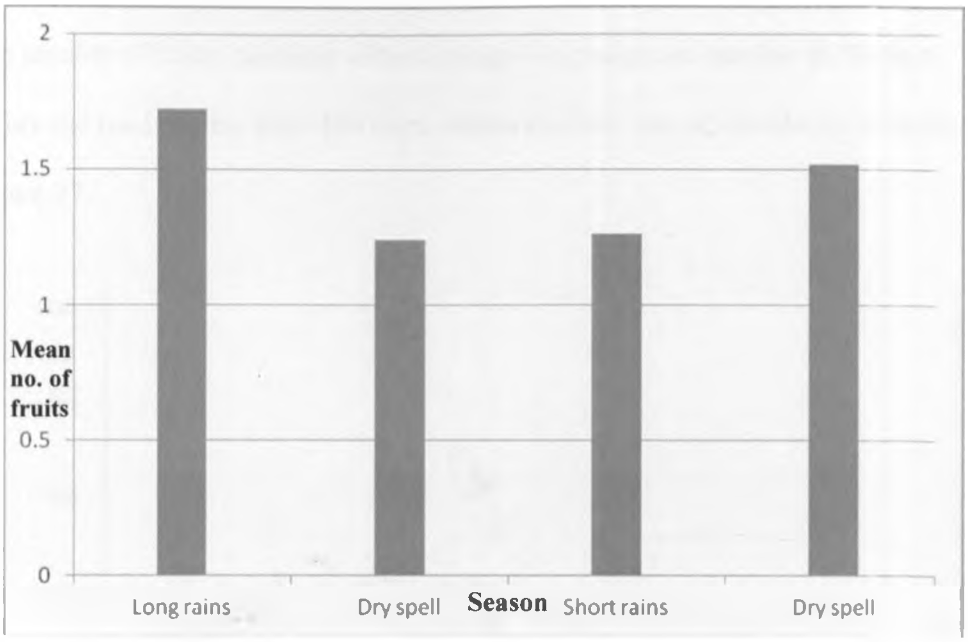


Figure 25: The annual mean number of fruits harvested per season.

There was significant interaction between season and strawberry variety (d.f.3; F<0.001,3.82). The demarcation between dry spells and rainy periods was complicated by climate change attributes, Figure 25.

4.5.2 Strawberry fruit variation due to stem-age

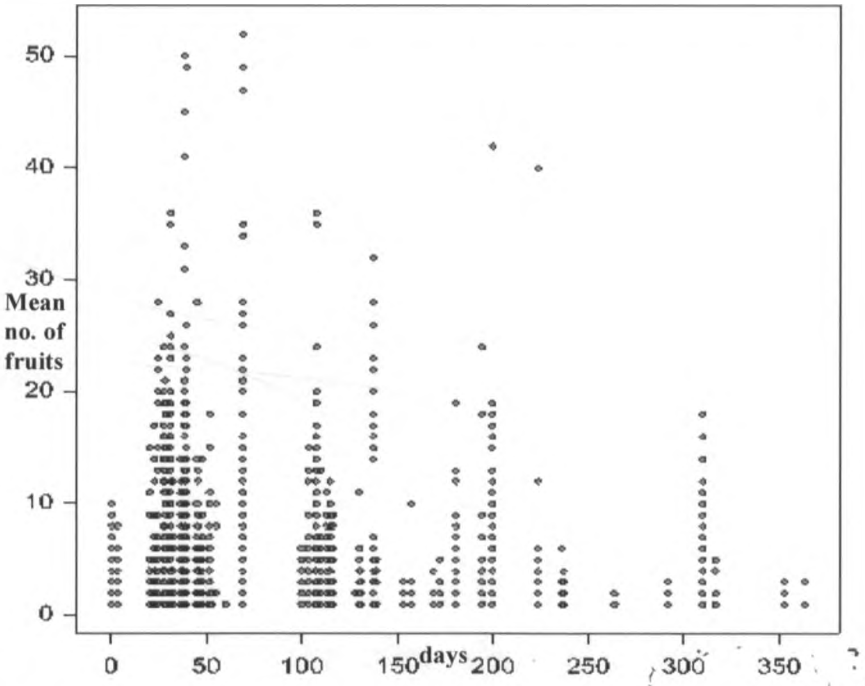


Figure 26: The mean number of strawberry fruits harvested per season in a year

The number of fruits increases with stem-age to a maximum number at 200 days before the final decline after 400 days, within the first year of strawberry production, Figure 27.

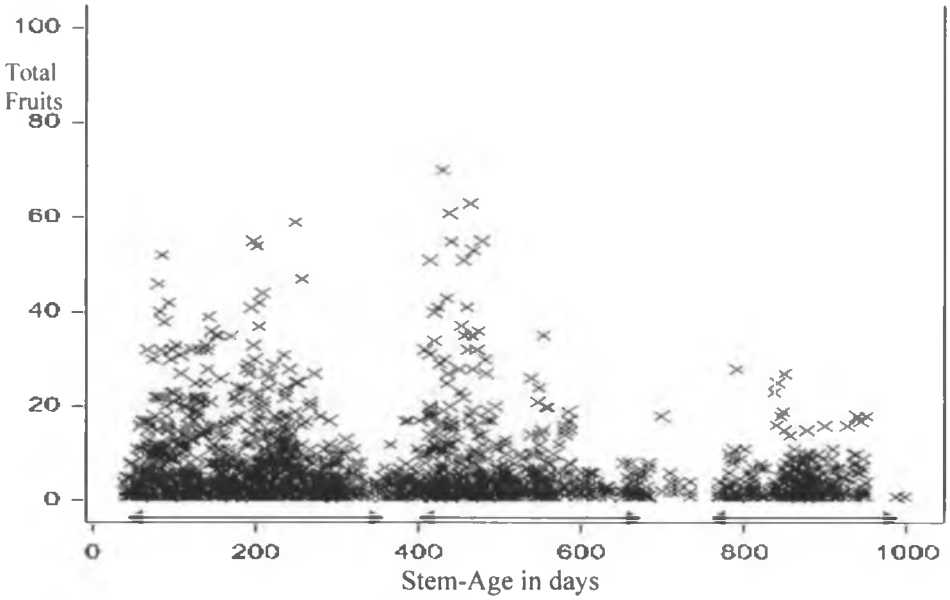


Figure. 27: Mean number of strawberry fruits picked per day by stem age, within 3 years. There are three distinct patterns: Day 40-370, 400-600 and above 600

Figure 27 depicts a typical 3 year strawberry production. The first and second year are the most productive. Plants should be replaced in the third year.

4.5.3 Strawberry fruit variation due to location

There was significant association between the number of strawberry fruits picked and locality, Nairobi and Kima (d.f=1, p=0.042). This was, however, marginal.

4.6 Regression with dummy variables

Regression with dummy variables was found to be suitable because bee species and location are fixed effects. The other variables included in the model were season, rainfall and average daily temperatures.

Table 16 : The analysis of variance with dummy variables

Model		df	Sum of Squares	Mean Square	F	Sig.
1						
	Regression	11	52042.122	4731.102	15.732	.000[a]
	Residual	85	25561.549	300.724		
	Total	96	77603.670			

R-square (r^2)=0.67 and the adjusted R-square (r^2)=0.628
Dependent Variable: fruits per day

The fitted model had an R-square value of .671 which indicates that the explanatory variables explained the variation in the number of fruits sufficiently, Table 16.

Table 17: Coefficients for the two-way regression model

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-107.949	81.052		-1.332	.186
	Season	-11.693	1.876	-.520	-6.232	.000
	Rainfall	-.074	.029	-.231	-2.510	.014
	Daily temp. mean	7.500	3.619	.174	2.073	.041
	Hypotrigona gribodoi	16.960	4.740	.286	3.578	.001
	Meliponula ferruginea	21.011	6.254	.311	3.359	.001

Plebeina hildebrandti	-16.177	8.552	-.174	-1.892	.062
Kima	16.415	9.356	.168	1.754	.083
Kakamega	13.424	6.710	.172	2.001	.049
Showground_max	23.982	6.513	.298	3.682	.000

a. **Dependent Variable: fruits per day**

b. ***Hypotrigona ruspolii* and *Meliponula bocandei* were removed from the model since they were found to be insignificant.**

There was positive correlation between the number of fruits picked per day and the warm temperature (coefficient 7.5 with a p-value 0.04). Season and location were found to be important factors that influence the number of fruits picked per day, Table 17.

CHAPTER FIVE

5.0 GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Discussion

5.1.1 Efficiency of pollination by the stingless bees (*Plebeina sp.*, *Hypotrigona sp.*, *Meliponula sp.*) and *Apis mellifera scutellata*.

Results from the study showed that stingless bees are efficient pollinators of strawberry. It was further observed in Figures 23, 24 and Tables 9, that *Hypotrigona gribodoi* was a more efficient pollinator of rotunda strawberry variety whereas *Meliponula ferruginea* was an efficient pollinator of chandler strawberry variety. There was high significant association between the stingless bee species and the strawberry variety (d.f=7; X^2 =2909, P<0.001) as observed in Table 23. In general *Hypotrigona* species were most effective on rotunda variety whereas *meliponula* species were effective in the pollination of chandler strawberry variety. Jaycox (1970) observed a solidary mining bee, *Andrena melanochroa*, as a highly effective strawberry pollinator, visiting only strawberries.

The honey bee was found to be efficient on both strawberry varieties, rotunda and chandler, with a relatively higher mean fruit production than the stingless bees. This was particularly apparent in the quality classification of fruits where the proportion of super quality fruits in the honey bee pollinated fruits was 100% for chandler and 97.45% for rotunda, depicted in Figures 23 and 24.

Hypotrigona species, *H. gribodoi* and *H. ruspolii*, pollinated rotunda strawberry variety efficiently. Although stingless bees are corbiculate, as seen in Plates 26.1-29.0, they carry pollen in their corbiculae in varying proportions, the honey bee, Apidae, carries the most pollen load. Other morphological differences like presence of hairs and body size play a big role in terms of pollination efficiency. Both the honey bee and stingless bees have hairs/bristles on the hind legs of the worker bee (Michener, 2000) as well as on the thorax and elsewhere on the body, making them competitive for pollen capture and transfer, as observed by Delaplane and Mayer (2000). The behaviour of the bee on the flower contributes to its effectiveness in pollination as observed in Plates 18-23. The honey bee is considered an efficient pollinator due to rapid movements from flower to flower in quick succession, movement from anther to stigma and vice versa, hence transferring pollen (Free, 1993). The large size of *Apis mellifera scutellata* would, however, be an impediment, with possible destruction of the flower. In this case, the relatively smaller stingless bees (*Hypotrigona* sp. *Plebeina sp.* and *Meliponula sp.*) would be favoured, respectively.

Temperature plays a major role in effective pollen transfer. The hotter, the more favourable, especially for small sized stingless bees, due to their large surface area, hence able to withstand higher temperatures, upto 40 C for *Hypotrigona sp.* and *Pleibena sp.*, unlike *Apis mellifera scutellata*, whose optimal temperature of operation is 28 C. The small stingless bees employ hovering as a cooling mechanism, each hover constituting a fresh flower visit, hence the effectiveness as was observed by Asiko (2004). From the regression coefficients, there was positive correlation between the number of fruits picked per day and the warm temperature, as observed in Table 17.

Stingless bees are efficient Pollinators of strawberries in an enclosed Environment. Their shorter, horizontal flight range makes it so. *Hypotrigona* species has a flight range of 0.5-1.5 whereas *Meliponula* species has a flight range of 1.5-2.5 Kilometre radius. The honey bee flight range is 5 Kilometre radius, hence confining them to a shorter flight distance is destructive to the colony due to death 'en mass,' as a result of exhaustion from unsuccessful escape attempts observed in Plate 3.

5.1.2 Strawberry fruit Productivity by strawberry variety, bee species and locality

Productivity of strawberry as indicated by the number of strawberry fruits harvested per day/per strawberry variety/per pollinator species, showed that chandler strawberry variety produced an average of 7 fruits per day, whereas rotunda produced 4 fruits per day, on a 11 x 6 metre plot, Tables 5 and 6. The effect of pollinator introduction was profound for *Hypotrigona gribodoi* and *Hypotrigona ruspolii*, compared to the controls in the net. The number of fruits produced ranged from 4-9 for rotunda and 6-9 for chandler, which was a positive increase. *Hypotrigona gribodoi's* pollination of chandler strawberry variety had a negative impact, with a 6-4 fruit decrease. *Meliponula ferruginea's* pollination of chandler strawberry variety, however, had a positive impact, with a 7-9 fruit harvest increase, Figure 20.

On other plots, *Hypotrigona gribodoi* and *Hypotrigona ruspolii's pollination of* chandler strawberry variety resulted in decreased fruit productivity, but increased the amount of quality fruits for rotunda from 6 to 12 and 6, respectively. On the other hand, *Meliponula ferruginea* and *Plebeina hildebrandti's* pollination of chandler strawberry variety increased the amount of quality fruits from an average 9 to 14 and 9, respectively, Table 15.

Different varieties of strawberries respond differently when pollinated by the same or different stingless bee species. This was true for the Nairobi plots (National Beekeeping Station and Jamhuri Show ground) comparative results on *Hypotrigona ruspolii* pollination. Although the species was introduced in all the three sites in Nairobi, it performed better at the National Beekeeping Station 2 and Jamhuri Show ground, than at National Beekeeping Station 1, which had a mean of 2 fruits per day, for chandler variety. *Hypotrigona ruspolii,* therefore pollinated rotunda strawberry variety, resulting in a mean fruit production of 8, compared to 3 and 2 at the National Beekeeping Station2 and Jamhuri Show ground, respectively. *Hypotrigona gribodoi pollinated* chandler variety at the National Beekeeping Station, yielding more fruits than at Bukura, but much better on rotunda than chandler variety at the same locality, Bukura. *Meliponula bocandei* behaved similarly at Kakamega forest, for the species and both controls, as observed in Tables 2, 3, 4, 5, 6, 7, 8, 11, 12 and 14. There was association between quality of fruits and ecological zones (d.f=3; X^2=46.79; P<0.001) for Kakamega and Nairobi and (d.f=3; X^2=7.83; P<0.05) for Kima and Nairobi. Similarly between the number of fruits harvested from different localities (d.f=1; P=0.042) for Nairobi and Kima, and between strawberry variety and fruit quality (d.f=3; P=0.05, 9.24).

There was high significant correlation between strawberry variety and bee species (d.f =7; X^2=2909.80; p<0.001). *Hypotrigona spp.* was more sensitive to strawberry variety, and responded differently. *Meliponula and Plebeina spp.* responded similarly, with regard to strawberry variety. *Apis mellifera scutellata* pollinated rotunda strawberry variety and produced better fruit yields, compared to their pollination of chandler variety. *Hypotrigona gribodoi* and *Meliponula ferruginea* significantly performed better than *Apis mellifera scutellata*, with regard to strawberry pollination, possibly due to their relatively smaller size, flight range and foraging trend. *Hypotrigona gribodoi* forages in groups and complements the honey bee in pollination to yield optimal results. Combined stingless bee and honey bee pollination increased the fruit yields to four fold, in the open control plot. Thus, there was improved efficiency and effectiveness as suggested by Buchman (1983). This concurs with Harmon's results, who noted a five-fold increase in yields (Harmon, 2007). *Hypotrigona ruspolii* and *Plebeina hildebrandti* performed similarly with the honey bee but the performance was not significant, (df=1, p=0.06), for *Plebeina hildebrandti*.

Variation was very small in chandler but remarkable in rotunda variety. *Meliponula ferruginea* and *Plebeina hildebrandti* performed better on chandler variety at the National Beekeeping Station 2, but poorly on rotunda at the same locality, National Beekeeping Station 1. *Meliponula bocandei* effect could not be determined at the National Beekeeping Station, because it absconded almost immediately after introduction to the experimental plot. It did, likewise at the Kakamega plot. There could be adaptation problem with this species, requiring specialized management.

Apparently, the species in the open manages well. Due to its large size, together with the honey bee, they do not like restricted enclosures.

Generally, *Meliponula sp.* is more stable whereas the *Hypotrigona sp.* is specific to variety and locality. Chandler strawberry variety, on the other hand, was the most sensitive variety, in terms of water requirement, compared to rotunda, though it was superior, in terms of yields and perishability. Rotunda variety had a higher establishment percentage (97%) than chandler variety (76%) but had lower fruit yields with shorter shelf life, prone to perishability.

5.1.3 Quality and quantity strawberry fruit production through honey bee and stingless bee pollination

Strawberry is pollinated by self (53%), wind and bees. The relative contribution of each agent varies by variety, weather and bee population size as noted by Delaplane and Mayer (2000). From ethological observations and research experiment results, the honey bee pollination yielded most super fruits, 40.5% increase (Fig. 23) which is comparable to, Free and other researchers' findings, who established 19 to 25 per cent yield increase (Free, 1993; Antonelli *et al.*, 1988; Connor and Martin 1973 and Connor, 1970). *Meliponula ferruginea* increased super class strawberrry fruits by 14% whereas *Hypotrigona gribodoi* increased class one strawberry fruits by 17%. *Plebeina hildebrandti* similarly increased class one fruits, by 14%. There was high significant association between between bee species and fruit weight (d.f=7; P<0.001; 3562). Likewise, between bee species and fruit size (d.f=7; P<0.001; 3562). *Meliponula bocandei* was completely unsuitable for pollination in enclosures, due to the large size and flight pattern, upward, like the honey bee. Earlier work on effectiveness of honey bees as pollinators of strawberry had revealed 36.7 percent increase in yields, 13.5 percent decrease in malformed fruit, 49 percent decrease in culled fruit and 6.4 percent increase in fruit size (Free, 1993).

Although the introduction of the pollinator species changed the production quantity and quality of fruits per day, its effect was not the same on the two strawberry varieties and for the different bee species. *Hypotrigona gribodoi* and *Hypotrigona ruspolii* performed poorly on chandler but increased the amount of quality fruits for rotunda from 6 to 12 and 6 respectively. On the other hand, *Meliponula ferruginea* and *Plebeina hildebrandti*, performed better on chandler by increasing the amount of quality fruits from an average of 9 to 14 and 9 respectively. The Chi-square test for association between class and locality was significant (d.f=3;P=0.050,7.83). Likewise, the Chi-square test for association between class and variety was highly significant (d.f=3; P=0.001,259). Fruit quality and bee species were significantly associated (d.f =21; X^2 = 62.95; P<0.001). From the results, quality is dependent on the pollinating bee species and cultivar variety. When the strawberry is not completely pollinated, the fruit is malformed. Efficient and effective pollination guarantees super quality fruits.

5.1.4 Ecological zone, season, bee species, strawberry variety, locality, stem-age and crop husbandry

The effect of location was found to be significant in terms of bee behaviour and strawberry productivity. The stingless bee, *Meliponula bocandei* did not adapt immediately, when moved from Kakamega to Nairobi. The species escaped from the enclosed cage after two weeks. *Plebeina hildebrandti,* on the other hand adapted well, when moved from Kima to Nairobi. This ability to adapt was not seen in the productivity of *P. hildebrandti* pollinated fruits which had a mean of 4.

Different ecological zones do not influence pollination efficiency of the predominant pollinator species in strawberry pollination. With regard to location, Jamhuri Show ground was significantly better than the National Beekeeping Station, followed by Kakamega forest. Kima site, was not significantly different from the National Beekeeping Station. *Plebeina hildebrandti*, the predominant bee species in Kima, performed well at both the endemic locality and at the National Beekeeping Station, with regard to strawberry pollination.

Hypotrigona gribodoi pollinated chandler strawberry variety, resulting in better fruit yields at the National beekeeping Station than at Bukura, but much better on rotunda than chandler, at the same locality. *Hypotrigona ruspolii* pollinated strawberries better in its endemic environment, Kakamega, than in Nairobi, resulting in quality fruit production. *Plebeina hildebrandti* pollinated strawberry fruits better in Nairobi than at Kima, resulting in high quality fruits picked. However, the t-test statistic for size and average weight was not significant, but the amount of fruits harvested was significantly different for the two areas (p-value= 0.042).

Meliponula ferruginea and *Plebeina hildebrandti* pollinated chandler strawberry variety and yielded better results at the National Beekeeping Station, but performed poorly on rotunda, at the same locality, National Beekeeping Station 2. The honey bee pollinated rotunda strawberry variety fairly well, compared to chandler strawberry variety. This could be due to mode of pollen transfer or flower structure. According to Jaycox (1979), the structure of the flower differs between strawberry cultivars and between primary and the subsequent flowers. Some cultivars have short stamens and tall receptacles, benefiting most from insect pollination. Cultivars with tall stamens in relation to receptacle height, are largely self-pollinated, like rotunda strawberry variety, and receive less benefit from insect visits. Strawberry flowers are self-pollinated readily if the pollen is released above or at the same level with the stigmas, as noted by Connor and Martin (1973). *Apis mellifera scutellata* preferred to pollinate rotunda strawberry variety. Similarly with *Hypotrigona* species, both of which exhibit similar foraging behaviour, circular movements at the base of the anthers, as described by Free (1993).

Wind, and the resulting movement of the flower contribute to pollination. However, when the anthers are lower than the receptacle, as in the case of chandler strawberry variety, not enough pollen reaches the stigmas to set a well-formed fruit without the help of insect pollinators, usually bees. The smaller stingless bee, *Hypotrigona* species, performed best on rotunda strawberry variety whereas *Meliponula* species performed best on chandler strawberry variety. *Hypotrigona gribodoi* was specific to strawberry variety. This specialization is directly linked to strawberry morphology, as suggested by Jaycox (1979). Flower morphology was noted as a possible cause for reduced bee visits (Delaplane and Mayer, 2000). Most insect-pollinated strawberries have flower morphology that do not favour self pollination. the reverse is true for self-pollination, as concluded by Jaycox (1970, 1979).

Apis mellifera scutellata was the predominant pollinator species in the open environment only in the Nairobi plots, which harbour bee hives in the viscinity. Other flower visitors included butterflies and solitary bees. At Kima, stingless bees, as well as solitary bees were observed as the frequent flower visitors. *Apis mellifera scutellata* was rare, in the viscinity. Similarly in Bukura, implying that other bee species are more important in strawberry pollination than the honey bee, in the open. This tallies with Jaycox and Richard's finding that native bees could be as good as honey bees, if not better, in the pollination of selected crops (Jaycox, 1970, 1979 and Richards, 1993). The localities that fringe the forest edge and other natural habitats (kakamega, Bukura, Lenana, Jamhuri show ground and Kima) have a diversity of bee species best suited for strawberry pollination. It is true that bees would visit other more attractive flowers in the vicinity, for strawberry, which is comparatively less attractive as concluded by Delaplane and Mayer, 2000; Jaycox, 1970 and 1979. The authors suggested an increase in honey bee densities to increase competition, thereby forcing honey bees to visit unattractive crop blooms, such as strawberry, whose nectar concentration is only 30 percent.

There was positive correlation between the number of fruits picked per day and the warm temperature that prevailed (coefficient 7.5 with a p-value 0.04). Warm temperatures enhance pollination due to increased bee activity. There is no anther dehiscence at a temperature below 14°C or 57.2°F (Jaycox, 1979). Weather, as concluded by Jaycox (1970), is an important aspect in strawberry pollination. Cool temperatures slow flower opening and the release and germination of pollen. They also reduce the number of bee visits, thereby negatively affecting pollination and the quality of fruit.

Crop husbandry was important in quality and quantity fruit production, besides the pollinator species and strawberry variety. Other notable parameters include: Rainfall/weather, season, soil fertility, temperature, light intensity among others. From the results, it appears that fertilizer application as demonstrated at the Jamhuri Show ground plot did not have much effect on quality and quantity of strawberry fruits produced. The initial organic manure at strawberry planting time suffices for the nutritional requirements, as fertilizer application was not significant, in terms of quantity and quality strawberry fruit production during the first year.

When rotunda and chandler varieties were inter-cropped, yields from both varieties drastically reduced as a result of competition for nutrients, with rotunda variety tending towards dominance due to its growth habits. Chandler variety almost obliterated. More fruits were obtained from rotunda variety, devoid of pollinator species than from chandler in a similar enclosure. Rotunda self- pollinates itself more frequently as opposed to chandler, which is a smaller and less branched plant.

Shading, natural or artificial, significantly reduced fruit production. Shaded plots recorded adverse reduction in fruit numbers. It was stated that light intensity is critical for fruition of strawberries (Jaycox, 1970), hence should be adequately provided. Shading drastically hampers fruit production and slows down the ripening process. The temperature has to be right for anther dehiscence to occur. This will not be possible at temperatures below 14 C (Percival, 1955). Smaller bee species have an advantage over larger ones, since they can withstand higher temperatures that are suitable for optimal anther dehiscence. Stem-age too has a role in productivity. The latter declines with the age of the plant. Aging plants seem to produce small and round-shaped fruits, even on the original chandler stem. The reverse is not true. This implies that rotunda variety is dominant as opposed to chandler variety, which is a hybrid.

5.2 conclusion

It can be concluded that there are endemic bee species in some ecological zones of Kenya, best suited for strawberry pollination, other than *Apis mellifera scutellata*, in terms of efficiency and effectiveness. However, *Hypotrigona* species seems to be specialized on rotunda strawberry variety, irrespective of locality and are more efficient pollinators of strawberries than *meliponula* and *plebeina species*. *Hypotrigona* species and *Apis mellifera scutellata*, seem to complement each other, in terms of pollination efficiency, foraging at different trophic levels. *Meliponula ferruginea* and *Plebeina hildebrandti*, appear adaptable and specialized for use on chandler strawberry pollination in most ecological zones. *Meliponula bocandei* pollinates strawberry optimally in its endemic environment, Kakamega forest, but is least adaptable elsewhere.

The two strawberry varieties, rotunda and chandler, require differrent stingless bee species, *Hypotrigona gribodoi* and *Meliponula ferruginea*, respectively, for optimal pollination. Stingless bees are as good pollinators as honey bees, if not better, on selected crops, such as strawberry, hence should be utilised in cage or greenhouse pollination services for increased horticultural production. Farmers in Kakamega should be be advised to cultivate chandler strawberry variety for increased food and nutrition security, whereas those in Kima should cultivate rotunda, since it is capable of withstanding stress conditions, to some extend, as opposed to chandler variety.

Farmers in Nairobi may cultivate both, rotunda and chandler, and use the bee species best adapted to the climatic condition for their pollination requirement.

Pollinator/plant relationships should be understood as an ecosystem service for sustainable Agriculture as concluded in an earlier study by Richards (1993). This includes protection of appropriate insect nesting sites, coupled by intense public awareness on the importance of pollinator conservation. A concerted plan to overcome taxonomic impediment, particularly with emerging insect pollinator species, should be put in place.

5.3 Recommendations

1. It was recommended that the stingless bee, *Meliponula ferruginea* be utilized for chandler strawberry variety pollination, whereas *Hypotrigona* species was recommended for rotunda variety, in strawberry pollination services.

2. Generally, *Meliponula spp.* is more stable and responds similarly to strawberry variety, in terms of pollination requirements. It is highly adaptable and can be used for pollination services in practically every ecological zone.

3. *Hypotrigona spp. is* specific to strawberry variety and locality and respond to pollination requirements differently. Each species should be assessed on its own accord and utilized appropriately, at the local level, for optimal pollination services.

4. The larger bee species, *Apis mellifera scutellata,* and *Meliponula bocandei,* should strictly be used for pollination services in the open environment, due to their

behavioural traits. Domestication of bee pollinator species, at their endemic locality, would yield greater economic returns. *Hypotrigona* species, for instance, performs optimally at the endemic site, Bukura, hence should be utilized at the local level, for pollination services.

5. Chandler is the most sensitive strawberry variety, compared to rotunda hence requires tender care during propagation and adequate water, for plant establishment and maintenance, than rotunda. It should be cultivated in high rainfall areas such as Kakamega, unless when supplemented by irrigation.

6. Chandler variety is economically very productive in terms of fruit numbers per hectare. Rotunda variety establishes fast. It is more robust and can withstand water stress conditions, to some extent. This variety should be cultivated in ASAL Areas, such as Kima. The two strawberry cultivars should never be intercropped since rotunda appears to be dominant.

7. Commercial production of strawberries should be limited to the first 200 days of planting as productivity decreases with stem-age. The plant gets prone to diseases in the latter days.

8. Organic manure should be used to boost organic strawberry production, for niche markets, which fetch premium prices at the global market.

9. Utilize *Hypotrigona species* on suitable crops/fruits, since they are more efficient pollinators than *meliponula* and *plebeina species.*

10. Farmers and growers should consider using stingless bees, since they are as good pollinators as the honey bees, if not better, on selected crops, as noted by several researchers, for off-season horticultural production in cages or greenhouses, to increase food security.

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Table 18: Accumulated analysis of variance for fruit size

Change	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	1	4922.01	4922.01	170.72	<.001
Beesp	7	2357.33	336.76	11.68	<.001
Residual	3554	102465.42	28.83		
Total	3562	109744.76	30.81		

Bee species effect was highly significant on fruit size **(P<0.001, d.f 7, 3562).**

Table 19: Accumulated analysis of variance for fruit weight

Change	d.f.	s.s.	m.s.	v.r.	F pr.
+ Variety	1	2547.244	2547.244	427.04	<.001
+ Bee species	7	893.648	127.664	21.40	<.001
Residual	3554	21199.220	5.965		
Total	3562	24640.112	6.917		

Bee species effect was highly significant on fruit weight **(P<0.001, d.f 7, 3562).**

Table 20: Analysis of variance for mean number of fruits per day for location, Nairobi and Kima

Change	d.f.	s.s.	m.s.	v.r.	F pr.
+ Location2	1	677.2	677.2	4.18	0.042
Residual	273	44271.8	162.2		
Total	274	44949.0	164.0		

Table 21: Total fruit numbers per bee pollinator species in relation to strawberry variety, for three months

Variety	*control*	*control netted*	*H. gribodoi*	*H. ruspolii*	*hb*	*M. bocandei*	*M. ferruginea*	*P. Hildebrandti*
Chandler	3356	1526	464	109	16	0	1334	149
Rotunda	1381	1055	1342	335	170	0	107	46

Table 22: Analysis of variance for number of fruits harvested per season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety*Season	3	11.4662	3.8221	25.21	<.001
Residual	705	106.8794	0.1516		
Total	709	118.9619			

Table 23: Summary of Regression analysis between chandler strawberry variety and bee species

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	9	2797.	310.78	9.95	<.001
Residual	2046	63888.	31.23		
Total	2055	66685.	32.45		

Regression analysis revealed significant association between chandler strawberry variety and bee species **(d.f =9; P<0.001, 2055).**

Table 24: Summary of regression analysis between rotunda variety and bee species

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	6	132	21.997	22.00	<.001
Residual	499	1152	2.308		
Total	505	1284	2.542		

Regression analysis revealed significant association between rotunda variety and bee species **(d.f=6; P<0.001, 505).**

Table 25: Accumulated analysis of variance for mean number of fruits per day per location 2

Change	d.f.	s.s.	m.s.	v.r.	F pr.
Location 2	1	677.2	677.2	4.18	0.042
Residual	273	44271.8	162.2		
Total	274	44949.0	164.0		

There was a marginal significance in the number of fruits picked from Nairobi and Kima localities **(df=1, p=0.042).** The predicted means for Kima was 9, while that of Nairobi was 14 fruits per day.

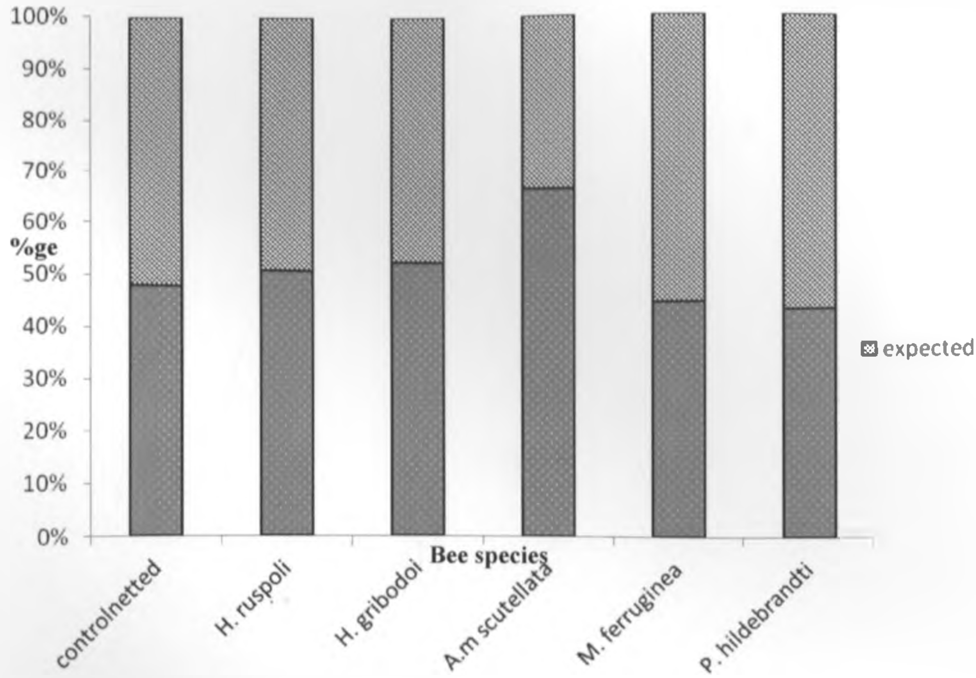

Figure 28: Class one strawberry fruits, observed and expected for each bee pollinator species

Average number of fruits produced per day by strawberry stem age

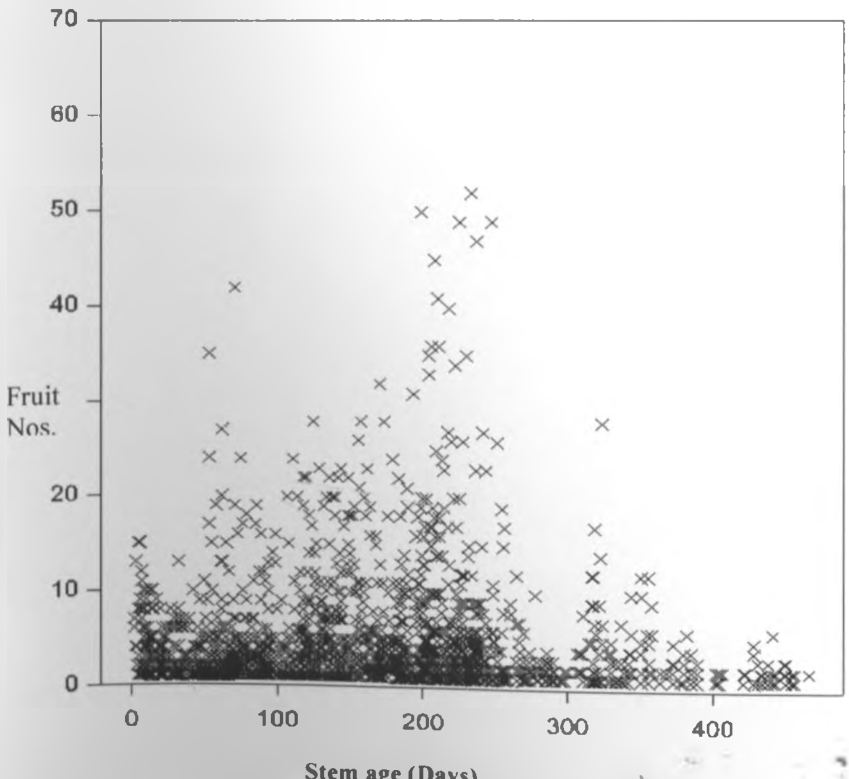

Figure 29: Number of fruits picked per day by stem age during the first 400 days