GEOGRAPHICAL RACES OF THE HONEYBEES (*APIS MELLIFERA* L.) OF THE NORTHERN REGIONS OF ETHIOPIA

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Declaration

This thesis is my own work and has not been submitted for degree purposes at any other university.

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Supervisors

Professor Randall Hepburn

and

Professor Sarah Radloff

The thesis is dedicated to my children

Zekarias, Lina and Elias

This thesis is based in part on the following papers

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2. Nuru, A., Amssalu, B., Hepburn, R.H., Radloff, S.E. (2002) Reproductive swarming and migration biology of honeybees (*Apis mellifera* L.) of Ethiopia. *Journal of Apicultural Research* (in press).
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Abstract

The ideal climatic conditions and diversity of floral resources allow Ethiopia to sustain millions of honeybee colonies. Beekeeping is widely practiced and plays a significant role in the livelihood of the farming community of the country. Despite this, information on the types of geographical races of honeybees, their behavioural characters and the related ecological factors are not established. In this work an attempt was made to characterise the honeybee populations of the northern parts of Ethiopia based on the analyses of morphological, behavioural and ecological characteristics. For morphological analysis, 155 honeybee colony samples from 31 localities were collected. 20 worker honeybees per colony sample totalled 3100 individual worker honeybees and thirteen morphological characters per bee, a total of 40 300 measurements were recorded following Ruttner's (1988) protocols. The behavioural characters such as reproductive swarming, migration, temperament and colony seasonal cycles were assessed based on survey work of a pre-structured questionnaire.

Various univariate and multivariate statistical methods were employed to analyse the data. The principal components and step-wise linear discriminant analyses revealed the existence of four discrete morphoclusters or geographical races: *A. m. jemenitica* from eastern, northwestern and northern arid and semi-arid lowlands, *A. m. scutellata* from the western humid mid-lands, *A. m. bandasii* from sub-moist central highlands and *A. m. monticola* from the northern mountainous parts of the study areas. These different geographical races were found to be distinctively distributed in the different ecological parts of the study area. High intercolonial and intracolonial variances were observed in all localities, however particularly high values were obtained in areas of transitions between ecological zones indicating a region of gene flow or zones of hybridisation among the statistically defined populations. Such high variances were observed mostly in areas where *A. m. jemenitica* borders the other geographical races.

Moreover, distinct behavioural variations were also noted among these geographical races. Generally, the highland and mountainous honeybees *A. m. bandasii* and *A. m. monticola* are relatively larger in body size, have less tendency to swarm, less inclination to migrate and are relatively gentle while the converse traits were noted for the lowlands and mid-lands honeybees *A. m. jemenitica* and *A. m. scutellata*. Both morphological and behavioural variations were highly correlated with environmental factors and the variations seem to be the result of long adaptation to the interrelated ecological factors in their respective areas. Variations in reproductive swarming periods were also noted among these honeybee populations as a result of variations in rainfall pattern, altitude and temperature in their respective ecological areas which are believed to alter the honeybee colonies' seasonal cycles and leads to partial temporal reproductive isolation among these different honeybee populations.

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Acronyms

E	Equatorial diameter
EMA	Ethiopia Mapping Agency
GDP	Gross Domestic Production
LM	Light microscopy
MOA	Ministry Of Agriculture
NECOFE	National Ecofarming of Ethiopia
P	Polar axis
SEM	scanning electron microscopy

Code numbers of Ruttners' morphological characters

Morphological characters	Code numbers
Scutellum pigmentation	(35)
Scutellar plate pigmentation	(36)
Hair length on tergite 5	(1)
Pigmentation tergite 2	(32)
Pigmentation tergite 3	(33)
Pigmentation tergite 4	(34)
Tergite 3 longitudinal	(9)
Tergite 4 longitudinal	(10)
Sternite 3 longitudinal	(11)
Wax plate transversal	(13)
Wing angle B4	(22)
Wing angle N23	(30)
Wing angle O26	(31)

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Structural organisation of the thesis

The thesis is presented in seven major chapters. Chapter 1, the introduction emphasises the general background information on major ecological features of the study areas, apiculture in Ethiopia and its economic importance and the objectives and the significance of this study. Chapter 2, deals with the literature reviews in areas of historical background and recent development of morphometric classification of *Apis mellifera* L., with special emphasis on African honeybees in general and those of East and the Horn Africa in particular. The biological and ecological aspects of honeybees within tropical African context were also reviewed.

The detailed materials and methods: sampling localities, sample collection, survey work, morphometric analysis and statistical procedures are treated in chapter 3. The results on morphometric, behavioural and ecological aspects are presented in Chapter 4. Chapter 5, the discussion, deals with the classification of honeybees, their seasonal cycles, geographical distribution and zones of hybridisation among them. The roles of ecological factors on both morphometric and behavioural characteristics of honeybees are also treated here. Conclusions and possible recommendations are also given in this chapter. Information on beekeeping activities and major honeybee plants of the different parts of study area, the colony means of each character and survey questionnaire are included as part of this document in Chapter 6 as appendices. Finally the references are given in Chapter 7.

CHAPTER 1

Introduction

1.1 General

Ethiopia is located at the Horn of Africa between $3.24^0 - 14.53^0$ latitudes north and between $32.42^0 - 48.12^0$ longitudes east. The country borders Kenya to the south, Sudan to the west, Eritrea to the north and Somalia and Djibuti to the east. The total land area is around 1.1 million km^2. It is not only large but also physiographically and climatologically diverse and complex (Mammo, 1976; Van Chi-Bonnardel, 1973). It varies from depression lands below sea level to plains, plateaus and mountainous lands over 4000 m above sea level.

Even though the country is located near the equator, the climatic conditions are moderated by elevated altitude (Van Chi-Bonnardel, 1973). However, it varies from hot to warm arid climates to cool humid afroalpine conditions. Based on relief categorisation, more than 62% of the country is lowland, 18% massifs and 20% plateaus (Mesfin, 1970). Moreover, according to the agroecological zonation of Ethiopia (MOA, 1998) 18 major and 48 sub-agroecological zones are recognised. The variability in the physiographic conditions of the country result in diverse agroclimatic conditions, which create environments conducive to the existence of a large and unique biodiversity both in plants and animals including honeybee subspecies. As a result, the country is well known for its endemism and as a centre of biodiversity for a number of plant and animal species.

1.2 The general ecological features of the study area

Knowledge of the environmental conditions, where the bees live is obviously important because, the types of bees, their morphological and behavioural characters reflect their ecology. Moreover, in Tropical Africa in the absence of clear geographical barriers, ecological variations were considered as major isolating factors for geographical races of honeybees (Ruttner, 1988). So it is very important to consider the ecological features of the study area to fully understand the morphological and behavioural variations of the honeybee populations of the area and to interpret the variations in their biogeographic context.

Physiographically, the study area is very complex and diverse. The two extremes places in the country such as the Danakil depression, which is about 126 m below sea level, and the highest mountain, Ras Dejen, which is about 4620 m above sea level are found in this region of the study area. The area is not only variable but also the various agroecological types intermingle such that very high and low altitude areas are located in very close proximity. The changes of altitude are very abrupt, as a result of which extremely different ecological areas occur within very short distances. According to the agroecological zonation of Ethiopia (MOA, 1998), 10 major and 19 sub-agroecological areas occur in the study areas. However, in a broader sense these can be categorised into four major ecological areas: warm to hot lowlands, humid midlands, the central sub-moist to moist highlands and the northern mountainous highlands.

1.2.1 Warm to hot lowlands

1.2.1.1 The eastern arid lowlands

The eastern arid lowlands occur in Afar regional state where the majority of the area is lowland plain, which is associated with the River Awash valley and the Danakil depression. The larger portion of the plain is the upper part of the great Rift Valley of East Africa. The elevation of this area drops abruptly from the rest of the central highlands and ranges from below sea level to 1200 m above sea level towards the western parts, which are mostly associated with valleys and escarpments.

The climatic conditions of this area are generally warm, hot, arid and belong to the typical Sahel climatic zone. The mean annual temperatures exceed 27°C and the maximum temperature exceeds 35°C. The dry period is very long and extends from October to June and the wet season is very much compressed. The rainfall pattern is unimodal, and occurs in July and August. The mean annual rainfall ranges from 100 mm to 400 mm in the arid lowland plains and 100 mm to 600 mm in the arid valleys and escarpments. Due to the limited rainfall, the area has no adequate growing periods. Cultivation of crops is mostly based on irrigation from the Awash River. The vegetation is characterised by semi-desert steppe, which includes bush grassland and wood grassland types.

1.2.1.2 The northwest lowlands

The northwest lowlands are the areas along the Sudan border, which extends from Kumruk in the south, passes through Guba, Metema, Angereb, Humera and reaches up to

Shiraro. Based on Mesfin (1970) these areas are collectively called the Angereb lowlands. The general physiographic condition of the area is lowland, which includes plains, valleys, gorges and escarpments. The elevations of these areas are generally between 400–2000 m above sea level.

The climatic conditions vary from hot, warm moist conditions in the south to sub-moist in the centre and semi-arid towards the north. The rainfall pattern in most places is unimodal with a long dry season and a short rainy one. Rainfall is relatively high towards the south and gradually decreases towards the northern semi-arid parts. In the southern parts the annual rainfall varies between 250–1600 mm while in the northern parts between 200–1000 mm. The mean annual temperatures of these areas vary from 21°C to 28°C and in some places the maximum temperature exceeds 35°C. The general vegetation types are tropical woodland and thornbush, which includes wooded grassland, bush grassland and woodland shrubs. In this area the dry season is accompanied by forest fires, which is part of the great forest fire belt of Africa, that extends 5000 km from Senegal in west Africa via Sudan to western part of Ethiopia.

1.2.2 Humid midlands

The humid midlands occur in the western part of the study areas, which include west Wollega, the western part of east Wollega, Benshangul and the southwest part of Gojjam around Bir Sheleko and Chagni. According to the agroecological zonation of Ethiopia (MOA, 1998) the area is classified into three major agroecological areas. However the general ecological features of these areas are hot to cool, moist to sub-humid lowlands and midlands. The general physiographic conditions of the area are midland and the elevations of most places are between 1000–2000 m above sea level.

The climatic condition of the area is wet and warm. The area has extended rainfall periods with a bimodal rainfall pattern. Sometimes the small rainy period merges with the big rainy season. In most places, the big rainy season starts in June and extends to October. The annual rainfall varies from 900–2200 mm. The mean annual temperature of the area is 16°C – 25°C. The vegetation types vary from woodland, wooded grassland, bush land to shrub lands. In these areas such as in the Dedessa valley the dry period is also followed by forest fires.

1.2.3 The central sub-moist to moist highlands

This area includes parts of south Gonder, east and west Gojjam, north and west Shoa and part of east Wollega. According to the agroecological zonation of Ethiopia (MOA, 1998), this region is classified into five major agroecological zones. However the general ecological feature of these areas is mild to cool, moist to sub-moist highlands with plateaus, mountains and highland plains. Except for low altitude areas associated with rivers, valleys and gorges, the general elevations of these areas are between 2000–3000 m above sea level.

Even if the climatic condition of the area is generally categorised as dry tropical, it is moderated by high altitude. The annual mean temperatures of these areas are between 11°C–21°C, however areas along the river gorges have higher annual mean temperatures.

The region has short rainy seasons and longer dry seasons. Some places have a bimodal rainfall pattern in which the big and small rainfall seasons alternate with two dry seasons. The big rainy season, in most places occurs between June and September. The small rainy season is in most cases very erratic. The annual rainfall of the area varies from 700–2200 mm. Generally, the area is intensively cultivated and the ecology is under high human and livestock populations pressure.

1.2.4 The northern mountainous highlands

The northern mountainous highlands include parts of the Amhara Regional state such as south and north Wollo, the eastern parts of south and north Gonder and the southern parts of Tigray Regional state. These areas include Guguftu, Ambassel, Mekdela, Wag, Korem, Maychew, Ambalage, and extends to the Semen Mountains in north Gonder. This area is part of the Northern massifs (Mesfin, 1970). Based on the agroecological classification of Ethiopia four major agroecological zones occur in this area and vary from mild, cool to afroalpine conditions. Except areas associated with the river valleys, the general relief features of these areas are rugged mountains and plateaus. The elevations of most of these areas vary from 2000–4000 m above sea level. In this area there are number of isolated mountains like Mt. Ras Dejen (4620 m), Mt. Abune Yosef (4190 m), Mt. Amba Farit (3979 m) and Mt. Abuye Meda (4000 m).

The climatic zone of the area is of the dry tropical type, but moderated by elevation. These areas have shorter rainy seasons and longer dry seasons in which the big and small rains alternate with two dry seasons. In these places the small rainy period is also very erratic. The total annual rainfall of the area is between 700–1800 mm. The temperature conditions vary from mild to cool to very cold conditions with mean annual temperatures of 7.5°C–21°C. In the cold season at the top of the mountains the temperature falls below 0°C. Even if the area is under intensive cultivation, large portions of the rugged mountains and hills are inaccessible to cultivation and livestock grazing, which would otherwise be very useful for apicultural development programmes. The vegetation varies from the highland vegetation type to the typical afroalpine type.

1.3 Economy

The Ethiopian economy mostly depends on the agricultural sector. The type of agriculture is mainly subsistence farming, which largely depends on rainfall conditions. Agriculture contributes 60% of the country's GDP, and generates 90% of its exportable commodities. Coffee, hides and skins, oil crops, pulses and beeswax are some of the major exportable commodities. Agriculture provides 85% of all employment opportunity (NECOFE, 1999) and also 70% of the raw materials for local agro-industries (World Bank, 1995).

Even though the country is rich in natural resources, the increasing human population pressure and the associated ecological degradation become major challenges for the country. Particularly, in the northern parts of the country where a large portion of the areas are rugged mountains, the increasing human population and the high demand for farm lands put pressure on mountainous areas to be used for crop production and livestock grazing. This creates deforestation, soil erosion and irreversible ecological degradation.

Apiculture, which is a sustainable resource based farming system without negative impact on the ecology and that can be practiced without competing with other agricultural activities, would be one of the major intervention areas for sustainable development of agriculture in such a fragile environments. Moreover, apiculture can be run with conservation and as well as rehabilitation programs of ecology. Generally, apiculture is very important, as a source of additional cash income, for intensification of land uses and diversification of the economy of the country in general and the farming communities in particular.

1.4 Apiculture in Ethiopia

The diversified agroclimatic conditions of the country create environmental conditions conducive for the growth of over 7000 species of flowering plants of which most are bee plants. The country is rich in various endemic species of flowering plants and a high proportion of Ethiopia's flowering plants are endemic to the country (Edwards, 1976). The ideal climatic conditions and diversity of floral resources allow the country to sustain around 10 million honeybee colonies, of which 7 million are kept in local bee hives by farmers, the remaining exist in the forests as wild colonies (EMA, 1981) which makes the country that with the highest bee density in Africa. Beekeeping has a very long-standing practice in the farming communities. It seems as old as the history of the country (Mammo, 1976; Kassaye, 1990) and it is an integral part of the life style of the farming communities of Ethiopia (Verma, 1990). Except for a few extreme areas, beekeeping is a common practice in every place where human beings have settled.

In the country around one million farmers are estimated to keep bees (Mammo, 1976). The farmers have a well-developed and deep-rooted traditional experience of beekeeping. Traditional beekeeping is mostly practiced with different types of traditional hives. The types of hives and the ways of keeping bees vary from area to area. In places where the natural forests remain intact, honey hunting is still a common practice. In some places, especially in the western and southern parts of the country, forest beekeeping by hanging a number of traditional hives on trees is widely exercised. In other of parts of the country backyard beekeeping with relatively better management is common. Along with traditional beekeeping in the country, box hive beekeeping has been gradually developing since 1978 (Kassaye, 1990).

Because of a moderate climate, Ethiopia is one of the most successful countries in the tropics in box hive beekeeping (Ruttner, 1988). The current annual honey production is estimated at 23 000 tonnes (Kassaye, 1990). This makes the country the leading honey producer in Africa and one of the ten largest honey producing countries in the world, accounting for about 23.58% and 2.13% of the total African and world honey production respectively. Moreover, the annual production of beeswax is estimated at 5 000 tonnes (Kassaye, 1990). This again places the country as one of the four largest beeswax producing countries in the world.

Apiculture plays a significant role in the national economy of the country. It serves as a source of additional cash income for hundreds of thousands of farmer beekeepers. Beekeepers are estimated to earn about Eth. Br. 360-480 (US$ 45-60) million annually from the total annual honey production. In the country honey marketing serves, to move money from the urban people with a relatively high living standard to rural farmers with a relatively low standard of living. Beekeeping not only serves as a source of additional income in the country, but also quite a number of people entirely depend on traditional beekeeping and honey selling for their livelihoods. Beekeeping supports the national economy through foreign exchange earnings. At present beeswax is one of the 12 major exportable agricultural products. Ethiopia is the 3rd largest beeswax exporter in Africa

(Mammo, 1976). The annual average value of beeswax is about Eth. Br.125 (US$ 15) million. Beekeeping is also believed to play a significant role in the food security of the country through honeybee pollination services of major cultivated crops.

1.5 Beekeeping conditions of the study area

Bee husbandry is one of the major practices in most of farming communities of the study area. However, traditional knowledge about bees and methods of handling them are very different within the study areas. This varies from simple honey hunting and elementary beekeeping practices in Afar, Benshangul and Gumuz areas to well developed and fascinating traditional beekeeping in Amhara and Tigray Regions. Besides the traditional beekeeping practices, box hive beekeeping is also in the state of gradual dissemination in most parts of the study area. For many farmer beekeepers, beekeeping is a very lucrative business and the high proportion of their annual income is from beekeeping. The detailed beekeeping activities of the study areas are treated in Appendix I section 6.1 – 6.1.4.

In spite of its significance and economic contribution to the nation and its great potential for sustainable development, the attention given to the sector is very low. The types of bees and their behavioural characteristics with relation to their ecologies have not been studied. The ways of managing bees and handling their products still remain far behind what could be achieved. Most of the honey is utilized in very crude form and more than 50% of beeswax is wasted at different levels. Due to lack of basic and applied apicultural research programs the attainments are not satisfactory. Thus the farmer beekeepers of the country in particular and the nation in general are not benefiting from the sector at as high a level as the economic potential of the apicultural resources of the country would allow.

Today even though improved beekeeping is gradually expanding throughout the country, the ways of managing local bees are not based on knowledge of their biology, behaviour and ecology. Rather, management is mainly based on adopting the experience and knowledge of temperate region bees and beekeeping. The bees and the environment of temperate regions are quite different from bees and the ecology of tropics in general. Since the success of beekeeping is believed to be the result of basic knowledge of the biology the honeybees (Hepburn and Radloff, 1998), it is of primary importance to characterise honeybees of the country systematically by considering their morphology, behaviour and their native environmental conditions. Such a systematic characterisation of the honeybees of the country could serve as a springboard for different applied and basic apicultural research and to develop appropriate local bee management systems for better utilisation of unexplored economic potential of the apicultural resources of the country. These would also promote sustainable development in the areas of bee husbandry, apicultural agro-industries, cottage industries and exporting the various high values honeybee products.

1.6 Significance of the study

In the country, despite widespread beekeeping activities, apicultural research still remains in the infancy stage and many of the gaps and problems areas have not yet been addressed. Characterisation of the geographical races of honeybees and identifying their diversity is of primary importance for any basic and applied research programs on honeybee populations of an area. Moreover, their characterisation is important to mitigate the various problems associated with swarming, migration and temperament and to fully understand their relationships with the various environmental factors in their respective ecological areas. The significance of this study would be to fill the major gaps of information on the honeybee populations of the study area. This would serve as base line information for different basic and applied apicultural research and also would initiate various apicultural researches in the country. It is also essential if we are to follow an appropriate honeybee management system suitable to the types of honeybee races and their ecological conditions. Furthermore it will be important to formulate and design an appropriate beekeeping development plan for the different agroecological areas of the region.

1.6.1 General objectives

To generate base line data on the types of geographical races of honeybees of the area and their behavioural activities in their respective ecological zones.

1.6.2 Specific objectives

1. To classify the geographical races of honeybees of the area.

2. To delineate the geographical distribution of the honeybee populations.
3. Investigate important morphological, biological and behavioural characteristics of the honeybee populations of the area.
4. To study major ecological features under which the bees exist.
5. To extend the study to many untouched areas of the region.
6. To analyse the relationships between the morphological and behavioural characters with the various environmental factors.

CHAPTER 2

Literature review

2.1 General

Apis mellifera is one of the most successful species in the animal kingdom and occupies vast and varied geographical areas. Its distribution extends from Scandinavia to the Cape of Good Hope and from Dakar in the west to southern Oman in the east and adapts to a very wide range of climatic conditions (Ruttner *et al.*, 1978). *Apis mellifera* colonies are found from sea level to 1000 m in temperate zones; from sea level to 3700 m in the tropics and also reported to survive in the hot and arid zones of Oman at 200 m (Dutton *et al.*, 1981). Its distribution over vast areas of land with extremely different climates resulted in the diversification of morphological and behavioural characters, which resulted in the evolution of different lineages and subspecies. The different types originated as a result of long periods geographical isolation and ecological adaptation (Ruttner *et al.*, 1978).

Based on morphometric studies, four lineages of *A. mellifera* (A, M, C and O) are recognised (Ruttner *et al.*, 1978; Ruttner, 1988). Frank *et al.* (2001) using microsatellite, and mitochondrial DNA data analyses confirmed the existence of these four lineages and further reported the 5th lineages 'Y'. Among these lineages high degrees of geographical variability ranging from slight differences in local populations to well defined and distinct geographical races are recognised (Ruttner, 1988; Cornuet and Garnery, 1991a). The analysis of this variability is a basis for the characterisation of the present geographical races of *Apis mellifera* in Ethiopia.

2.2 Morphometrics

Morphometrics is the measurement and analysis of morphological structures of organisms. It is widely used in the study of insect life history, physiology, ecology and systematics (Daly, 1985). Morphometric analysis is very important because it deals with variations in phenotypic characters which are induced both by genetic and environmental factors (Daly, 1991). Since morphological characters generally have a higher heritability than physiological characters (Soller and Bar Cohen, 1968; Falconer, 1989), the analysis of morphological characters is an important tool in the discrimination of different populations of honeybees.

2.2.1 Historical background

The first man who used the name *Apis mellifera* was Linnaeus in 1758, (Ruttner, 1988). Morphometric classification of *Apis mellifera* started in the early 1900's by Russians scientists, when they were searching for bees with a long proboscis for the efficient pollination of red clover and when apiculturists sought bees with longer tongues that could reach nectar in flowers with long corolla tubes (Daly, 1991, 1992). The early exact morphometric measurement of honeybees was started by Koshevnikov (1900) and followed by Martynov (1901) and Kulagin (1906) (see Alpatov, 1929). However the early classification of honeybees was based on individual bees without statistical analysis.

Since then various investigators at different times continued to improve the gradual development of morphometric analysis of honeybees. The earliest apparently advanced morphometric measurement with adequate honeybee samples for statistical analysis was done by Chochlov (1916). Following the work of Chochlov, Michailov (1924) and Alpatov (1929) classified honeybee races based on morphometric measurements. Besides their attempts to classify honeybees, they were also able to recognise the effects of environmental factors on geographical variation in honeybees. They demonstrated the linear relationship between the honeybee tongue and hind leg lengths with latitude in the area along a line from the Baltic Sea to the Caucasus Mountains.

In addition to tongue length, Alpatov included more characters like femur, tibia, metatarsus, length and width of wing and size of wax mirror. As Alpatov (1929) took more characters, he found trends in geographical variation, opposite to tongue length, which is a decrease in body size from north to south in the plains of Russia. Moreover, he tried to indicate the roles of genetics and environment in the geographical variation of honeybees by transplanting colonies to new localities. Recently Ruttner (1988) proved the presence of gradual variations in quantitative characters of honeybees with geographical latitude changes along the east coast of the Atlantic Ocean from Scandinavia to the Cape of Good Hope.

Michailov (1924) recognised the pronounced effects of season, temperature, cell size, larval stage feeding and the individuality of the colony on variation within and among colonies. Alpatov (1929) also noted the difficulty of measuring the overall body size of honeybees and substituted single parts of the abdomen (sternites and tergites), which are closely correlated to the overall size of the honeybee (Ruttner, 1988).

The early biometrics of honeybees was initially based exclusively on characters related to size of body parts. Goetze (1930, 1940, 1964) introduced two taxonomically significant quantitative characters to Alpatov's list like indices of venation of the forewing and length of hair on the abdominal tergites, which proved very efficient in discriminating European races. Louis (1963) also made an extensive study on the geographical variability on wing vein crossing points.

Along with the development of morphometric measurements in the 1930's statistical methods such as mean, standard deviation, coefficient of variation, ratios of difference and correlation coefficients were introduced to compare the geographical variability between European races of honeybees. Before 1964 morphometric analysis of honeybees was entirely based on sample statistics and univariate methods. For the first time DuPraw (1964, 1965) used multivariate analysis to classify honeybee races. Moreover, DuPraw (1965) used discriminant function analysis of 15 variables, based on venation of 13 forewing angles and length and width of the forewing and was able to establish cluster groups of European, African and Asian honeybees, which are very similar to Ruttner's (1988) geographical races of honeybees.

2.2.2 Recent biometry of *Apis mellifera*

Ruttner *et al.* (1978) established a standard biometry of honeybees based on 40 morphometric characters, by screening the less significant ones and including more characters than Alpatov (1929), Goetze (1930, 1940, 1964), and DuPraw (1964, 1965). Based on the standard biometry, Ruttner (1988) recognised 24 distinct taxonomic groups or geographical races of *Apis mellifera*, 7 in the Near East, 10 in Africa and 7 in north and southeast Europe. However, by applying a step-wise discriminant analysis procedure, Ruttner *et al.* (1978) and Daly and Balling (1978) showed the possibilities of discriminating one race from another using fewer numbers of selected characters based on the region under investigation.

Ruttner (1988) particularly suggested the possibilities of using one third of the original selected characters to discriminate African races of honeybees, however he emphasised the inclusion of different categories of characters such as size, hair, colour and wing venation. Crewe *et al.* (1994) also showed that 10 characters are fully adequate to discriminate honeybees of the southern African region. Moreover, Hepburn and Radloff (1996, 1997); Radloff and Hepburn (1997a,b) using 11 morphometric characters were able to classify African honeybee populations into distinct geographical races.

Along with the development of morphometric measurements, the introduction of different multivariate techniques likes principal components and factor analyses were used to detect clusters of colonies within populations (Ruttner *et al.*, 1978; Ruttner, 1988). Step-wise discriminant analysis was used to confirm the separation of the clusters, to determine the most discriminatory variables and to calculate the percentage of correctly classified colonies (Ruttner, 1988; Daly, 1992). To depict the distances between clusters, dendrograms and Mahalanobis distances were introduced (Tomasson and Fresanaye, 1971; Cornuet *et al.*, 1975; Cornuet and Garnery, 1991a,b; Daly, 1992). The introduction of different multivariate techniques proven to be powerful tools in the discrimination of honeybee races, ecotypes or strains within a race and between genetic lines (Louis *et al.*, 1968) and even to the level of F_1 hybrids (Rinderer *et al.*, 1990).

2.2.3 Classification of African honeybee races

The presence of morphological variability within the honeybees of Africa has been recognised since the 1920's (Rotter, 1920, 1921; Baldensperger, 1922, 1924, 1932; Rueher, 1926; Giavarini, 1937). However classification was mainly based on colour variations. Such descriptive classification continued until the 1950's (Aurelien, 1950; de Roeck, 1950; Dubois and Collart, 1950; Alber, 1952; Hassanein and El-Banby, 1956; Kaschef, 1959). In this period all honeybees of the sub-Saharan region of Africa were considered as one taxon due to the presence of common behavioural characters and uniform yellow pigmentation.

Kerr and Portugal-Araújo (1958) by means of genetic crossing confirmed that the honeybees of Africa, south of Sahara belong to the same species of *Apis mellifera*. For the first time they recognised five morphologically distinct races: *A. m. scutellata* in all areas south of Sahara (except the Cape region), *A. m. capensis* in southwest parts of the Cape region, *A. m. lamarckii* in Egypt along the Nile Valley, *A. m. unicolor* in Madagascar and *A. m. intermissa* in northwest Africa between Libya and Morocco, which are geographically separated in different regions of the continent of Africa.

Smith (1961) classified the honeybees of East Africa based on univariate analysis of morphometric measurements. Besides morphometric measurements he included behavioural and ecological characters and he recognised three races, *A. m. scutellata*, *A. m. litorea* and *A. m. monticola*. DuPraw (1964, 1965) in his multivariate methods of honeybee morphometric study, tried to discriminate the honeybees of Africa as well on the bases of size of forewing and venation of wing angles.

In his comprehensive multivariate study of geographical variation in African honeybees Ruttner (1975, 1988) recognised 10 races of honeybees in different regions of the continent: *A. m. adansonii, A. m. lamarckii, A. m. litorea, A. m. jemenitica, A. m. monticola, A. m. scutellata, A. m. sahariensis, A. m. intermissa, A. m. unicolor* and *A. m. capensis*. He found that climate is one of the major isolating factors for races of honeybees in tropical Africa. However, he also noted that the same race of honeybee (*A. m. adansonii* in west Africa) occurs in distinct ecological areas over vast geographical distances. He also observed the existence of different races of honeybees (*A. m. jemenitica* and *A. m. adansonii*) without substantial ecological differences.

The work of Ruttner was based on a macrolevel sampling at continental level (Hepburn and Radloff, 1998) and, as Ruttner (1988) stated, his morphometric studies of all Africa honeybees does not achieve a complete analysis of all variability in the huge continent nor does it indicate the borders for the identified geographical races. Recently, different authors tried to classify African races of honeybees based on morphometric, DNA and pheromone analyses and got a more refined pictures for different regions of the continent (Saeed, 1981; Mohamed, 1982; Mogga, 1988; Meixner *et al.*, 1989, 1994; Kassaye, 1990; Smith *et al.*, 1991; Lebdi-Grissa *et al.*, 1991b; Cornuet and Garnery, 1991b; Kerr, 1992; El-Sarrag *et al.*, 1992; Crewe *et al.*, 1994; Mortiz *et al.*, 1994; Hepburn *et al.*, 1994; Garnery *et al.*, 1995).

Moreover, morphometric classification of honeybees at the continental level with large sample sizes across five major transects of the continent with different multivariate procedures was conducted by Hepburn and Radloff (1996, 1997, 1998), Radloff (1996), Radloff and Hepburn (1997a,b), Radloff *et al.* (1997) and Radloff *et al.* (1998). Along with the morphometric data they also used pheromone analysis to discriminate the cluster groups and were able to recognise a number of variations and ecotypes, which were not detected earlier (different morphoclusters of *scutellata, jemenitica* and *monticola*).

They also observed variations in races across the different ecological and climatological zones of the continent and tried to locate zones of introgression and hybridisation of natural populations in different regions. However, the classification of honeybees into well-defined subspecies still remains a controversial issue (Hepburn and Radloff, 1998). Today three major thoughts are reflected in presenting the observed geographical variations between populations of honeybees. These are: (1) as subspecies or geographical races (Ruttner, 1988, 1992), (2) as adaptive ecotypes derived from adjacent populations (Kerr, 1992), (3) as products of asynchronous gene fluctuations within a contiguous metapopulation for which the term "subspecies" may not be appropriate (Hepburn and Crewe, 1991; Hepburn and Radloff, 1998).

Due to high migration, absconding and swarming behaviour and consequential genetic mixing, low molecular differentiation is observed among African subspecies (Franck *et al.*, 2001). Moreover, the presence of gene flow among honeybee populations; lack of coherence between the distribution of the biological traits and morphometrically defined subspecies of Africa (Hepburn and Radloff, 1998) and the existence of the same subspecies in distinct ecological areas and the occurrence of different subspecies without substantial ecological differences (Ruttner, 1988) make the classification of honeybees of the continent more complex. Besides these general problems of classification of African honeybee populations, certain regions of the continent like the Horn of Africa in general and Ethiopia in particular have not yet been adequately studied.

2.2.4 Honeybee Races of East Africa

Relatively more work has been done and more information is available on the honeybees of East Africa for countries like Kenya, Tanzania and Sudan than many other areas of Africa. The honeybees reported from the east African region include: (1) *A. m. scutellata* at mid-altitudes between 500 – 2400 m in woodland and tall grass savannah of Kenya and Tanzania (Smith, 1961). Ruttner (1988) and Hepburn and Radloff (1998) indicated the wide distribution of *A. m. scutellata* from Ethiopia down to South Africa including countries such as Rwanda, Burundi, Uganda, Malawi and Zimbabwe; (2) *A. m. monticola*, reported to occur in East African mountainous areas between altitudes of 2400 – 3200 m (Smith, 1961; Ruttner, 1988). The distribution of this subspecies is thought to be unique and consists of disjunct areas, which are isolated by ecological factors (Ruttner, 1988). This bee is reported to occur in Tanzania, Kenya, Burundi and Ethiopia; (3) *A. m. jemenitica,* a small yellow bee, is reported from hot and arid zones of east Africa (Ruttner, 1988). However, the distribution of this bee is large, extending 4500 km from Chad (Gadbin *et al.,* 1979), Sudan (Ruttner, 1975; Rashad and El-Sarrag, 1980), Somalia and Saudi Arabia (Ruttner, 1988), Yemen (Ruttner, 1975) up to Oman (Dutton *et al.,* 1981); (4) *A. m. litorea* is reported to occur in the warm and humid coastal plains of Kenya and Tanzania at altitudes between 0 – 500 m above sea level (Smith, 1961). This bee is replaced by *A. m. jemenitica* in the arid coastal plain of Somalia, but it extends southwards to the coastal plains of Mozambique (Ruttner, 1988); (5) *A. m. sudanensis* was reported to occur in Sudan (Mogga, 1988) and in Ethiopia (Radloff and Hepburn, 1997a) and (6) *A. m. bandasii* has been reported from Sudan (Mogga, 1988) and Ethiopia (Radloff and Hepburn, 1997a).

2.2.5 Classification of Ethiopian honeybee races

The first honeybee race reported to occur on the Ethiopian plateau was *A. m. monticola* (Smith, 1961). Ruttner (1975) reported the existence of *A. m. jemenitica* and *A. m. scutellata*. Later on Ruttner (1988) reported the existence of large and yellow *monticola* bees. However none of the reports indicated the sampling localities and the distribution of these bees. Some of the reports were mainly based on zoogeographic point of view. Kassaye (1990) reported the existence of five honeybee races, *A. m. monticola* (in the southeastern mountains), *A. m. jemenitica* (in eastern lowland), *A. m. litorea* (in southwest lowlands), *A. m. adansonii* (in the southern mid-altitude areas) and *A. m. abyssinica* (central plateau and southwestern tropical forest). His study did not cover the northern parts of the country (areas covered in this study). The latest work, a transect study of the Horn of Africa from Mega to Adi Arkay, (Radloff and Hepburn, 1997a) suggested the existence of three races, *A. m. jemenitica, A. m. bandasii* and *A. m. sudanensis*. However, Hepburn and Radloff (1998) later suggested that these last two races (*A. m. bandasii* and *A. m. sudanensis*) be considered as ecotypes of *A. m. jemenitica* until further detailed studies take place in the area.

In the reports made so far on the classification of honeybee populations of Ethiopia, the various findings do not support each other and serious contradictions exist among them. Some of the disagreements between the reports are: *A. m. litorea*, which was considered as a honeybee race of the east coast of Africa (along the Indian Ocean) by Smith (1961) and Ruttner (1975, 1988), was reported from the mainland in the extreme western parts of the country by Kassaye (1990). Again *A. m. scutellata,* which had been reported from the country by Ruttner (1975 and 1988), could not be confirmed by either Kassaye (1990) nor Radloff and Hepburn (1997a).

Moreover, honeybees of Awassa were identified as *A. m. adansonii* by Kassaye (1990) but bees of Shashemene, with similar ecology and only 10 km away from Awassa, were identified as *A. m. bandassii* by Radloff and Hepburn (1997a). On the other hand, *A. m. adansonii* (which was restricted to west and south west Africa by Ruttner, 1975, 1988, 1992 and Hepburn and Radloff, 1998) has been reported to exist in Ethiopia (Kassaye, 1990).

In spite of various attempts made by different authors to classify the honeybees of Ethiopia, the picture of the honeybee populations of the area were remained blurred. There was no clear idea on the types of races found in the country. Hepburn and Radloff (1998) stated that the Horn of Africa, particularly the highlands of Ethiopia are physiographically and climatologically complex and the population of the honeybees of the area are also interesting and complex. They reported high degrees of variability both in size and pigmentation throughout the country.

Kassaye (1990) indicated the existence of different cluster groups of honeybees, which are different from those so far mentioned and he reported them as *A. m. abyssinica* and suggested further detailed studies for the area. The occurrence of distinct types of bees in the region was also supported by DNA analyses (Franck *et al.*, 2001). According to their mitochondrial DNA analyses, the honeybees from Ethiopia are different from previously known *Apis mellifera* lineages and they emphasize the importance of further study in the region.

Despite the attempts made to study the honeybees of Ethiopia, due to inaccessibility and security reasons (past wars), still many places in the country in general, and the northern parts of the country in particular had not been investigated. Moreover, information on the types of honeybee races found in the area, their geographical distribution across different ecological zones and the relationship of behavioural and morphological characters with the ecological factors were lacking. Generally, because of limited work on the honeybees of the area, many authors have suggested further studies on the honeybee populations of the Horn of Africa in general and Ethiopia in particular.

Today in the classification of honeybees, there is a great trend to incorporate characters other than morphometric measurements. Ruttner (1977) besides morphometric characters suggested including the unique biology of the Cape honeybee (*A. m. capensis*) such as diploid egg from workers, size of the spermatheca and ovariole number to easily separate from its neighbour *A. m. scutellata*. Moreover, Spivak *et al.* (1988) used multi-technique comparisons such as behaviour, cell diameter, morphometric and allozyme analysis to discriminate Africanized and European honeybees. Many authors indicated the possibilities of biased measures of genetic diversity of honeybees when only morphometric analysis is considered. In the methods of classification of honeybees there is a trend to gradually shift from morphometric analysis alone to incorporate variables like biological characters (swarming, migration and absconding), analysis of DNA and pheromones, which help to resolve variations which could not be detected by morphometric measurements alone (Hepburn and Radloff, 1998).

To establish a reliable and natural taxonomic classification of honeybee populations (Ruttner, 1988) suggested, "integrated biometrics" that is, classification by including all possible data on biology, genetics and ecology of honeybee populations under investigation. Ruttner (1988) further emphasised the importance of supplementing morphometric analysis by essential characteristics of the biological unit like specific ecological adaptation, behavioural characters and clear geographical demarcations.

2.3 Biological and ecological aspects

Apis mellifera is a highly polytypic species with large geographical variations not only in morphology but also in behaviour and physiology. Merrill (1922) noticed the geographic variation and the inheritance of morphological characters and the influence of environment on the morphological characters of honeybees. The biology of honeybees is variable within and between races of *Apis mellifera* which is believed to be a result of adaptive responses to diverse ecological conditions like climate, patterns of resource abundance and predation pressure (Ruttner, 1988; Hepburn and Radloff, 1998). As a result, temperament, duration of developmental stages, patterns of seasonal variability like brood rearing, migration, swarming and absconding of bees vary from one race to another.

Moreover, geographical variations in behaviour, like orientation, defence, tendency towards propolis collection and utilisation, robbing and drifting vary from race to race (Lauer and Lindauer, 1971, 1973; Ruttner, 1975). Understanding the biology and ecology of honeybees of an area is very important not only for classification purposes but also for the efficient and profitable management of honeybees according to their biological behaviour and respective ecology.

2.3.1 Biological factors

2.3.1.1 Migration

In the tropics migration of honeybee colonies is considered as an evolutionary adaptation to escape harsh periods and also as a means of exploiting resources available in different ecological habitats at different times (Chandler, 1976; Castagné, 1983; Hepburn and Radloff, 1995). In an evolutionary sense, the honeybees of tropical and temperate regions develop different means of surviving to escape harsh periods. The honeybees of the tropics adapt by migrating to resource rich areas while the temperate bees survive by means of massive hoarding (Chandler, 1976).

Seasonal migration of honeybees is considered as a unique characteristic of tropical honeybees (Ruttner, 1988). Honeybees of most sub-Saharan Africa are reported to migrate on a seasonal basis, following dry periods: *A. m. adansonii* (Woyke, 1989; Adjaloo, 1991; Adjare, 1990; Mutsaers, 1991); *A. m. scutellata* (Smith, 1961; Chandler, 1976; Nightingale, 1983); *A. m. monticola* (Smith, 1961; Ntenga, 1976); *A. m. jemenitica* (Rashad and El-Sarrag, 1978; Peterson, 1985; Sawadogo, 1993; Woyke, 1993); *A. m. litorea* (Ntenga, 1976); *A. m. capensis* (Hepburn and Radloff, 1998).

However, the tendency of migration differs from ecotype to ecotype, from one ecological zone to another and also depends on responses to different stimuli (Chandler, 1976). Lack of food and water, over heating and fire were reported to be the major causes of migration in tropical Africa (Fletcher, 1978).

Hepburn and Radloff (1998) indicated that the migration of African honeybees is not a completely fixed trait and can vary within and between races depending on varying environmental conditions. In Kenya the migration of *A. m. scutellata* is reported to be facultative depending on the availability of resources (Nightingale, 1983). Moreover, *A. m. jemenitica* is reported to not migrate in north Oman and Yemen but commonly migrates in Sudan and Chad (Hepburn and Radloff, 1998). In tropical Africa even if migration is generally considered as an adaptation to the type of environment where bees live, losing colonies partially or totally as a result of migration every season could be one of the discouraging factors in the development of beekeeping programs in the region.

In Ethiopia, honeybee migration is a common phenomenon in the western and southwestern parts of the country. However, there is no literature on the types or races of bees, which commonly migrate, the nature of ecology where most migration takes place, the periods and extent of migration, where the bees migrate and the possible causes of migration. Such information is very valuable not only from the biological point of view but also from a practical beekeeping point of view to understand the real causes and associated factors contributing to the migration of bees. The information would be very important to formulate possible recommendations to minimise the migration of bees and to develop an appropriate systems to manage bees with migratory behaviour.

2.3.1.2 Reproductive swarming

The general factors associated with reproductive swarming are considered the same for temperate and African races of bees (Smith, 1961; Anderson *et al.,* 1983; Ruttner, 1983, 1988, 1992). However, unlike temperate races, African races invest more in a reproductive swarming than in a hoarding strategy (Hepburn and Radloff, 1998), which is believed to be a natural mechanism of balancing the loss of myriad colonies annually due to various hazards in their environment (Fletcher, 1978; Schneider and Blyther, 1988). The high reproductive swarming potential of African honeybees is believed to be attributed to many of their adaptive characters such as fecundity, short developmental period, high foraging efficiency and small body size (Fletcher, 1978). Moreover, it seems more influenced by within nest conditions than genetic factors (Fletcher, 1978).

Georges (1912) indicated that bees kept in small volume hives show more inclination to swarm than those in large hives. On the other hand, it was observed that relatively weak colonies in large volume box hives also swarm (Hepburn, 1993). Regardless of the population size of a colony and volume of hive space it was also observed that in some seasons and years most colonies tend to swarm while in some other seasons and years even highly overcrowded and strong colonies do not show signs of swarming (Nuru and Dereje, 1999).

However, the tendency to swarm still differs from race to race (Ruttner, 1975). The reproductive periods can also vary between races and may also be biphasic depending on the agroclimatic conditions of the localities. In African honeybees the close correspondence of the phenology of reproductive swarming with the local climates, weather and the availability of forage has been reported (Hepburn and Radloff, 1998). Moreover, reproductive swarm time variation within the same subspecies as the result of ecological and climate variations were observed for *A. m. scutellata, A. m. adansonii* and *A. m. capensis* (Hepburn and Jacot Guillarmod, 1991; Hepburn and Radloff, 1998). The number of queens produced by a reproductive swarm colony of African honeybees also varies from 10-200 depending on race and agroecological conditions (Hepburn and Radloff, 1998).

In Ethiopia information on reproductive swarming such as the period of swarming, the reproductive swarming tendency and the number of swarms per colony is lacking. Moreover, the types of honeybee populations with high swarming tendencies and the ecological conditions at which honeybees mostly swarm, are not known. Such information is essential to develop an appropriate management system for bees with a high swarming tendency and in the long run the information would be important for selecting honeybee colonies with relatively high hoarding strategy rather than emphasising extreme brood rearing and subsequent swarming.

2.3.1.3 Seasonal cycles of honeybee colonies

Every honeybee race is specifically adapted to its environment of origin through long periods of natural selection (Ruttner, 1976). The development of seasonal cycles according to changes in the environmental conditions is one of the fundamental evolutionary successes of honeybee colonies (Hepburn and Radloff, 1998). In tropical Africa, unlike temperate regions, seasonal cycles of the honeybee colony are governed by dry and wet seasons and the associated flowering patterns of honey plants (Hepburn and Radloff, 1998).

The close association of seasonal cycles of honeybee colonies (brood rearing, population build-up, swarming and declining of population (dearth period) with environmental conditions (rainfall pattern, flowering time and dry periods) and the existence of time shifts in reproductive swarming within and between races in different climatic zones of Africa are well established (Hepburn and Radloff, 1998). Hepburn and Radloff (1998) also observed significant correlations between brood rearing and swarming and the phenology of bee plants for some of major climatological and ecological zones of Africa. Moreover, depending on the rainfall and flowering patterns of an area the honeybee colony cycle can be monophasic or biphasic, short or long, depending on the duration of flowering. Honeybee populations, which adapt well to synchronise to the changes in the environmental condition would have a better chance to survive in the dearth periods and are believed to be more productive.

In Ethiopia where highly diversified ecological conditions exist there is no adequate information on seasonal cycles of honeybee colonies and associated factors like rainfall and flowering patterns for different ecological zones of the country. Information on colony seasonal cycles is very important to develop a seasonal colony management calendar for different agro-ecological zones of the country. Moreover, the information would be valuable to select the types of honeybee populations, which easily synchronise to the change of environmental situations. Strains of honeybee populations with a fast colony build-up ability and fast honey storing tendency would be important to meet the conditions of most parts of the country where flowering periods are short.

2.3.1.4 Temperament

Generally, all tropical African honeybees are considered as highly defensive or aggressive. The defensive nature of tropical African honeybees is believed to have arisen due to the extreme pressures of predators and disturbance in their ecology. However, in some areas of tropical Africa, beekeeping can be done with out protective clothes (Clauss, 1983), while in some other areas the bees are reported to be swift and violent (Fletcher, 1978). Moreover, the presences of variations in the degree of aggressiveness among different races of tropical African honeybees and its association with genetic variations have often been reported (Chandler, 1976; Fletcher, 1978; Hepburn and Radloff, 1998). Collins *et al.* (1989) demonstrated the presence of significant variations in sting alarm pheromone levels between genetically and behaviourally different bees. Moreover, Fletcher (1978) indicated the existence of inter and intracolonial variations among different honeybee population.

Besides the genetic factors, temperament is also believed to be influenced largely by climate (Castagné, 1983). Temperature is considered the most important environmental factor that lowers the threshold responses of bees (Fletcher, 1978). As a result, honeybees believed to be more aggressive at hot, low altitude areas than cool, higher ones (Corner, 1985). On other hand the same subspecies of honeybee, *A. m. jemenitica,* is reported to be docile in very hot North Oman and North Yemen, but aggressive in Sudan and in Chad (Rashad and El-Sarrag, 1980; Dutton *et al*., 1980; Field, 1980; Gadbin, 1976). Moreover, the presence of aggressive and docile bees within apiary and its association with colony size and its variations from season to season and within the day with the changes of weather have also been reported (Hepburn and Radloff, 1998).

Information on the relative defensive behaviour of different honeybee populations of different ecological areas and factors associated with temperament variation is not available for Ethiopia. Along with morphometric analysis of local honeybee populations, having information on the degree aggressiveness of different honeybee populations would be important to supplement the morphometric classification of honeybees of the area with behavioural characters. The information would be also important to select honeybee population with relatively gentle and reasonably manageable behaviour.

2.3.2 Honeybee plants

Beekeeping is more dependable on ecological suitability of an area than any of other livestock production. If the ecological conditions of an area are not suitable to honeybees, a management skill alone doesn't improve the productivity of bees. Generally, the honeybee population and their productivities are mainly influenced by the nature of honeybee flora of an area. Information on honeybee flora is very essential to assess the potentiality of an area for beekeeping, to select an appropriate apiary sites and to integrate beekeeping with different agricultural activities, conservation and rehabilitation programme of an ecology. Moreover, since, a linear chain relationships exist between peak flowering of bee plants and maximum brood rearing and subsequent reproductive swarming of honeybees (Hepburn and Radloff, 1998), it is of paramount important to have inventory of the honeybee plants of an area with their seasonal flowering patterns to properly manage honeybees following their seasonal cycles.

Moreover, in the field of apiculture melissopalynological analysis is become very important for many of its practical applicabilities, to determine the botanical and geographical origin of honey (Louveaux *et al.,* 1978), to study the pollen spectrum of honey from which to reveal the true nature of bee forage of an area and to determine the role of each plants for bees and honey production (Sawyer, 1988). Palynological analysis alone has been used to reconstruct the floral landscape and the diversity of plant community (Damblon, 1987, 1988). From change of pollen spectra of honey, it has been possible to assess the change of vegetations, the occurrences of invader plants and environmental disturbances of an area (Barth, *et al*., 1998; Feller-Demalsy *et al*., 1987).

Based on the analyses of pollen grains from the gut of forager bees (Sharma *et al.,* 1986), the stomach content of dead people (Erdtman, 1969) and a toxic honey (Kerkvliet, 1981), it has been possible to detect and confirm the botanical origin of several poisonous honeys. Some bee plant species from the families Ericaceae, Euphorbiaceae, Ranunculaceae and Solanaceae are well known for their toxicity to honeybees (Crane, 1990). Moreover in the country several plant species are also reported to be poisonous to honeybees and livestock and honeys from such plant are reported to be toxic to humans. So information on morphological features and having references of pollen grains of poisonous honeybee plants of an area are important to confirm poisoning cases and to give some possible practical recommendations.

2.3.3 Ecological factors

Along with morphometric analyses and behavioural characterisation of honeybees, knowledge of the environmental conditions where the bees live is obviously important. Different authors have indicated that, with some exceptions, the general morphometric and behavioural characters of honeybees have been found to be influenced by environmental factors (Daly and Balling, 1978; Spivak *et al.*, 1988; Cornuet and Garnery, 1991a; Daly and Morse, 1991; Nazzi, 1992). Alpatov (1929) and Ruttner (1988) demonstrated morphological variations across latitude.

Ruttner (1988) stated that subspecies are a result of an adaptation in physiology and behaviour to given types of environment, which are associated with secondary variation in the external morphological characters. Murphy (1973) and Falconer (1989) also indicated the effects of environmental influences on morphological and behavioural characteristics of honeybees. Falconer (1989) documented that phenotypic characters in a population are the result of the combined effects of genotypic variance, environmental variance and gene-environment variances. Tsurata *et al.* (1989) and Spivak *et al.* (1990) found that the colour pattern of *Apis mellifera* queens depends on the developmental temperature at the pupal stage; at lower temperatures the pigmentation becomes darker. Again Szabo and Lefkovitch (1992) showed that the colour patterns of honeybees is less than 40% heritable, while more than 60% is attributable to environmental, gene-environment variation and error.

In tropical Africa the presence of clear correlations between climatic conditions and morphometric characters like pigmentation, hair length and body size are well recognised (Ruttner, 1988). Gradual variation in morphological characters was also observed with changes in altitude (Smith, 1961). Smith observed three distinct geographical races *A. m. litorea, A. m. scutellata,* and *A. m. monticola* in Tanzania across a 300 km distance involving a change of altitude of 3000 m from the coast to the rain forest of Mt Kilimanjaro. The effects of altitude and the existence of short-distance ecoclines are also well recognized (Mattu and Verma, 1984; Ruttner, 1988; Meixner *et al.*, 1989, 1994).

In a country like Ethiopia with contrasting physiographical and agroclimatical features, it is very important to consider the environmental factors (like altitude, temperature and rainfall) along with the morphometric characterisation of honeybees of the area to fully understand the variations, from the biogeographic context. Today in the classification of geographical races of honeybees, holistic approaches, including all possible data such as morphometric, biological, behavioural and ecological characters have become more important to understand the interaction of various factors and to obtain clear pictures of the geographical races or ecotypes of honeybees of a given area. Therefore in this work an attempt was made to classify the honeybee populations of the area with greater sampling distance resolution by obtaining morphometric, behavioural, biological and ecological characters of the honeybees of the northern region of Ethiopia.

CHAPTER 3

Materials and methods

3.1 Components

The study was based on morphometric analysis of honeybees and survey work on their behavioural and ecological aspects.

3.2 Study area

The study area is located between 9^0 and 14.53^0 latitudes north and 34^0 and 44^0 longitudes east. The area represents nearly half of the land area of Ethiopia. Physiographically and climatologically, the study area is extremely variable. According to the agroecological zonation of Ethiopia (MOA, 1998) there are 10 major agroecological regions in the study area. However, these can be broadly categorised into the following four major ecological areas:

1 The eastern and northwestern, hot to warm, arid to semi-arid lowlands;

2 The western humid midlands;

3 Submoist to moist central highlands;

4 The northern mountainous highlands.

The detailed ecological features of the study area is given in section 1.2 – 1.2.4.

3.3 Sampling

The sampling localities were selected based on the agroecological zonation of Ethiopia. Accordingly, 31 sampling localities were systematically selected to represent different agroecological parts of the study area. However, the numbers of sample localities per agroecological area varied according to the proportional land coverage of each agroecological type. The following localities were selected in their respective ecological areas. Inchini, Gedo, Aykel, Dabat and Debre Tabor from the mild to cool, moist mid-highlands; Dangla, Hinde, Nejo, Shambu and Nekemte from mild to cool, sub-humid mid-highlands; Mekele, Korem, Woldeya, Deneba, Sendafa and Salayish from mild to cool, sub-moist mid-highlands; Wohni, Angereb and Abi Adi from hot to warm, sub-moist lowlands, Dedessa, Bir Sheleko and Manbuk from hot to warm, moist lowlands; Humera and Shiraro from hot to warm, semi-arid lowlands; Bambasi and Menge from mild to cool, sub-humid mid-highlands; Feres Bet and Debark from cold to very cold moist, sub-afroalpine to afro alpine; Guguftu, from cold to very cold, sub-moist afroalpine and lastly Gewane and Melkasedi from hot to warm, arid lowland plains.

Detailed information on the names of sampling localities, regions, map reference numbers and their geographical co-ordinates are shown in Table 1 and the sampling localities with their code numbers are indicated in a map of Ethiopia in Figure 1. The average interlocality sampling distance was 97 km. From each sampling locality honeybee samples were taken from five different traditional hives for a total of 155 samples. From each colony about 50 individual worker honeybees were taken from the hive entrance. The bees were immediately killed and preserved by putting them in 70% ethanol.

3.4 Survey work

Along with sample collection, survey work was done to collect the necessary information on the major behavioural aspects of the honeybee populations of the study areas. For this purpose an average of five farmer beekeepers and experienced bee technicians per locality, for a total of 155 individuals were interviewed based on a pre-structured questionnaire (Appendix IV). During interviews beekeepers of each sampling locality were brought together to discuss their opinions on the points of the questionnaire and their final consensus was recorded. In the survey, data on major behavioural features such as reproductive swarming, migration, temperament and colony seasonal cycles were treated. The data was based on total number of 1884 colonies owned by interviewed beekeepers in the study period (1999/2000).

3.4.1 Reproductive swarming

Reproductive swarming of the honeybee populations of the area was assessed based on interviews under the following conditions.

A. Extent of reproductive swarming was calculated from the ratio of colonies that reproductively swarmed to the total number of colonies owned by interviewed beekeepers.
B. Maximum number of swarms per colony per reproductive season was recorded.
C. Frequency of swarming was recorded based on the occurrence of swarming every year or not.
D. Phase of swarming: the presence and absence of reproductive swarms in phases, in different seasons of the same year were recorded.
E. The occupation rates of bait hives by swarms were recorded (for 1555 bait hives) to indirectly estimate the extent of reproductive swarming tendency of honeybees of the area.

F. Swarming tendencies of colonies by colour based on beekeepers' reports were also recorded.

G. Period of reproductive swarming: to determine if any shifting in periods of reproductive swarming, peak reproductive months were recorded for each locality.

3.4.2 Migration

The migratory behaviour of the honeybee populations of the study area was evaluated based on interviewing beekeepers under the following conditions.

A. Occurrence of migration: beekeepers were interviewed on the presence or absence of seasonally based movements of honeybees in the area.

B. Extent of migration: in the localities where migration was reported, the magnitude of migration was estimated from the proportion of colonies that migrated to the total number of colonies owned by interviewed beekeepers in that particular locality.

C. Reasons of migration: to investigate the major reasons of migration, beekeepers were interviewed on the possible factors contributing to the migration of honeybees in their localities.

D. To determine the time calendar at which migration takes place, major migration periods of each locality were recorded.

Along with these, data on the periods at which immigration of honeybee colonies had taken place were also recorded.

3.4.3 Temperament

Aggressiveness of honeybee populations was assessed based on beekeepers' responses to the following different temperament conditions of colonies.

A. Qualitative evaluations like docile, aggressive and very aggressive terms were used to categorise the temperaments of colonies in the area.
B. The presence or absence of unprovoked attacking by bees was recorded.
C. The temperament of the bees in relation to colour was compared.
D. Factors attributed to defensiveness were also recorded.
E. The proportion of colonies that were reported as aggressive to the total number of colonies was recorded.

3.4.4 Colony seasonal cycles

The colony seasonal cycles such as brood rearing and dearth periods with relation to rainfall periods were recorded and compared among localities and morphoclusters.

3.4.5 Honeybee plants

During the survey work, the major honeybee plants of the area were recorded in vernacular and common names with the consultation of beekeepers and bee technicians. Moreover, their flowering periods and the altitude range at which the plants grow were also recorded. Their scientific names were determined using the Glossary of Ethiopian plant names (Wolde Micha'el, 1978) and Honeybee Flora of Ethiopia (Fichtl *et al.*, 1994).

Along with this, samples of pollen grains of bee plants, which are reported to be poisonous to bees and honeys from such plant toxic to humans, were collected. For this purpose samples of ripe pollen grains were taken from mature flower buds, directly from the field after the plants had been confirmed as bee plants by close observations that bees were foraging either for nectar or pollen or both. Pollen grains samples were also taken from previously identified herbarium specimens at the Holetta Bee Research Centre. To avoid contamination, each sample was kept in separate paper bags. The pollen grains prepared for both light and scanning microscopy observation. For light microscope analyses the pollen grains were prepared based on the protocol of Louveaux *et al.* (1978). For scanning electron microscopy dried pollen grains were dusted directly on to brass stubs provided with double sided tape and coated with gold for 2 minutes using Balzers sputtering device.

The important morphological features of the pollen grains were described mostly based on the light microscope (LM) preparations, X1000 and supported with the scanning electron microscopy (SEM) observations. Pollen grain characters like symmetry, form, size, shape, aperture (type, number and diameter), surface pattern, sexine and nexine thickness were described. The average sizes of the pollen grains were determined by measuring 20 pollen grains each for polar axis and equatorial diameter using a calibrated ocular micrometer. The shapes of the pollen grains were expressed as the ratio of the length of polar axis to the equatorial diameter using the standard of Erdtman (1969). For aperture diameter, sexine and nexine thickness, an average of 10 measurements was taken. Photomicrographs of the pollen grains were taken under both light and scanning electron microscopy.

3.5 Ecological conditions

Along with sample collections and survey work, ecological features such as weather conditions, (temperature, amount and pattern of rainfall), were taken from the nearest metrological stations and from the district agricultural offices of each of the sampling locality. The altitude and the geographical co-ordinates of the localities were also taken using GPS instrumentation and the general physiographic features were described.

3.6 Morphometric analysis

From each of 155 colony samples 20 bees totalling 3100 individual worker honeybees were morphometrically measured. Even though Ruttner (1988) used 36 characters in the analysis of world honeybees, he noted that the characters used to classify the European races would not necessarily have the same values in discriminating between honeybees of other regions. So he suggested the possibility of using 10 of these selected characters to discriminate the African races of honeybees by applying step-wise discriminant analysis without any substantial deterioration in the result.

Crewe *et al.* (1994) also showed that 10 characters were as adequate as Ruttner's (1988) full set of characters to discriminate southern African races of honeybees. Using 11 morphometric characters Hepburn and Radloff (1996, 1997) and Radloff and Hepburn (1997a,b) were able to classify the honeybee races of the African continent. Moreover, Hepburn and Radloff (1998) and Radloff *et al.* (1998) were able to discriminate the honeybees of Africa using nine characters.

In this study the same nine morphological characters which were shown to have high discriminatory power (in African honeybees) plus four morphological characters (2 related to body size and 2 on pigmentation) total of thirteen selected characters were used. These include four categories of characters such as hair, pigmentation, sizes of body parts and venation of forewing angle. These are length of hair on abdominal tergite 5 (1), pigmentation of scutellum (35), pigmentation of scutellar plate (36), pigmentation of abdominal tergite 2 (32), pigmentation of abdominal tergite 3 (33), pigmentation of abdominal tergite 4 (34), tergite 3 longitudinal (9), tergite 4 longitudinal (10), sternite 3 longitudinal (11), transverse of wax plate on sternite 3 (13), wing angle B4 (22), wing angle N23 (30) and wing angle O26 (31). Numbers in parentheses are designate Ruttner's (1988) morphological characters.

Accordingly, a total of 40 300 morphometric characters were measured and analysed. The measurements of the characters such as size of body parts and length of hair were made using an ocular micrometer in a dissecting microscope under magnification of x25 – x50. The micrometer unit was calibrated and finally presented in millimetres. The classification of pigmentation, was done by adopting the empirical series of pigmentation patterns developed by Goetze (1940, 1964) and Ruttner *et al.* (1978). Scores from 0 to 9 were given, 0 for completely black and 9 for completely yellow pigmentation. The wing angles were measured using a computer digitiser and the values were recorded in degrees.

In classification of pigmentation, in addition to the empirical series of pigmentation pattern, the proportion of yellow to black bees in the colony was determined by taking the abdominal tergite 2 (32) colour conditions of each bee (Radloff, 1996). For each colony 40 individual worker bees were determined and the percentage of yellow to black bees for a colony, locality and cluster was calculated. In addition to the primary measurements, secondary values for tergite 3 longitudinal (9) plus tergite 4 longitudinal (10) were calculated to compare the over all size variations among morphoclusters (Ruttner, 1976).

3.7 Statistical analysis

Different methods of statistical analysis were used to analyse the phenotypic variation among the honeybee populations, to determine the correlations within the various phenotypic and behavioural characters and the interactions between the various environmental factors acting on different phenotypic and behavioural characters. The statistical analysis was also used to discriminate the honeybee populations into possible cluster groups. To analyse the various data, the statistical package, Statistica (1999–2000) was employed.

3.7.1 Univariate analysis

For morphometric analyses, data of 40 300 measured characters from 3100 individual worker honeybees were used. For behavioural aspects the survey record data were taken. To obtain average values and to observe the range of variations of morphometric characters, the mean, minimum, maximum and standard deviation values of each of the thirteen characters for 3100 bees were analysed.

To determine morphological variations among colonies, analysis of variance for each morphometric character was calculated from colony means data. To observe where the significant variations exist, pair-wise comparisons of Tukey's HSD were used. Before the analyses of variances, the assumptions of ANOVA such as the homogeneity of the variance using the Levene's test and for the normal distribution of data using Kolmogorov Smirnov tests were checked. When the data failed to meet the homogeneity and the normal distribution test appropriate transformations (i.e. Arcsin square root for proportion and square root for counting data) were used. When the transformed data failed to meet the ANOVA assumptions the non-parametric test (Kruskal-Wallis Anova test) was used. In such situations pair-wise mean comparisons of Mann-Whiteny U test were used. In this case the P-level of significance was adjusted to $\alpha < 0.05/k$ where k is the number of pair-wise comparisons.

Correlation analysis was carried out to establish the relations among various phenotypic and behavioural characters. Regression analyses were used to determine the correlations between each phenotypic and behavioural character versus each environmental factor. In this case the P-level of significance was determined based on significance correlations using the sequential Bonferroni's adjustment ($\alpha < 0.05/K$ to the level of significance for multiple comparisons, where K is the number of factors in multiple comparison) to insure that the overall level of significance was not larger than 0.05 (Miller, 1981). For the categorical data collected in the survey work, the Chi-square test was used. In this analysis Yates' correction with Delta 0.50 level was used for low frequency data.

3.7.2 Multivariate analyses

Different multivariate statistical analyses such as principal components analyses and linear step-wise discriminant analyses were carried out using the colony means data. The principal components analysis was used to detect the presence of possible clusters of colonies among the scatter scores, from a plotted plane graph of the first two high loading factors.

Step-wise linear discriminant analysis was carried out to confirm the separations of clusters of colonies, which were detected in the principal components analysis. Step-wise discriminant analysis was also carried out to determine the most discriminatory variables that entered the discriminatory function analysis. The discriminant functions were used to classify the colonies and to determine the percentages of correctly classified colonies. Based on the discriminant functions the highest posterior probability of each colony being in any cluster groups was computed.

Wilks' Lambda statistic was used to test for significant differences in the cluster vector of means of each character used in the discriminant function (Johnson and Wichern, 1998). The Mahalanobis distances between cluster groups were determined (Cornuet, 1982). To detect where high variances occur intra and intercolonial variances were computed for each locality based on factor analysis procedures, using the first unrotated factor scores of each bee and colony means of each morphometric character respectively. The heterogeneity of the variances at each locality was tested using Levene's F statistic. This test procedure is based on analysis of variance using the absolute deviation of each case from its locality mean (Brown and Frosythe, 1974).

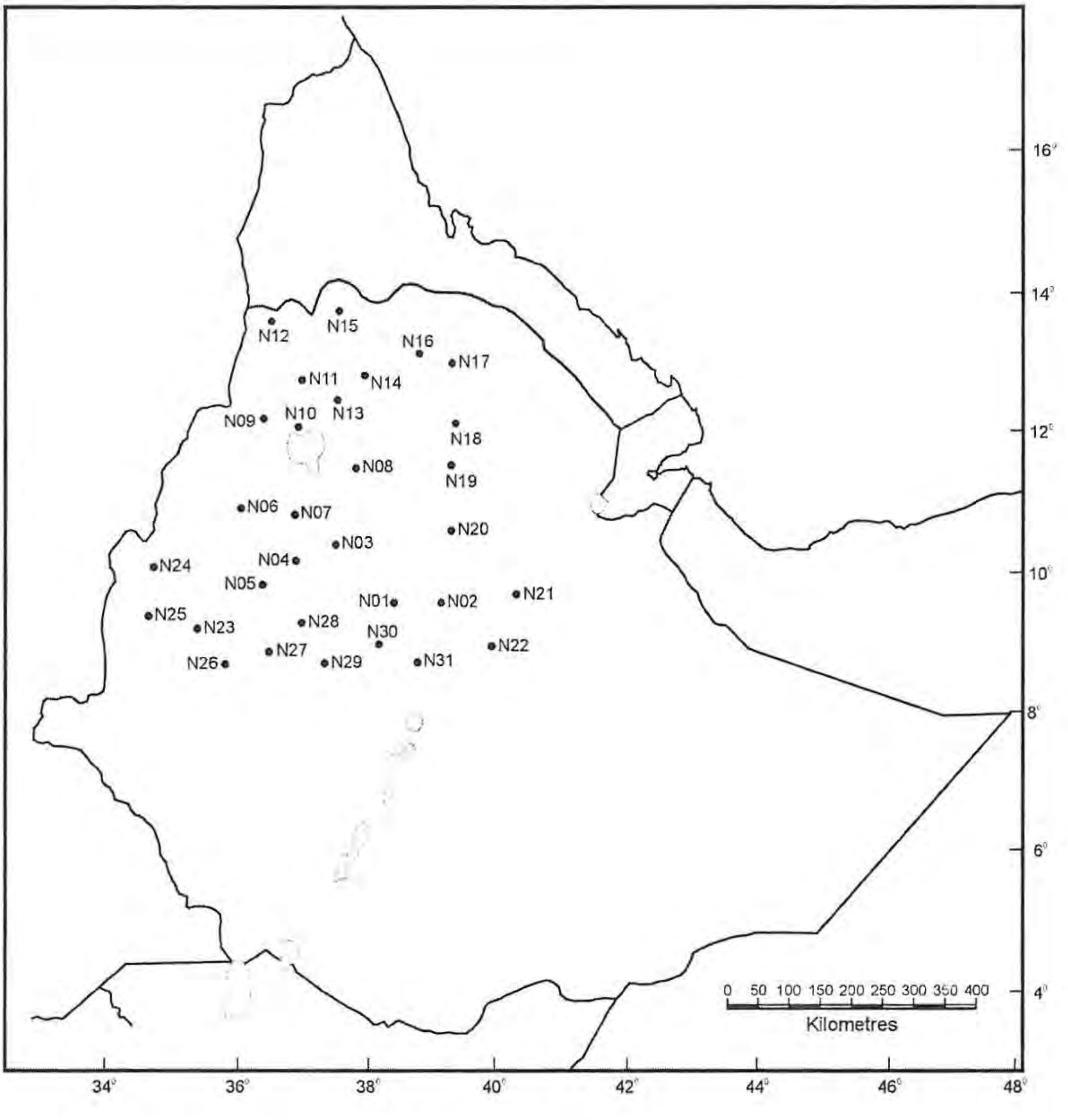
Table 1 Sampling localities, respective regions, map reference numbers and geographical co-ordinates of honeybee localities analysed in this study.

Sampling localities	Region	Map reference	Co-ordinates
Abi Adi	Tigray	N16	13.37N, 38.59E
Angereb	Amhara	N11	13.13N, 37.08E
Aykel	Amhara	N10	12.32N, 37.03E
Bambasi	Benshangul	N25	09.44N, 34.43E
Bir Sheleko	Amhara	N04	10.33N, 37.10E
Dabat	Amhara	N13	12.59N, 37.43E
Dangla	Amhara	N07	11.12N, 36.51E
Debark (Milligebsa)	Amhara	N14	13.23N, 38.10E
Debre Tabor	Amhara	N08	11.54N, 37.57E
Dedessa	Oromia	N26	09.01N, 36.01E
Deneba	Amhara	N02	09.47N, 39.12E
Feres Bet	Amhara	N03	10.46N, 37.38E
Gedo	Oromia	N29	09.00N, 37.27E
Gewane	Afar	N21	09.58N, 40.32E
Guguftu	Amhara	N20	10.55N, 39.27E
Hinde	Oromia	N05	10.08N, 36.27E
Humera	Tigray	N12	14.17N, 36.36E

Continuation of Table 1.

Sampling localities	Region	Map reference	Co-ordinates
Korem (Ashenge)	Tigray	N18	12.34N, 39.32E
Inchini	Oromia	N30	09.20N, 38.21E
Manbuk	Benshangul	N06	11.17N, 36.14E
Mekele	Tigray	N17	13.31N, 39.30E
Melkasedi	Afar	N22	09.15N, 40.07E
Menge	Benshangul	N24	10.22N, 34.45E
Nejo	Oromia	N23	09.30N, 35.29E
Nekemte	Oromia	N27	09.05N, 36.33E
Salayish	Amhara	N01	09.50N, 38.54E
Sendafa	Oromia	N31	09.04N, 38.54E
Shambu	Oromia	N28	09.34N, 37.06E
Shiraro	Tigray	N15	14.19N, 37.43E
Wohni	Amhara	N09	12.39N, 36.41E
Woldeya (Woko)	Amhara	N19	11.53N, 39.26E

Figure 1 Sampling localities of study areas with their reference numbers in map of Ethiopia.



CHAPTER 4

Results

4.1 Morphometric characters

4.1.1 Univariate analyses results

The mean, minimum, maximum and standard deviation values of each morphometric character from 3100 individual worker bees indicated the presence of a wide range of variability within the honeybees of the study area (Table 2). The analysis of variance means for the phenotypic characters of 155 colonies also revealed the existence of extensive variability in all characters across all localities ($P < 0.0001$) except the wing angles B4 (22) and O26 (31) (Table 3).

Generally, characters related to pigmentation, such as the pigmentation of tergite 2 (32), pigmentation of tergite 3 (33), pigmentation of tergite 4 (34) scutellum pigmentation (35), hair length on tergite 5 (1), and sizes of body parts like sternite 3 longitudinal (11), tergite 3 longitudinal (9) and tergite 4 longitudinal (10) had high F values than the rest of characters. The summary of the analysis of variance of each character with its respective F and P values is shown in Table 3.

The pair-wise comparison of Tukey's HSD test of the colony means for the phenotypic characters, to indicate which localities differed also showed a significant variability in most characters across most localities except for the wing angles. According to this test all three wing angles had no significant variations between most study localities except wing angle N23 (30) from two localities, Inchini and Guguftu had relatively significant variations with few localities. This wing angle value from Inchini varied significantly only with localities such as Nekemte, Dedessa, Shambu, Sendafa, Menge, Dabat and Guguftu, and the same wing angle from Guguftu significantly varied with those of localities such as Dangla, Debark Deneba, Inchini, Manbuk and Melkasedi.

Table 2 Mean, minimum, maximum and standard deviation of each morphometric character from the 3100 individual bees measured (measurements in mm, angles in degree).

Characters	Mean	Minimum	Maximum	Std.Dev.	n
Scutellum pigmentation (35)	1.79	0.00	9.00	2.29	3100
Scutellar plate pigmentation (36)	0.83	0.00	7.00	1.37	3100
Hair length on tergite 5 (1)	0.20	0.10	0.40	0.04	3100
Pigmentation tergite 2 (32)	2.75	0.00	9.00	3.86	3100
Pigmentation tergite 3 (33)	2.73	0.00	9.00	3.81	3100
Pigmentation tergite 4 (34)	1.98	0.00	9.00	2.94	3100
Tergite 3 longitudinal (9)	2.07	1.80	2.40	0.08	3100
Tergite 4 longitudinal (10)	2.01	1.72	2.32	0.09	3100
Sternite 3 longitudinal (11)	2.57	2.04	2.88	0.11	3100
Wax plate transversal (13)	2.13	1.76	2.48	0.10	3100
Wing angle B4 (22)	104.90	74.82	124.85	6.20	3100
Wing angle N23 (30)	89.97	74.43	103.42	4.05	3100
Wing angle O26 (31)	37.57	24.68	52.09	4.03	3100

The analysis of correlations between the different phenotypic characters revealed the presence of strong correlations within measured phenotypic characters except wing angles (Table 4). Generally, positive correlations were observed among the different pigmentation characters and also among the sizes of different body parts. Negative correlations were observed between pigmentation and sizes of body parts.

Table 3 Analysis of variance of the colony means for each phenotypic character.

Characters in Ruttners No.	SS effect	df effect	MS effect	SS error	df error	MS error	F	P
(35)	402.43	30	13.41	65.24	124	0.53	25.49	< 0.0001
(36)	81.90	30	2.73	56.77	124	0.46	5.96	< 0.0001
(1)	0.12	30	0.00	0.02	124	0.00	32.50	< 0.0001
(32)	1296.03	30	43.20	170.49	124	1.37	31.42	< 0.0001
(33)	1255.36	30	41.85	166.25	124	1.34	31.21	< 0.0001
(34)	767.32	30	25.58	109.67	124	0.88	28.92	< 0.0001
(9)	0.50	30	0.02	0.12	124	0.00	17.04	< 0.0001
(10)	0.56	30	0.02	0.13	124	0.00	18.52	< 0.0001
(11)	0.88	30	0.03	0.18	124	0.00	20.07	< 0.0001
(13)	0.65	30	0.02	0.25	124	0.00	10.73	< 0.0001
(22)	259.55	30	8.65	1205.35	124	9.72	0.89	= 0.6330
(30)	351.10	30	11.70	376.24	124	3.03	3.86	< 0.0001
(31)	115.25	30	3.84	385.14	124	3.11	1.24	= 0.2089

Hair length was negatively correlated with pigmentation and positively correlated with the sizes of body parts. The correlation values greater than an absolute value of 0.23 were significant at (P < 0.0006 as determined by Bonferroni's adjustment). The correlation values within wing angles, and wing angles with other phenotypic characters are not statistically significant (Table 4).

Table 4 Correlation values (r) within each phenotypic character (numbers in brackets are Ruttners, 1988 character numbers).

Characters	(35)	(36)	(1)	(32)	(33)	(34)	(9)	(10)	(11)	(13)	(22)	(30)	(31)
(35)	1.00												
(36)	.64	1.00											
(1)	- .69	-.36	.00										
(32)	.94	0.44	- .70	1.00									
(33)	.94	0.44	- .70	1.00	1.00								
(34)	.93	0.45	- .71	.97	.97	1.00							
(9)	- .48	-.30	.58	-.46	-.45	-.47	1.00						
(10)	- .47	-.28	.55	-.44	-.43	-.45	.95	1.00					
(11)	- .56	-.33	.63	-.53	-.53	-.55	.89	.88	1.00				
(13)	- .52	-.30	.57	-.49	-.49	-.50	.84	.83	.89	1.00			
(22)	.10	.14	- .04	.08	.09	.08	.03	.06	.04	.01	1.00		
(30)	- .12	-.09	.23	-.10	-.12	-.15	.17	.18	.16	.15	-.08	1.00	
(31)	- .11	-.07	.15	-.16	-.16	-.15	.02	.03	-.02	0.00	-.11	.08	1.00

* The absolute values of r > 0.23 are significant at P < 0.0006 as determined by Bonferroni's adjustment to the level of significance for multiple testing.

The correlation values within characters related to pigmentation such as scutellum pigmentation (35), pigmentation tergite 2 (32), 3 (33) and 4 (34) were very high with r values between 0.93 – 1.00, and the correlation values within characters related to sizes of body parts like tergite 3 longitudinal (9), tergite 4 longitudinal (10), sternite 3 longitudinal (11) and wax plate transversal on sternite 3 (13) had high r values between 0.83 – 1.00. Except for scutellar plate pigmentation (36), strong negative correlation values were obtained between hair length and all characters related to pigmentation. Generally, the observed correlation values between pigmentation and sizes of body parts were not as strong as correlations within different pigmentation classes and within different sizes of body parts. The correlation values within different wing angles and also between wing angles and other phenotypic characters were not significant in most cases.

4.1.1.1 Correlations of each phenotypic character versus environmental factors

Simple regression analyses were carried out to determine the correlations between each phenotypic character versus each environmental factor. The analyses showed that environmental factors such as altitude and temperature have strong influences on all phenotypic characters except the three wing angles. Generally, pigmentation was negatively correlated while body sizes and hair length positively correlated with altitude. The correlation values (r) between altitude and characters related to pigmentation were between -0.77 and -0.79, except for the low correlation value of scutellar plate pigmentation (36) in which r = -0.36. The values of coefficient of determination of characters related to pigmentation with altitude were $R^2 > 0.59$ except scutellar plate pigmentation (36).

The correlation values (r) between sizes of body parts versus altitude were between 0.71 – 0.77. The values of coefficient of determination of characters related to size of body parts with altitude were $R^2 > 0.50$. A high correlation value of r = 0.74 was obtained between hair length and altitude. The correlation values of wing angles and altitude were very insignificant. The summaries of regression analyses for each phenotypic character versus altitude are shown in Table 5.

Table 5 Summaries of simple regression analyses of the altitude of sampling localities versus each phenotypic character from colony mean data.

Characters	r	t values	P-levels
Scutellum pigmentation (35)	- 0.77	- 14.77	< 0.0001*
Scutellar plate pigmentation (36)	- 0.36	- 4.73	< 0.0001*
Hair length on tergite 5 (1)	0.74	13.56	< 0.0001*
Pigmentation on tergite 2 (32)	- 0.78	-15.60	< 0.0001*
Pigmentation on tergite 3 (33)	- 0.78	-15.57	< 0.0001*
Pigmentation on tergite 4 (34)	- 0.79	-15.99	< 0.0001*
Tergite 3 longitudinal (9)	0.71	12.43	< 0.0001*
Tergite 4 longitudinal (10)	0.71	12.36	< 0.0001*
Sternite 3 longitudinal (11)	0.77	14.76	< 0.0001*
Wax plate transversal (13)	0.72	12.72	< 0.0001*
Wing angle B4 (22)	- 0.05	- 0.59	= 0.5555
Wing angle N23 (30)	0.11	1.33	= 0.1859
Wing angle O26 (31)	0.10	1.30	= 0.1963

* Correlations are significant at $P < 0.0125$ as determined by Bonferroni's adjustment to the level of significance for multiple testing.

In the case of temperature, the correlations were opposite to altitude; that is pigmentation was positively correlated while sizes of body parts and hair length were negatively correlated with temperature. The correlation values of characters related to pigmentation with temperature were between 0.76 – 0.79, except scutellar plate (36) pigmentation for which the r-value was 0.33. The values of coefficients of determination of characters related to pigmentation with temperature were $R^2 > 0.57$ except scutellar plate (36) pigmentation. The correlation values of sizes of body parts with temperature were between -0.68 and -0.73 with values of coefficient of determination $R^2 > 0.46$. The correlation value of hair length with temperature was $r = -0.70$. Wing angles were not significantly correlated with temperature. The summaries of regression analyses for each phenotypic character versus temperature are shown in Table 6.

In the case of rainfall, relatively strong negative correlations were observed only for characters related to pigmentation and hair length. The correlation values for characters like scutellum pigmentation (35), pigmentation tergite 2 (32), 3 (33) and 4 (34) were between -0.55 and -0.57, and that of hair was 0.35. The correlation values for sizes of body parts and wing angles with rainfall were not significant. The summaries of correlation values of phenotypic characters versus rainfall are shown in Table 7.

Table 6 Summaries of simple regression analyses of the temperature of sampling localities versus each phenotypic character from colony mean data.

Characters	r	t values	P-levels
Scutellum pigmentation (35)	0.76	14.55	< 0.0001*
Scutellar plate pigmentation (36)	0.33	4.39	< 0.0001*
Hair length on tergite 5 (1)	- 0.70	-12.09	< 0.0001*
Pigmentation on tergite 2 (32)	0.79	15.92	< 0.0001*
Pigmentation on tergite 3 (33)	0.79	15.83	< 0.0001*
Pigmentation on tergite 4 (34)	0.79	15.72	< 0.0001*
Tergite 3 longitudinal (9)	- 0.68	-1.37	< 0.0001*
Tergite 4 longitudinal (10)	- 0.68	-11.44	< 0.0001*
Sternite 3 longitudinal (11)	- 0.73	-13.36	< 0.0001*
Wax plate transversal (13)	- 0.70	-12.13	< 0.0001*
Wing angle B4 (22)	0.06	0.73	= 0.4633
Wing angle N23 (30)	- 0.11	-1.39	= 0.1668
Wing angle O26 (31)	- 0.08	- 0.96	= 0.3400

* Correlations are significant at P < 0.0125 as determined by Bonferroni's adjustment to the level of significance for multiple testing.

Table 7 Summaries of simple regression analysis of the amount of rainfall at sampling localities versus each phenotypic character from colony mean data.

Characters	r	t values	P-levels
Scutellum pigmentation (35)	- 0.55	- 8.19	< 0.0001*
Scutellar plate pigmentation (36)	- 0.28	-3.55	= 0.0005*
Hair length on tergite 5 (1)	0.35	4.66	< 0.0001*
Pigmentation on tergite 2 (32)	- 0.56	- 8.43	< 0.0001*
Pigmentation on tergite 3 (33)	- 0.56	- 8.39	< 0.0001*
Pigmentation on tergite 4 (34)	- 0.57	- 8.64	< 0.0001*
Tergite 3 longitudinal (9)	0.00	0.06	= 0.9549
Tergite 4 longitudinal (10)	0.02	0.27	= 0.7856
Sternite 3 longitudinal (11)	0.10	1.28	= 0.2016
Wax plate transversal (13)	0.09	1.07	= 0.2849
Wing angle B4 (22)	- 0.12	-1.51	= 0.1319
Wing angle N23 (30)	0.12	1.52	= 0.1318
Wing angle O26 (31)	0.05	0.61	= 0.5428

* Correlations are significant at $P < 0.0125$ as determined by Bonferroni's adjustment to the level of significance for multiple testing.

According to this analysis, correlations between phenotypic characters versus latitude were not as strong as those of altitude and temperature. Relatively strong positive correlations were observed only for characters related to pigmentation such as scutellum pigmentation (35) and pigmentation of tergites 2 (32), 3 (33) and 4 (34). The correlation values of these characters ranged between 0.38 – 0.46. In the case of sizes of body parts, even if the trends of correlations were positive, the values of (r) were not significant except in the case of tergite 4 longitudinal (10). The summaries of regression analyses are shown in Table 8.

The variation in longitude does not reflect changing environmental conditions, as do variations across latitude. As a result of absence of environmental variation across longitude, it has no significant influences on phenotypic and behavioural characters. So longitude has been omitted from regression analyses in both phenotypic and behavioural characters.

Table 8 Summaries of regression analyses of each phenotypic character versus latitude of the sampling localities.

Characters	r	t values	P-levels
Scutellum pigmentation (35)	0.38	5.02	< 0.0001*
Scutellar plate pigmentation (36)	0.10	1.23	= 0.2221
Hair length on tergite 5 (1)	- 0.27	- 3.45	= 0.0007*
Pigmentation on tergite 2 (32)	0.46	6.4	< 0.0001*
Pigmentation on tergite 3 (33)	0.46	6.48	< 0.0001*
Pigmentation on tergite 4 (34)	0.38	5.14	< 0.0001*
Tergite 3 longitudinal (9)	0.13	1.67	= 0.0963
Tergite 4 longitudinal (10)	0.22	2.70	= 0.0069*
Sternite 3 longitudinal (11)	0.10	1.26	= 0.2083
Wax plate transversal (13)	0.08	0.98	= 0.3291
Wing angle B4 (22)	0.11	1.41	= 0.1597
Wing angle N23 (30)	- 0.02	- 0.25	= 0.8028
Wing angle O26 (31)	- 0.17	- 2.14	= 0.3428

* Correlations are significant at $P < 0.0125$ as determined by Bonferroni's adjustment to the level of significance for multiple testing.

4.1.2 Multivariate analysis results

4.1.2.1 Principal components analysis

The principal components analysis of morphometric characters of 155 colony means data was used to detect the presence of possible cluster groups of colonies. According to this analysis three factors with eigenvalues greater than 1 were extracted. The cumulative eigenvalue of these factors was 9.70. Factor 1 had the highest eigenvalue of 6.64 followed by factors 2 and 3 with eigenvalues of 1.94 and 1.11 respectively. Except for the three wing angles, scutellar plate pigmentation (36) and hair length (1) which had low absolute value of factor loadings between 0.56 – 0.64, the remaining characters had absolute values of factor loading between 0.87 – 0.95.

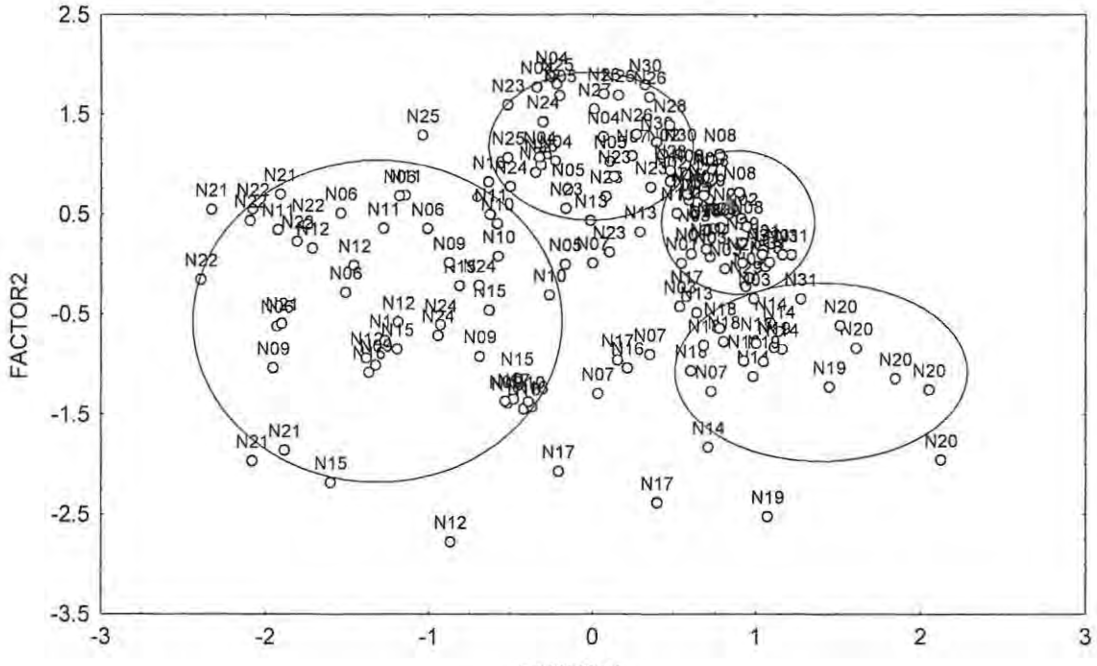
Based on varimax rotation factor loadings analysis, characters such as scutellum pigmentation (35), pigmentation of tergite 2 (32), pigmentation of tergite 3 (33) pigmentation of tergite 4 (34) and hair length on tergite 5 (1) had high loading values in factor 1 and 51.09% of the variance in the data is attributed to this factor. While all characters related to sizes of body parts such as tergite 3 longitudinal (9), tergite 4 longitudinal (10), sternite 3 longitudinal (11) and wax plate transversal (13) had high loading values in factor 2, this accounted for 14.94% of the variance in the data. All three wing angles had high loading values in factor 3 and accounted for only 8.56% of the variance in the data. Generally these three factors accounted for 74.59% of the variance in the data. The values of factor loading of each character in the respective group of extracted factors are shown in Table 9.

Table 9 Factor loadings in varimax rotation for each character in the principal components analysis.

Characters	Factor 1	Factor 2	Factor 3
Scutellum pigmentations (35)	0.94	- 0.28	0.04
Scutellar plate pigmentations (36)	0.56	- 0.16	0.13
Hair length on tergite 5 (1)	- 0.64	0.49	- 0.15
Pigmentation tergite 2 (32)	0.95	- 0.24	0.03
Pigmentation tergite 3 (33)	0.95	- 0.24	0.04
Pigmentation tergite 4(34)	0.93	- 0.26	0.05
Tergite 3 longitudinal (9)	- 0.25	0.93	- 0.02
Tergite 4 longitudinal (10)	- 0.22	0.93	- 0.03
Sternite 3 longitudinal (11)	- 0.34	0.90	0.02
Wax plate transversal (13)	- 0.30	0.87	0.00
Wing angle B4 (22)	0.11	0.13	0.63
Wing angle N23 (30)	0.01	0.26	- 0.63
Wing angle O26 (31)	- 0.17	- 0.08	- 0.59
Explained Variance	4.61	3.90	1.19
Proportion total variance	0.36	0.30	0.09

The scatterplot graph of factor scores of factor 1 and 2 of the principal components analysis of 155 colony means of all morphometric characters revealed the presence of four possible groups of clusters of colonies (Figure 2). In addition to this, the principal components analysis was carried out excluding the data for the three wing angles. In this case only two factors with eigenvalues greater than one were obtained. However the groups of colony clusters obtained in this analysis were more or less the same as that of groups of clusters obtained using all morphometric characters.

Figure 2 Scatterplot graph of factor scores of factor 1 and factor 2 from principal components analysis of 155 colony means of all morphometric data (numbers with N in the scatterplot graph indicate the locality code).



Again all characters except pigmentation characters were used in the principal components analysis. In this case two factors with eigenvalues greater than 1 were also extracted. Since the scatterplot graph of these two factor scores were mainly based on the variation of body size only, reasonably distinct clusters were not observed. The scatterplot graph showed only horizontal gradation according to body size variability. In this scatterplot graph light coloured bees from the arid lowland areas and dark bees from the wet mid-altitude areas fell in the same region of the scores plotted on the plane.

Based on the first two principal components factor scores of all characters, the relative position of each colony in the scores plotted on the plane (Figure 2) was sorted out. Accordingly, out of 155 colonies from 31 localities, 140 colonies from 28 localities were reasonably separated into the four morphoclusters. Based on this analysis, honeybees from the eastern lowland arid areas of the Afar plain such as Gewane and Melkasedi and also honeybees from the sub-moist and semi-arid lowland areas of the northwestern parts of the study areas such as Shiraro, Humera, Angereb, Wohni, Aykel, Manbuk and Menge fell into cluster 1 in the extreme left-hand quadrant of the plot (Figure 2). Except for the locality Aykel, the altitude range of these areas is 587 m – 1230 m above sea level.

These bees are generally yellow and small in size. In this morphocluster the percentages of yellow bees varied from 61.5% at Aykel at an altitude of 2230 m above sea level to 100% yellow at Gewane with an altitude of 587 m above sea level. The total cluster mean percentage of yellow bees was 80.9% (Table 10). In this group very yellow worker bees up to abdominal tergite 4 (34) and yellow drones were observed from sampling a locality such as Gewane.

Honeybees from wet, mid-altitude western parts of the study area such as Bambasi, Nejo, Dedessa, Hinde and Bir Sheleko formed the second cluster group, upper-most middle quadrant of the plot (Figure 2). Except for the locality Hinde, the altitude range of these localities is between 1320 m – 1890 m above sea level. These bees are generally, slightly larger in size but darker in colour than those in cluster 1. In this cluster the percentage of yellow bees was relatively low, and varied from 5% at Dedessa to 33.5% at Bambasi. The total mean percentage of yellow bees in the cluster was 17.2% (Table 10).

Honeybee colonies from mild to cool, sub-moist highland plains, mountains and the plateau of the central and western highland areas like Nekemte, Shambu, Gedo, Sendafa, Deneba, Salayish, Feres Bet (Dega Damot), Dangla and Debre Tabor fell in the third cluster group, the right-hand middle quadrant of the plot in figure 2. The altitude range of these areas is between 2000 m – 3000 m above sea level. These bees are darker in colour and generally larger in size than those bees from cluster 2. In this cluster, except the locality Dangla with 40.5% yellow bees, the remaining localities were darker in colour. The percentages of yellow bees for other localities varied from 0% to 10.5%. The total percentage of black bees in this cluster was 93.8% (Table 10).

Honeybee samples from very cold, moist to sub-moist and very high mountainous areas of the northern region including Guguftu, Woldeya (Woko), Korem (Ashenge), Debark (Milligebsa) formed the fourth cluster group, lower most right-hand quadrant (Figure 2). The altitude range of these areas is between 2400 m – 3600 m above sea level. These bees are very large and dark in colour and are also covered with long and dense hairs. In cluster 4 the percentages of black bees varied from 86.5% at Woldeya (Woko) to 100% black at Guguftu. The total percentage of black bees was 92.9% (Table 10). Colonies from localities such as Dabat, Abi Adi and Mekele were very variable in size and also in colour and appeared in different clusters. Most colonies from these localities either did not fall in any of the clusters or they formed a separate cluster.

Table 10 The colour percentage distribution of bees by locality and by clusters based on abdominal tergite 2 (32) pigmentation.

Clusters	Localities	Altitudes (m) a.s.l.	No. of Yellow bees	% of Yellow bees	No. of Black bees	% of Black bees
Cluster 1	Angereb	910	162	81.0	38	19.0
	Aykel	2230	123	61.5	77	38.5
	Humera	600	195	97.5	5	2.5
	Manbuk	1230	149	74.5	51	25.5
	Melkasedi	770	160	80.0	40	20.0
	Gewane	587	200	100.0	0	0.0
	Shiraro	1100	170	85.0	30	15.0
	Menge	1000	153	76.5	47	23.5
	Wohni	1000	145	72.5	55	27.5
	Cluster total		1457	80.9	343	19.1
Cluster 2	Bambasi	1460	67	33.5	133	66.5
	Bir Sheleko	1545	31	15.5	169	84.5
	Dedessa	1320	10	5.0	190	95.0
	Hinde	2195	27	13.5	173	86.5
	Nejo	1890	37	18.5	163	81.5
	Cluster total		172	17.2	828	82.8

Continuation of Table 10.

Clusters	Localities	Altitudes (m) a.s.l.	No. of Yellow bees	% of Yellow bees	No. of Black bees	% of Black bees
Cluster 3	Dangla	2060	81	40.5	119	59.5
	Deneba	2670	0	0.0	200	100.0
	Gedo	2517	21	10.5	179	89.5
	Inchini	2650	1	0.5	199	99.5
	Nekemte	2166	10	5.0	190	95.0
	Feres Bet	3000	5	2.5	195	97.5
	Sendafa	2500	1	0.5	199	99.5
	Shambu	2570	5	2.5	195	97.5
	Debre Tabor	2650	1	0.5	199	99.5
	Salayish	2248	0	0.0	200	100.0
	Cluster total		125	6.3	1875	93.8
Cluster 4	Debark	3000	16	8.0	184	92.0
	Korem	2600	27	13.5	173	86.5
	Woldeya	2400	14	7.0	186	93.0
	Guguftu	3600	0	0.0	200	100.0
	Cluster total		57	7.1	743	92.9
Not in any cluster	Mekele	2025	107	53.5	93	46.5
	Dabat	2656	38	19.0	162	81.0
	Abi Adi	1800	143	71.5	57	28.5
	Total		288	48.0	312	52.0

4.1.2.2 Discriminant analysis

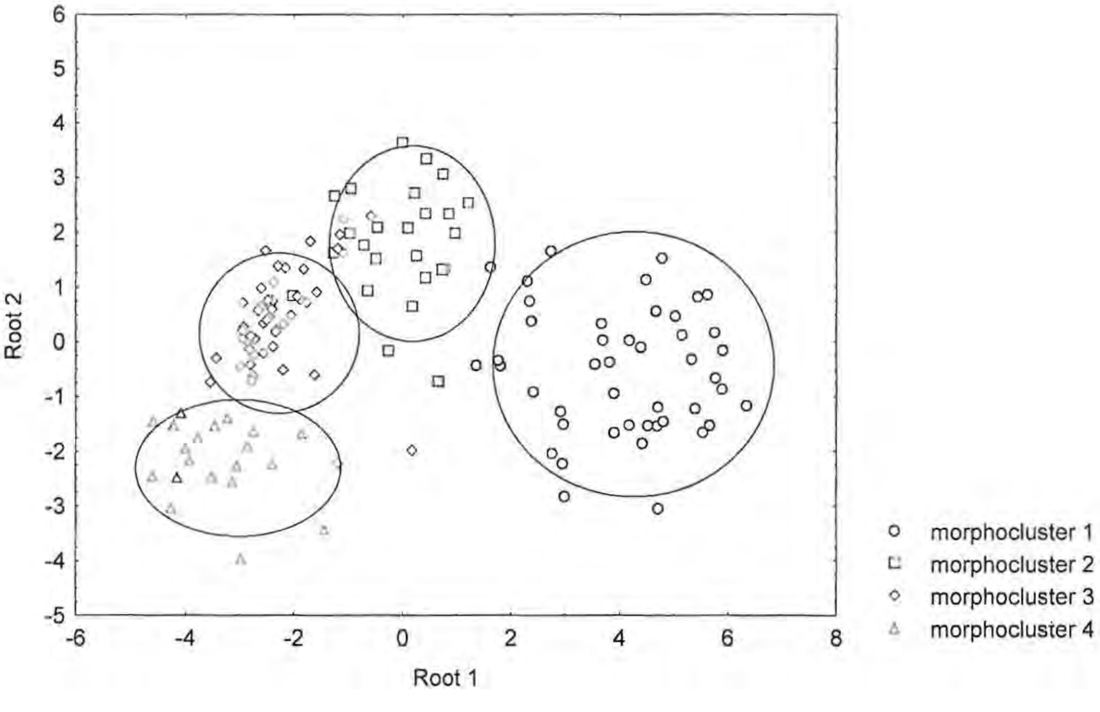
The cluster groups observed in the principal components analysis were further tested in step-wise discriminant analyses. In this case the colony means data were also used. According to the step-wise discriminant analysis the following characters: pigmentation of tergite 2 (32), sternite 3 longitudinal (11), pigmentation of tergite 4 (34), tergite 4 longitudinal (10) and tergite 3 longitudinal (9) had high discriminatory powers, while the remaining characters had less discriminatory power. Based on this analysis, pigmentation of tergite 2 (32) and sternite 3 longitudinal (11) had strong discriminatory powers. Characters according to their discriminatory powers, with their respective F values and P-levels are shown in Table 11.

Table 11 Morphological characters in the discriminant functions according to their discriminatory powers.

Characters	df	F statistic	P-level
Pigmentation of tergite 2 (32)	3,136	251.80	< 0.0001
Sternite 3 longitudinal (11)	3,135	77.33	< 0.0001
Pigmentation tergite 4 (34)	3,134	5.87	= 0.0008
Tergite 3 longitudinal (9)	3,132	5.04	= 0.0024
Tergite 4 longitudinal (10)	3,133	4.39	= 0.0056

The discriminant analysis of the colony means data also confirmed the presence of four morphoculsters of colonies (Figure 3). In the analysis each colony was assumed to have equal a priori probability of being in any particular cluster. Based on this analysis, out of 45 colonies grouped in cluster 1, 44 of them or 97.78% were correctly classified in cluster 1. The remaining one colony from Menge was classified in cluster 2. Out of the 44 correctly classified colonies, 37 had posterior probabilities of 1.00 for being in cluster 1. Five colonies had posterior probabilities between 0.73 – 0.92 and the remaining 2 colonies had low posterior probability of 0.54 – 0 .65 for being in this cluster.

Figure 3 Graph of cluster groups of 140 colonies based on step-wise discriminant analysis, (the sign, circle = cluster 1, square = cluster 2, rhombus = cluster 3 and triangle = cluster 4).



From 25 colonies grouped in cluster 2, 24 of them, or 96%, were correctly classified in cluster 2. The remaining one colony from Hinde was classified in cluster 3. In this cluster, out of the 24 correctly classified colonies, 16 had posterior probabilities between 0.92 – 1.00 of being in cluster 2 and 4 colonies between 0.80 – 0.83 while the remaining 4 colonies had low posterior probabilities between 0.56 – 0.75 of being in cluster 2.

Out of the 50 colonies grouped in cluster 3, 48 of them or 96 % of them were correctly classified in cluster 3. The remaining two colonies (one from Nekemte and one from Shambu) were predicted to be in cluster 2. Out of the 48 colonies correctly classified in cluster 3, 40 had posteriori probabilities of 0.90 – 1.00 being in cluster 3, and 7 colonies were between 0 .72 – 0.89, and the remaining one colony had low a posteriori probability of 0.59 of being in cluster 3.

In cluster 4, out of 20 colonies grouped in this cluster, 19 of them or 95% were correctly classified. The remaining one colony from Korem was predicted in cluster 3. From 19 colonies classified in this cluster, 15 had posteriori probabilities of 0.92 – 1.00, and the remaining 4 colonies were found with posteriori probabilities between 0.63 and 0.81 being in cluster 4. Generally, out of 140 colonies entered into the step-wise discriminant analysis 135 or 96.43% of the colonies were correctly classified in four cluster groups. The classification matrix of cluster groups is shown in Table 12.

Table 12 Classification matrices of colonies in cluster groups based on step-wise discriminant analysis.

Clusters	Total No. of colonies	No. of colonies in Cluster 1	No. of colonies in Cluster 2	No. of colonies in Cluster 3	No. of colonies in Cluster 4	Percentage of classification
Cluster 1	45	44	1	0	0	97.78
Cluster 2	25	0	24	1	0	96.0
Cluster 3	50	0	2	48	0	96.0
Cluster 4	20	0	0	1	19	95.0
Total	140	44	27	50	19	96.43

Based on the step-wise discriminant analysis, higher Mahalanobis distances $D^2 = 60.79$ and $D^2 = 42.36$ were observed between clusters 1 and 4 and between clusters 1 and 3 respectively. The lower $D^2 = 9.21$ and $D^2 = 8.33$ were observed between clusters 4 and 3 and clusters 2 and 3 respectively. The Mahalanobis distances between different cluster groups are shown in Table 13.

Table 13 The Mahalanobis distances D^2 between cluster groups.

Clusters	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Cluster 1	0.00	23.72	42.36	60.79
Cluster 2	23.72	0.00	8.33	27.89
Cluster 3	42.36	8.33	0.00	9.21
Cluster 4	60.79	27.89	9.21	0.00

The separation of cluster groups was highly significant for all cluster groups. High separation of F values of 91.69 and 75.32 were obtained among clusters 4 and 1 and between clusters 3 and 1 respectively. Lower F values of 11.78 and 12.53 were observed between clusters 3 and 2 and between clusters 3 and 4 respectively. The F values with their corresponding P-levels for all cluster groups separation are shown in Table 14.

Table 14 F values and their corresponding P-levels of separation among cluster groups in the step-wise discriminant analysis.

Clusters	Cluster 1		Cluster 2		Cluster 3		Cluster 4	
	F	P-level	F	P-level	F	P-level	F	P-level
Cluster 1			34.40	< 0.0001	75.32	< 0.0001	91.69	< 0.0001
Cluster 2	34.40	< 0.0001			11.78	< 0.0001	27.62	< 0.0001
Cluster 3	75.32	< 0.0001	11.78	< 0.0001			12.53	< 0.0001
Cluster 4	91.69	< 0.0001	27.62	< 0.0001	12.53	< 0.0001		

The Wilks' lambda test also indicated that highly significant differences were found between the means of the four cluster groups, $\Lambda = 0.034$, $F = 26.511$ with (30, 373) df, $P < 0001$. The means and the standard deviations of each character for the four cluster groups are shown in Table 15.

Table 15 Clusters means and standard deviations (S.d.) of each character of 140 colonies from 28 localities (measurements are in mm and angles in degrees).

Characters	Cluster 1 n = 45		Cluster 2 n = 25		Cluster 3 n = 50		Cluster 4 n = 20	
	Mean	S.d.	Mean	S.d.	Mean	S.d.	Mean	S.d.
Scutellum pigmentation. (35)	4.03	1.25	1.05	0.59	0.47	0.57	0.73	0.58
Scutellar plate pigmentation (36)	1.35	1.22	0.81	0.76	0.37	0.51	0.63	0.81
Hair length (1)	0.18	0.02	0.20	0.02	0.22	0.02	0.23	0.03
Pigmentation tergite 2 (32)	6.64	1.74	1.28	0.85	0.33	0.85	0.74	1.04
Pigmentation tergite 3 (33)	6.66	1.69	1.28	0.86	0.38	0.95	0.77	1.10
Pigmentation tergite 4 (34)	5.05	1.80	0.92	0.90	0.24	0.63	0.46	0.73
Tergite 3 longitudinal (9)	2.02	0.04	2.02	0.03	2.10	0.04	2.17	0.04
Tergite 4 longitudinal (10)	1.96	0.05	1.97	0.03	2.03	0.04	2.12	0.04
Tergite (3 + 4) longitudinal	3.98	0.09	3.99	0.06	4.13	0.08	4.29	0.06
Sternite 3 longitudinal (11)	2.50	0.05	2.51	0.04	2.61	0.04	2.70	0.03
Wax plate transversal (13)	2.07	0.06	2.09	0.03	2.17	0.04	2.23	0.06
Wing angle B4 (22)	105.25	3.45	104.47	3.05	104.60	3.01	105.20	2.30
Wing angle N23 (30)	89.58	2.13	90.26	1.73	89.79	2.37	90.35	2.31
Wing angle O26 (31)	37.26	2.06	37.63	1.70	37.90	1.52	37.72	1.66

Generally, the mean and standard deviation values of characters related to pigmentation such as scutellum pigmentation (35), scutellar plate pigmentation (36), pigmentation of tergite 2 (32), 3 (33), and 4 (34) were much higher for cluster 1 than the rest of the clusters. The variations in the intensity of pigmentation among clusters 2, 3 and 4 were relatively low. The lowest mean values were recorded for cluster 3 in all characters related to pigmentation (Figures 4 - 8).

In terms of hair length on tergite 5 (1) distinct variations were observed across all cluster groups (Figure 9). The shortest and the longest hair lengths were observed for cluster 1 and 4 with mean values 0.18 ± 0.02 and 0.23 ± 0.03 respectively. The means and standard deviation values of hair length for clusters 2 and 3 were 0.20 ± 0.02, and 0.22 ± 0.02 respectively.

Figure 4 Boxplot graph of scutellum pigmentation (35) for cluster groups.

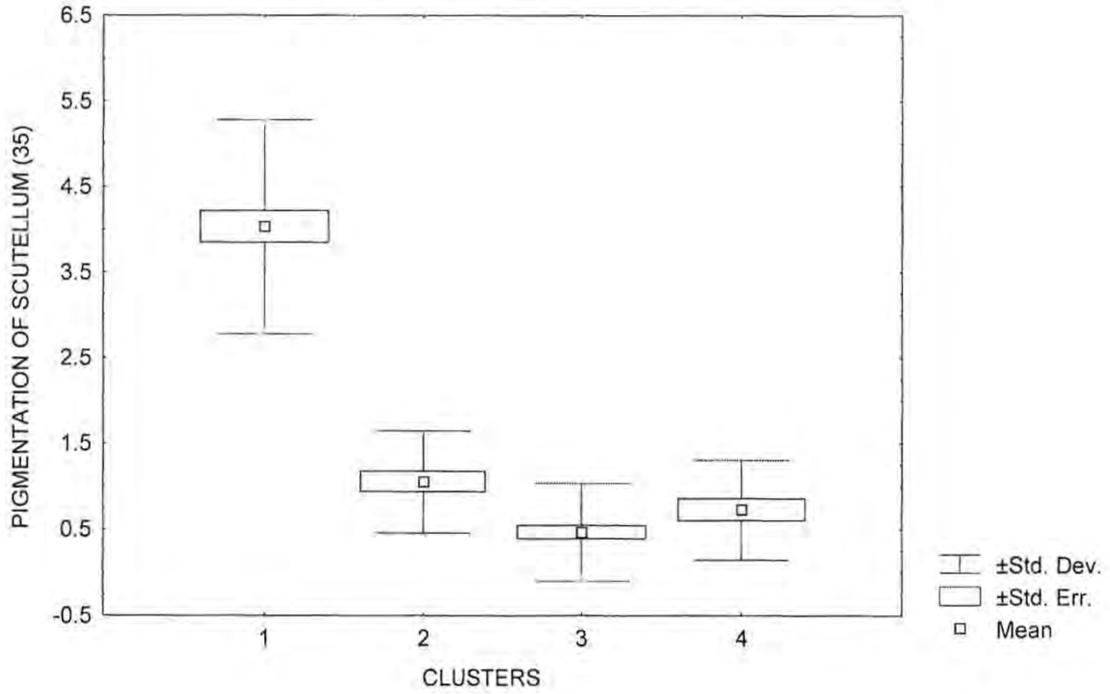


Figure 5 Boxplot graph of scutellar plate pigmentation (36) for cluster groups.

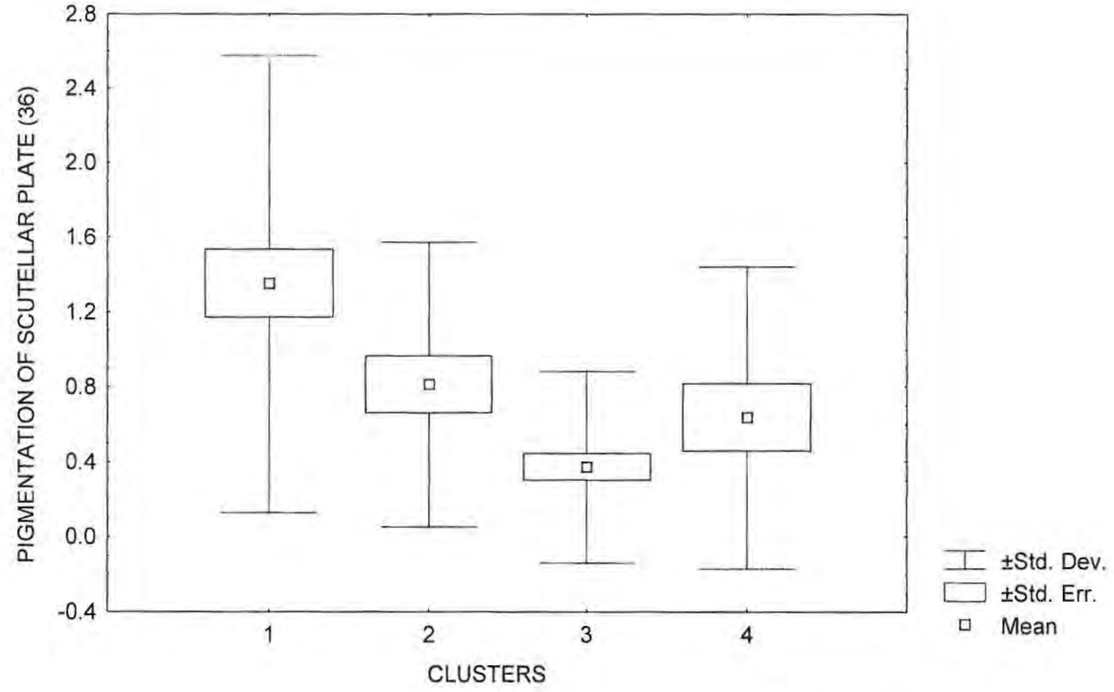


Figure 6 Boxplot graph of pigmentation of tergite 2 (32) for cluster groups.

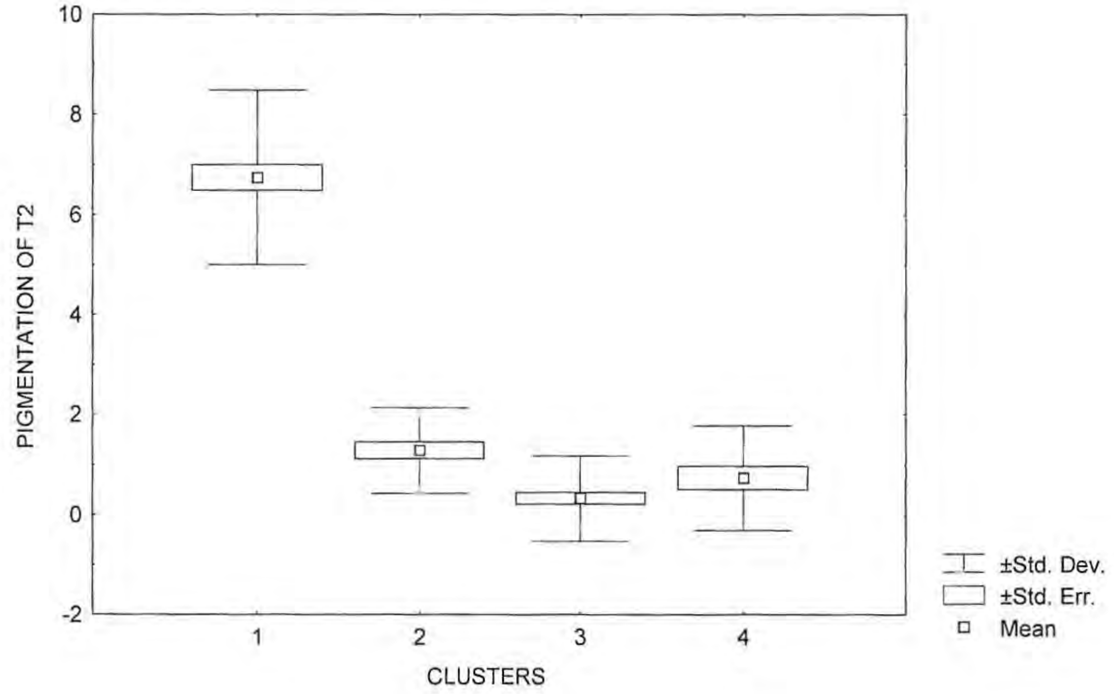


Figure 7 Boxplot graph pigmentation of tergite 3 (33) for cluster groups.

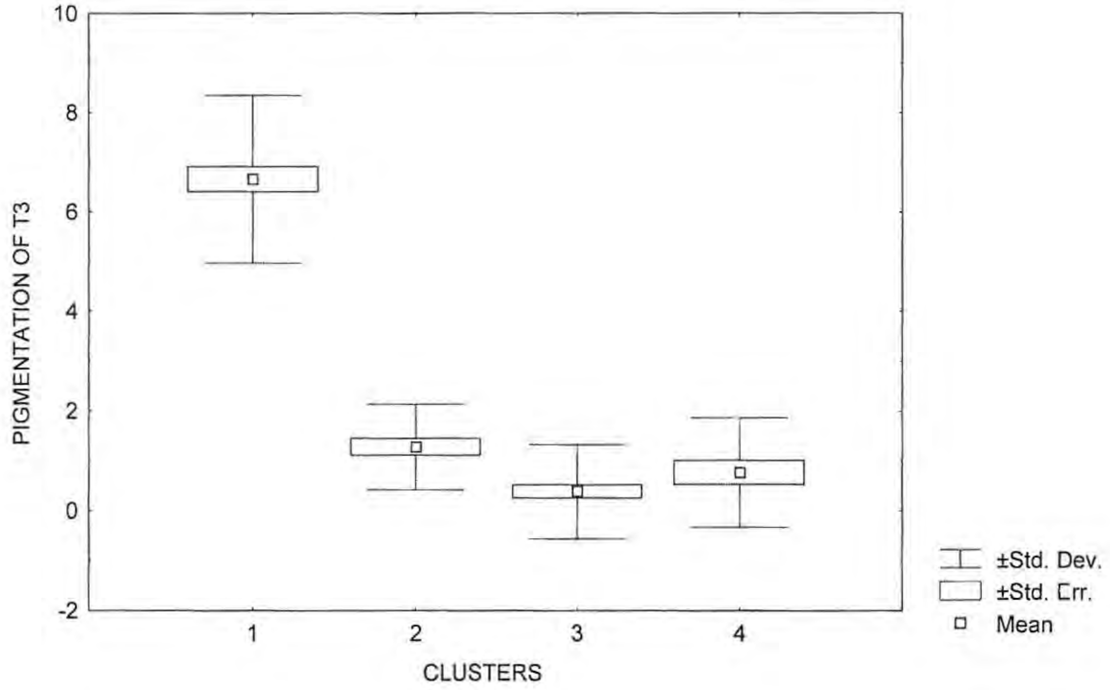
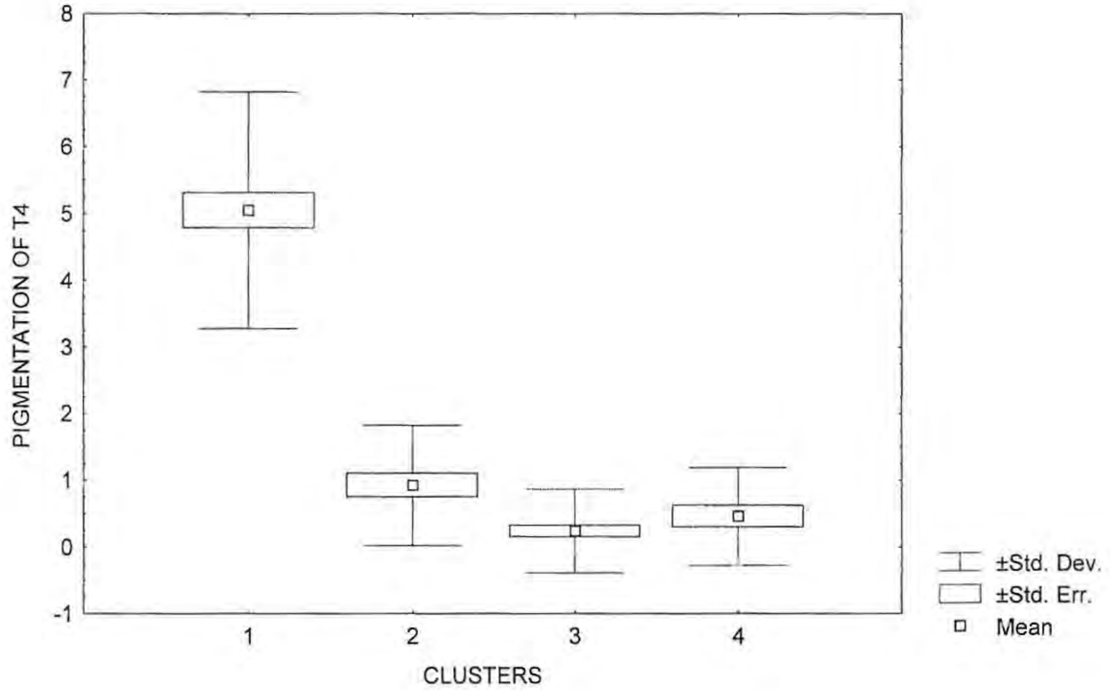
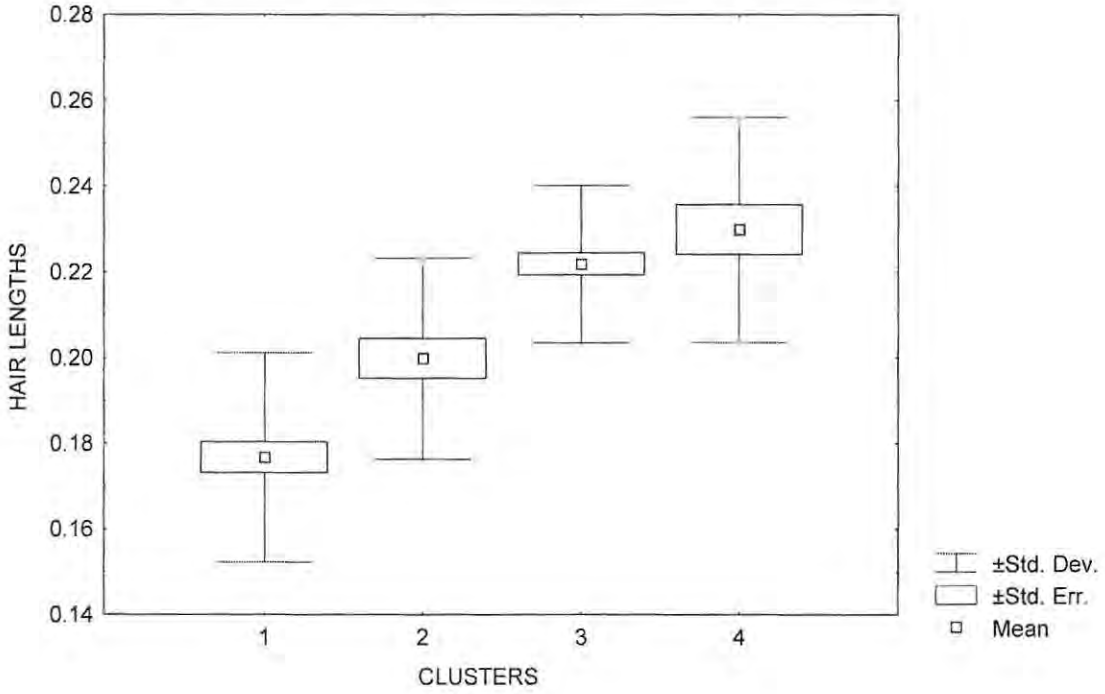


Figure 8 Boxplot graph of pigmentation of tergite 4 (34) for cluster groups.



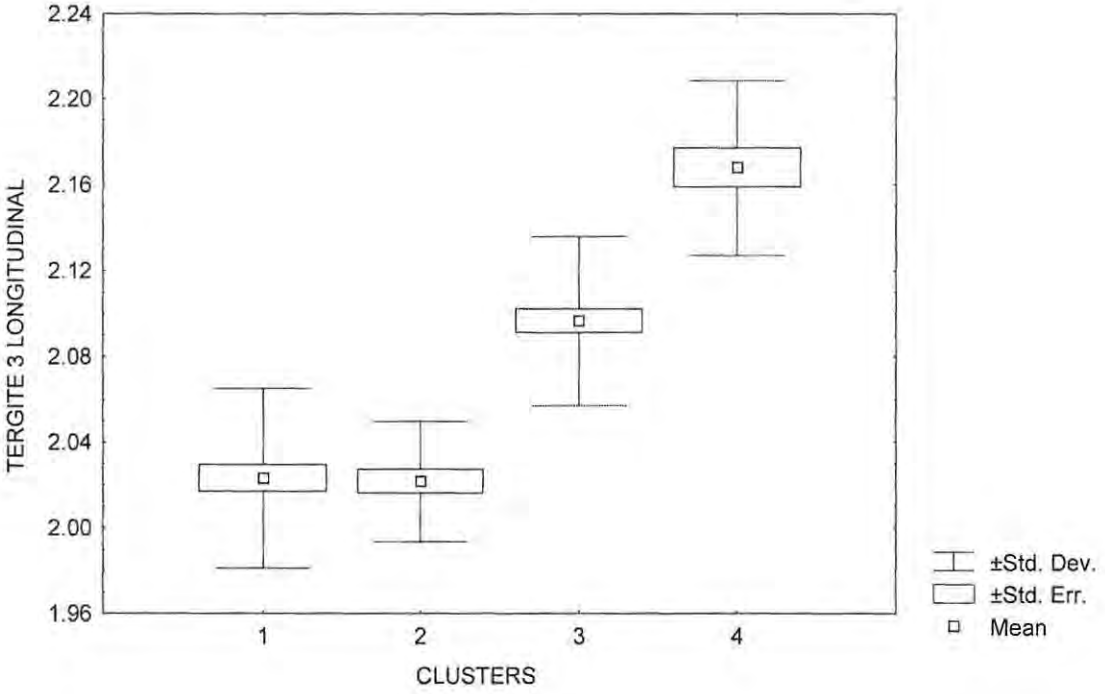
High variations were observed in mean values for all cluster groups for all characters related to sizes of body parts. However, the size variations between clusters 1 and 2 were relatively low compared to the variations among the other cluster groups (Figures 10 – 14). In the tergite 3 longitudinal (9) the same mean value of 2.02 was obtained for cluster 1 and cluster 2 with standard deviation values of 0.04 and 0.03 respectively. The variations in mean values of this character were relatively large among the other cluster groups (Figure 10).

Figure 9 Boxplot graph of hair length on tergite 5 (1) for the cluster groups.



In the case of tergite 4 longitudinal (10) large mean value variations were observed among all cluster groups (Figure 11). The sum of tergite 3 (9) and tergite 4 (10) longitudinal ($T_3 + T_4$) values were used to observe the cumulative size variations among cluster groups. Relatively close size values of 3.98 ± 0.09 and 3.99 ± 0.06 were obtained for clusters 1 and 2 respectively. Relatively high $T_3 + T_4$ values of 4.12 ± 0.08 and 4.28 ± 0.06 were obtained for clusters 3 and 4 respectively. The graph of mean values of $T_3 + T_4$ (Figure 12) indicates the existence of large size variations among clusters except for clusters 1 and 2.

Figure 10 Boxplot graph of tergite 3 longitudinal (9) for cluster groups.



In sternite 3 longitudinal (11) relatively low mean values of 2.50 ± 0.05 and 2.51 ± 0.04 were recorded for clusters 1 and 2 respectively and high mean values of 2.61 ± 0.04 and

2.70 ± 0.03 were obtained for clusters 3 and 4 respectively (Figure 13). The variations in the mean and standard deviation values of wax plate transversal (13) were high among the cluster groups 1, 2, 3 and 4 with values of 2.07 ± 0.06, 2.09 ± 0.03, 2.17 ± 0.04, 2.23 ± 0.06 respectively (Figure 14).

Generally, the overall mean values of characters related to pigmentation were very important in the separation of cluster 1 from the rest of clusters and characters related to body size were very strong in the separation among all cluster groups except for clusters 1 and 2. In the case of all three-wing angles the mean and standard deviations values did not strongly vary among the cluster groups (Figures 15-17).

Figure 11 Boxplot graph of tergite 4 longitudinal (10) for cluster groups.

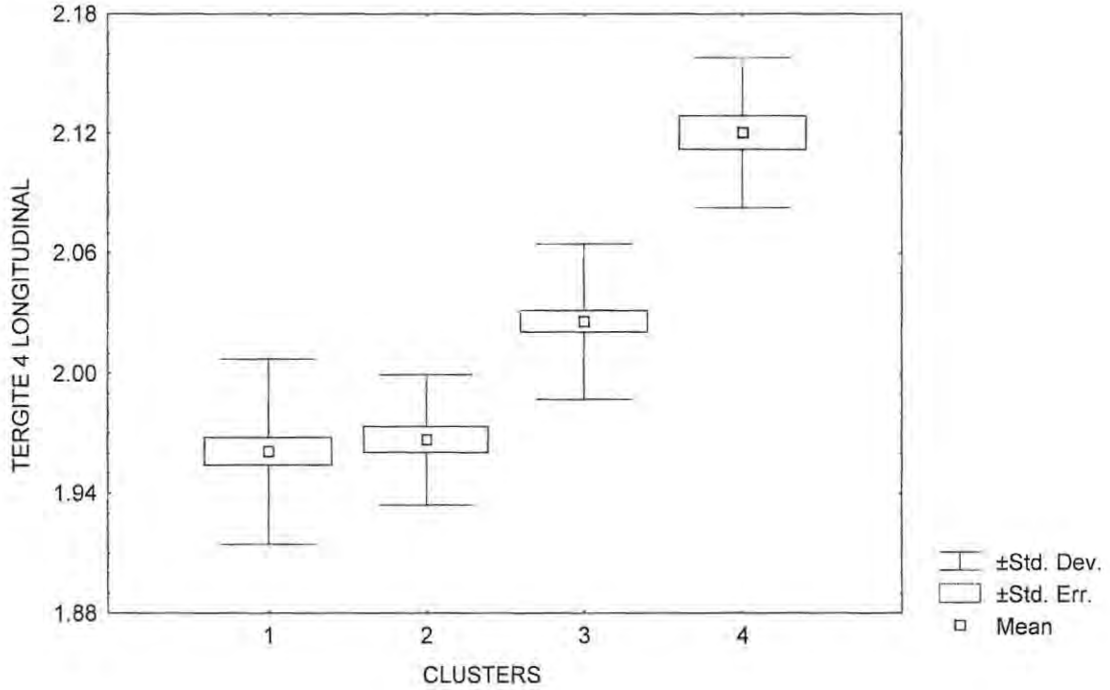


Figure 12 The cumulative means values of tergite 3 plus tergite 4 longitudinal.

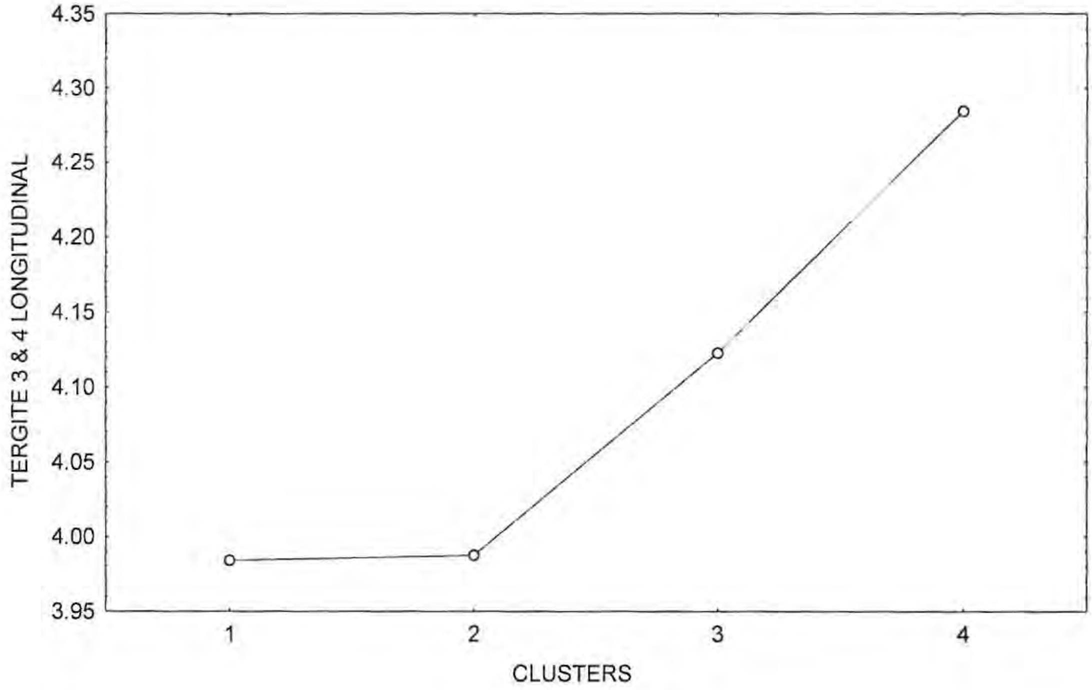


Figure 13 Boxplot graph of sternite 3 longitudinal (11) for the cluster groups.

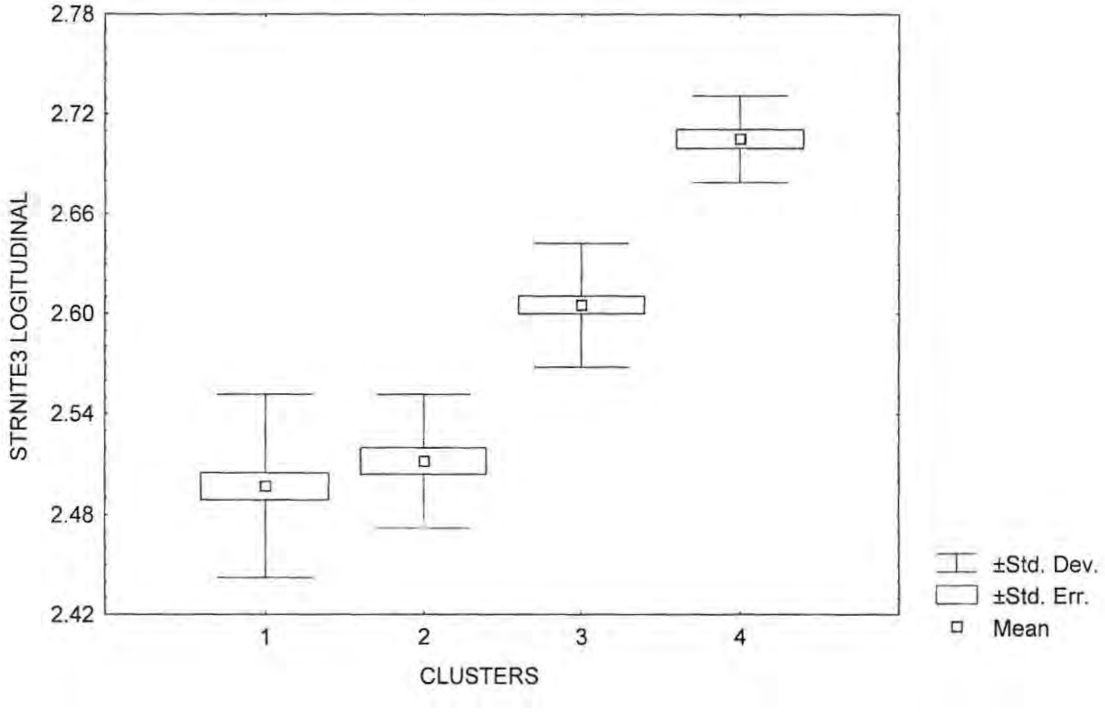


Figure 14 Boxplot graph of wax plate transversal (13) for cluster groups.

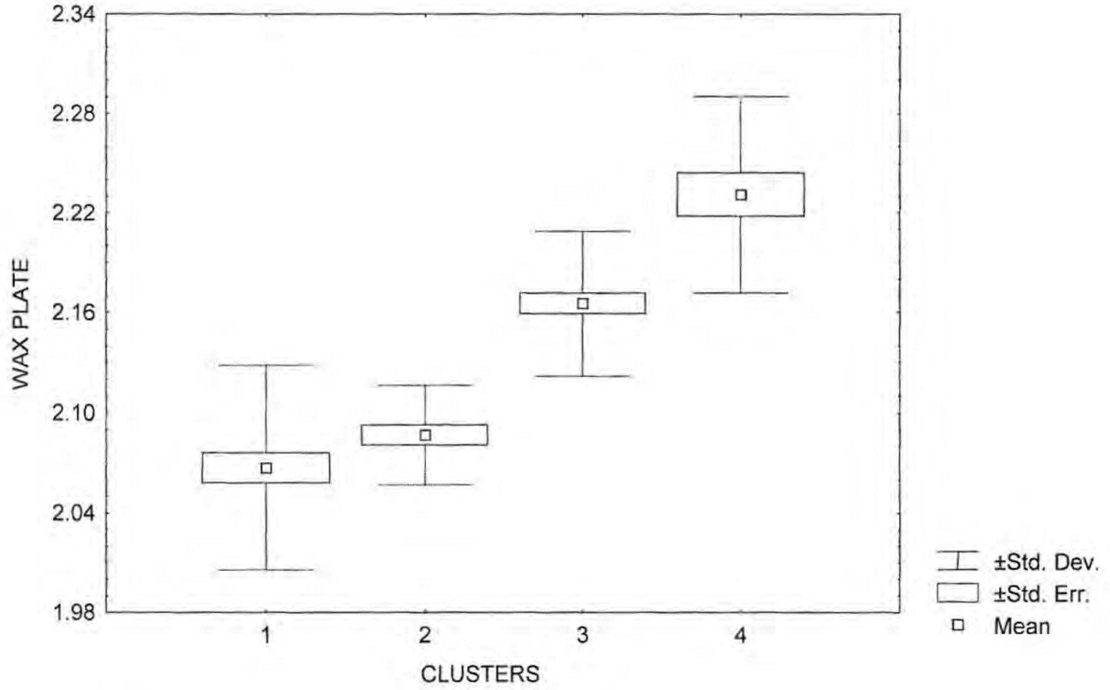


Figure 15 Boxplot graph of wing angle B4 (22) for cluster groups.

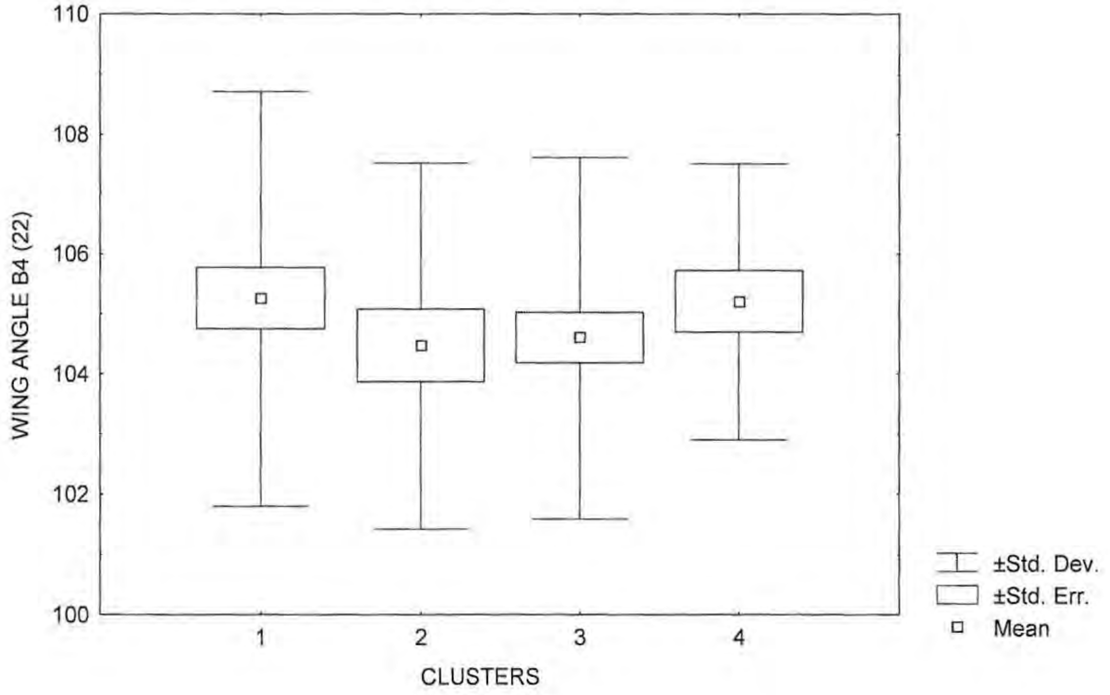


Figure 16 Boxplot graph of wing angle N23 (30) for cluster groups.

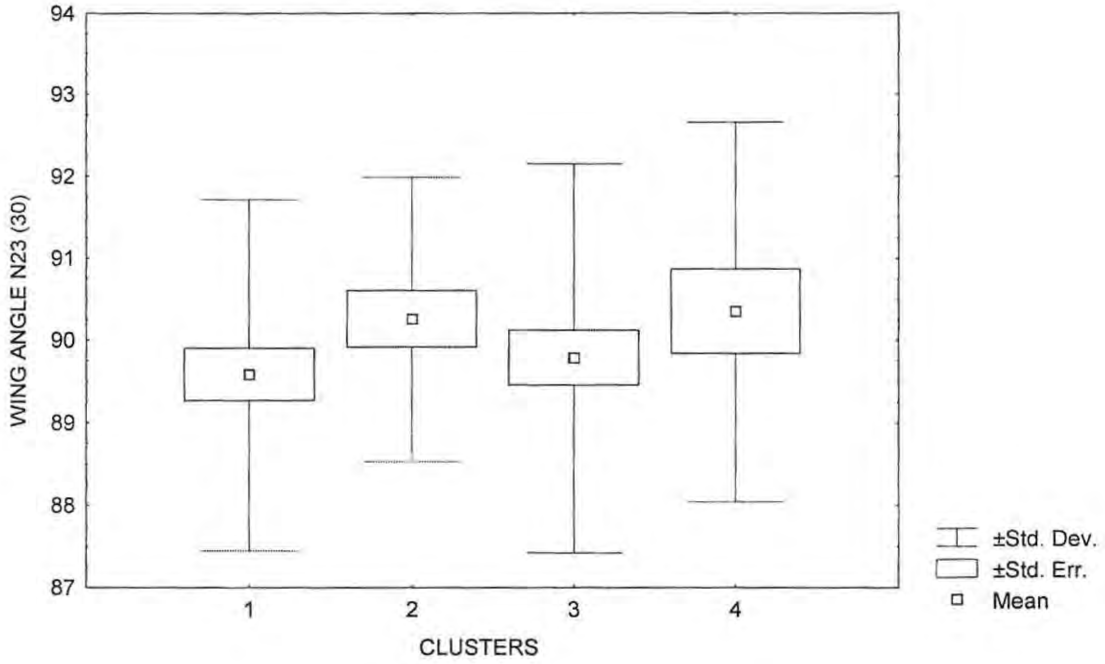
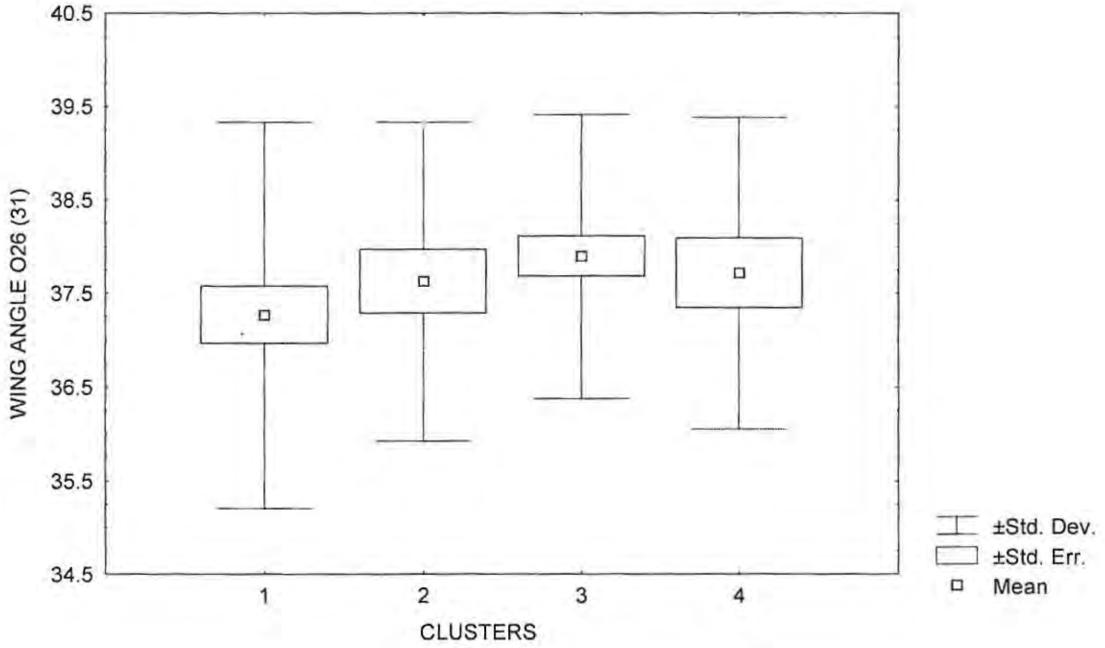


Figure 17 Boxplot graph of wing angle O26 (31) for cluster groups.



To check the discriminatory powers of the measured morphometric characters, the same colony means data were also entered into the standard discriminant analysis. In this analysis, except for the changing of ranks in discriminatory power, the very same five characters obtained in the step-wise discriminant analysis also had high discriminatory power. In the standard discriminant analysis 134 or 95.71% of 140 colonies used in the analysis were correctly classified in the same four cluster groups. The Mahalanobis distances D^2 between the cluster groups and the posteriori probability of each colony being in the cluster groups were found to be very close to the results obtained by step-wise discriminant analysis.

4.1.2.3 Intracolonial and intercolonial variances

The principal component coefficients of the morphometric characters from individual bee data were used to determine the factor scores of each bee from the unrotated factor 1 scores. The variance and standard deviation of these factor scores were analysed to determine the intracolonial variations at each locality. The variances of each of the factor scores were also used to test the homogeneity of the variances at each locality. Accordingly, highly significant differences were obtained among the intracolonial variances across all localities (Levene's test, $F = 25.29$ with (30, 3069) df, $P < 0.0001$).

For the determination of intercolonial variances, the same procedure was applied, but in this case the principal component coefficient factor scores were obtained from the colony means data. In this case significant differences were also obtained between colonies at 5% level of significance ($F = 1.61$ with (30,124) df, $P = 0.0381$). Generally, high intracolonial variances were observed in all localities of which relatively high variances were obtained for Melkasedi (N22), Wohni (N09), Mekele (N17), Dangla (N07), Abi Adi (N16), Angereb (N11), Aykel (N10), Dabat (N13), Manbuk (N25), Bambasi (N25), Nejo (N23) Shiraro (N15) and Menge (N24) localities (Table 16).

Table 16 Intracolonial and intercolonial variances of unrotated factor 1 scores of the morphometric characters data at each locality.

Localities	Intracolonial	Intercolonial
Melkasedi	0.79	0.26
Wohni	0.78	0.57
Mekele	0.75	0.43
Dangla	0.75	0.29
Abi Adi	0.74	0.56
Angereb	0.72	0.46
Aykel	0.67	0.13
Manbuk	0.66	0.35
Dabat	0.66	0.38
Bambasi	0.61	0.33
Bir Shileko	0.49	0.16
Debark	0.38	0.18
Deneba	0.26	0.24

Continuation of Table 16

Localities	Intracolonial	Intercolonial
Gedo	0.32	0.09
Humera	0.42	0.31
Inchini	0.27	0.17
Korem	0.49	0.17
Nekemte	0.45	0.33
Feres Bet	0.30	0.17
Gewane	0.34	0.18
Shiraro	0.63	0.45
Woldeya	0.45	0.19
Dedessa	0.42	0.12
Hinde	0.59	0.32
Nejo	0.61	0.33
Sendafa	0.23	0.10
Shambu	0.30	0.14
Menge	0.58	0.27
Guguftu	0.30	0.26
Salayish	0.30	0.24
Debre Tabor	0.25	0.14

4.2 Behavioural characters

4.2.1 Reproductive swarming tendency

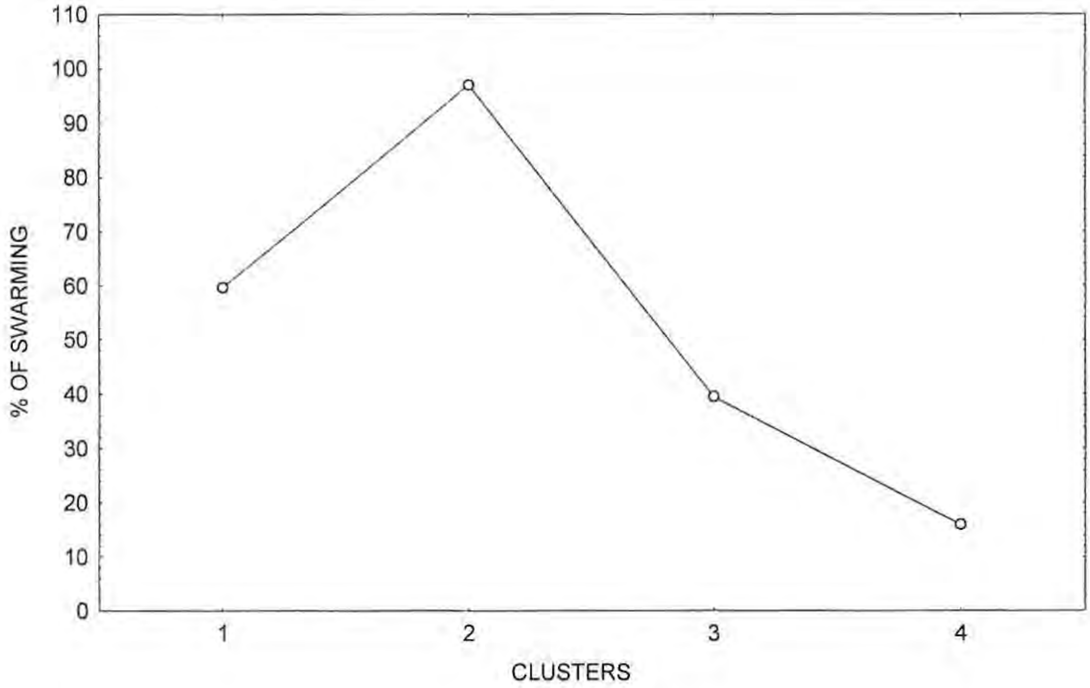
Reproductive swarming was reported in all localities of the study area. However, the extent of swarming, maximum number of swarms per colony, frequency of swarming, phase of swarming and period of swarming varied from place to place and also from cluster to cluster. The reproductive swarming periods and its extent by localities and clusters are shown in Table 17.

4.2.1.1 The extent of reproductive swarming

The extent of reproductive swarming was estimated from the percentage of colonies that underwent reproductive swarming in the period of 1999/2000. A high swarming rates of 85% to 100%, with mean of 97% of cases, was reported for honeybee populations in cluster 2, followed by cluster 1 with a swarming proportion of 33% to 85% with mean of 59.67%. Relatively low swarming proportions were reported in most localities where clusters 3 and 4 honeybee samples were collected. The proportions of reproductive swarming in clusters 3 and 4 were 17% to 75% with mean of 39.5% and 13% to 20% with mean of 16% respectively.

The assumptions of normality and homogeneity of the variance were not met (Kolmogorov Smirnov test = 0.13, $P < 0.05$ and Levene's test $P < 0.0001$) hence non-parametric (Kruskal-Wallis Anova) test was used. Accordingly, the proportions of swarmed colonies significantly varied from cluster to cluster, (Kruskal-Wallis test H (3, N=140) = 101.19, $P < 0.0001$). The pair-wise comparison of Mann-Whitney U test indicated that the proportions of swarming significantly ($P < 0.0001$) varied among all cluster groups with Bonferroni correction to the level of significance (i.e $\alpha/k = 0.05/6 = 0.0083$). The mean percentage of reproductive swarming by cluster groups is shown in Figure 18.

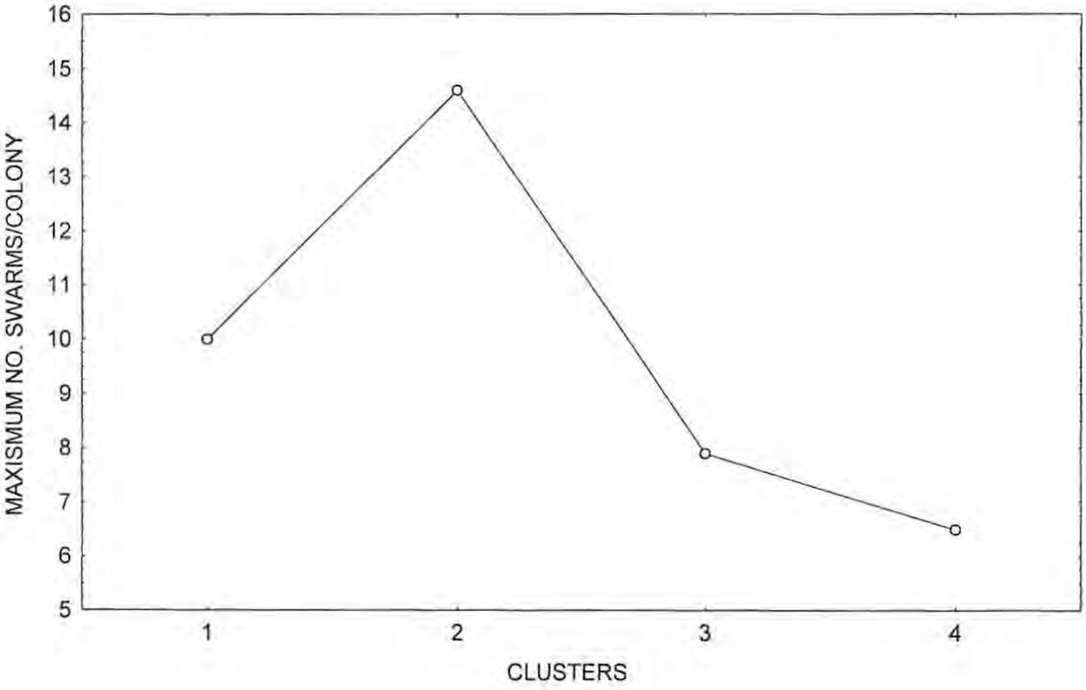
Figure 18 The mean percentage of swarming by cluster groups.



4.2.1.2 Maximum number of swarms per colony

The highest number of swarms per colony was reported for cluster 2, (13 – 16 with mean of 14.6 swarms per colony), followed by cluster 1, with 8 – 12 with a mean of 10 swarms per colony. Relatively low numbers of swarms per colony were reported for clusters 3 and 4, 5 – 10 with a mean of 7.9, and 6 – 8 with mean of 6.5 swarms per colony respectively. The data met the Anova assumptions (Kolmogorov Smirnov test = 0.0957, $P < 0.20$ and Levene's test = 0.0510) and the variation in the numbers of swarms per colony is significantly different (F (3,136 df) =186.49 with $P < 0.0001$) among cluster groups. The Tukey's HSD pair-wise test confirmed the presence of highly significant variations among all cluster groups ($P < 0.0001$) with Bonferroni correction to the level of significance $\alpha/k = 0.05/6 = 0.0083$. The mean of maximum number of swarms per colony for each cluster groups is shown in Figure 19. In Dangla, beekeepers reported that more than 4 queens would accompany a single reproductive swarm at a time.

Figure 19 The average maximum number of swarms per colony in different cluster groups.



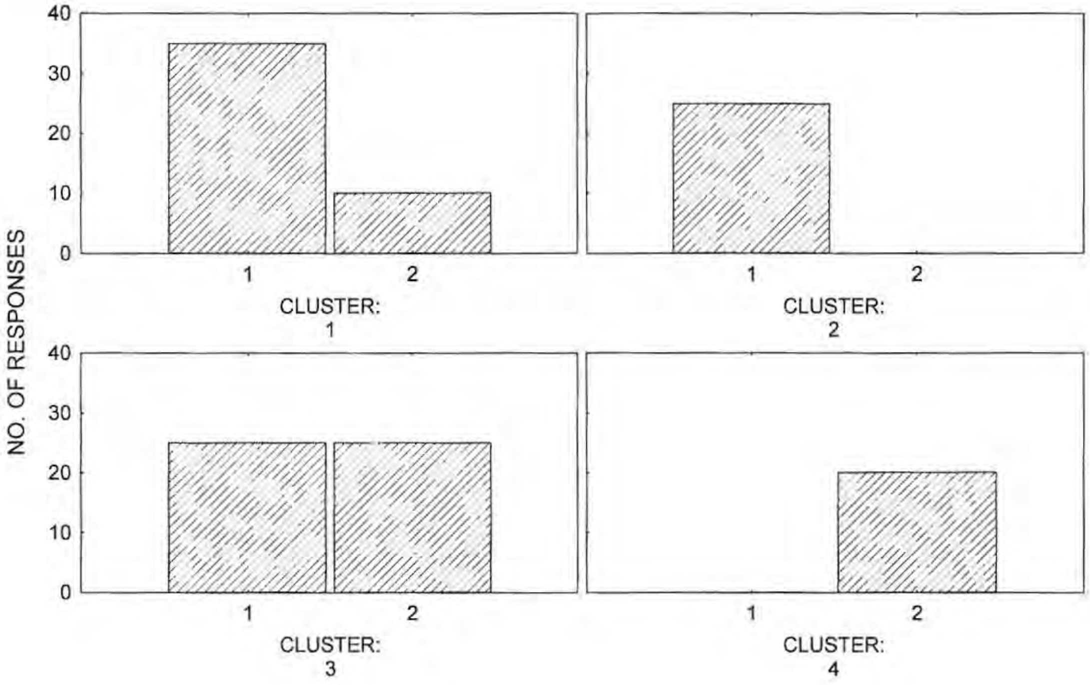
4.2.1.3 Frequency of swarming

The frequency of swarming was based on the occurrence of swarming every year or not, at that particular locality. According to beekeepers' reports, the frequency of swarming significantly varied from cluster to cluster (Pearson Chi-square with Yates' correction = 52.71 with 3 df, $P < 0.0001$).

In cluster 1, 77.8% of the reports indicated that swarming occurs every year, while 22.2% of the reports, from Gewane and Humera indicated swarming does not take place every year. In cluster 2, all the reports supported the occurrence of swarming every year in all localities where cluster 2 colonies were sampled. In cluster 3, 50.0% of the reports indicated the occurrence of swarming every year while the remaining reports from Deneba, Inchini, Sendafa, Debre Tabor and Salayish did not support the occurrence of swarming every year. In cluster 4 in all cases the reports indicated that swarming does not take place every year. The frequency of swarming by cluster is shown in Figure 20.

According to the beekeepers' reports, in many sampling localities where clusters 3 and 4 honeybee samples were collected, the occurrence of swarming varied from every year to every 2 to 5 years, depending on the optimum conditions of raining and subsequent flowering of bee plants. Furthermore in these areas beekeepers reported that some colonies remaining up to 10 to 20 years without any reproductive swarming. However, the succession of queens has to be takes place by supersedure means.

Figure 20 Frequency of swarming by clusters on the bases of occurring of swarming every year or not, (1 = Every year 2 = Not every year).

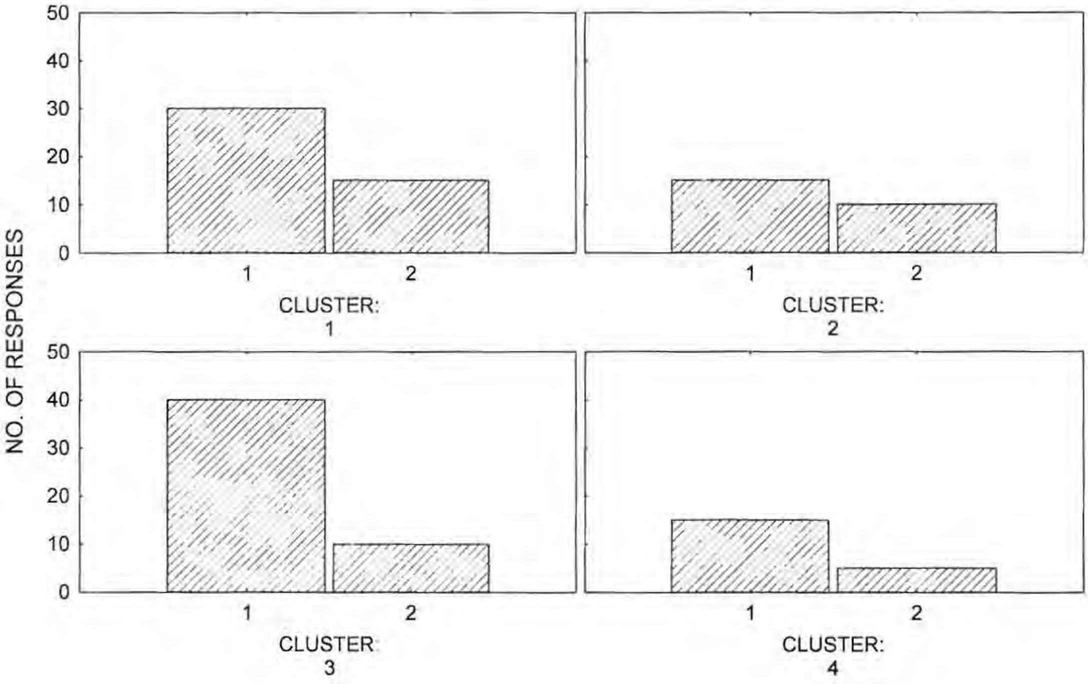


4.2.1.4 Phase of swarming

Phase of swarming was based on the occurrence of swarming in phases in different seasons in a single year. According to beekeepers' reports in most cases in all cluster groups swarming takes place once a year during or after a major rainy period depending on the localities. In all cluster groups 60% – 80% of cases indicated swarming is monophasic. However a few cases of biphasic swarming were reported in areas where there are adequate trees and optimum rainfall between March and June (Table 17). According to beekeepers' reports, the occurrence of a second phase of swarming in the period of March to June is very rare. The variations in monophasic and biphasic swarming were not statistically significantly different among cluster groups (Pearson

Chi-square with Yates' correction = 3.95 with 3 df, P = 0.2672). The reported cases of swarming phases for each cluster group are shown in Figure 21.

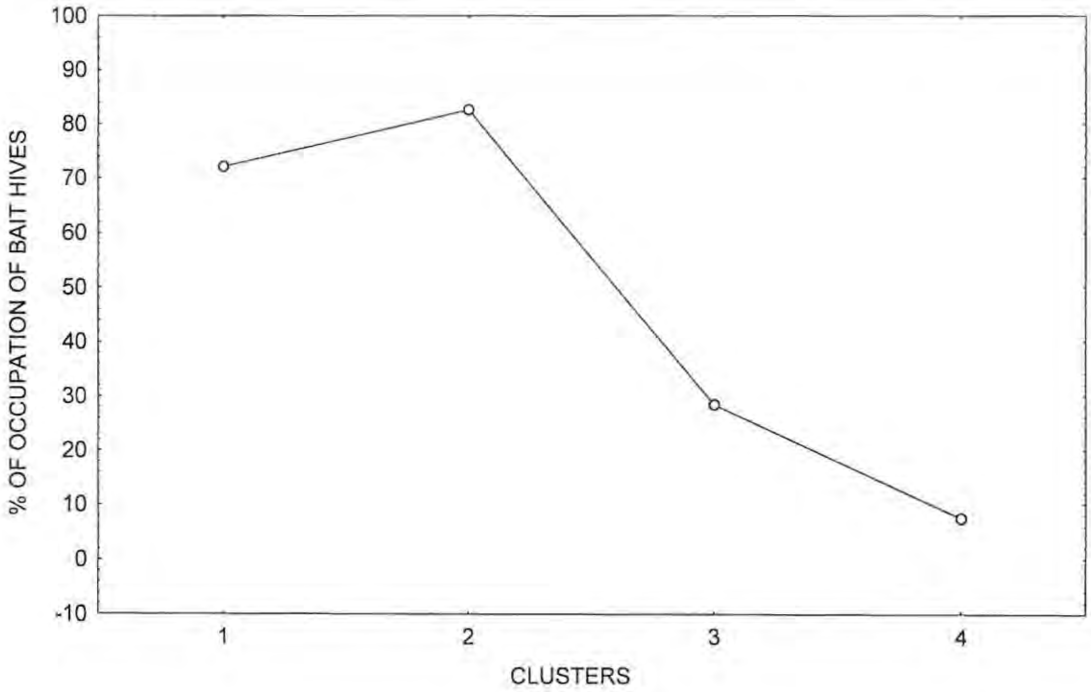
Figure 21 Reported cases of swarming phases by cluster based on occurrences of swarming in phases in different seasons in one year, (1 = monophase, 2 = biphasic swarming).



4.2.1.5 Swarm occupation rate of bait hives

To get an indirect estimate of the extent of reproductive swarming tendencies of bees of the study areas, records were taken on the occupation rate of bait hives. The information was based on 1999/2000 of beekeepers' experiences. According to their reports high rates of occupation, 50% – 98% with mean of 72.1% and 68.8%% – 98% with mean of 82.6% were recorded for clusters 1 and 2 respectively. Relatively low rates of occupation 5% to 66% with mean of 28.4% and 5% to 10% with mean of 7.5% were reported for clusters 3 and 4 respectively. The assumptions of normality and homogeneity of the variance were not met (Kolmogorov Smirnov test = 0.15, $P < 0.01$ and Levene's test $P < 0.0001$), so a non-parametric Kruskal-Wallis Anova test was used. The variations in occupation rate of bait hives were significantly different among cluster groups, (Kruskal-Wallis test: H (3, N = 135) = 103.27, $P < 0.0001$). The pair-wise comparison of Mann-Whitney U test indicated that the variation in the occupation rate among clusters 1 and 2 was not significant ($P = 0.0431$) with the Bonferroni correction to the level of significance ($\alpha/k = 0.05/6 = 0.0083$), while the variations among all other clusters groups were highly significantly different ($P < 0.0001$). The graph in occupation rate of bait hives by cluster groups is shown in Figure 22.

Figure 22 The mean swarm occupation rate of bait hives in different cluster groups.

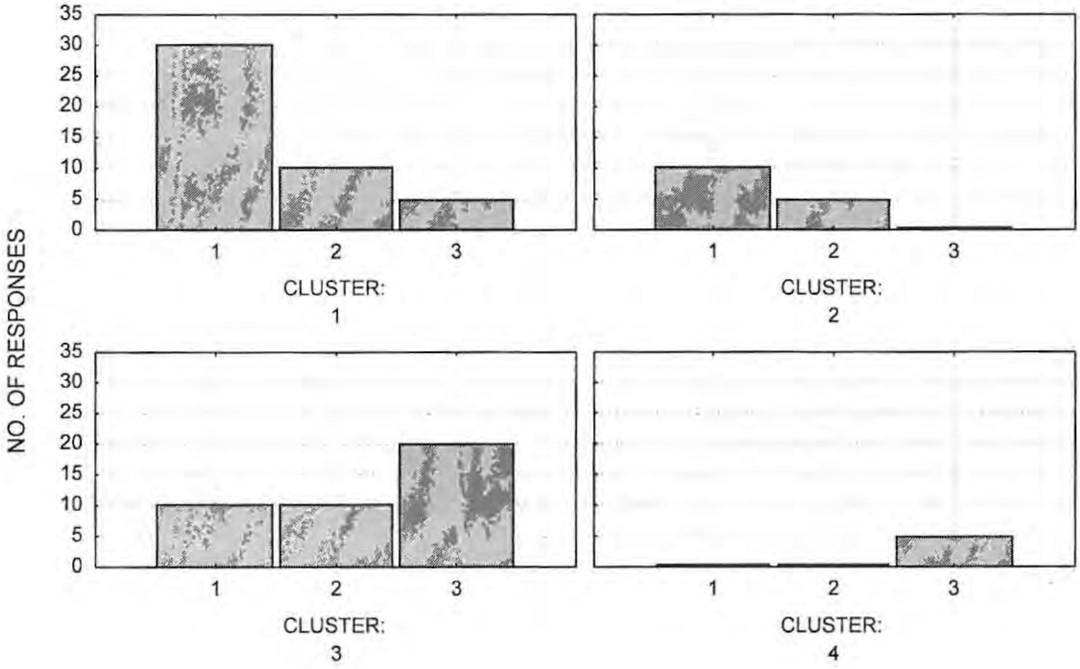


4.2.1.6 Reproductive swarming tendencies by colour

To determine if there is any variation in reproductive swarming tendencies, among yellow and black bees, beekeepers were interviewed on swarming tendencies with respect to different colours of bees. The interview was limited to those localities where yellow and black bee colonies were found. Accordingly, in both clusters 1 and 2, 66.7% of the reports supported a view that yellow bees have higher reproductive swarming tendencies than black bees, while 22% in cluster 1 and 33% in cluster 2, indicated black bees have a higher reproductive swarming tendency than yellow bees. Only 11% of the cases from cluster 1 reported the absence of differences in reproductive swarming among yellow and black bees. On the other hand 50% and 100% of reports for clusters 3 and 4 respectively supported no differences in swarming tendencies among differently coloured bees. In cluster 3, 25% of the reports were in support of each colour.

Generally, when all reports are taken into consideration 47.7% of them supported the view that yellow bees have high reproductive swarming tendencies while 23.8% of the reports supported the high swarming tendencies of black bees. 28.6% of the reports indicated the absence of reproductive swarming tendency differences among yellow and black bees. The variations of the reports (among yellow and black bees) were statistically significantly different (Chi-square = 11.25, df 1, $P < 0.001$). The reports were also significantly different among cluster groups, (Pearson Chi-square with Yates' correction = 33.66, with 6 df, $P < 0.0001$). According to some beekeepers reports, one new reproductive swarm of a yellow colony could build up its population and undergo further reproductive swarming in the same flowering season. The swarming tendencies of bees by colour and in cluster group according to beekeepers views to which colour of bees has a high swarming tendency is shown in Figure 23.

Figure 23 High warming tendencies of colonies by colour and cluster groups, (1 = yellow, 2 = black, 3 = no difference).



4.2.1.7 Period of reproductive swarming

To determine if there are any time differences in reproductive swarming periods among cluster groups, the reproductive swarming months for different cluster groups were recorded. The analysis of this data indicated the presence of high variations in reproductive swarming periods among the cluster groups (Chi-square value with Yates' correction = 156.84, 9 df, with $P < 0.0001$). Variations in time were also observed between localities in the same cluster group.

In cluster 1, even if time variations between localities exist within the same cluster group, mostly swarming was earlier than in the rest of clusters. In this cluster, localities such as Humera, Shiraro, Wohni, Angereb, Gewane and Melkasedi have swarming periods relatively earlier and very short, which take place between the months of August and September. While in the remaining localities, the reproductive swarming periods extended to October and only in one locality (Menge (N24)), it was reported to take place up to November. For this cluster, 66.67% of the reports indicated that reproductive swarming occurred between August and September while the remaining 22.2% and 11.1% of the reports indicated that peak reproductive swarming were between September and October and October to November respectively. In general in this cluster in most localities reproductive swarming takes place between August and September.

Reproductive swarming period in cluster 2 is much later than in the rest of the other cluster groups. The initial and the final months of swarming extended between October and December. In this cluster, 40% of the reports indicated the reproductive swarming is between October and November while the remaining reports indicated that the reproductive swarming period is between November and December. In cluster 3, reproductive swarming was reported to occur between September and November. Variations in swarming periods were observed between localities in the same cluster group, for which 40% of the reports indicated that swarming occurred between September and October while the remaining 60% between October and November. In cluster 4 the swarming periods occur between September and November with 75% of the reports indicating the occurrence of swarming between September and October and the remaining 25% was between October and November. The reproductive swarming periods for each cluster group are shown in Figure 24.

Figure 24 The major reproductive swarming periods for different cluster groups.

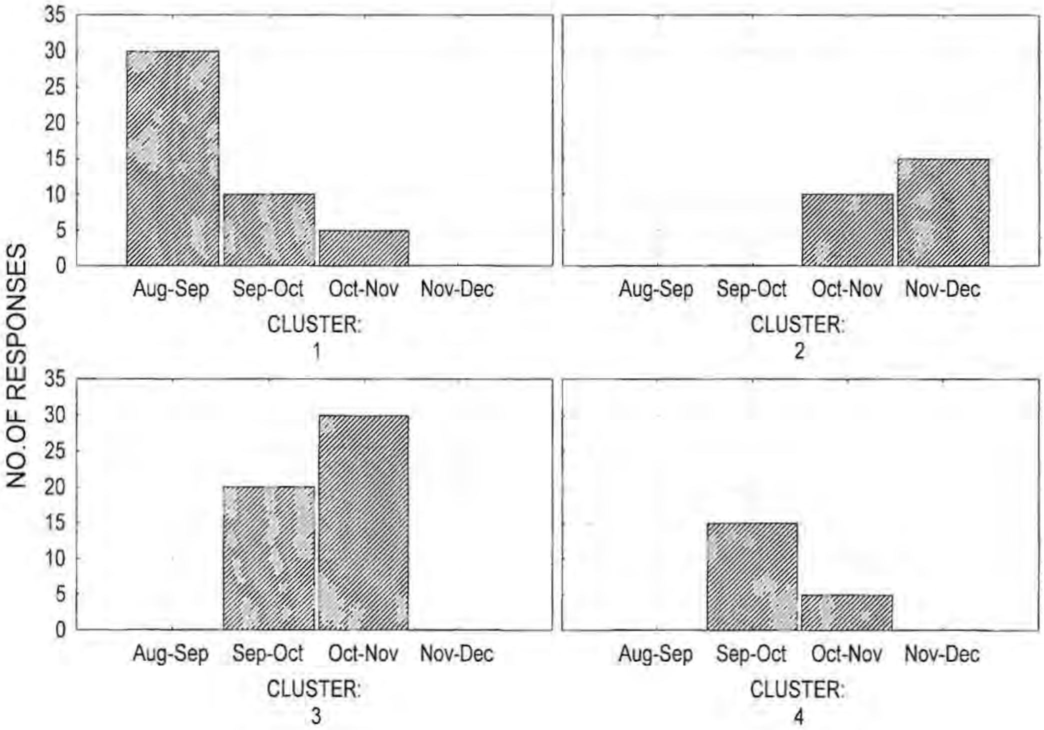


Table 17 Reproductive swarming periods and extent by locality and cluster, (numbers under swarming periods indicate months, 3 = March, 4 = April, 5 = May, 6 = June, 8 = August, 9 = September, 10 = October, 11 = November, 12 = December).

Clusters	Localities	Swarming periods		Percentage of swarming
		Major peak	minor	
Cluster 1	Angereb	8 – 9	5 – 6	75
	Aykel	9 – 10	–	41
	Humera	8 – 9	–	38
	Manbuk	9 – 10	5 – 6	85
	Melkasedi	8 – 9	–	65
	Gewane	8 – 9	–	50
	Shiraro	8 – 9	–	33
	Menge	10 – 11	5 – 6	70
	Wohni	8 – 9	–	80
Cluster 2	Bambasi	11 – 12	5 – 6	100
	Bir Sheleko	11 – 12	–	100
	Dedessa	11 – 12	–	100
	Hinde	10 – 11	–	85
	Nejo	10 – 11	5 – 6	100

Continuation of Table 17.

Clusters	Localities	Swarming months		percentage of swarming
		Major peak	minor	
Cluster 3	Dangla	10 – 11	–	75
	Deneba	10 – 11	–	17
	Gedo	10 – 11	–	33
	Inchini	9 – 10	–	50
	Nekemte	10 – 11	–	67
	Feres Bet	10 – 11	5 – 6	25
	Sendafa	9 – 10	–	20
	Shambu	10 – 11	4 – 5	55
	Debre Tabor	9 – 10	–	33
	Salayish	9 – 10	–	20
Cluster 4	Debark	10 – 11	3 – 5	14
	Korem	9 – 10	–	20
	Woldeya	9 – 10	–	13
	Guguftu	9 – 10	–	17
Localities not in clusters	Mekele	8 – 9	–	50
	Abi Adi	8 – 9	–	44
	Dabat	9 – 11	–	35

4.2.2 Migration

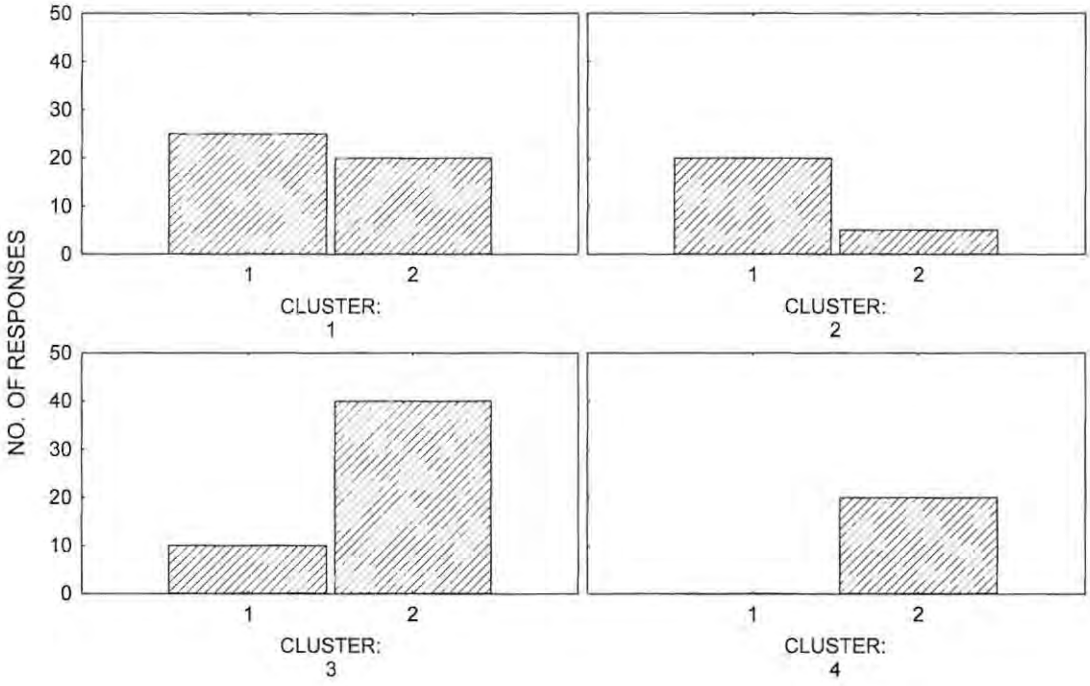
The migratory behaviour of honeybees such as the occurrence of migration, its extent, period and causes of migration were found to vary among cluster groups.

4.2.2.1 Occurrence of migration

In the survey, beekeepers were interviewed the presence and absence of seasonally based movements of honeybee populations in their localities. Accordingly, it was found that the seasonally based migration of honeybees greatly varied among cluster groups (Pearson Chi-square with Yates' correction = 41.44 with 3 df, $P < 0.0001$). For cluster 1, 55.6% of the reports (those from locality Menge, Manbuk, Wohni, Angereb and Humera) confirmed the occurrence of migration, while 44.4% of the reports from Gewane, Melkasedi, Aykel and Shiraro noted the absence of migration.

For cluster 2, 80% of the reports from Hinde, Dedessa, Nejo and Bambas indicated the presence of migration, while 20% of the reports from Bir Sheleko indicated its absence. For cluster 3, out of 10 localities, seasonally based migrations of honeybee colonies were reported only from two, Nekemte and Dangla. For cluster 4, in all cases migration was reported not to occur. The presence and absence of migration by cluster are shown in Figure 25. Localities where migrations were reported are indicated in Table 18.

Figure 25 Migration of honeybees by cluster, based on reports of presence or absence of migration, (1= presence of migration, 2 = absence of migration).



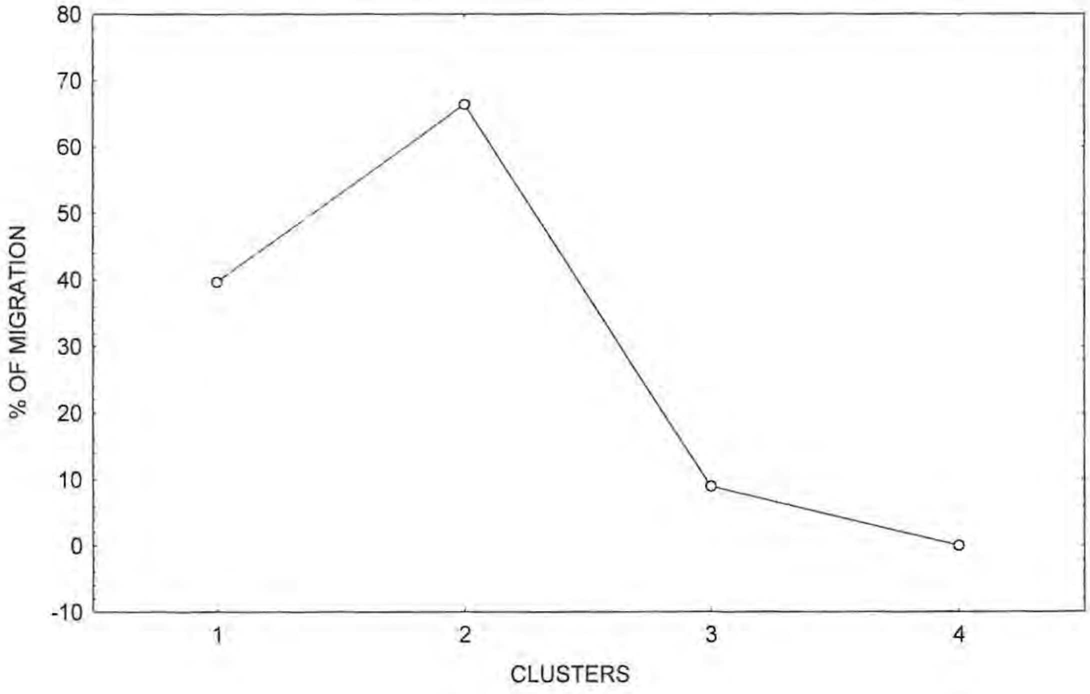
4.2.2.2 The extent of migration

The extent of the seasonally base migration of honeybees was estimated from the proportions of colonies that migrated to the total number of colonies owned by interviewed beekeepers in the period of 1999/2000. In morphocluster 2, migration was reported in all localities except Bir Sheleko. In this cluster 75% to 100%, with mean of 66.4% cases has been recorded. In morphocluster 1, out of 9 localities migration was reported only in five localities with 55% to 100% with mean of 39.7% cases of migration. In morphocluster 3, only in two localities, Dangla (15%) and Nekemte (75%) cases of migration was reported, while in morphocluster 4, migration is not reported. The extent of migration by localities is shown in Table 18.

The assumption of normality and homogeneity of the variances were not met (Kolmogorov Smirnov test (K-S) = 0.37, $P < 0.01$ and Levene's test, $P < 0.0001$) hence a non-parametric Kruskal-Wallis Anova test was used. High variations in the extent of migration were observed among the cluster groups, (Kruskal–Wallis: H (3, N=140) = 47.86, $P < 0.0001$). The pair-wise comparison of the Mann-Whitney U test showed statistically significant differences (with Bonferroni correction to the level of significance $\alpha = 0.05/6 = 0.0083$) between clusters 1 and 2, $P = 0.0021$; 1 and 3, $P = 0.0015$ and clusters 1 and 4 at ($P < 0.001$) and between clusters 2 and 3 and clusters 2 and 4 ($P < 0.0001$). In this analysis no significant variation was observed between clusters 3 and 4 ($P = 0.19359$). The mean percentage of migration by cluster groups is shown in Figure 26.

In some of the areas where clusters 3 and 4 honeybee samples were collected, beekeepers reported that some colonies could stay 10–15 years without leaving their hives. Even in conditions of starvation they remain in their hives until they gradually become weak and finally die.

Figure 26 The mean percentage of migrations by cluster groups.



4.2.2.3 Period of migration

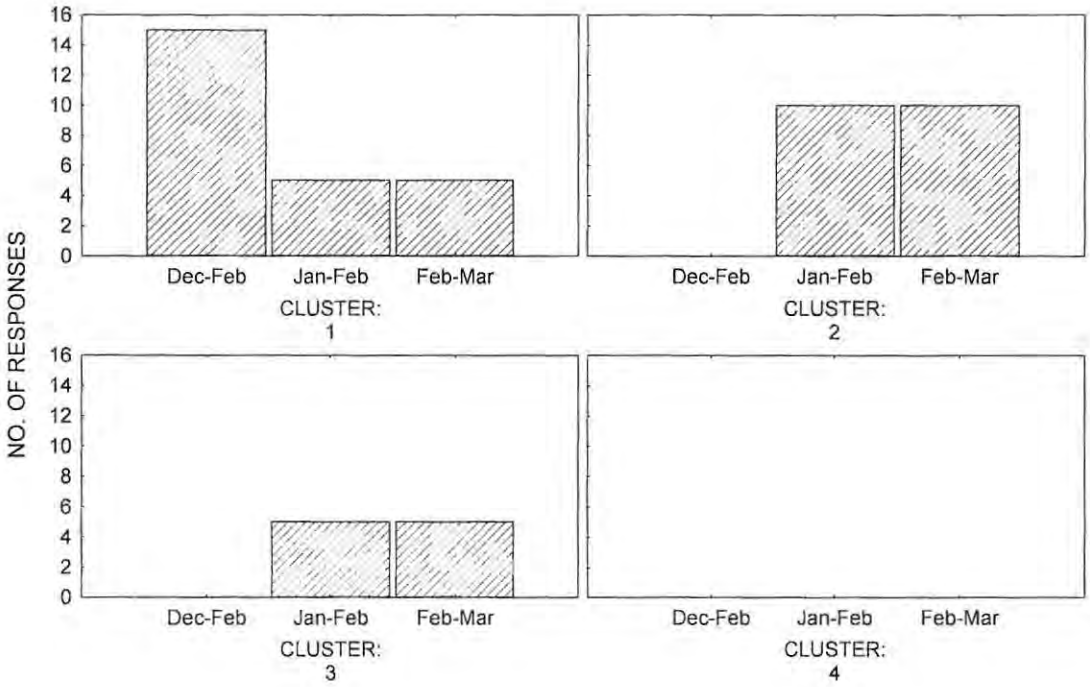
The periods at which migrations occur were recorded for localities where migrations were reported. Significant variations in shifting of migratory periods were observed among the cluster groups (Pearson Chi-square with Yates' correction = 22.53, 6 df, $P < 0.001$). According to the survey, variations in migratory periods were also observed among localities in the same cluster group. In cluster 1 the peak migration period extended between December and March. 60% of the reports indicated that migration took place within the months of December to February, while 20% within the months of January to February and the remaining 20% in February to March.

For clusters 2 and 3 the reported periods of migration were between January to March. In both clusters 50% of the reports indicated that migrations occurred in the months of January to February while the remaining 50% were between the months of February to March. In both clusters, unlike cluster 1, the migration periods were shifted to January to March. The reported months of migration by clusters is shown in Figure 27.

4.2.2.4 Frequency of migration

Frequency of migration was based on the occurrence of migration every year or not. According to this survey work, the seasonal base movements of bees were reported to occur every year where migration is common.

Figure 27 The reported months of migration for localities of the different cluster groups.



4.2.2.5 Reasons of migration

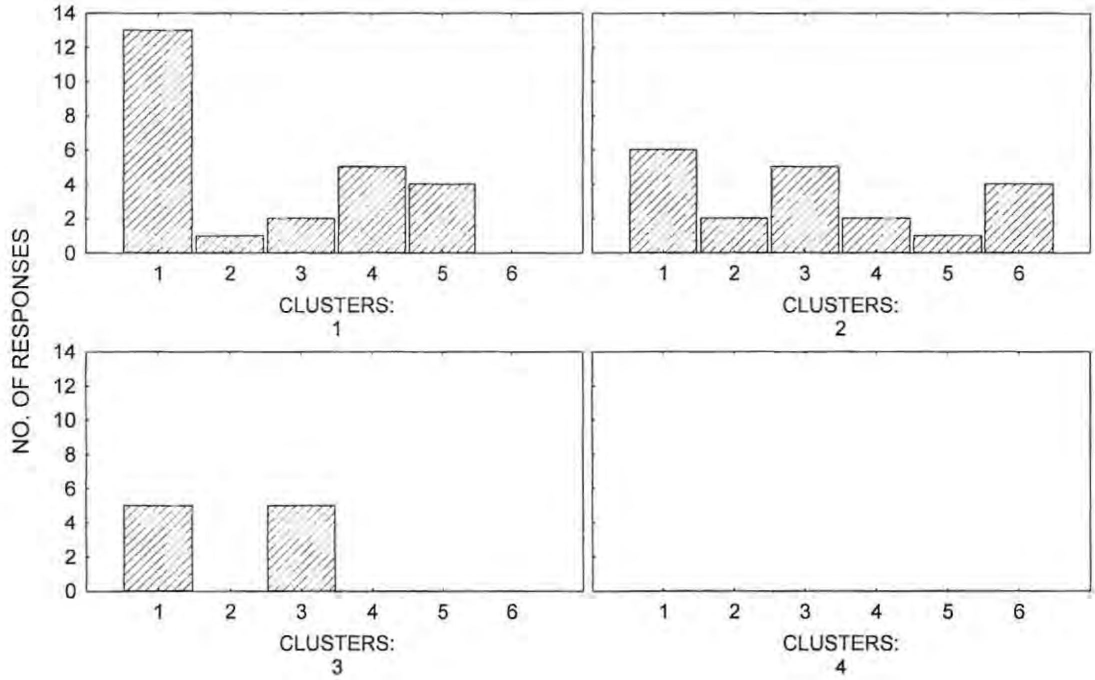
According to beekeepers' reports, the seasonal base migrations of honeybees were associated with various reasons. The causes of migration and their degrees of importance varied from place to place. Generally, in most places shortage of food and water in dry seasons, forest fires, management problems, high temperatures and the nomadic nature /strains/ of the bees were reported as major possible reasons of migration.

In most localities, a frequently reported cause of migration was shortage of food. According to beekeepers' reports for cluster 1, next to a shortage of forage, forest fires and high temperatures were the major causes of migration. For cluster 2, next to shortage of forage, the more frequently reported reasons of migration were management problems, nomadic behaviour/strains/ of the bees and forest fires. For cluster 3, shortage of forage and management problems were reported as equally important causes of migrations. The variation in the reasons of migration is not statistically significantly different (Chi-square = 23.84, df 15, P = 0.0678) among the morphoclusters. However all cases are not equally important in all localities. The reported reasons of migration in each cluster are shown in Figure 28.

In the survey, beekeepers were interviewed about where the bees migrate. The places indicated largely differed form beekeeper to beekeeper and also from locality to locality. Since most migrations were reported from the lowland and midland areas, most beekeepers said that the bees migrate from lowlands to midlands or to highlands. However some beekeepers reported that bees migrate from the lowlands and midlands to further lowland areas where certain bee plants are flowering at that particular time. In some cases movements of bees towards the river basins were also reported. This could be due to the presence of flowering plants along the riverbanks and the cooling effect of the water in hot and dry seasons. Some beekeepers reported having no knowledge of where the bees are migrating. In all cases most beekeepers agreed on the reasons for the movements of honeybees were largely associated with search of better forage. The migratory conditions of honeybee population by cluster and by localities are shown in Table 18.

Besides the seasonal base migration of honeybees, absconding of colonies was reported to occur at any time of the year, and was mostly associated with disturbances by the honeybee enemies. The major reported causes of absconding are attacks of safari ants, honey badgers, monkeys, tree squirrels (Mogoza vernacular name), big birds, wax moths and when the nests are ruined by heavy rain. Honey badgers, monkeys, tree squirrel, and big birds mostly destroy the nest and eat the content of the nest. The economic importance of the honeybee enemies vary from ecology to ecology, however safari ants and wax moths are very serious problem to beekeeping in most parts of the study area. These problems are more pronounced in the forest beekeeping areas where there is no attendance of colonies.

Figure 28 The reported reasons of migration by clusters.



Numbers in the figure indicate the reasons of migration

1 = shortage of food
4 = forest fires
2 = shortage of water
5 = high temperature
3 = handling problem
6 = nomadic nature /strains/ of the bees

4.2.2.6 Immigration of honeybee colonies

Honeybee colonies that migrated in unfavourable seasons were reported to return during flowering seasons to their original areas. However, the periods of immigrations varied among clusters. In cluster 1, immigration was reported to start in July and peak in August and September. In cluster 2 colonies were reported to return at two flowering seasons between April to June and August to October. In cluster 3 the immigration was reported to occur between the months of September and October.

Table 18 Migratory conditions of honeybees and time of migration and immigration in localities where migration was reported, (numbers under periods indicate months of a year).

Clusters	Localities	Percentage of migration	Period of migration	Period of immigration
Cluster 1	Angereb	75	12 – 2	9 – 10
	Humera	55	12 – 2	8 – 9
	Manbuk	67	12 – 2	8 – 9
	Menge	100	2 – 3	8 – 9
	Wohni	60	1 – 2	7 – 8
Cluster 2	Bambasi	100	2 – 3	9 – 10
	Dedessa	90	1 – 2	9 – 10
	Hinde	67	1 – 2	4 – 5, 8 – 9
	Nejo	75	2 – 3	5 – 6, 8 – 9
Cluster 3	Dangla	15	1 – 2	9 – 10
	Nekemte	75	2 – 3	9 – 10

4.2.3 Temperament

The temperament of colonies was evaluated from the beekeepers' points of view. Qualitative evaluations like "docile", "aggressive" and "very aggressive" were used to categorise the degree of colony aggressiveness. Accordingly for cluster 1, 66.7% of the reports indicated that the bees are very aggressive while 33.3% were aggressive. For this cluster no docile cases were reported. For cluster 2, 60% and 32% of cases were reported as aggressive and very aggressive respectively, while the remaining 8% only as docile. For cluster 3, 40%, 48% and 12% cases were reported as docile, aggressive and very aggressive respectively. For cluster 4, 70% and 30% of cases were reported as docile and aggressive respectively. Based on these categorisations significant variations were obtained among cluster groups, (Pearson Chi-square with Yates' correction = 64.23, 6 df, $P < 0.0001$). The temperament condition of honeybee colonies by clusters is shown in Figure 29.

4.2.3.1 Proportion of aggressiveness

Besides the qualitative categorisations, aggressiveness of the bees was estimated from the proportion of the number of colonies in the apiaries, which were reported for aggressive behaviour. For cluster 1, relatively high proportions of the colonies, 45% – 85% with a mean of 74.3% were reported as aggressive. For cluster 2, 33% – 75% with a mean of 56.6% of the colonies were reported to be aggressive. Relatively low proportions of aggressiveness, 15% to 50% with a mean of 30.9% and 5% to 15% with a mean of 10% were reported for clusters 3 and 4 respectively.

The assumption of normality and homogeneity of variances were not met (K-S = 0.14, $P < 0.05$, Levene's test = $P < 0.0001$) hence to analyses the variations among morphoclusters a non-parametric (Kruskal-wallis Anova) test was used. The variations in the proportions of aggressiveness were statistically significantly different among cluster groups, (Kruskal-Wallis test H (3, N =140) = 100.5, $P < 0.0001$). The pair-wise comparison of Mann-Whitney U test indicated the degree of aggressiveness was statistically significantly different (with Bonferroni correction to the level of significance $\alpha = 0.05/6 = 0.0083$), among clusters 1 and 2 at $P < 0.001$, while the variations among all other cluster groups were significant at ($P < 0.0001$). The proportion of aggressiveness by clusters is shown in Figure 30.

Figure 29 Temperament conditions of bees by clusters, (1 = docile, 2 = aggressive 3 = very aggressive).

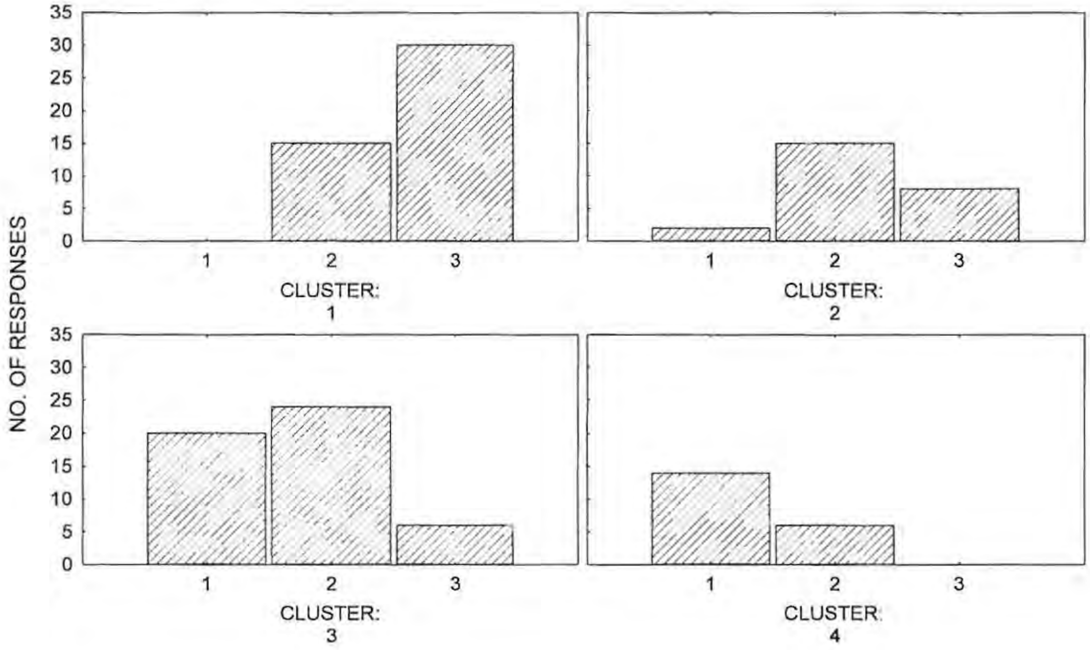
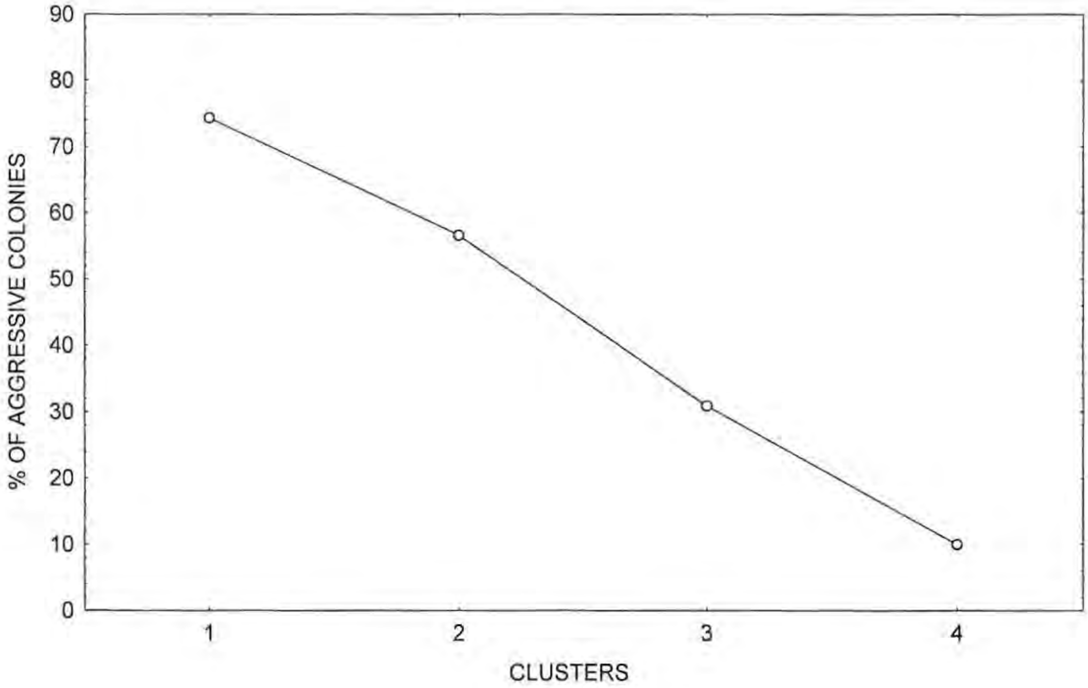


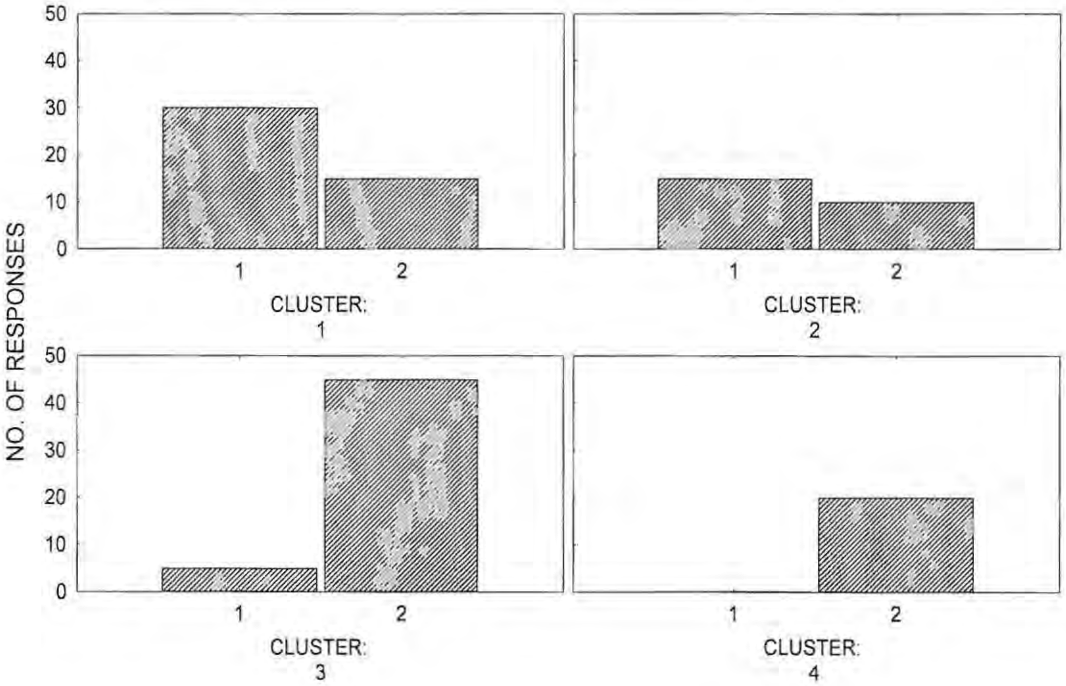
Figure 30 Mean proportions of aggressive colonies by cluster groups.



4.2.3.2 Unprovoked attacks

To evaluate the general aggressiveness of honeybees, beekeepers were interviewed as to the occurrence of unprovoked attacks of bees. In cluster 1, 66.7% of cases reported the presence of unprovoked attacks while 33.3% of cases reported the absence of unprovoked attacks. In the case of cluster 2, 60% of the reports supported the presence of unprovoked attacks while 40% did not. In cluster 3 only 10% of the cases reported unprovoked attacks while 90% of the cases supported the absence of unprovoked attacks. In cluster 4, in all cases unprovoked attacking was not reported. The variations in the presence or absence of unprovoked attacks were significantly varied among cluster groups, (Pearson Chi-square with Yates' correction = 48.94, 3 df, $P < 0.0001$). The reports of the presence and absence of unprovoked attacks of bees by cluster is shown in Figure 31.

Figure 31 Reported cases of presence and absence of unprovoked attacks by clusters, (1 = yes, 2 = no).

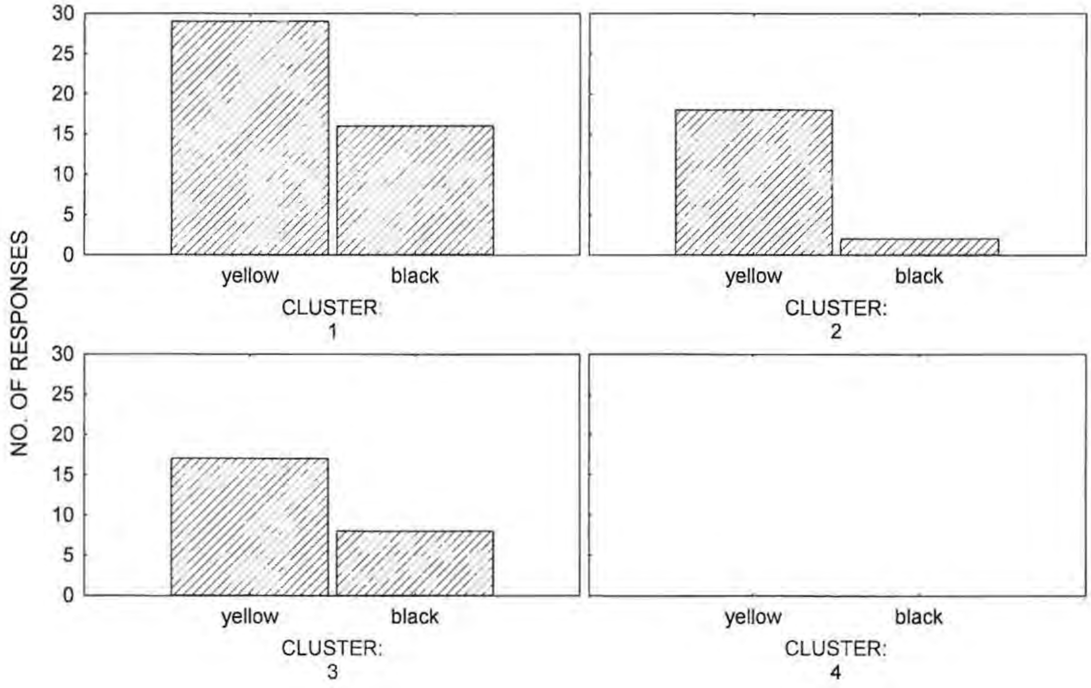


4.2.3.3 Temperament of bees in relation to colour

To judge whether the temperament of bees is related to their colours, beekeepers were interviewed as to which colour of bees is more aggressive than the other. According to their responses 64.4%, 90% and 68% of cases supported that yellow bees are more aggressive than black bees in clusters 1, 2 and 3 respectively. The variation in the reports of aggressiveness between yellow and black bees was not statistically significantly different among clusters (Pearson Chi-square with Yates' correction = 4.32, 3 df, P = 0.2285). But for the total number of cases yellow bees were reported as more aggressive than black bees and the reports were statistically significantly different (Chi-square = 16.04, df 1, P < 0.001).

However, beekeepers reported high variations in the degree of aggressiveness within yellow and black bees. The aggressiveness reports of bees by colour in cluster are shown in Figure 32.

Figure 32 Temperament of bees in relation to colour by cluster (beekeepers report to which colour of bees is more aggressive).



* In Figure 32 there was no beekeepers responses for cluster 4.

4.2.3.4 Conditions of aggressiveness

Beekeepers were interviewed to assess which conditions make the bees more aggressive. Accordingly, four major conditions such as brood rearing time, honey flow period and honey harvesting and when being attacks by enemies were among the major reported conditions for aggressiveness.

4.2.4 Correlations of behavioural characters

To observe the relations within different behavioural characters analysis of correlations were carried out. Accordingly, statistically significant positive correlations ($r = 0.48 - 0.85$ with $P < 0.0001$ with Bonferroni correction to the level of significance $\alpha = 0.05/6 = 0.0083$) were obtained within various behavioural characters such as proportion of swarming, migration, aggressiveness and maximum number of swarms per colony. A very strong linear correlation value of $r = 0.85$ was obtained between the percentage of swarming and maximum number of swarms per colony. The values of correlations within different behavioural characters are shown in Table 19.

4.2.4.1 Regression analyses of behavioural characters versus environmental factors

To observe the effects of environmental factors on various behavioural characters, simple regression analyses were carried out. In the analyses it was observed that altitude has a strong negative correlation ($r = -0.50$ to -0.79 with $P < 0.0001$) with behavioural characters such as percentage of swarming, migration, aggressiveness and maximum numbers of swarms per colony. Relatively very strong negative correlation value of $r =$

-0.79 was obtained between percentage of aggressiveness and altitude. The summaries of regression analyses of altitude versus behavioural characters with corresponding t values and P-levels are shown in Table 20.

Table 19 Correlations values (r) within different behavioural characters.

Behavioural characters	Percentage of swarming	Maximum No. of swarm	Percentage of migration	Percentage of aggressiveness
% of swarming	1.00	0.85	0.68	0.58
Max. No. of swarms	0.85	1.00	0.59	0.48
% of migration	0.68	0.59	1.00	0.65
% of aggressiveness	0.58	0.48	0.65	1.00

* The (r) values are highly significant $P < 0.0001$

Table 20 Summaries of regression analyses of behavioural characters versus altitude.

Behavioural characters	r values	t values	P-levels
Percentage of swarming	- 0.57	- 8.15	< 0.0001*
Max. numbers of swarms	- 0.56	- 7.87	< 0.0001*
Percentage of migration	- 0.50	- 6.81	< 0.0001*
Percentage of aggressiveness	- 0.79	- 15.56	< 0.0001*

* Correlations are significant at $P < 0.0125$ as determined ay Bonferroni's adjustment to the level of significance for multiple tests.

In the case of temperature a strong positive correlation (r = 0.49 – 0.75 with P < 0.0001) was obtained for behavioural characters such as swarming, migration, aggressiveness and maximum number of swarms per colony. A very strong positive correlation value of r = 0.75 was obtained between aggressiveness and temperature. The regression summaries of behavioural characters versus temperature of the sampling localities with respective t values and P-levels are shown in Table 21.

Table 21 Summaries of regression analyses of behavioural characters versus the mean temperatures of the sampling localities.

Behavioural characters	r values	t values	P-levels
Percentage of swarming	0.53	7.31	< 0.0001*
Max. numbers of swarms	0.55	7.80	< 0.0001*
Percentage of migration	0.49	6.54	< 0.0001*
Percentage of aggressiveness	0.75	13.33	< 0.0001*

* Correlations are significant at P < 0.0125 as determined ay Bonferroni's adjustment to the level of significance for multiple tests.

Rainfall was positively correlated with all behavioural characters except aggressiveness. The correlations between annual rainfall at the sampling localities and the behavioural characters were not as strong as altitude and temperature except the values (r = 0.29, P = 0.0006) between rainfall and percentage of reproductive swarming. The summaries of regression analyses of behavioural characters versus annual rainfall of the sampling localities are shown in Table 22. In this regression analysis the effect of latitude on behavioural characters was not significant.

Table 22 Summaries of regression analyses of behavioural characters versus annual rainfall amount of sampling localities.

Behavioural characters	r values	t values	P-levels
Percentage of swarming	0.29	3.50	= 0.0006*
Max. numbers of swarms	0.20	2.35	= 0.0203
Percentage of migration	0.24	2.87	= 0.0047*
Percentage of aggressiveness	- 0.15	-1.79	= 0.0758

* Correlations are significant at $P < 0.0125$ as determined ay Bonferroni's adjustment to the level of significance for multiple tests.

4.2.5 Colony seasonal cycles and brood rearing periods

4.2.5.1 Colony seasonal cycles

The colony seasonal cycles such as brood rearing, subsequent swarming and dearth periods were found to be influenced by rainfall and its distribution. In the study areas the seasonal cycles of the colonies varied from cluster to cluster and also to some extent from locality to locality within clusters. In most localities one major brood rearing and two dearth periods were reported (Table 23). The two dearth periods are associated with long dry and heavy rain seasons. In the highlands and humid areas the major brood rearing periods occur mostly towards the end of the big rainy season and continue a few weeks after this.

While, in the arid and semi-arid lowlands, brood rearing commences as soon as the rains start and reproductive swarming occurs during the raining period. In most localities the major dearth period is associated with long dry periods, which mostly starts in November and in some localities extends to the month of May. In areas where migration of colonies is common it takes place in this long dry period. In some localities this long dry period was reported to be interrupted by a small raining period, which usually took place in the months of March to June. The minor dearth period is mostly associated with heavy rain, which is common in humid midland and highland areas, and mostly took place during the heavy rains of June, July and August. Generally, the dearth months in some localities is active period for some other localities and the minor dearth period in some localities is also a major dearth period for others. The colony seasonal cycles in relation to rainfall by cluster are shown in Table 23.

4.2.5.2 Brood rearing periods

Brood rearing time variations were observed among clusters and between some localities in the same cluster group. In cluster 1, brood rearing starts very early, between the months of July and August and mostly lasts from September to October depending on the localities. In this cluster the major brood rearing time is August to September (Figures 33 and 34). In cluster 2, the brood rearing period is much extended and starts in August and September and lasts through November and mainly December (Figures 33 and 34).

In cluster 3, brood rearing starts in months of August and mainly September and lasts until October and December in which 60% of the reports indicated brood rearing lasts in month of November (Figure 34). In cluster 4, brood rearing commences in August and September and continues until October with slight extensions in November. Significant variations were observed among cluster groups for both initial (Pearson Chi-square with Yates correction = 65.8, 6 df, $P < 0.0001$) and final months of brood rearing (Pearson Chi-square with Yate's correction = 134.25, 9 df, $P < 0.0001$). The initial and final months of brood rearing periods by clusters are shown in Figures 33 to 34. Besides, the major brood rearing period, small brood rearing periods were also reported for some localities after or during the small rainy period (Table 23).

Figure 33 Initial months of brood rearing periods for localities in the different cluster groups.

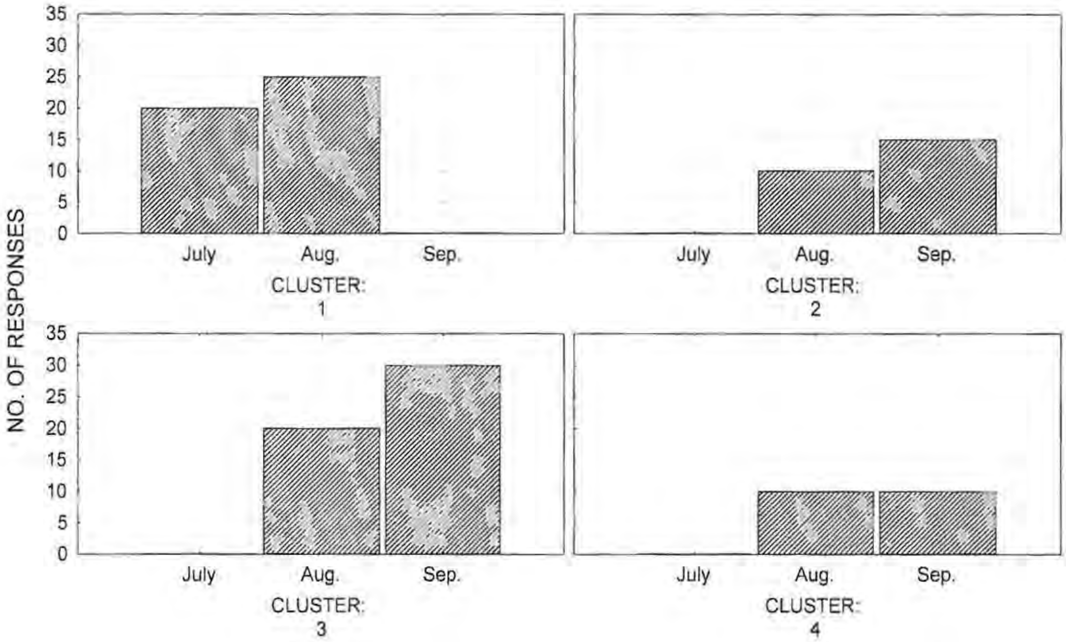


Figure 34 Final months of brood rearing periods for localities in different cluster groups.

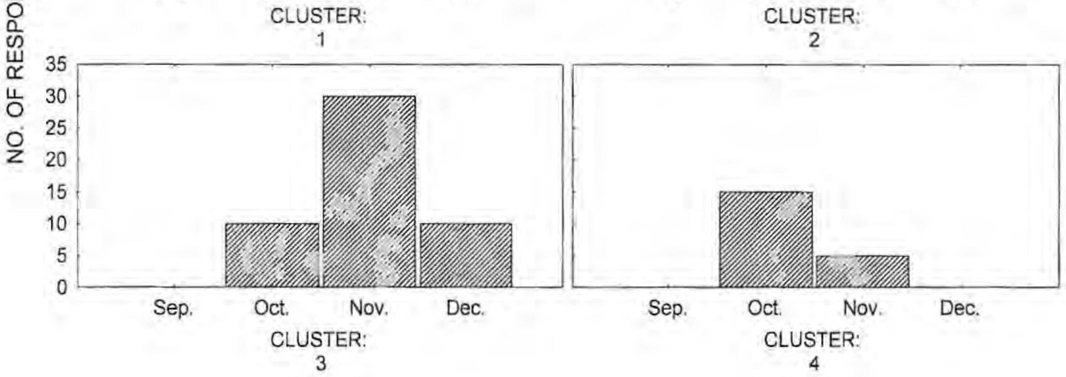


Table 23 Seasonal cycles of honeybee colonies by cluster and localities, (numbers under major and minor periods indicated months of a year, 1 = January, 2 = February, 3 = March, 4 = April, 5 = May, 6 = June, 7 = July, 8 = August, 9 = September, 10 = October, 11 = November, 12 = December).

Clusters	Localities	Raining periods		Brood rearing periods		Dearth periods	
		major	minor	major	minor	major	minor
Cluster 1	Angereb	7–9	5–6	8–9	5–6	12–3	–
	Aykel	6–9	–	8–10	–	12–3	6–7
	Humera	7–9	–	7–9	–	11–5	–
	Manbuk	6–10	5–6	8–10	5–6	12–3	6–7
	Melkasedi	7–9	–	7–9	–	11–5	–
	Gewane	7–9	–	7–9	–	11–5	–
	Shiraro	7–9	–	7–9	–	11–5	–
	Menge	6–10	5–6	8–11	5–6	12–3	–
	Wohni	6–9	–	8–9	–	12–3	–
Cluster 2	Bambasi	6–10	4–5	8–12	4–6	2–3	6–7
	Bir Sheleko	6–10	–	8–12	–	2–3	6–7
	Dedessa	5–10	–	9–12	–	1–3	7–8
	Hinde	6–10	4–5	9–11	4–5	1–3	7–8
	Nejo	610	5–6	9–11	5–6	2–3	7–8

Continuation of Table 23.

Clusters	Localities	Raining periods		Brood rearing periods		Dearth periods	
		major	minor	major	minor	major	minor
Cluster 3	Dangla	6–10	–	8–11	–	1–5	–
	Deneba	6–9	–	8–11	–	1–5	6–7
	Gedo	5–9	–	9–12	–	7–8	–
	Inchini	5–10	3–4	9–10	–	7–8	4–5
	Nekemte	4–10	–	9–11	–	2–3	7–8
	Feres Bet	6–10	4–6	9–12	4–6	7–8	–
	Sendafa	6–9	–	8–11	–	1–6	–
	Shambu	5–10	3–5	9–11	3–5	2–3	7–8
	DebreTabor	6–9	–	8–10	–	1–3	6–7
	Salayish	6–9	–	9–11	–	1–5	7–8
Cluster 4	Debark	6–9	3–5	9–11	3–5	1–2	7–8
	Korem	7–9		8–10	–	11–5	6–7
	Woldeya	7–9	4–5	8–10	4–5	1–3	6–7
	Guguftu	7–9	3–4	9–10	–	7–8	–
Colonies not in clusters	Mekele	7–8	–	8–10	–	1–5	–
	Dabat	6-9	–	9–10	–	12–4	–
	Abi Adi	7–8	–	7–10	–	12–5	–

4.3 Ecological factors

4.3.1 Rainfall

4.3.1.1 Major rainfall period

The amount of rainfall and its distribution largely varied from locality to locality. In most localities where cluster 1 honeybee samples were collected, the rainfall period is short, mostly for two months, and starts from June and July and lasts until September, except for localities such as Manbuk, and Menge where it extends to October. Annual rainfall for most localities is very low and ranges from 458 mm to 920 mm except for the localities Menge, Manbuk and Aykel, which receive an annual rainfall of 1150 mm, 1300 mm and 1439 mm respectively. The average annual rainfall for all localities in this cluster group was 881 mm.

The rainfall period for localities in cluster 2 is relatively long and starts in May to June and extends to October. The amount of rainfall at these localities is very high and ranges from 1164 mm to 2090 mm. The average annual rainfall for all localities in this cluster was 1594 mm. Localities in cluster 3 have also an extended rainy period, which starts in May and June at different localities and lasts until September and October. The annual rainfall of these localities is also relatively high and ranges from 1015 mm to 2156 mm. The average annual rainfall for all localities in this cluster was 1432 mm.

Localities in cluster 4 have a relatively short rainfall period, which starts from June and July and lasts until September. The mean annual rainfall of localities in this cluster was relatively low and ranges from 750 mm to 1181 mm. The average rainfall for all localities in this cluster was 1038 mm. Statistically significantly different time variations were obtained for both initial and final months of raining periods, (Pearson Chi-square with Yates' correction = 74.99, 9 df, $P < 0.0001$ and 54.95, 3 df, $P < 0.0001$, respectively) among the different cluster groups. The initial and final rainfall periods by cluster are shown in Figures 35 and 36.

4.3.1.2 Minor rainfall period

Besides the major rainfall period, a small rainfall period was reported from some localities such as Angereb, Manbuk and Menge from cluster 1, Bambasi, Hinde and Nejo from cluster 2, Inchini, Feres Bet, and Shambu from cluster 3, and Debark, Woldeya and Guguftu from cluster 4. This rainfall period mostly occurs between March to May and sometimes extends to June, which merges with the major raining period. The rain of this period is very erratic, and may not take place every year and the amount may not be adequate in all places to support the flowering of bee plants. The mean annual rainfall by localities is shown in Table 24.

Figure 35 The initial months of rain periods of localities by cluster groups.

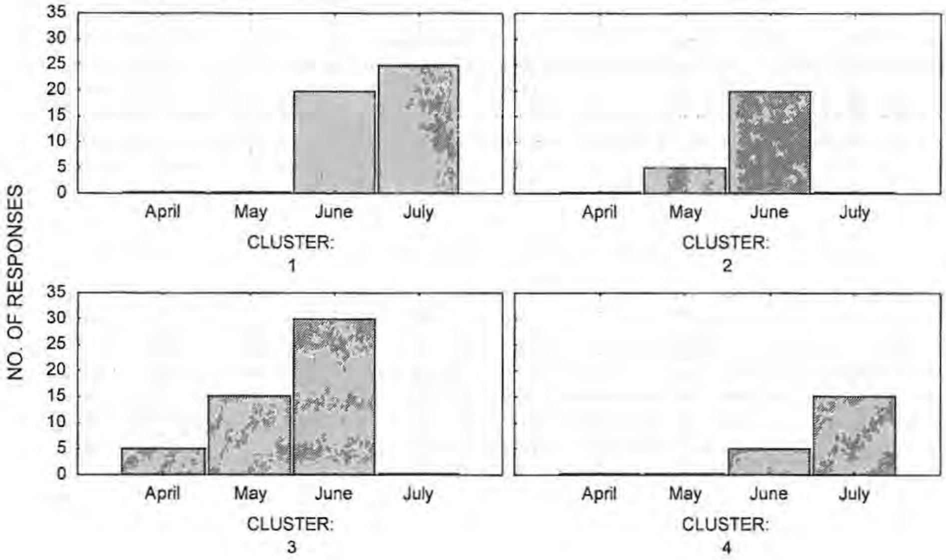
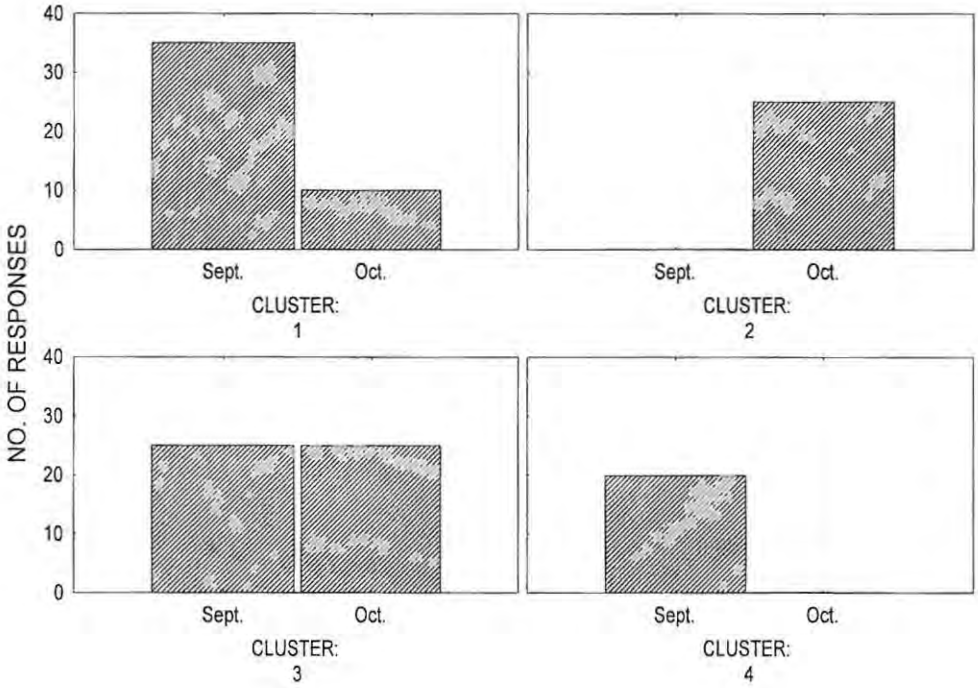


Figure 36 Final months of rain periods for localities by cluster groups.



4.3.2 Temperature

The minimum, maximum and mean annual temperatures of sampling localities were recorded from the nearest metrological stations. Accordingly, a minimum of 5.2°C and a maximum of 37.6°C were recorded for Guguftu and Humera respectively. Relatively higher temperatures were recorded for localities in cluster 1 than for the rest of localities. The minimum, maximum, and mean annual temperatures for all localities in this cluster were 16.9°C, 33.5°C and 25.1°C respectively.

The annual temperatures at localities in cluster 2, ranged from 11°C – 30°C. The minimum, maximum and mean temperatures for all localities were 13.9°C, 27.08°C and 20.06°C respectively. Relatively low temperatures were recorded for the localities of clusters 3 and 4. The annual average temperatures (minimum, maximum and mean) for the localities in cluster 3 were 8.7°C, 21.6°C and 15.2°C respectively. For localities in cluster 4, the average annual temperatures (minimum, maximum and mean) were 7.8°C, 19.9°C and 13.4°C respectively. The temperatures of sampling localities are shown in Table 24.

4.3.3 Altitude

The altitude of the sampling localities varied from 587 m above sea level at Gewane to 3600 m above sea level at Guguftu. The altitude range of localities in cluster 1 was low, with a minimum of 587 m and maximum of 2230 m above sea level. However the majority of localities in this cluster were below 1231 m above sea level.

The general relief conditions of localities in cluster 2 were midland type, which varies from 1320 m to 2195 m above sea level. The altitudes of most of localities in this cluster were below 2000 m above sea level. Relatively high altitudes were recorded for localities in cluster 3 and 4. The altitude range of localities in cluster 3 was from 2060 m at Dangla to 3000 m above sea level at Feres Bet. Altitude range of 2400 m to 3600 m above sea levels was recorded for localities in cluster 4. The altitudes of the sampling localities are shown in Table 24.

Table 24 Altitude and weather data of sampling localities.

Clusters	Sampling locality	Region	Code No.	Altitude (m).	Temperature (°C)			Rainfall (mm)
					Min.	Max.	mean	mean
Cluster 1	Angereb	Amhara	N11	910	18.0	36.0	26.5	850.0
	Aykel	Amhara	N10	2230	11.4	24.1	17.8	1439.0
	Gewane	Afar	N21	587	15.0	33.8	24.6	458.0
	Humera	Tigray	N12	600	20.2	37.6	28.9	620.0
	Manbuk	Benshangul	N06	1230	15.0	33.0	24.5	1300.0
	Melkasedi	Afar	N22	770	18.3	34.2	26.3	471.0
	Menge	Benshangul	N24	1000	19.5	33.5	26.0	1150.0
	Shiraro	Tigray	N15	1100	16.7	35.1	25.9	718.0
	Wohni	Amhara	N09	1000	18.0	34.5	25.5	920.0
Cluster 2	Bambasi	Benshangul	N25	1460	14.6	29.0	22.1	1283.0
	Bir Sheleko	Amhara	N04	1548	16.0	28.0	21.9	1450.0
	Dedessa	Oromia	N26	1320	14.6	30.4	22.5	1479.0
	Hinde	Oromia	N05	2195	11.0	23.0	17.0	2090.0
	Nejo	Oromia	N23	1890	13.1	25.0	19.3	1788.0

Continuation of Table 24.

Clusters	Sampling locality	Region	Code No.	Altitude (m).	Temperature (°C)			Rainfall (mm)
					Min.	Max.	mean	mean
Cluster 3	Dangla	Amhara	N07	2060	7.8	25.8	16.8	1481.2
	Debre Tabor	Amhara	N08	2650	8.4	22.5	16.8	1651.0
	Deneba	Amhara	N02	2670	6.5	18.0	12.5	1015.0
	Feres Bet	Amhara	N03	3005	6.0	17.0	10.4	1350.0
	Gedo	Oromia	N29	2517	7.5	20.0	14.9	1450.0
	Inchini	Oromia	N30	2650	9.5	22.0	16.3	1200.0
	Nekemte	Oromia	N27	2166	12.1	23.5	17.7	2156.0
	Salayish	Amhara	N01	2248	12.0	24.0	17.5	1150.0
	Sendafa	Oromia	N31	2500	11.0	21.0	15.0	1450.0
	Shambu	Oromia	N28	2570	6.5	22.1	14.5	1829.4
Cluster 4	Debark	Amhara	N14	3000	6.0	17.5	11.0	1181.0
	Guguftu	Amhara	N20	3600	5.2	16.0	9.5	1145.7
	Korem	Tigray	N18	2600	10.0	22.5	16.1	750.0
	Woldeya	Amhara	N19	2400	10.1	23.5	16.9	1073.0
Not in any clusters	Abi Adi	Tigray	N16	1800	16.0	28.0	22.4	767.0
	Dabat	Amhara	N13	2656	6.1	19.8	13.0	1254.0
	Mekele	Tigray	N17	2025	11.4	24.5	18.0	563.0

4.4 Honeybee plants

The honeybee plants of the study areas comprise trees, shrubs and various herbs, which include a number of cultivated (annuals and perennials) crops and weeds. In the central and northern parts of the study areas due to extensive cultivation of land, deforestation is a major problem. As a result the natural forests have disappeared. So in these areas the major dependable bee plants are mainly cultivated crops, which include pulses *(Lathyrus sativus, Cicer arientinum, Lens culinaris* and *Vicia faba*), oil crops (*Guizotia abyssinica, Helianthus annus* and *Brassica* spp.) and cereals (*Zea mays* and *Sorghum bicolor*). In western parts of the study areas besides the above mentioned various cultivated crops, the natural forest trees such as *Albizia* spp., *Cordia africana, Acacia* spp., *Croton macrostachys* and *Syzygium* spp. grow widely and are very useful honeybee plants. Moreover, in these areas the horticultural crops such as *Coffea arabica* and *Mangifera indica* are very common honeybee plants.

In addition to cultivated crops, in most parts of the study areas a number of weeds such as *Guizotia scabra,* different *Bidens* spp. and *Caylusea abyssinica* grow extensively and are very important to bees. In the highland areas various *Trifolium* spp. widely grow and play a major role as sources of nectar to honeybees. Moreover, *Eucalyptus globulus* and *Eucalyptus camaldulensis* are extensively planted and become good sources of honey to bees and beekeepers.

Generally, honeybee plants such as *Vernonia* spp., *Echinops* spp., *Acanthus* spp., *Helminthotheca echodes* and *Caylusea abyssinica* are well known for their dry period flowering and serving as subsistence forage to bees in dearth periods. Honeybee plants such as *Slvia luecantha*, *Hypoestes forskaolii*, *Plantago lanceolata*, *Rumex nervosus* and *Urtica simensis* bear flowers all year round and are important to maintain bees throughout the year. Some bee plants like *Acanthus sennii*, *Anthemis tigreensis*, *Bidens prestinaria*, *Carissa edulis*, *Ehretia cymosa*, *Hypoestes forskaolii*, *Maytenus senegalensis*, *Ricinus communis*, *Rumex nervosus*, *Schinus molle* and *Vernonia amygdalina* have wide range of adaptability and observed to grow from very lowland to highland areas. Some of the major bee plants (which were recorded during sample collection) of the study areas with their families, flowering periods and growing altitudes are given in Appendix II.

4.4.1 Pollen grains of poisonous bee plants of the study area.

Along the record of honeybee plants, the pollen grains of some poisonous bee plants were collected. Accordingly, Pollen grains of 9 poisonous species of bee plants from the families Ranunculaceae, Solanaceae, Acanthaceae, Euphorbiaceae and phytolacaceae were analysed and documented.

Ranunculaceae

***Clematis hirsuta* Perr. & Guill.**, (Plate 1, A – F)

Symmetry and form: isopolar simple. Shape: spheroidal, circular outline in polar view. Dimensions: P = 24(22 - 28) μm, E = 23(21 - 25) μm. Aperture: tricolporate, colpi long, 2-3 μm in diameter at equator and fairly uniform throughout the length. Each pore circular 3-4 μm in diameter. Sexine: with fine verrucae and baculated, 1 - 1.5 μm thick, nexine 1 μm thick.

***Clematis simensis* Fresen,** (Plate 1, M – P)

Symmetry and form: isopolar, simple. Shape: spheroidal, circular outline in polar view. Dimensions: P = 20(18-21) µm, E = 22(20-28) µm. Aperture: tricolporate, colpi long and narrow, 2 µm in diameter at equator, each pore circular 2 µm in diameter. Sexine covered with relatively scattered and fine warts (verrucae), baculated. Sexine, 1-1.5 µm thick, nexine 1 µm thick.

Euphorbiaceae

***Croton macrostachys* Hochst ex, Del.,** (Plate 2, A – D)

Form, simple. Shape: spheroidal. Dimensions: D = 73 (64 - 80) µm. Aperture: not observed. Sexine, covered with large and very dense warts (gemmae), baculated. Sexine, 4 µm thick, nexine 1 µm thick.

Solanaceae

***Datura stramonium* L.,** (Plate 2, E – I)

Symmetry and form: isoplar, simple. Shape: spheroidal, circular to subangular outline in polar view. Dimensions: P = 46(43-50) µm, E = 47(43-51) µm. Aperture: tricolporate, colpi, fairly uniform, 2 µm in diameter at equator, each pore circular 1-1.5 µm in diameter. Sexine, irregularly striated and the striae are branched, baculated. Sexine 2 µm thick, nexine 1-5 µm thick.

***Discopodium penninervium* Hochst.**, (Plate 1, K – L)

Symmetry and form: isopolar, simple. Shape: spheroidal, circular to subangular outline in polar view. Dimensions: P = 27(27 - 28) µm, E = 29(27 - 32) µm. Aperture: tricolporate; colpi 2 µm in diameter, relatively narrow, fairly uniform throughout their lengths; each pore circular 5 µm in diameter. Sexine, baculated, 1.5 – 2 µm thick, nexine 0.5 µm thick.

Euphorbiaceae

***Euphorbia abyssinica* Gmel.**, (Plate 3, G – I)

Symmetry and form: isopolar, simple. Shape: spheroidal, circular to semiangular outline in polar view. Dimensions: P = 35 (31 - 36) µm, E = 39 (35 - 42) µm. Aperture: tricolporate; colpi 10 - 12 µm wide at equator, fairly uniform throughout their remaining length; each pore circular 5 µm in diameter. Intine protrudes at apertures. Sexine baculated, 2 µm thick, nexine 1 µm thick.

Acanthaceae

***Justicia schimperiana* T. Anders.**, (Plate 3, A – C)

Symmetry and form: isopolar, simple. Shape: prolate, circular outline in polar view and some of the pollen grains are constricted at the equator. Dimensions: P = 66 (60 - 76) µm, E = 47 (45 - 48) µm. Aperture: dicolporate; colpi long, 20-25 µm and fairly uniform throughout their length; each pore with 6 - 10 µm in diameter and the entine is protruded at pore. Sexine, finely reticulated, baculated and 1.5 µm thick, nexine 1 µm thick.

Phytolaccaceae

Phytolacca dodecandra **L'Herit,** (Plate 1, G – J)

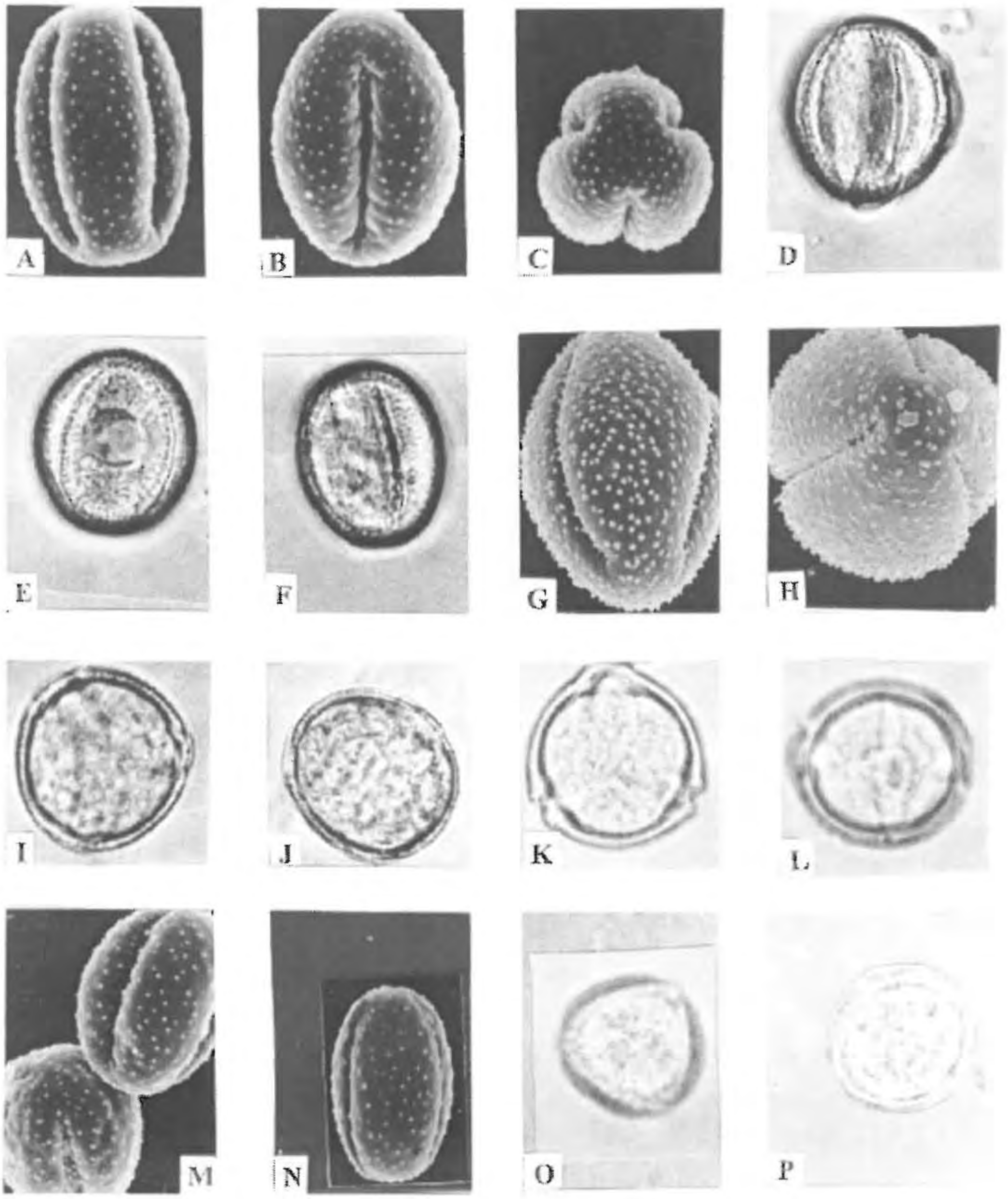
Symmetry and form: isopolar, simple. Shape: spheroidal, circular outline in polar view. Dimensions: P = 27 (26 - 28) µm, E = 30 (27 - 31) µm. Aperture: tricolporate; colpi 4 - 5 µm wide at equator, long and narrow; each pore circular 4 - 5 µm in diameter. Sexine, is covered with relatively dense verrucae and baculated and 2 µm thick, nexine 1 µm thick.

Ranunculaceae

Ranunculus multifidus **Forssk.,** (Plate 3, D – F)

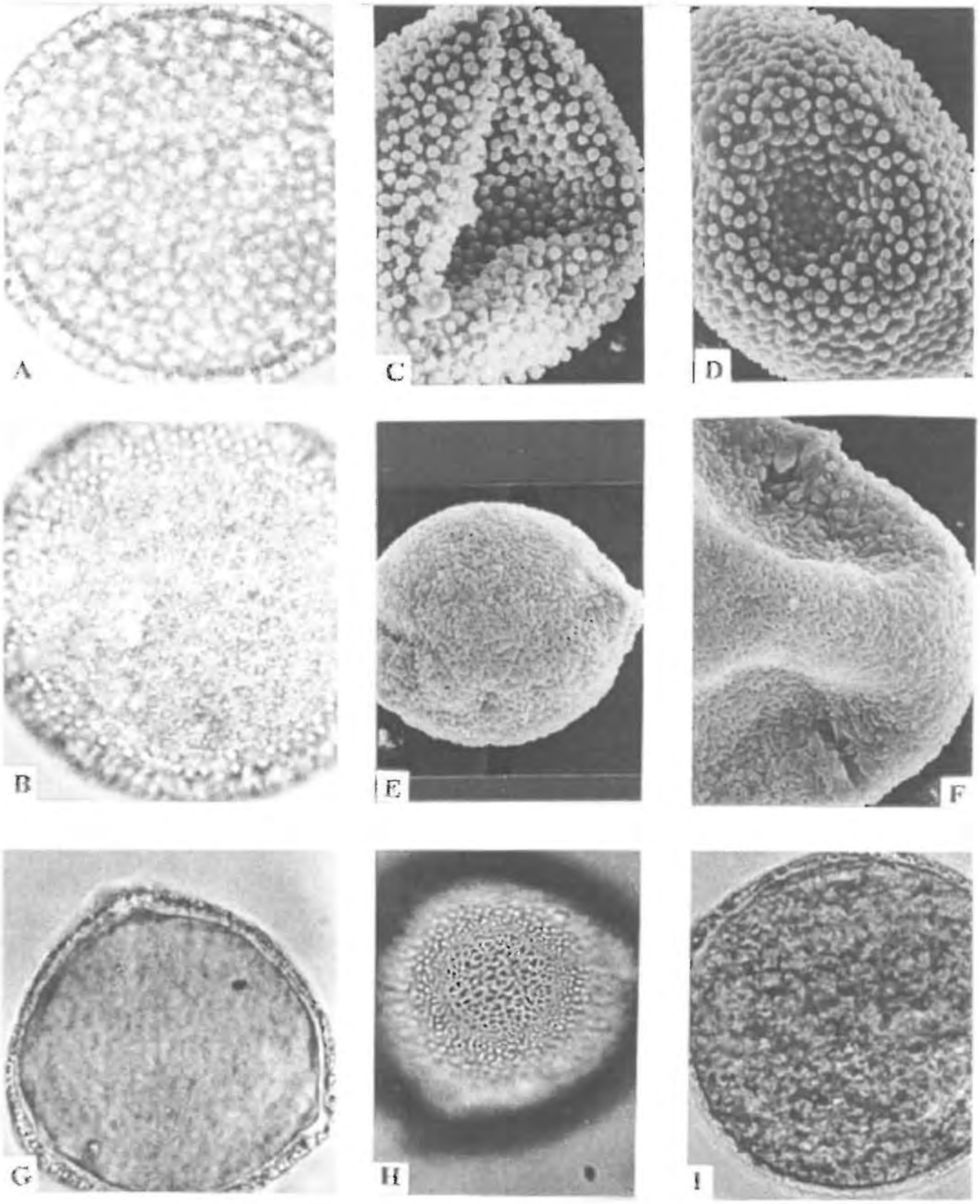
Symmetry and form: isopolar, simple. Shape subobate, circular outline in polar view. Dimensions: P = 30(26 - 32) µm, E = 35(32 - 39) µm. Aperture: triporate, sometimes tetra porate; each pore 5 µm in diameter. Sexine is covered with verrucae and baculated. Sexine 1 µm thick, nexine 0.5 - 1 µm thick.

Plate 1



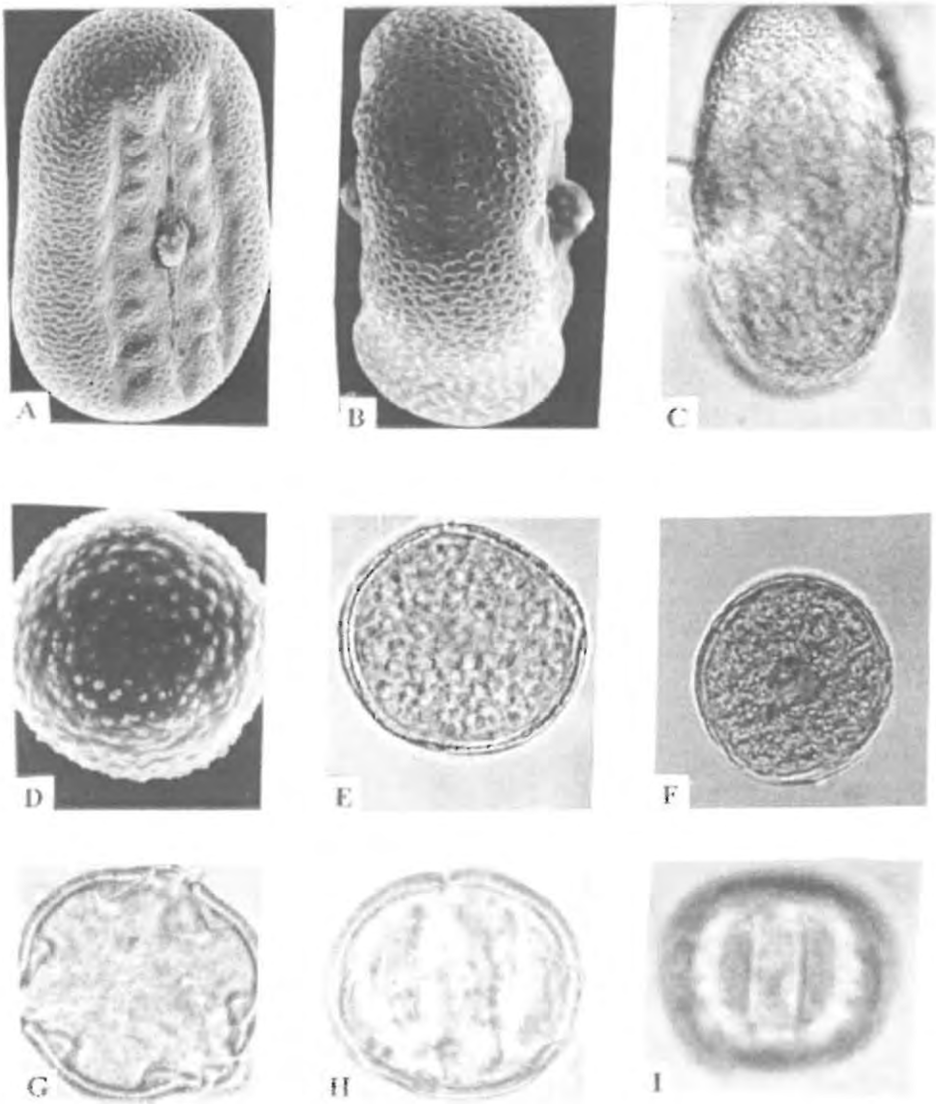
Clematis hirsuta (A - C (X1500) SEM, D – F (X1000) LM); *Phytolacca dodecandra* (G – H (X1500) SEM, I- J (X1000) LM); *Discopodium penninervium* (K – L (X1000) LM); *Clematis simensis* M (X1100) N (X1000) SEM) (O – P (X1000) LM).

Plate 2



Croton macrostachys (A – B (X1000) LM, C- D (X1000) SEM);
Datura stramonium E (X1000) SEM, F (X1500) SEM; G – I (X1000) LM).

Plate 3



Justicia schimperiana (A (X1000) SEM, B (X1500) SEM, C (X1000) LM); *Ranunculus multifidus* (D (X1500) SEM, E –F (X1000) LM); *Euphorbia abyssinica* G –H, (X1000) LM).

CHAPTER 5

DISCUSSION

5.1 Classification

Analyses of the morphometric and behavioural characters of the honeybees of the northern Ethiopia revealed a high degree of variability in size, pigmentation and behaviour (swarming, migration and aggressiveness) within and among the statistically defined morphoclusters. Such high degrees of variability seem due to the results of the diversification of the physiographic and climatic conditions of the regions and their intermingling in very proximity. The findings agree with the results of Radloff and Hepburn (1997a) who also observed high degrees of variability in size and pigmentation of Ethiopian honeybees along a transect of the country. Similar variability was also observed for the neighbouring Sudanese honeybees (Rashad and El-Sarag, 1978, 1980; Saeed, 1981; Mohamed, 1982; Mogga, 1988; and El-Sarrag *et al.,* 1992). The multivariate statistical analyses of the northern Ethiopia honeybees revealed the existence of four distinct morphoclusters (Figure 3).

Honeybees from the eastern and northwestern parts of the country (morphocluster 1) are the smallest and lighter in colour than the rest of morphoclusters. The morphometric values of this group were close to those of the honeybee subspecies, *A. m. jemenitica,* which was reported from semi-desert parts of Sudan, Somalia, and northern parts of Ethiopia (Mogga, 1988; Ruttner, 1988; Radloff and Hepburn, 1997a). Values for the hair length of this group were within the range of values of *A. m. jemenitica* (Mogga, 1988; Ruttner, 1988; Radloff and Hepburn, 1997a). The sternite 3 longitudinal (11), wax plate transversal (13), scutellum pigmentation (35) and scutellar plate pigmentation (36) mean values of this group matched the values obtained for *A. m. jemenitica* of eastern Africa (Radloff and Hepburn, 1997a; Hepburn and Radloff, 1998). The mean values of tergite 3 longitudinal (9) plus tergite 4 longitudinal (10) for this group fall within the range of values of *A. m. jemenitica* population of Somalia (Ruttner, 1988). Based on morphometrical similarities, this morphocluster is classified as *A. m. jemenitica.*

Behaviourally, morphocluster 1 is the second highest in a rate of reproductive swarming after morphocluster 2 (Figure 18), and has as many as 8–12 swarms per colony, which agrees with the reports of Ruttner (1988) and Karpowicz (1989) for *A. m. jemenitica.* This morphocluster is reported to have a fast population build-up ability. Rapid build-up is an important adaptive feature of *A. m. jemenitica* to cope up with a semi-arid habitat where rainfall and flowering periods are very short and fast respectively (Chandler, 1976).

Morphocluster 1 has a relatively high incidence of migration, after morphocluster 2 (Figures 25 and 26), which agrees with similar reports for *A. m. jemenitica* in sub-Saharan, Chad and Sudan (Gadbin, 1976; Rashad and El-Sarrag, 1980). The aggressiveness of the bees of this morphocluster was reported to be higher than that of other morphoclusters (Figures 29, 30 and 31), which is in agreement with the quick reaction and nervous behaviour reported for *A. m. jemenitica* (Karpowicz, 1989; Gadbin, 1976).

The physiography of the sampled localities for morphocluster 1, was mainly lowlands with a range of altitudes between 587 – 2230 m, of which 90% are below 1231 m. The climatic features of the majority of these areas are hot, semi-arid to arid conditions with minimum, maximum and mean annual temperatures of 16.9°C, 33.5°C and 25.1°C respectively. The mean annual rainfall for the sampled localities was 881 mm and the majority of the localities receive less than 1000 mm, (the detailed ecological features of morphocluster 1 distribution areas are given in section 1.2.1 – 1.2.1.2). This agrees with the ecological conditions of *A. m. jemenitica,* which are reported to be distributed in the Sahel climatic zone with temperatures of 27 - 31°C and low rainfall of 50 – 600 mm in semi-desert parts of Chad, Sudan, Somalia and Yemen (Ruttner, 1988). The distribution of this morphocluster is adjacent to *A. m. jemenitica* distribution areas in the west along the Sudan and in the east along Somalia borders. So the combined morphological, behavioural, ecological and biogeographical similarities strengthen the classification of this group as *A. m. jemenitica.*

Honeybees from the western, humid midlands (morphocluster 2) are relatively larger than those of morphocluster 1 and smaller than those of morphoculsters 3 and 4 and much darker than those of morphocluster 1. When the morphometric values of this morphocluster were compared with different honeybee subspecies of Africa, they were found to be much closer to the *A. m. scutellata* of east Africa. The mean value for hair length of this group corresponded with similar values obtained for *A. m. scutellata* by Hepburn and Radloff (1998) and Ruttner (1988). The mean values of sternite 3 longitudinal (11), wax plate transversal (13) and scutellar plate pigmentation (36) of this morphocluster match those obtained for *A. m. scutellata* of east Africa (Radloff and Hepburn, 1997a; Hepburn and Radloff, 1998).

However, the abdominal tergite pigmentation of this morphocluster was darker than that obtained for *A. m. scutellata* (Ruttner, 1988; Radloff and Hepburn, 1997a; Hepburn and Radloff, 1998). However, obvious colour variability within *A. m. scutellata* populations was noted (Kerr and Portugal-Araújo, 1958; Smith, 1961). Moreover, Radloff and Hepburn (2000) in their population structure and morphometric variance study of *A. m. scutellata,* recognised significant differences within the local populations of this subspecies. These indicate the possibilities of occurrence of a darker *A. m. scutellata* population depending on the ecological conditions of the populations. The bees of this morphocluster occur in high annual rainfall (1164 mm – 2090 mm) areas, which have a strong negative correlation with pigmentation (Table 7). Based on observed morphometric similarities, this group is classified as *A. m. scutellata.*

In relation to behaviour, the seasonally-based movement of colonies was reported from all localities except Bir Sheleko. The occurrence of migration and the proportion of colonies reported to migrate were higher than that for the rest of clusters (Figures 25 and 26). This agrees with the report of high migratory tendencies of *A. m. scutellata* (Ruttner, 1976). In this area beekeepers reported the absconding of colonies when they are disturbed during honey harvesting, which also agrees with the absconding behaviour of *A. m. scutellata* associated with disturbance (Ruttner, 1976).

The highest proportions of swarming and largest number of swarms per colony were recorded for this morphocluster (Figures 18 and 19), and this also agrees with the high swarming tendencies of *A. m. scutellata* (Ruttner, 1976). The degree of aggressiveness and the presence of unprovoked attacks by bees in this morphocluster were reported to be second only to cluster 1 bees, (Figures 30 and 31), which agrees with reports on the high aggressiveness of *A. m. scutellata* (Ruttner, 1976; Dietz *et al.*, 1986).

Ecologically, morphocluster 2 bees occur in midland areas, with an altitude range of 1320 m to 2195 m with humid and extended rainfall reaching a mean annual rainfall of 1594 mm for sampling localities. The minimum, maximum and mean annual temperatures of the sampling localities in this cluster were 13.9°C, 27.8°C and 20.6°C respectively, (the detailed ecological features of morphocluster 2 distribution area are given in section 1.2.2). These agree with the ecological features of *A. m. scutellata* reported to occur in the mid-lands with an altitude range of 500 m – 2400 m and annual temperatures of 16°C–23°C (Ruttner, 1988) in thorn tree, tall grass savannah and tropical semi-evergreen deciduous forest (Fletcher, 1978). The morphological, behavioural and ecological characters of this morphocluster are much closer to *A. m. scutellata* than other honeybee species, of eastern Africa and support the classification of these honeybees as *A. m. scutellata*.

Honeybees from the central parts of the country (morphocluster 3) are generally larger than those of morphoclusters 1 and 2 and smaller than 4. The morphometric values of these bees were compared with different honeybee subspecies reported from east Africa and were found to be closer in most characters to *A. m. bandasii*, reported from the central highlands of the Ethiopia (Radloff and Hepburn, 1997a) and in dry savannah of central Sudan (Mogga, 1988). The mean values of the hair length (1), scutellum pigmentation (35), scutellar plate pigmentation (36), pigmentation of tergite 2 (32), sternite 3 longitudinal (11) and wax plate transversal (13) fall within the same range obtained for *A. m. bandasii* (Radloff and Hepburn, 1997a). Except for localities like Dangla and Gedo, this morphocluster is dark, with a 15:1 black to yellow ratio for abdominal tergite 2, which is close to that of *A. m. bandasii* of Ethiopia (Radloff and Hepburn, 1997a). Morphometrically cluster 3 is intermediate in position between morphocluster 2 (*A. m. scutellata*) and morphocluster 4 (*A. m. monticola*) (Figures 9 – 14) but is a statistically very significantly distinct group. Based on morphometric similarities this group is classified as *A. m. bandasii.*

Behaviourally, morphocluster 3 exhibits relatively less reproductive swarming tendency and a lower number of swarms per colony than morphoclusters 1 and 2, but slightly higher than morphocluster 4 (Figures 18 and 19). Compared to morphoclusters 1 and 2, the migratory tendency of these bees is very low and it does not significantly differ from morphocluster 4. In this cluster, migrations were reported only in localities like Nekemte and Dangla, which are adjacent to distribution areas of *A. m. scutellata* and *A. m. jemenitica.* The aggressiveness of this morphocluster is relatively low and few cases of unprovoked attacks were reported (Figures 29 – 31). Generally, these honeybees also exhibit behavioural characters intermediate between *A. m. scutellata* and *A. m. monticola.*

Ecologically this morphocluster occurs in the central highland parts of the country within the dry tropical climate zone. However, the dry tropical climate of the highlands of Ethiopia is moderated by altitude (Van Chi–Bonnardel, 1973). The altitudes of the sampling localities vary from 2060 m to 3000 m with a mean annual rainfall of 1432 mm for all localities. The minimum, maximum and mean annual temperatures of the sampling localities were 8.7°C, 21.6°C and 15.2°C respectively, (the ecological features of morphocluster 3 distribution area are given in section 1.2.3). *A. m. bandasii* was reported from similar areas in the central highlands of Ethiopia with an altitude range of 1800 m to 2400 m (Radloff and Hepburn, 1997a). Even if the behavioural aspect of these bees is not well documented, the ecological similarities support the morphometric classification of this group as *A. m. bandasii*.

Although Radloff and Hepburn (1997a) reported *A. m. bandasii* from Ethiopia, later they suggested that these bees are a population of *A. m. jemenitica* until an extensive study of the area is carried out (Hepburn and Radloff, 1998). As more detailed studies indicate, these bees are very different from *A. m. jemenitica* in a discriminant analysis (Figure 3 and Table 13), in morphology (Figures 9–14), in behaviour (Figures 18, 19, 25, 26 and 30) and in ecology. So this honeybee population is entirely different from *A. m. jemenitica* and should retain the former name *A. m. bandasii*.

Honeybees from the mountainous highland regions of the northern parts of the study area (morphocluster 4) were the largest bees in all values related to body sizes and hair length (Figures 9–14). The mean values of this group were also greater than those of *A. m.*

scutellata, A. m. bandasii and *A. m. sudanesis*, reported from the Horn of Africa (Radloff and Hepburn, 1997a). The mean values of sizes of body parts of this morphocluster were also larger than values recorded for most of the sub-Saharan subspecies (Hepburn and Radloff, 1998).

The sternite 3 longitudinal (11), wax plate transversal (13) values of this group were much closer to values obtained for *A. m. sahariensis* (Hepburn and Radloff, 1998), but *A. m. sahariensis* are light bees while these bees are dark. However, in terms of pigmentation, hair length and sizes of body parts values, this morphocluster is closer to the *A. m. monticola* of east Africa. The mean value of the scutellum pigmentation (35) for this group was within the range values obtained for *A. m. monticola* (Ruttner, 1988; Hepburn and Radloff, 1998). The scutellar plate pigmentation (36) and wax plate transversal (13) mean values of this group corresponded with values obtained for *A. m. monticola* (Hepburn and Radloff, 1998). The mean value of tergite 3 longitudinal (9) plus tergite 4 longitudinal (10) and hair length (1) values of this group also matched values obtained for *A. m. monticola* (Ruttner, 1988). Hence, morphometrically this group is classified as *A. m. monticola*.

In relation to behaviour, morphocluster 4 has a lower reproductive swarming tendency and lower number of swarms per colony than the other morphoclusters (Figures 18 and 19) and swarming does not take place every year. Beekeepers reported that some colonies remain up to 10 to 20 years without reproductive swarming. This generally indicates that the honeybee population of this morphocluster is less inclined to swarm. Migration of colonies is not reported from this area, even in dearth conditions the colony stays in the same hive gradually becoming weak and finally dieing, which agrees with Chandler's (1976) report that some ecotypes of African honeybees, stay in the same hive for many years through many generations of queens.

The temperament of morphocluster 4 bees is generally gentle: more cases of docility, a low proportion of aggressiveness and the absence of unprovoked attacks were reported (Figures 29, 30 and 31). In these areas the bees stay in the home yards with domestic animals and family members. This agrees with reports on the gentleness and manageability of *A. m. monticola* as European honeybees (Smith, 1961; Ruttner, 1988; Fletcher, 1978; Dietz *et al.,* 1986; Hepburn and Radloff, 1998).

Ecologically, these bees occur at high altitudes between 2400 m to 3600 m in areas where a number of isolated mountains with altitude range of 3979 m to 4620 m are found. The minimum, maximum and mean annual temperatures of sampling localities were 7.8°C, 19.9°C and 13.4°C respectively. However, in some seasons in some localities the mean annual temperature drops below 7.5°C and on the top of mountains the minimum temperature falls below 0°C (MOA, 1998; Goebel *et al.,* 1983). The occurrence of bees in the Semen Mountainous in morphocluster 4 distribution areas was observed despite an overnight temperature of –3.0°C (Rea, 1974). The mean annual rainfall of the sampling localities varies from 750 mm to 1181 mm, (the ecological features of morphocluster 4 are treated in section 1.2.4). *A. m. monticola* was reported to occur at high altitudes between 2400 – 3200 m in east African mountains with a mean annual temperature of

11.2°C (Ruttner, 1988; Smith, 1961). Based on morphometric, behavioural and ecological similarities it is evident that this morphocluster should be classified as *A. m. monticola.* The existence of a number of isolated populations of *A. m. monticola* in different parts of east Africa like Mt. Kilimanjaro and Mt. Meru in Tanzania, Mt. Elgon and Mt. Kenya in Kenya and in Burundi have been reported (Ruttner, 1988; Smith, 1961). Radloff and Hepburn (1997b) in their multivariate analysis of honeybees of west Africa resolved a "*monticola*-like" morphocluster in the Cameroon highlands. Kassaye (1990) also reported the existence of *A. m. monticola* in southeast parts of the country in Dinsho highland, which is far from the sampling localities of this morphocluster, and which support the possibility of the occurrence of disjunct populations of *A. m. monticola.*

Even if various authors agree on the existence of isolated *A. m. monticola* populations, they have different hypotheses on the origins and the relationships of these *monticola* groups. Ruttner (1988, 1992) suggested that these widely geographically separated *A. m. monticola* populations form an archipelago of genetically related bees, which are relics of a once large and a more or less coherent population during the last pluvial period. Meixner *et al.* (1989, 1994) on the basis of their morphological and allozyme studies supported the hypothesis of a common ancestor of *A. m. monticola* populations and thought that they were isolated by climatic changes.

On the other hand Kerr (1992) suggested that *A. m. monticola* is derived from the neighbouring *A. m. scutellata* as a result of selection to cold ecological adaptation like black colour. Hepburn *et al.* (2000), using morphometric characters, flight dimensional measurements and mitochondrial DNA analysis tried to demonstrate that the isolated *monticola* populations are differentiated from subspecies surrounding each particular mountain and thus are only isolated ecotypes.

The correlation analyses of the morphometric characters and the environmental factors in this study (Tables 5 and 6) indicate that size and pigmentation are highly influenced by environmental factors. Smaller and lighter coloured honeybees are found at lower altitudes (morphocluster 1) and size gradually increases so that very large and dark bees are obtained at high altitudes in mountain areas (morphocluster 4). This agrees with the findings of Smith (1961) who indicated the presence of phenotypic variations as altitude varies from the coast, to the highlands and finally mountains. The highly adaptive value of size in honeybees was also well recognised (Ruttner, 1988).

The mountain bees, *A. m. monticola,* are larger than the lowland bees, which, complies with Bergmann's rule (lower surface/volume ratio is important to reduce the heat loss in colder climates). So, variations that exist among the morphoclusters of this study seem to be the result of the gradation of environmental factors that select bees to adapt to specific ecological conditions, which further supports the hypothesis that differentiation of *A. m. monticola* from its surrounding subspecies is an adaptive process.

Moreover, in this study the *A. m. monticola* population shares close similarities in many behavioural characters with the surrounding population of *A. m. bandasii* (Figures 18, 26, and 30), which occurs in closely related ecological conditions. This shows that the behavioural characters are also a reflection of environmental conditions and this further strengthens the idea of differentiation of *A. m. monticola* as result of ecological adaptation. Environmental influences on both morphological and behavioural characters of honeybees are well recognised (Daly and Balling, 1978; Spivak *et al.*, 1988; Ruttner, 1988; Cornuet and Garnery, 1991a; Daly and Morse, 1991; Nazzi, 1992; Hepburn *et al.*, 2000). Generally, in this study the four distinct morphological clusters are also behaviourally different and both morphological and behavioural characters are also believed to be the result of ecological factors. The geographical distribution of these subspecies is treated in section 5.2 and their delineation is depicted in Figure 37.

5.2 Distribution of the subspecies in the study areas

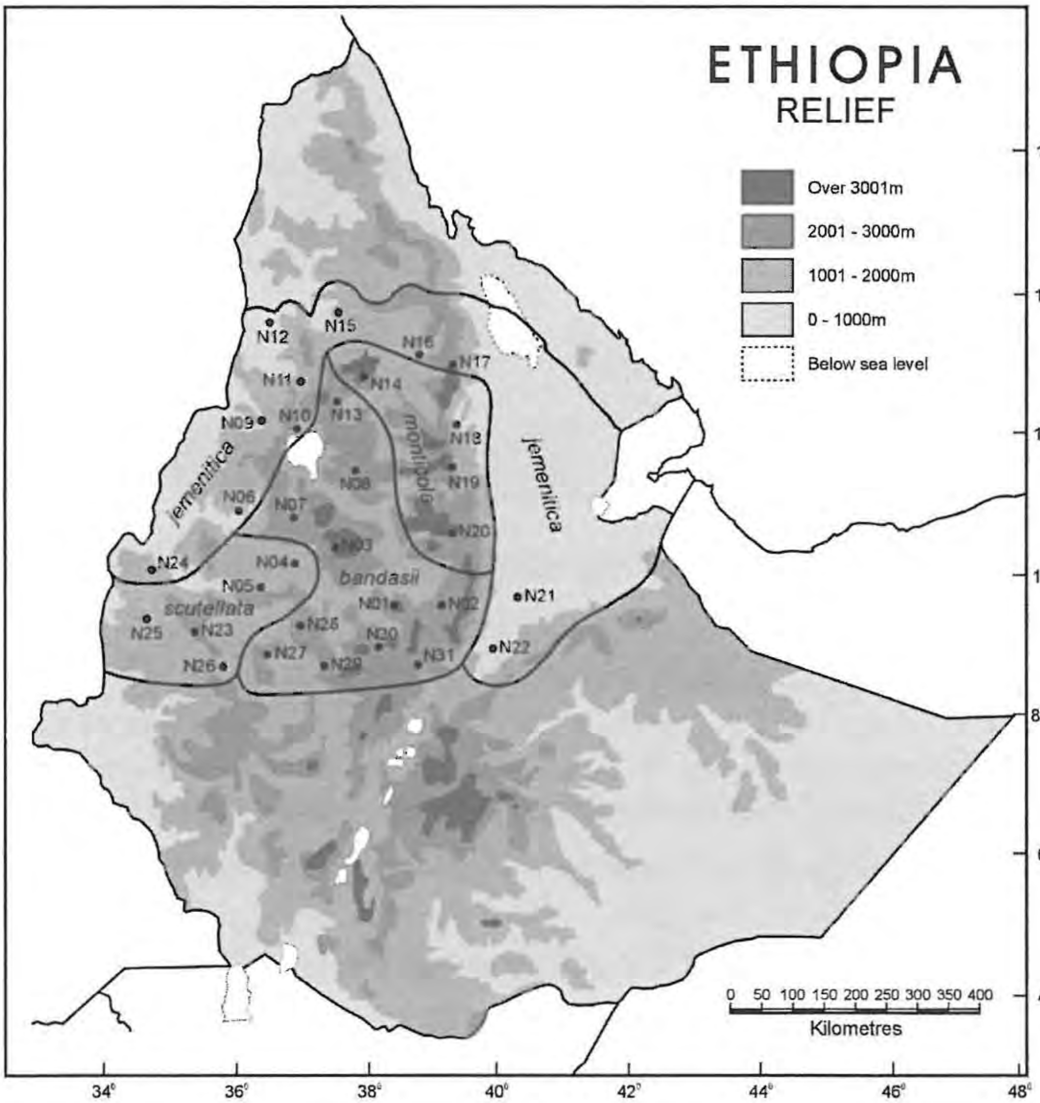
The distribution of subspecies is predicted with the following assumptions: the gene flow within African honeybees is very high due to high swarming and migratory behaviour (Hepburn and Radloff, 1998) and subsequent low molecular differentiation among African subspecies is well noted (Frank *et al.*, 2001). The average movement (over 45 years) of Africanized honeybees in America was also estimated to be 272km per year (Kerr, 1992), while the average inter-localities distance in this study was less than 100 km, so it is reasonable to assume that the honeybees between sampling localities of the same cluster belong to the same group of bees. Accordingly, the distributions of these subspecies were extrapolated by considering honeybees between sampling localities of the same group as belonging to the same cluster. Moreover, during extrapolation, ecological similarities were taken into consideration. Fletcher (1978) tried to predict the distribution of African honeybee races based on climatic correlations of the area in which Ruttner (1988) in his morphometric analyses confirmed that Fletcher's (1978) prediction was absolutely correct.

Based on this, *A. m. jemenitica* is distributed in the northwest parts of the study area along the Sudan border areas above Kumruk, west of Manbuk, west of Aykel up to Metema, west of Lay Armacho (all areas of the Angereb lowland); in the north, the western Tigray zone places like Humera and Shiraro. In the east, the distributions of these bees include all areas of the Afar lowland plains and the associated valleys and escarpments. Honeybees from Abi Adi (N16), even if they were scattered among different clusters, had more affinity to *A. m. jemenitica*. The ecology of Abi Adi is warm lowland, which is similar to the ecology of other groups of *A. m. jemenitica*. Honeybees of Mekele (N17) were intermediate between *A. m. jemenitica* and *A. m. monticola*. So until further confirmation, the areas above Mekele including Abi Adi can be considered as an *A. m. jemenitica* distribution area, which connects the eastern and western *A. m. jemenitica* populations (Figure 37). *A. m. scutellata* is distributed in the western humid mid-land parts of the country, which includes southwestern parts of Gojjam (around Bir Sheleko and Chagni), all areas of Wollega, west of Nekemte and Shambu up to Assosa and Dembidolo. The continuous distribution of this group was observed in similar ecological areas in southwest parts of the country in places like Gecha and Masha (Amssalu *et al.*, 2002)

A. m. bandasii is distributed in all areas of the central highlands up to western parts of south Gonder, west and east Gojjam, north Showa and west Showa up to Nekemte and Shambu. The continuous occurrence of this group was noted in southern parts of the central highlands of Ethiopia in areas like Wolliso and Hossana (Amssalu *et al.*, 2002). However, the distribution of *A. m. bandasii* is not continuous with that of the population of *A. m. bandasii* of Sudan, which was reported to occur from the dry savannah of the central Sudan (Mogga, 1988). Its distribution has been interrupted by the distribution of *A. m. jemenitica* and *A. m. scutellata* in the western lowland parts of the study area along the Sudan border (Figure 37). According to the sampling localities, the *A. m. monticola* population occurs as a continuous population starting from Guguftu in south Wollo up to Woko (west of Woldeya) and the highland areas of east of Debre Tabor, the plateau of Korem (around Lake Ashenge) and south of Mekele. These bees are distributed to north

Gonder near Milligebsa in Debark, and the Semen Mountains areas. Except for river valleys, the majority of sampling localities of this morphocluster are highlands and rugged mountains. The distribution of these subspecies is shown in Figure 37.

Figure 37 The distribution of subspecies of *A. mellifera* L. in the northern parts of Ethiopia, (numbers with N indicate the sampling localities).



Generally, the distribution of these subspecies match the major ecological areas, described in section 1.2.1 – 1.2.4. However there are a number of small sub-ecological areas within the major ecological ones. In such small sub-ecological areas significant morphological variations were not observed. Even if variations appeared as a result of local adaptation could be homogenised by the large population from the surrounding major ecological areas as a result of movements of bees. Such conditions observed in the honeybee samples collected from the low altitude areas of the strips of Dedessa river valley and from Salayish around the Jema river valley in which, in both cases the bees were morphologically similar with the population of bees from the high altitude of the major surrounding ecologies, in their respective areas. However such types of strip of sub-ecological areas could be important from the behavioural and seasonal bee management point of view.

These statistically defined morphoclusters occur as continuous populations without geographical barriers, so that an exchange of genes among them occurs naturally, due to the movements of bees during swarming and migration. As a result, they are interlinked and connected by transitional types (Figures 2 and 3). Similar conditions were also observed in the classification of African honeybees (Ruttner, 1981). However in Africa, in the absence of geographical barriers, the occurrence of different subspecies as result of ecological barriers was recognised (Ruttner, 1981, 1988; Dietz *et al.*, 1986).

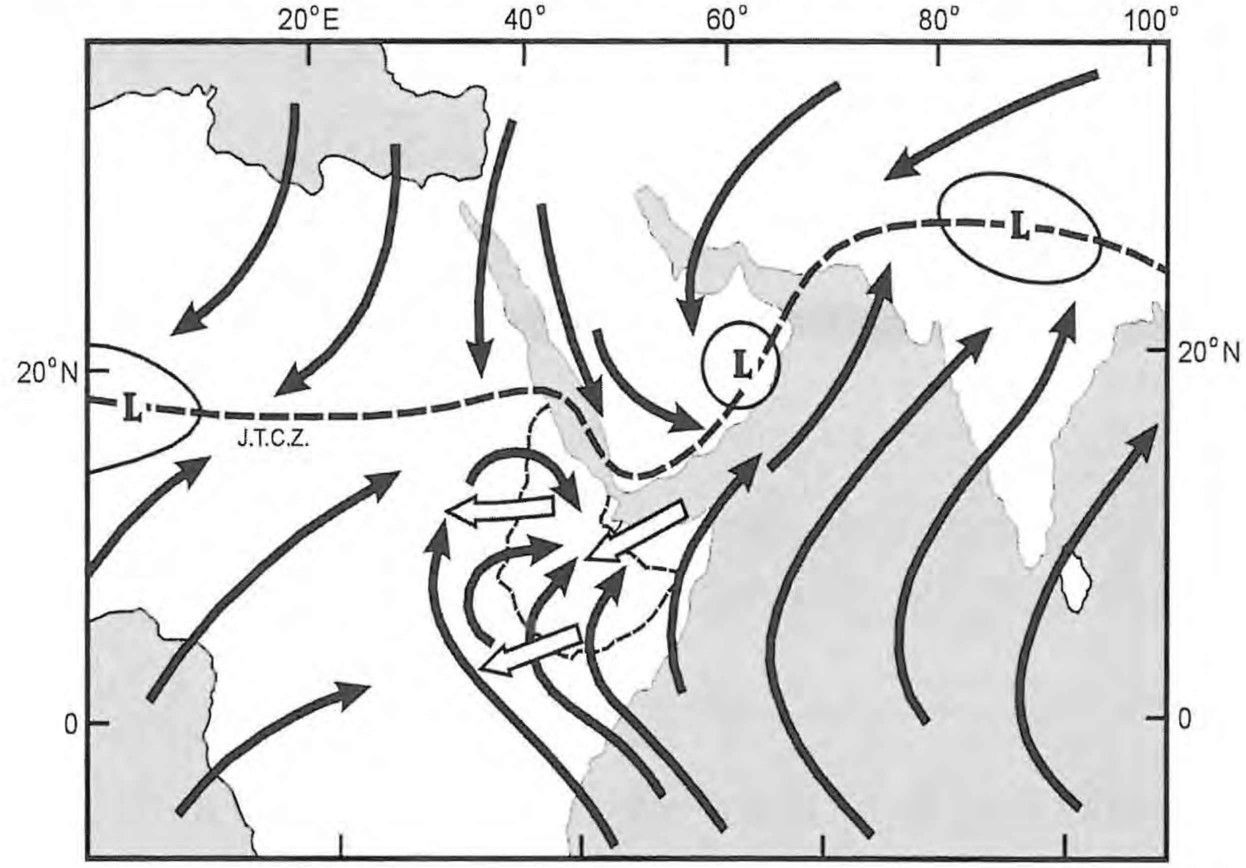
Ruttner (1988) emphasised that climate is the main factor for isolating honeybee subspecies in tropical Africa. Moreover in the absence of physical and reproductive barriers, the occurrence of clinal changes between the adjacent populations has been well noted (Futuyma, 1986). In this study, variations in ecological factors (rainfall, altitude and temperature) are the major factors that alter the colony seasonal cycles and lead to subsequent partial reproductive isolation among these defined morphoclusters.

5.3 Colony seasonal cycles

The colony seasonal cycles such as brood rearing and swarming periods are governed by the climatic conditions of the area. Although the study areas generally fall into two major climatic zones, the Sahelian (northwest and eastern part) and dry tropical (the rest of the study area), variations in altitude, temperature and rainfall (amount and distribution) further create significant ecological variables within these major climatic zones. Temperature and rainfall variations within the same climatic zones of Africa (within Mediterranean climate (in northwest Africa) and within dry tropical climate (in southeast Africa)) and the occurrence of variations in colony seasonal cycles among different subspecies of the same climatic zones were observed (Hepburn and Radloff, 1997).

It was observed that the commencement of flowering and brood rearing times of colonies highly varied depending on the rainfall pattern of the area. In Ethiopia, the major rains occur when humid air starts to flow towards the country from the southwest (Figure 38). The rain gradually extends to the central highlands and reaches the extreme northern and eastern parts of the country last. Again, the rains end first in the same extreme north and east, when humid air is pushed by dry and cold air from central Asia and Arabia (Figure 39). The humid air is gradually pushed back to the central and, finally, to extreme southwest parts of the country.

Figure 38 Air flow patterns around Ethiopia during summer, when humid air starts to enter the country from the southwest which bring rainfalls, (After Goebel *et al.*, 1983).



In this rainfall pattern, the northern and eastern parts of the country receive rain relatively late and for relatively short periods while in the extreme southwest, raining starts early and stops very late while the central highlands have intermediate conditions. In this process the rainfall is long and high in the southwest and short and low in the extreme eastern, northern and northwestern parts of the study area (Figure 40).

Figure 39 Air flow patterns around Ethiopia during autumn when the dry air starts to enter the country from central Asia and Arabia in which dry period starts, (After Goebel *et al.*, 1983).

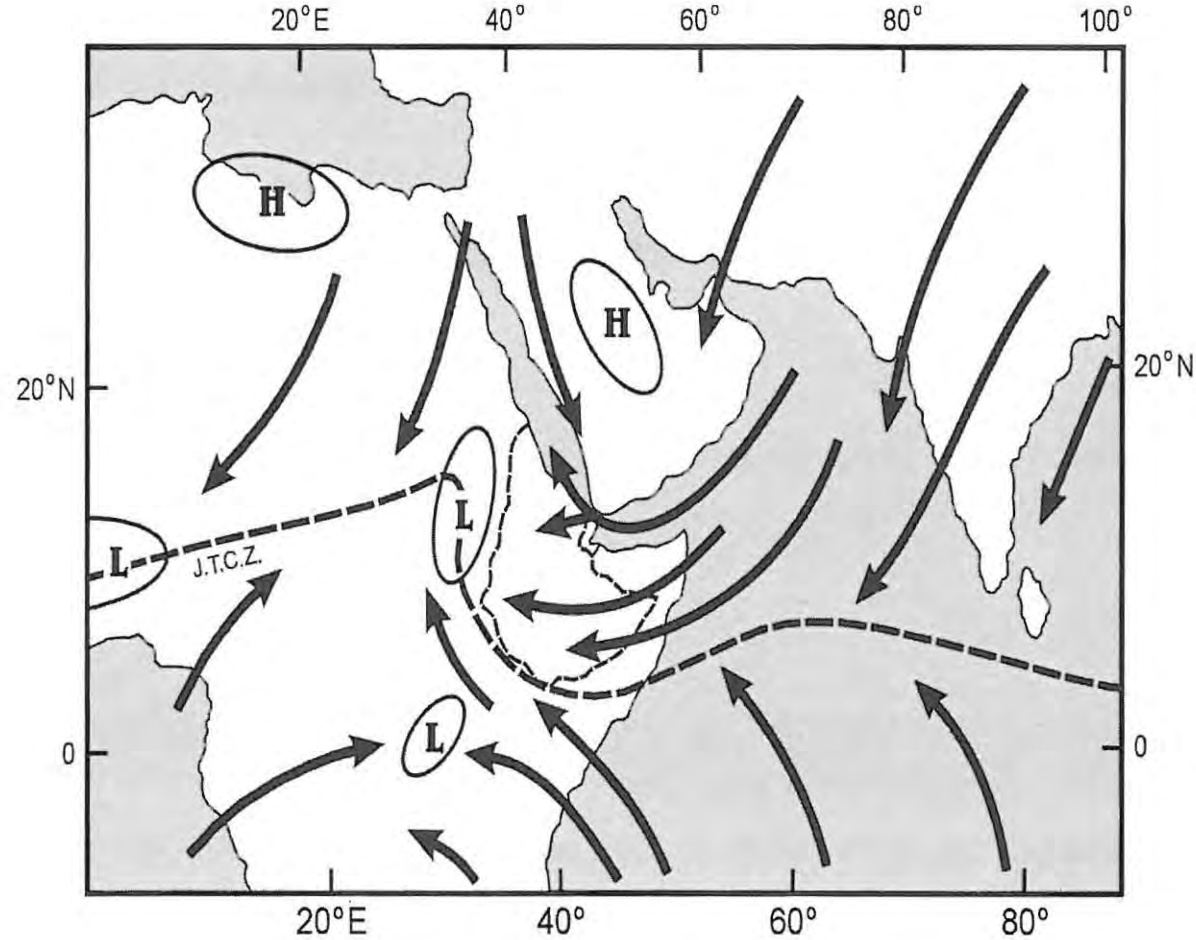
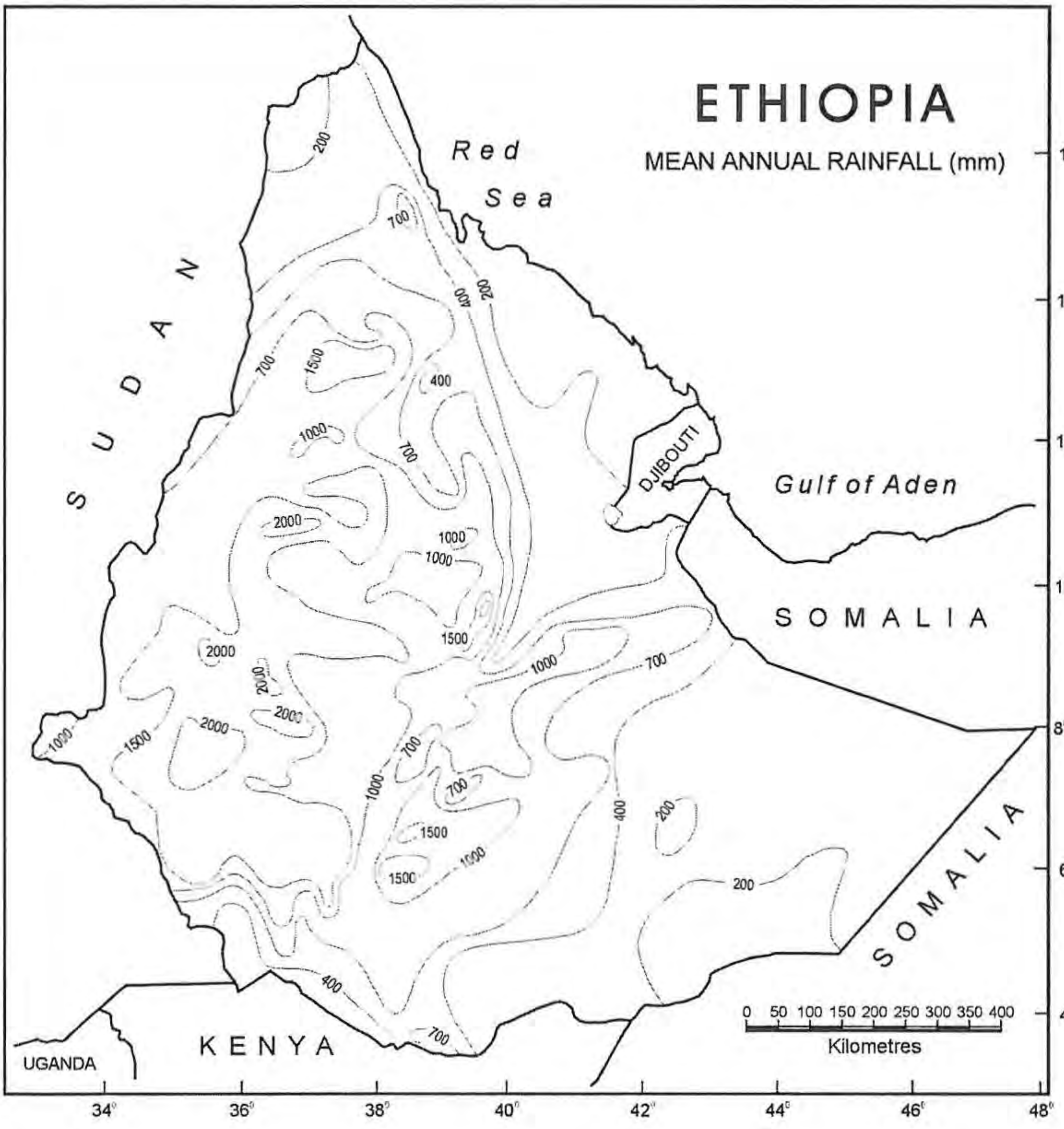


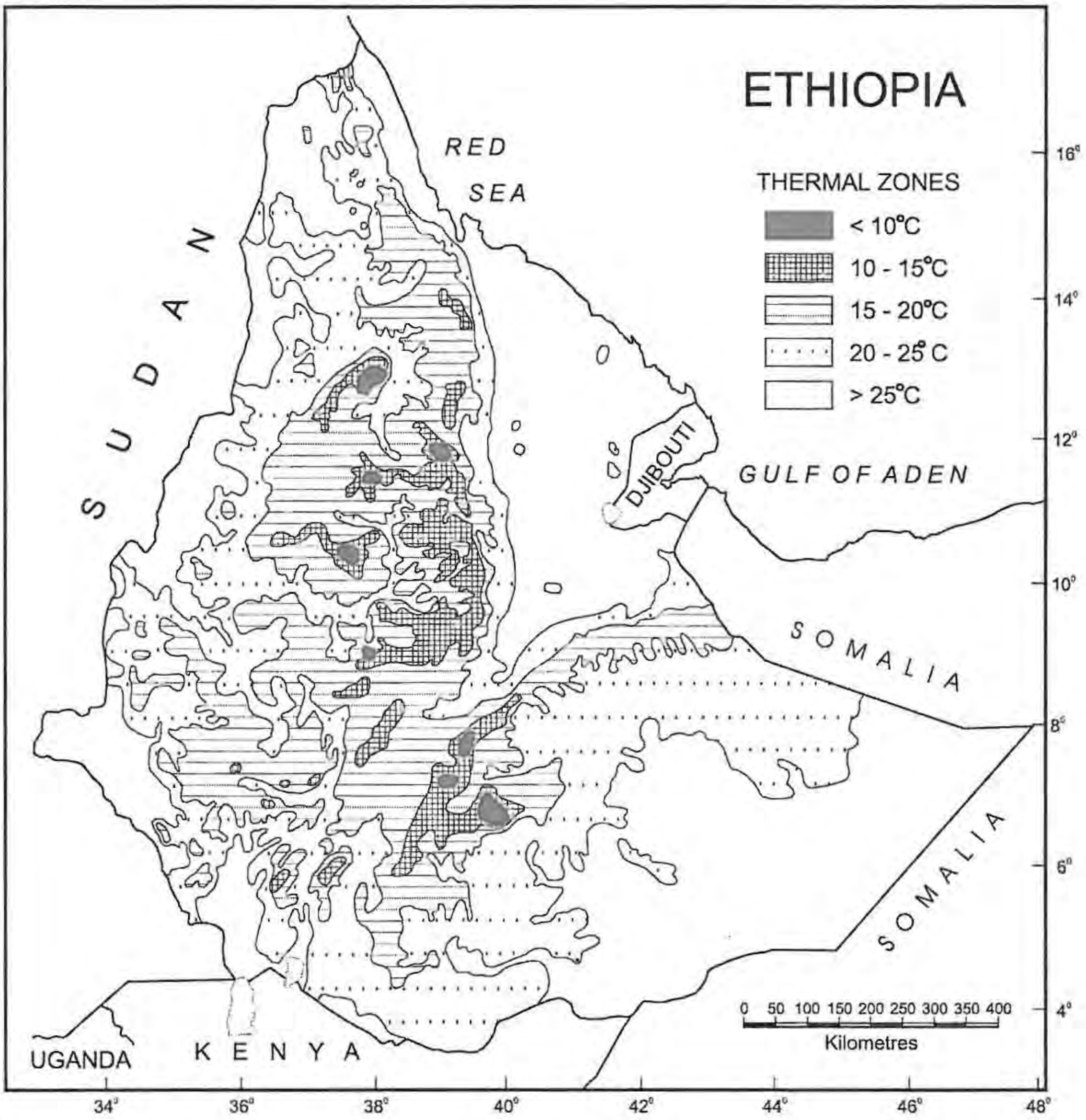
Figure 40 Annual rainfall distribution of Ethiopia, (After Goebel *et al.*, 1983).



The flowering of bee plants and the seasonal cycle of honeybee colonies are highly influenced by this rainfall pattern. Besides the rainfall pattern, the altitude and temperature of an area play a significant role in changing the seasonal cycles of honeybee colonies. In low altitude, high temperature areas, the growth and flowering of plants are fast, starting as the rains start, while in high altitude with low temperature areas the growth of plants is very slow and flowering mainly starts towards the end of rains and continues after that. Moreover, 10% of the soil of the highlands of Ethiopia is vertisoil (Tekelign *et al.,* 1993), which is well known for its high water-logging characteristics during the rains. In such soil the growth of annual plants is very slow during raining and the flowering usually occurs well after the rains stop, which might also cause differences in the seasonal cycles of honeybee populations of the area.

In the eastern and northwestern parts of the country where morphocluster 1 *A. m. jemenitica* occurs the rains are late (June and July) (Figure 35) and mainly end early September (Figure 36) (except for Menge (N24) and Manbuk (N06) which are adjacent to the southwestern parts of the study area (Figure 37) where rainfall is relatively extended). Since most of the *A. m. jemenitica* areas are lowlands with relatively high temperature (northeast and northwest Figure 41) and short rainy period conditions, the plants have adapted to flower very fast, as soon as the first rains occur. As a result in the arid and semi-arid lowlands peak flowering was observed early in July and August during rain period (Figure 42). In this area, unlike the areas of the other cluster groups, the rainy season is an active period for the bees and brood rearing is intense and short, starting in early June and August and mainly lasts up to September (Figures 33 and 34).

Figure 41 Major temperature regions of Ethiopia, (After Goebel *et al.*, 1983).



Unlike the other morphoclusters areas, peak swarming (66.67%) occurs very early between August and September (Figure 24), except Menge, Manbuk and Aykel where swarming is relatively late. So in this cluster the initial rains, brood rearing and swarming times generally occur very closely (Figure 43) and brood rearing and swarming ceases simultaneously as soon as the rains stop (Figure 44). This brings a time shift in the swarming period between this cluster and the rest of clusters, which may serve as a partial reproductive isolation barrier among them. The very fast and rapid build-up and subsequent swarming of morphocluster 1 agrees with other reports for *A. m. jemenitica* (Ruttner, 1988).

Figure 42 Early peak flowering of plants in July and August in Afar lowland plains.

In western humid parts where morphocluster 2, *A. m. scutellata* occurs the rains start in early May and continue to October (Figures 35 and 36). In this area, even if rain starts early, because of its intensity, raining time is a dearth period for bees. The flowering of the plants starts in late August and continues even after the rains, because of high moisture in the soil. So in this cluster area, brood rearing starts in late August and early September and extends to December (Figures 33 and 34), in which the majority of brood rearing and swarming occur much later from the initial rainfall periods and continue after rains (Figures 43 and 44). As a result, peak swarming is highly shifted towards October to December (Figure 24). 60% of the reports indicated that the peak swarming period is November–December. This also shows temporal variations in reproductive swarming, which may serve as partial reproductive isolation barriers among adjacent cluster groups.

In the northern mountainous highlands, where morphocluster 4 *A. m. monticola,* occurs even if the rainfall pattern is similar to that of the eastern and northern *A. m. jemenitica* areas, because of the high elevation, moist and cold temperature, the growth and flowering of plants are very slow, and flowering starts toward the end of the rains and continues for weeks after that. In this area unlike the adjacent morphocluster 1 areas the rainy period (June to early August) is a dearth period for bees and brood rearing only starts in late August and continues up to November (Figures 33 and 34), in which the majority of initial brood rearing and swarming occurs relatively later than initial rainfall times and continues even after rains (Figures 43 and 44). As a result peak swarming is shifted to September to October (Figure 24). This also indicates the presence of a time shift in reproductive swarming between adjacent morphoclusters.

The slight peak swarming time overlaps between morphoclusters 1 and 4 (Figure 24) is due to the occurrence of late swarming from the southwest parts of the morphocluster 1 populations at Menge (N24) and Manbuk and (N06). Since these localities are far from *A. m. monticola* distribution areas (Figure 37), it seems not to affect the reproduction isolation among them. Statistically the largest Mahalanobis distance of 60.79 was obtained between these morphoclusters, which supports the presence of high differences as result of isolation between them.

In the central highlands where morphocluster 3, *A. m. bandasii,* occurs brood rearing mainly starts in September and lasts until November (Figures 33 and 34). Since this morphocluster areas are highlands the initial brood rearing and swarming occur much later the initial raining period and continue even after the rains. The peak reproductive swarming is reported to occur between September and November, mainly October to November (Figure 24), which also shows a time shift in peak swarming from the rest of morphoclusters.

Based on the peak time of reproductive swarming generally, four swarming periods were recognised (Figure 45). However, the swarming periods distributions do not perfectly match the morphometric clusters distributions (Figures 37 and 45). As a result the morphological cluster boundaries were shifted based on the reproductive swarming periods of localities. Similar situations were also observed for the rest of Ethiopian honeybee populations (Nuru *et al.,* 2002). This agrees with the findings of Hepburn and Radloff (1998) who noted the lack of coherences between the distribution of the biological traits and morphologically defined subspecies of Africa. The over-lapping of reproductive swarming months between the different morphoclusters could be due to ecological similarities between adjacent localities from the periphery of different morphoclusters. Moreover, depending on rainfall distribution, swarming period variation was noted within the same *A. m. jemenitica* species (between southwestern and northeastern populations). The occurrence of time variation (two months lag) in reproductive swarming within the same subspecies, *A. m. capensis* as a result of peak flowering time variation has been reported (Hepburn and Jacot Guillarmod, 1991).

However, it is possible to see the general shifting of major reproductive swarming periods from August to September in morphocluster 1 (*A. m. jemenitica*), to September to October in morphocluster 4 (*A. m. monticola*), October to November in morphocluster 3 (*A. m. bandasii*) and November to December in morphocluster 2 (*A. m. scutellata*) (Figure 24). The variations in time of peak reproductive swarming were also statistically significantly different (Chi-square test with Yates' correction = 156.84, 9 df, $P < 0.0001$) among morphoclusters. These different swarming period clusters are formed as a result of variations in rainfall, physiography and temperature of the area, and it seems that no single environmental factor alone fully explains the reproductive swarming periods variations, which appear to be governed by the combination of environmental factors acting together.

Given two major climatic zones and variations in rainfall (distribution pattern), altitude and temperature within the same climatic zone, shifting in the reproductive timing could lead to reproductive isolation among these different honeybee populations.

Generally, linear trends were observed between rainfall, brood rearing and reproductive swarming period patterns for different morphoclusters (Figures 43, 44). In Africa the close correspondence of the phenology of reproductive swarming with local climate, weather and availability of forage and their linear chain relationships and their roles in colony seasonal cycles and swarming time variations were well recognised (Hepburn and Radloff, 1995; Hepburn and Radloff, 1997, 1998).

Even if such colony seasonal cycles can be observed for these morphoclusters, time variations as a result of alteration of the rainfall pattern from year-to-year, is expected. Reduction, total inhibition and unexpected occurrences of reproductive swarming and year-to-year variations have been reported for different subspecies of honeybees in different parts of tropical Africa (Ntenga, 1970; Nightingale, 1983; Eggers and Wurst-Henning, 1994; Eksteen, 1991; Mutsaers, 1991).

Figure 43 Linear relationship of initial rainfall with initial brood rearing and swarming Periods for different morphoclusters.

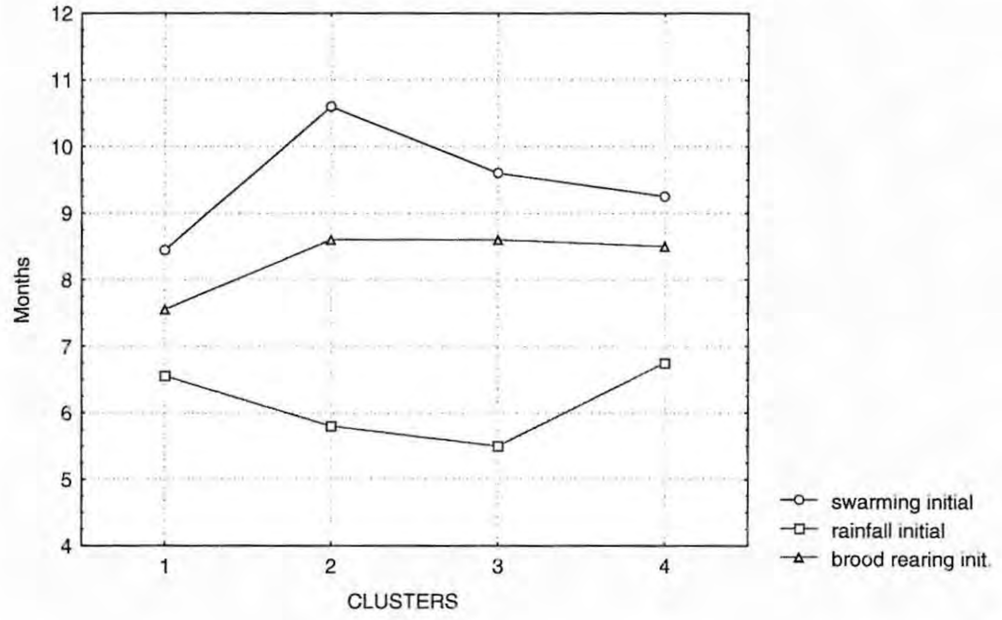
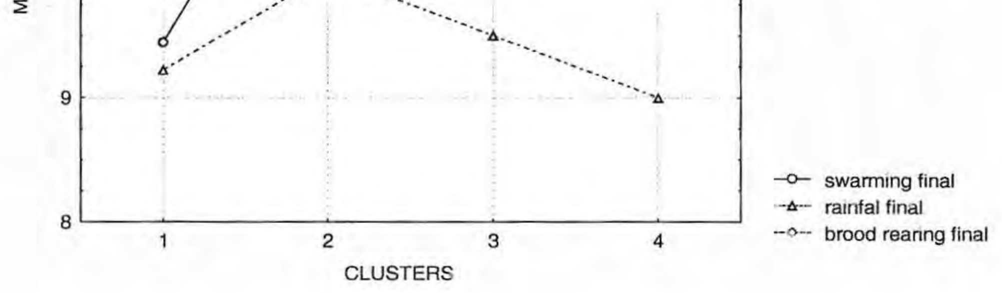
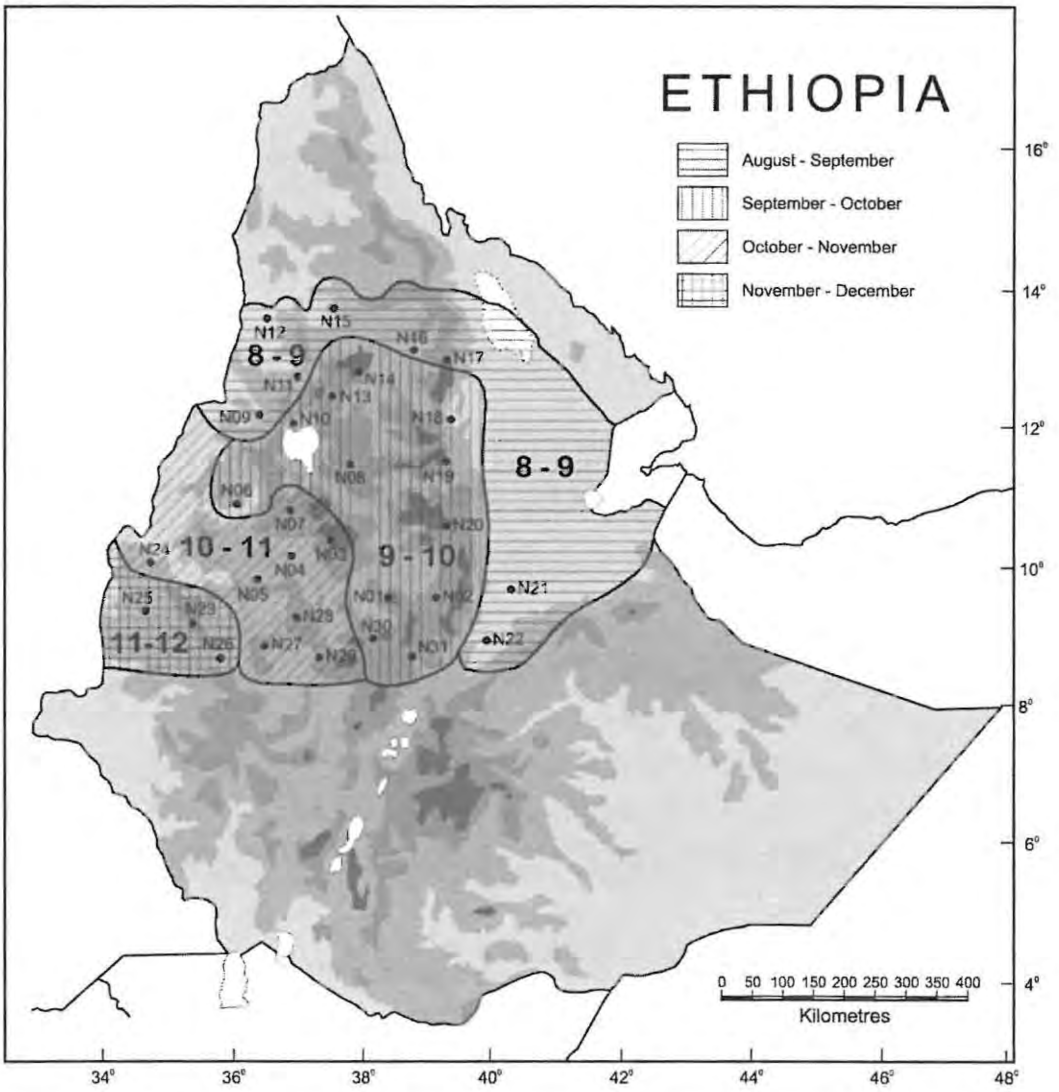


Figure 44 The linear relationship of the end of rainfall, with the end of brood rearing and swarming period for different morphoclusters.



Besides, this major reproductive swarming period, minor reproductive swarming was reported mostly during the small rains between March to June in some localities. However, due to erratic rainfall and limited flowering, the extent of swarming is very low.

Figure 45 Distribution of the major reproductive swarming periods across the study areas, (Numbers in bold are months of a year).



5.4 Zones of hybridisation among subspecies

In this study high inter and intracolonial variances were observed in all localities, however relatively higher values were obtained for honeybee groups that occur in areas of transition between ecological zones (Table 46), indicating a region of genetic flow, zones of hybridisation among statistically defined populations. Generally, high inter and intracolonial variances were observed in localities where *A. m. jemenitica* of arid and semi-arid lowland (Sahel climatic zones) bees borders with *A. m. bandasii*, *A. m. scutellata* and *A. m. monticola* (dry tropical climatic zone). This agrees with the findings of Radloff and Hepburn (1997a) and Hepburn and Radloff (1998) who mentioned that the transitions of climatic zones tend to be at the centre of genetic flow among statistically defined honeybee populations.

Although other morphological characters are very important, the occurrence of yellow and black bees in the same colony and in same locality (Table 10) is striking and contributes to the high inter and intracolonial variances (Table 16). The movements of the bees due to swarming and migration could contribute to gene flow between the different honeybee populations, hence high inter and intracolonial variances. The role of colony movement (reproductive swarming and migration) in altering the probability of gene flow within and between populations is well established (Hepburn and Radloff, 1997). Moreover the polyandrous nature of the honeybee queen (Adams *et al.*, 1997; Neumann *et al.*, 1999) would also contribute to high inter and intracolonial variances (Hepburn and Radloff, 2000).

According to the inter and intracolonial variances of this study, five major zones of hybridisation were observed (Figure 46). The zones of hybridisation, in most cases occur at the periphery of the morphoclusters, which again are related to the transition of ecological zones (Figure 46). This agrees with the findings of Hepburn and Radloff (1997) that high centroids of variance occur at the edges of morphometrically defined morphoclusters, which are associated with climatic and biological areas of transition. Moreover, they emphasized the significance of interpreting these variances in a biogeographical context.

The first indication of inter-cluster gene flow was noted in the two adjacent localities Dangla (N07) and Manbuk (N06) (Figure 46 western, I). The honeybees of Dangla were the same size as *A. m. bandasii* but light in colour compared to the usual black pigmentation, 40.5% of the bees were yellow (Table 10) as are neighbouring *A. m. jemenitica*. In spite of the difference in colour they were classified as *A. m. bandasii*. Honeybees of Manbuk next to Dangla were classified as *A. m. jemenitica* (yellow bees) but 25% black bees were recorded. These localities occur at the peripheries of zones of ecological transition between hot lowlands and cool highlands. In these areas swarming and migration of honeybees were reported which are the major contributing factors of gene flow. As a result, in both localities the honeybees show intermediate morphological characters between *A. m. jemenitica* and *A. m. bandasii* indicating zones of hybridisation.

A second zone of hybridisation was observed in honeybees at Aaykel (N10), Wohni (N09), and Angereb (N11) (*A. m. jemenitica* group) and Dabat (N13) (not in any cluster),

(Figure 46, northwestern, II). This hybridisation zone would be a centre of gene flow among three adjacent honeybee subspecies: the arid lowland bees, *A. m. jemenitica*, and the highland bees *A. m. bandasii* and the mountainous bees *A. m. monticola* both from a dry tropical climate. The hybridisation zone of this area confirmed the findings of Radloff and Hepburn (1997a) who noted the highest inter and intracolonial variances for Gonder, (which is situated between Aykel and Dabat) in their transect study of the honeybees of Horn of Africa, which supports the area as a high centroid of variance hence, zone of hybridisation.

The third zone of hybridisation was observed at Mekele (N17) and Abi Adi (N16), (Figure 46 northern, III). Honeybees from Mekele were as large as the neighbouring *A. m. monticola* but, unlike these bees, 53.5% were yellow. Honeybees from this locality did not join any of clusters in the factor analysis. Honeybees of Abi Adi varied in size and colour. This area is also transitional from the northern semi-arid climatic zone to the sub-moist mountainous highland of the dry tropical climate zones. In this area, besides the transition of climatic zones, the marketing of honeybee colonies from one area to the other may also contribute to gene flow among the honeybee populations.

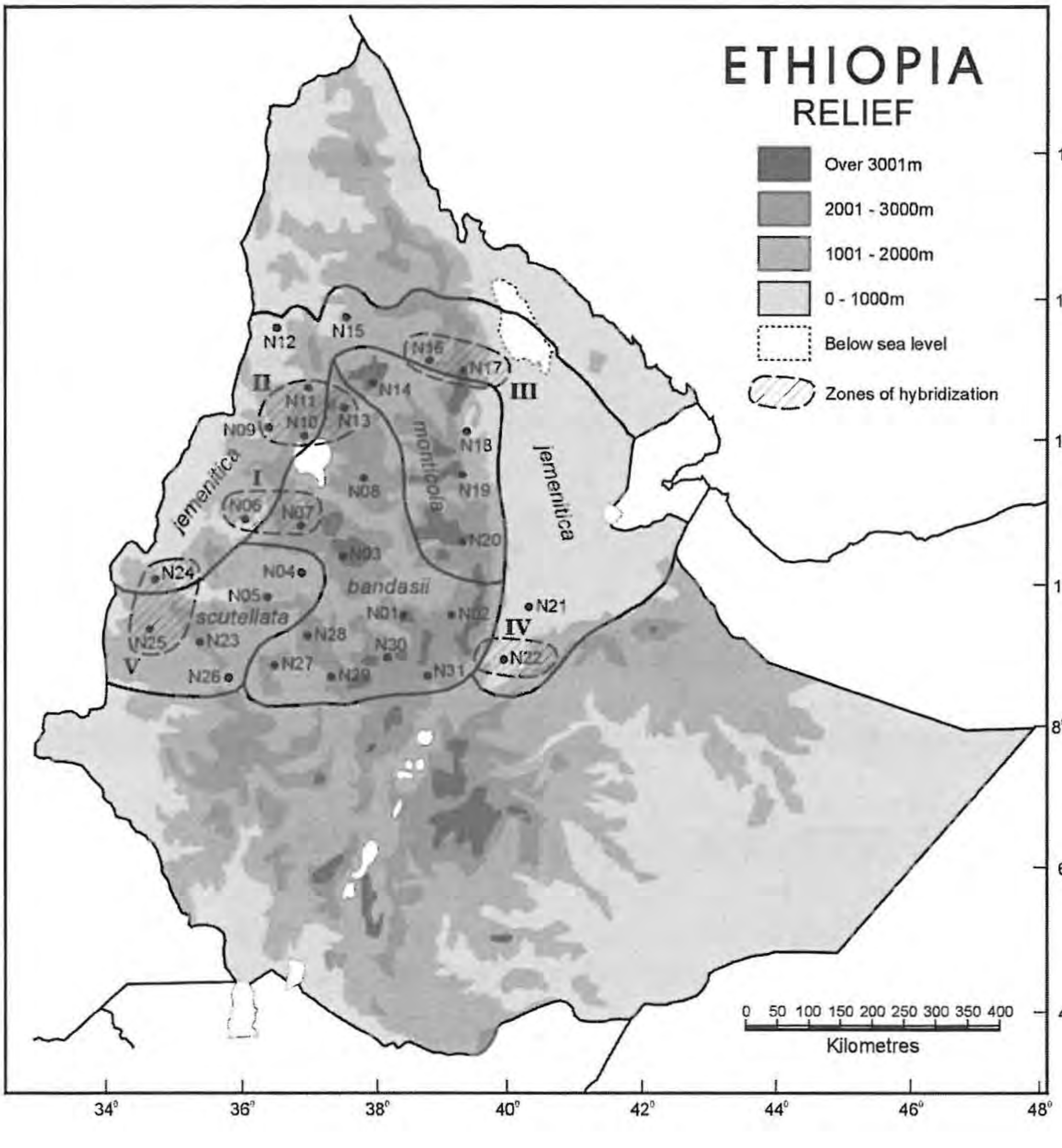
The fourth zone of hybridisation was observed in the eastern parts of the study area at Melkasedi (Figure 46; eastern, IV). This area is also located between the dry tropical climate zone of the central highlands and the typical Sahel zone of the eastern arid lowlands, which indicates a typical transition of climatic zones. In this area due to the development of widespread irrigation following the Awash River, makes the area to remain green through out the year, which allows the continuous occurrence and movements of bees from highland to lowland and vice-versa and subsequent gene flow between the adjacent morphoclusters.

The fifth zone of hybridisation was observed in areas where the wet, midlands bees, *A. m. scutellata* border the lowland bees *A. m. jemenitica* (Figure 46, southwestern, V). These areas include Bambasi (N25) from *A. m. scutellata* and Menge (N24) from *A. m. jemenitica.* Relatively high inter and intracolonial variances were also observed for localities like Nejo (N23), Shiraro (N15) and in Hinde (N05), which indicate the presence of gene flow between the adjacent populations.

Besides the inter and intracolonial variances, in the discriminant function analysis, situations were observed in which colonies of one cluster from the peripheral localities joined neighbouring clusters. Such conditions were observed in group 3 in which one colony from Nekemte and one colony from Shambu joined the neighbouring cluster 2 and one colony from Hinde (cluster 2) joined the neighbouring cluster 3. In cluster 1, one colony from Menge joined the neighbouring cluster 2, and one colony from cluster 4 to cluster 3. The affinity of these colonies in the posterior probability (in discriminant analyses), joining other neighbouring clusters would be based on sharing of morphometric similarities among them, which might also indicate the presence of gene flow among these defined populations.

On other hand relatively low inter and intracolonial variances were observed in most localities of *A. m. monticola* and *A. m. bandasii* groups. This may be due to the absence of, or reduced tendency to migrate among these bees; hence there is low genetic flow among these populations, which agrees with the findings of Roderic (1996) that in habitat persistent populations the degree of exchange of individuals and genes among populations is relatively low. The maintaining of purity and low level of hybridisation was also observed for *A. m. monticola* population of Kenya (Dietz *et al.,* 1986). The areas of zones of hybridisation are shown in Figure 46.

Figure 46 Zones of hybridisation among the morphoclusters in physiographic map of Ethiopia, (numbers with N indicate sampled localities; areas shaded with diagonal lines indicate places with high inter- and intracolonial variances hence zones of hybridisation).



5.5 Correlations of morphometric characters with environmental factors

In the correlation of morphometric characters and environmental factors, altitude was highly negatively correlated with pigmentation and positively with size of body parts and hair length. For these characters absolute values of $r > 0.70$ were observed except for scutellar plate pigmentation (36). The values of coefficients of determination were $R^2 > 0.50$ which indicate that more than 50% of the variances in pigmentation, body size and hair length were attributed to the change of altitude.

In the case of temperature, opposite effects were observed (Table 6). The coefficients of determination for pigmentation, body size and hair length were $R^2 > 0.46$ except for scutellar plate pigmentation (36), which again indicate that more than 46% of the variances in pigmentation, body size and length of hairs were attributed to the change of temperature. These show that the higher the altitude and the cooler the temperature, the larger the body size, the darker the pigmentation and the longer the hair length. The converse is also true.

Body size and surface colouration of insects have important roles in the regulation of body temperature. The larger the body size the lower, the surface/volume ratio (Bergmann's rule) which is important to reduce heat loss in cold climates of high altitude areas and the smaller the body size, the surface/volume ratio increases which facilitates a more rapid rate of heat loss at higher temperature in low altitude areas. Darker surface colour helps to absorb more radiant energy in cool areas, while lighter surfaces reflect more radiant energy under warm conditions. In insects the presence of large differences in the quantity of radiant energy absorbed by different surface colours and the adaptive values of colour in thermoregulation have been documented (Casey, 1981).

In this study mixed yellow and black bees in the same colony and also predominantly yellow or black colonies in the same localities were very common, which agrees with the observations of (Radloff and Hepburn, 1997a) in their transect study of the Horn of Africa. The occurrence of mixed colours of bees in most parts of the country could be due to the very close proximity and intermingling of highlands and lowlands and the easy movements of the bees over short distances during migration and swarming. Such preponderances of mixed colours were observed at the boundaries of lowland and highland areas. Even if colour is selected as an adaptive character to the type of ecology, it remains stable for a long time under new ecological conditions until it is eliminated by selection. On the other hand, as far as bees and genes continue to drift, the mixture of colours in bees will remain the same, since the realisation of the process of selection and adaptation are governed by the balance between selection and the countering effects of both genetic drift and gene flow (Slatkin, 1987).

Entirely pure yellow bees in all colonies were observed in the interior of the lowlands (Gewane at an altitude of 587 m) and pure black honeybee colonies at the interior of highlands (Guguftu 3600 m), which indicate how colour is highly selected by altitude and remain pure in the absence of drifting from neighbouring bees of the opposite colours. In pure or mixed yellow colonies, the numbers of yellow segments varied from 2–5 from colony to colony and locality to locality; however, within one colony a uniform number of yellow segments were observed. Moreover, depending on the localities, within the same apiary colour variations in the intensity of pigmentation range from jet-black to light brown, and from light-yellow to deep-orange. In high altitude areas, the hair of the bees was long and denser than in the lowland bees, which would be an adaptation to conserve the body heat in a cool climate.

Rainfall was highly significant but negatively correlated to pigmentation (Table 7), which agrees with the findings Radloff (1996). This seems reasonable because the more the rainfall, the cooler the environment, hence the darker the bees. In high rainfall (1283 – 1479 mm) areas at relatively low altitudes (below 1550 m like Dedessa, Bambasi and Bir Sheleko) more and darker (67%–95%) bees were observed than relatively at higher altitude areas (1800–2230 m), with lower precipitation (563–767 mm) like Abi Adi and Mekele with only 29%–47% black bees. It shows the effect of rain on pigmentation of honeybees.

In the case of latitude, except tergite 4 longitudinal (10), body size was not significantly correlated to latitude (Table 8). This may be due to the fact that over the small latitude range in this study, the effects of latitude would be masked by the stronger effects of altitude, which shifted the correlation with size more towards the direction of altitude than latitude. Again, latitude was positively correlated with pigmentation (Table 8). The higher latitude areas (the extreme northwest) are lowlands with a hot and semi-arid climate, so the positive correlation of latitude with pigmentation would be more due to hot conditions of these areas than high latitude effects.

Generally, the correlation of body sizes, pigmentation and hair length with environmental factors (altitude, temperature and rainfall) indicate the highly adaptive values of these characters to the ecological conditions of the area, which is in agreement with similar results reported by Ruttner (1988). In this study wing angles were not strongly significantly correlated with the different morphological characters and within different wing angles (Table 4). Moreover, wing angles were not significantly correlated to any of the environmental factors (Tables 5 – 8), which may indicate that wing angles have no significant adaptive values to ecological conditions and may not be important as discriminatory characters in the classification of local honeybee populations (Figures 15 – 17) which agrees with Ruttner's (1988) idea who noted that the characters used to classify the European races would not necessarily have the same values in discriminating between honeybees of other region. Characters with high discriminatory power and high correlation values with environmental factors indicate the high adaptive values of such characters and their significance in the classification of local honeybee populations.

5.6 Correlations of behavioural characters with environmental factors

Besides the morphological characters, the behavioural characteristics of the honeybee populations were found to have significant correlations with ecological factors except latitude.

5.6.1 Aggressiveness

Very high negative and positive correlation values were obtained between aggressiveness of bees and the altitude and temperature of the areas respectively (Tables 20 and 21). This indicates that honeybees in hot, low altitude areas are more aggressive than honeybees from cool, high altitudes. This agrees with the reports of Ruttner (1988), Fletcher (1978), Chandler (1975, 1976), Corner (1985), Mbaya (1985) and Smith (1994). Fletcher (1978) indicated that temperature is the most important environmental factor that lowers the threshold of responses of bees to the primary stimuli of aggressiveness.

In this study, mostly in highland and mountainous areas, the honeybees were gentle and kept in a village or home yard very close to domestic animals and family members (Figure 52). It was also observed that hundreds of honeybee colonies were traded in the market (Figure 53) leaving open the hive on one side, in which bees remain calm without having an inclination to attack people, which indicates the degree of gentleness of such honeybees. On other hand, honeybees of the midland and low altitude parts of the study area (*A. m. jemenitica* and *A. m. scutellata*) were reported for their aggressiveness and the problem of keeping them at home yards. Beekeepers reported that even if colonies are hung in very tall trees 20 metres above the ground, this still does not allow ploughing lands near them.

Beekeepers also reported that when highly defensive bees of the lowlands were brought to highlands, they became docile and the reverse is also reported to be true which agrees with a similar report of Mammo (1976) that indicated the roles of altitude and temperature in defensive behaviour of bees. In this survey more predation and nest destruction by man, monkeys, birds and ants were reported from lowland areas than highland ones, which may also contribute to the development of high defensive behaviour of bees in the lowlands as a result of predation pressure. Man is considered as one of the major selective forces in honeybee colonies defensive performance (Hepburn and Radloff, 1998).

Regardless of marked variations between populations and ecological conditions, there are a number of factors reported to contribute for the defensiveness nature of bees within the same localities. Beekeepers reported that colonies become more defensive during flowering periods when they become strong and have brood than in dearth periods when they are weak, which agrees with the reports of Chandler (1976), Dietz *et al.*, (1986), Woyke (1989) and Hepburn and Radloff (1998), who mentioned the strong influence of colony size on defensive behaviour of honeybees and its association with nectar flow. Moreover, most beekeepers reported that colonies become more defensive during honey harvesting and when they are disturbed by predators.

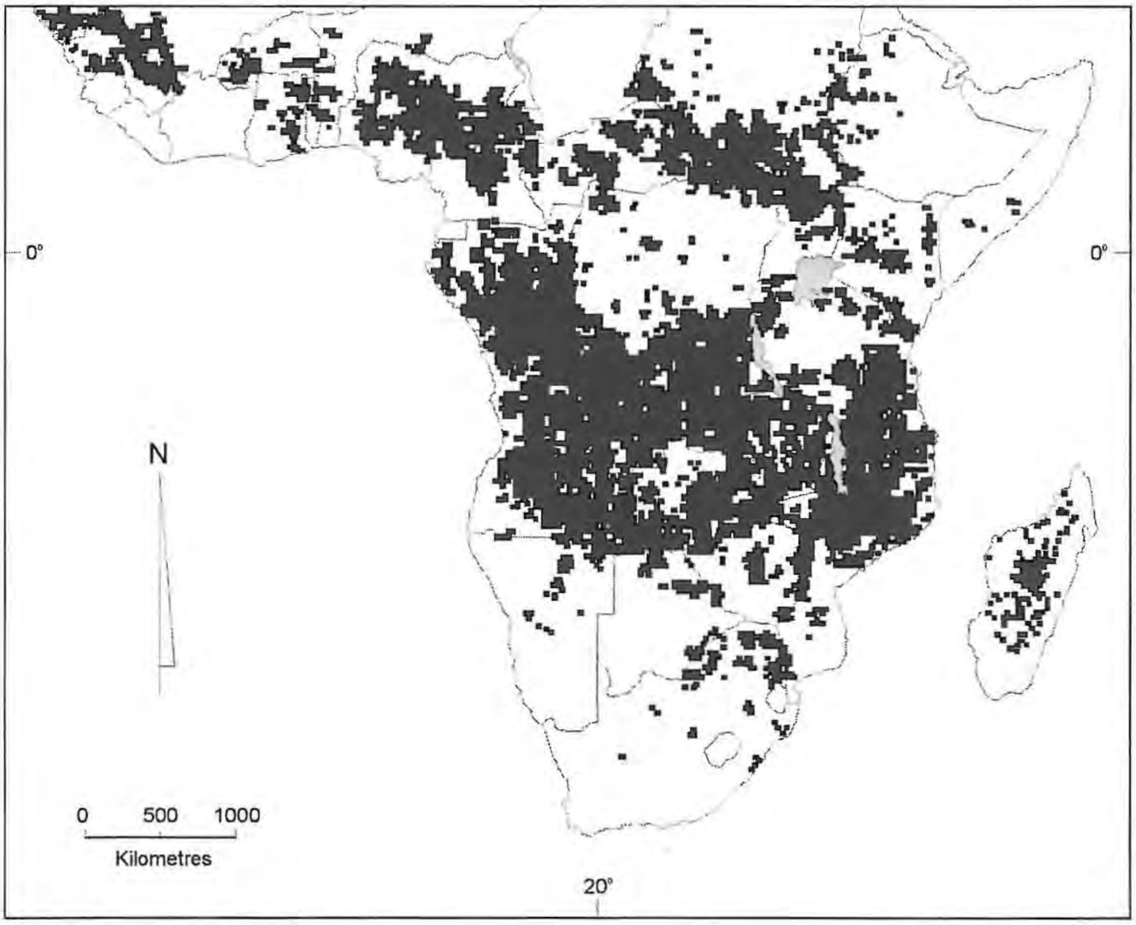
Beekeepers also reported that wild and isolated colonies are more vicious than colonies kept at backyards. They mentioned the possibilities of gradually changing defensiveness of bees by hanging old clothes near the hive entrances and regularly walking around the hives, which makes the bees become familiar with odour of human beings and animals and finally become docile. In terms of colour, even if the reports were contradictory from beekeeper to beekeeper and from place to place, yellow bees were reported to be more defensive than black bees in more cases, which seems reasonable because yellow bees are more often associated with lowland ecology and develop more defensive behaviour than highland black bees.

Generally, defensiveness is a very relative term and it is very difficult to quantify and correctly measure in different honeybee populations. The lack of a systematic and quantitative approach for analysis of defensiveness has been noted (Hepburn and Radloff, 1998). But, irrespective of colour, ecology and other contributing factors, it seems clear that certain strains of bees are more gentle than others. The presence of very aggressive and docile bees within the aggressive and docile bees of the same apiary was reported (Hepburn and Radloff, 1998). According to these reports the highland bees *A. m. monticola* are generally, docile followed by *A. m. bandasii* and the lowland bees *A. m. jemenitica* are more aggressive followed by the midland bees, *A. m. scutellata* (Figures 29 – 31).

5.6.2 Reproductive swarming

The proportion of reproductively swarmed colonies and maximum number of swarms per colony were found to be negatively correlated with altitude and positively with temperature (Tables 20 and 21). In the lowland and midland areas where both *A. m. jemenitica* and *A. m. scutellata* honeybee groups occur, a high proportion of reproductive swarming and a high number of swarms per colony were recorded (Figures 18 and 19). A high swarming tendency is believed to be an adaptation to replace the loss of countless colonies due to various enemies including man, safari ants, drought, fire, and starvation (Fletcher, 1978). Most of these contributing factors are more prominent in lowland than in highland areas. Moreover, in the lowland and midland areas dry periods are accompanied by forest fires, which destroy thousands of km^2 of forest and annually destroy thousands of colonies in their natural nests. The western parts of the study areas, along the Sudan border (between Gambella and Humera) are part of the great fire belt of Africa, which extends from Senegal through Chad and Sudan up to west part of Ethiopia (Figure 47).

Figure 47 Distribution of forest fires in sub-Saharan Africa for 1986, (After Hepburn and Radloff, 1998), dark spots represent fire prevailing areas.



Moreover, in this area man is the major enemy of honeybees and destroys thousands of colonies in the process of honey hunting and harvesting. During honey harvesting beekeepers destroy the whole nest by removing all the contents of the hives without care for the bees and finally shake away the whole colony to the ground. "I personally counted

250 dead bees (crushed during harvesting) from 0.5 kg of crude honey bought from the local market". During honey hunting and harvesting, there is a high potential risk of killing the queen and the whole fate of colony is in danger. Moreover, since honey harvesting takes place at the end of flowering periods, colonies that survived in the process of honey hunting and harvesting may die due of starvation. In Africa during the honey hunting and harvesting process the destruction of enormous colonies, their nests and depriving the bees provisions and subsequent dying due to starvation have been reported (Fletcher, 1978; Hepburn and Radloff, 1998). Moreover, unlike the highland areas, in the lowlands and mid altitude areas beekeeping is mainly practiced in the forest and a large number of colonies exist as wild in their natural nests, which are more vulnerable to various enemies. While in the highland areas beekeeping is practiced mainly at backyard level, in which the colonies being attacked by various enemies is very low.

So the high swarming tendencies of honeybees of the lowland and midland areas (*A. m. jemenitica* and *A. m. scutellata*) would be an evolutionary adaptation to replace the annual loss of myriads of colonies. In Africa the high tendency of swarming as result of climatic and predation pressure and the greater inclination to reproductive swarming and mobility have been recognised (Seely, 1985; Hepburn and Radloff, 1998). On other hand, in the lowland and mid altitude of the study areas, better vegetation coverage and warm temperature during brood rearing time may also favour the high swarming tendencies of these honeybee populations.

The occupation rate of bait hives was higher in *A. m. scutellata* and *A. m. jemenitica* areas than *A. m. bandasii* and *A. m. monticola,* which also indicates the high reproductive swarming tendency and movements of these bees. However, the occupied bait hives may not be all from the reproductive swarms, it could be occupied by immigrant swarm bees which are disturbed by enemies and also could be by those colonies forced to evacuate due to destruction of nests during honey hunting and harvesting which are very common in *A. m. scutellata* and *A. m. jemenitica.* Variations in swarming frequency were noted among morphoclusters. However, the variations may not be always the characteristics of subspecies, it could be due to variations in ecological factors like rainfall and flowering pattern of an area. As a result of rainfall pattern variations, swarming frequency variations were observed in different localities of the same morphocluster, *A. m. jemenitica* and *A. m. bandasii.*

In general, in the highlands and mountainous areas where *A. m. monticola* and *A. m. bandasii* occur, the swarming tendency is very low (Figures 18, 19 and 20) and may not take place every year. In this area beekeepers reported that some colonies stay for 10–20 years without reproductive swarming and catching a swarm is a good luck to beekeepers. As a result, the price of a colony is very high and becomes a good source of cash income to beekeepers. In these areas beekeepers induce reproductive swarming by means of overcrowding (keeping colonies in small size traditional hives). While in *A. m. jemenitica* and *A. m. scutellata* areas reduction in population size of a colony and decreasing or total absence of honey yield as a result of high successive swarming is one of the major problems of beekeeping. This indicates the presence of distinct reproductive swarming tendency variations among these honeybee subspecies, which could be attributable to the influences of multiple environmental factors and also could be the strains of bees.

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Although, the overall swarming proportion and occupation rate of bait hives were higher for *A. m. scutellata* (relatively darker bees) than *A. m. jemenitica* (relatively yellow bees), irrespective of morphoclusters within an apiary and within morphoclusters where yellow and black bees colonies occur, most beekeepers reported that yellow bees are very fast in colony build-up and subsequent reproductive swarming than black bees. Strains of bees with fast colony build-up ability and with reduced swarming tendencies would be important for areas with short rainfall and fast flowering conditions.

5.6.3 Migratory tendency

Migration was correlated negatively with altitude and positively with temperature, indicating that honeybees from cool, high altitude areas have less of a migratory tendency than honeybees from warm, low altitude areas. In this study the major causes of migration were reported to be the shortage of food and water in dry seasons, forest fire and high temperatures (Figure 28), which agree with similar reports of Fletcher (1978), Hepburn and Radloff (1998), Adjaloo (1991) and Adjare (1990).

In lowland areas if colonies kept in open places particularly in box hives high temperature is a serious problem for bees. It was observed and reported by bee technicians that the high temperature in the hive even melts the wax foundations and makes them to detach from the frame wires and fall to the hive bottom and it may deforms the shape of the cells in wax comb. In such temperature it is difficult for the bees to regulate hive temperature, which force the bees to migrate to cooler areas. Most of the factors, which reported as causes of migration, are more prominent in lowland than highland areas. However, the economic importance of each factor can be varies from ecology to ecology.

In lowland areas the dry period mostly begins towards the end of November and continues to May. This dry period causes a shortage of food and water and high temperature for bees. Moreover, in the western parts of the study areas the dry and hot conditions are annually followed by forest fires (Figure 47), which make the bees to develop migratory tendency to escape the harsh conditions.

Besides the environmental factors, the migratory behaviour of honeybee colonies seems partially attributable to the ways that beekeepers handle their bees. This can be realised by the fact that, within the *A. m. jemenitica,* areas in the eastern and northern parts, even if there is a long dry period and less vegetation, migration was reported absent while in the southwestern parts of *A. m. jemenitica* areas (Menge, Manbuk, Wohni) and in most parts of *A. m. scutellata* was common. One of the significant differences between these areas is the way handling of bees. In the northern and eastern parts, beekeepers carefully remove the honey only, without damaging the brood and leave some provision for dearth periods. Sheltering, feeding and watering in dearth seasons are well exercised. While in the southwest, beekeepers hang their hives in the forest without any attention and during harvesting remove all honey without leaving provisions and mostly remove all the contents of the hive. Since honey harvesting is mostly towards the end of the flowering period, those bees, left without provision force to move to other resource rich areas. Man is considered as a major selective force in the evolution of honeybee colony defensive performance (Hepburn and Radloff, 1998). So man also could have a major effect on the development of the migratory tendency of honeybees.

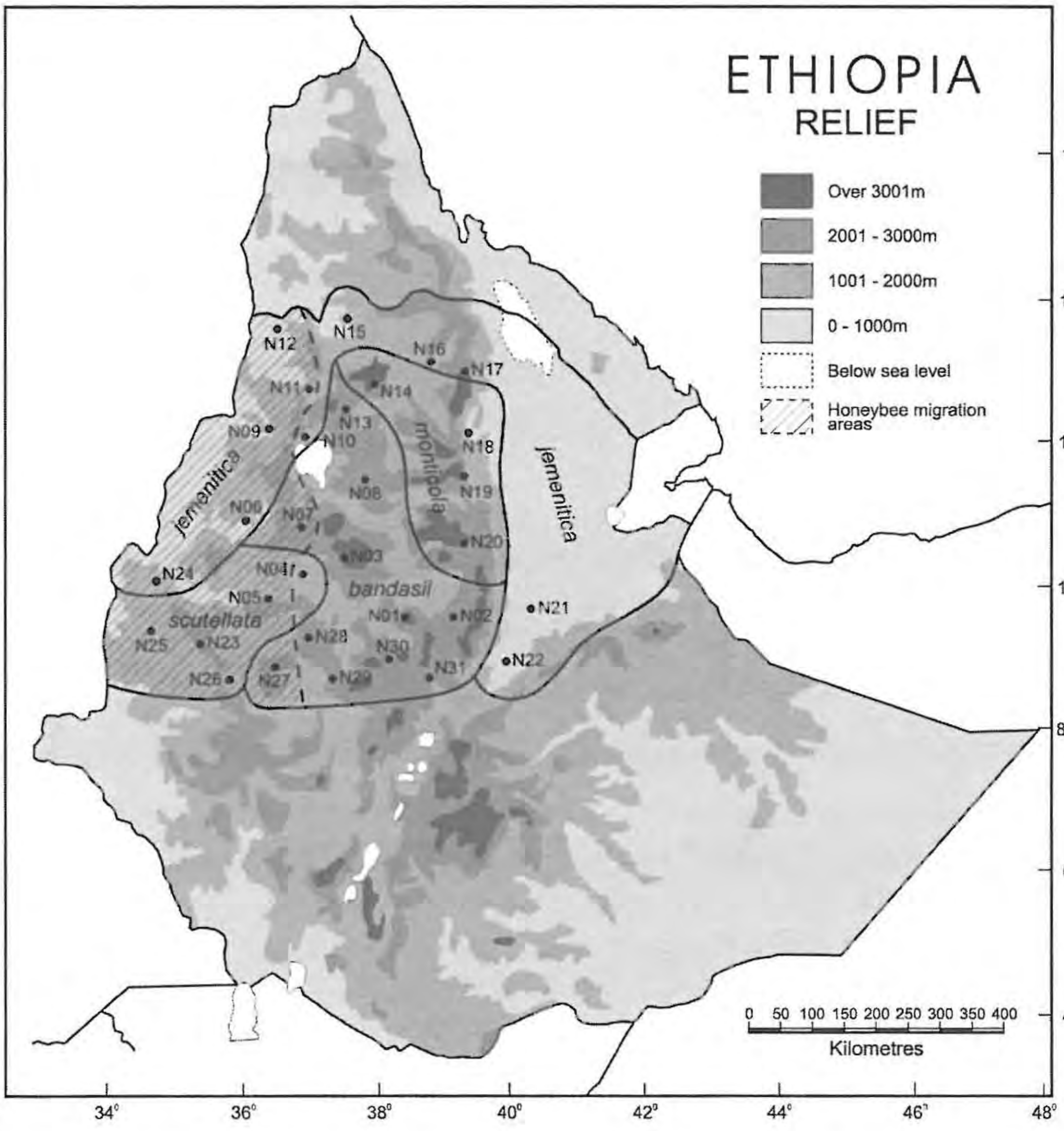
The second difference is that, in the northern and eastern parts, there is only one flowering period with limited bee plants and without alternate resources in different seasons, which might contribute to the adaptation of the bees for long dry periods without migration by storing adequate food for the dearth period. Adaptations of *A. m. jemenitica* to long dry conditions in Yemen and Oman and *A. m. lamarckii* in desertuous Egypt without absconding have been mentioned (Ruttner, 1988). While in the southwest, both in *A. m. jemenitica* and *A. m. scutellata* areas, the presence of different plant species which flower at different seasons, at different places may contribute to the bees to adapting the nomadic way of life to exploit the available alternate resources in different areas at different seasons.

In high migratory areas beekeepers reported that the tendencies of the bees are mainly focused on brood build-up and subsequent reproductive swarming and eventually evacuating without storing honey. In Africa the absence of a hoarding strategy of bees as the result of year round flowering conditions and a high tendency towards reproductive swarming and migration rather than storing of honey was previously suggested (Hepburn and Radloff, 1998).

Generally, the migratory tendencies of honeybees seem attributable to a combination of factors: shortage of food and water in dry periods, presence of alternate resources at different time and places, environmental factors (fires, temperature) and handling conditions, which may contribute to developing a nomadic way of life as a survival strategy to overcome such hazards. Areas where migrations are common are shown in (Figure 48). According to this study the mountainous bees *A. m. monticola* reported not migrate and the highland bees *A. m. bandasii* have low tendencies to migrate while the lowland and midland bees *A. m. jemenitica* and *A. m. scutellata* have high tendencies to migrate.

On other hand in both highly migratory areas of *A. m. jemenitica* and *A. m. scutellata* it was reported that some colonies stay without migration as a result of better management and adequate provision, which indicates the possibilities of minimising the migratory behaviour of bees by applying better management. The facultative migratory tendency of *A. m. scutellata* in Kenya has been reported (Nightingale, 1983). Moreover, Hepburn and Radloff (1998) reported that the migration of African honeybees is not a completely fixed trait. To better understand the migratory conditions of bees and to determine whether migration is adaptive fixed behaviour or it is stimulated by external factors, controlled experiments with close observations are highly recommended.

Figure 48 Areas where seasonally based migrations of honeybee colonies are reported to occur, in physiographic map of Ethiopia, (areas shaded with diagonal lines represent migration prevailing areas).



Generally, in this study honeybee populations with a high swarming tendency also show high migratory and high defensive behaviours and the reverse is also true. Statistically, positive strong correlations values were obtained to support this conclusion (Table 19). Moreover, as the altitude increases there is a high trend of decreasing in swarming, migration and aggressive tendencies of bees (Figure 49) while as the rainfall increases, swarming and migration show the general trend of increasing. Aggressiveness was not much influenced by rainfall (Figure 50). Again, as the temperature increases there was a general trend of increasing aggressiveness, swarming and migration (Figure 51) except the declining conditions of migration and swarming as the annual mean temperature goes beyond 20°C. These indicate that the behavioural characters are highly interrelated and governed by the combination of interrelated environmental factors acting together.

The declining conditions of reproductive swarming beyond 20°C could be due to the absence of adequate resources for high reproductive swarming conditions, and for that of migration could be due to absence of alternate resources for migration in hot and arid areas. Moreover, better handling conditions like sheltering and feeding were reported in some of the very hot arid and semi-arid localities of the study areas such as Shiraro, Melkasedi and Gewane, which may significantly contribute for the declining conditions of migration as a result of better handling of bees in such very hot and arid areas.

Figure 49 The effects of altitude on swarming, migration and aggressiveness.

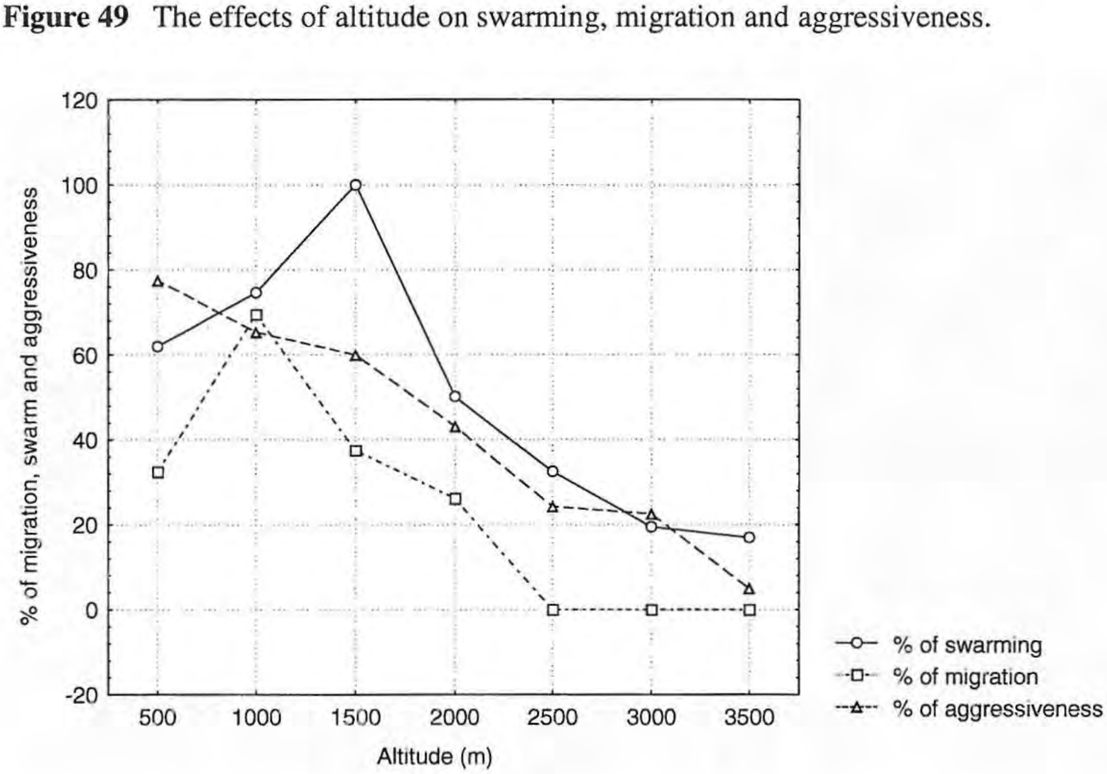


Figure 50 The effect of rainfall on swarming, migration and Aggressiveness.

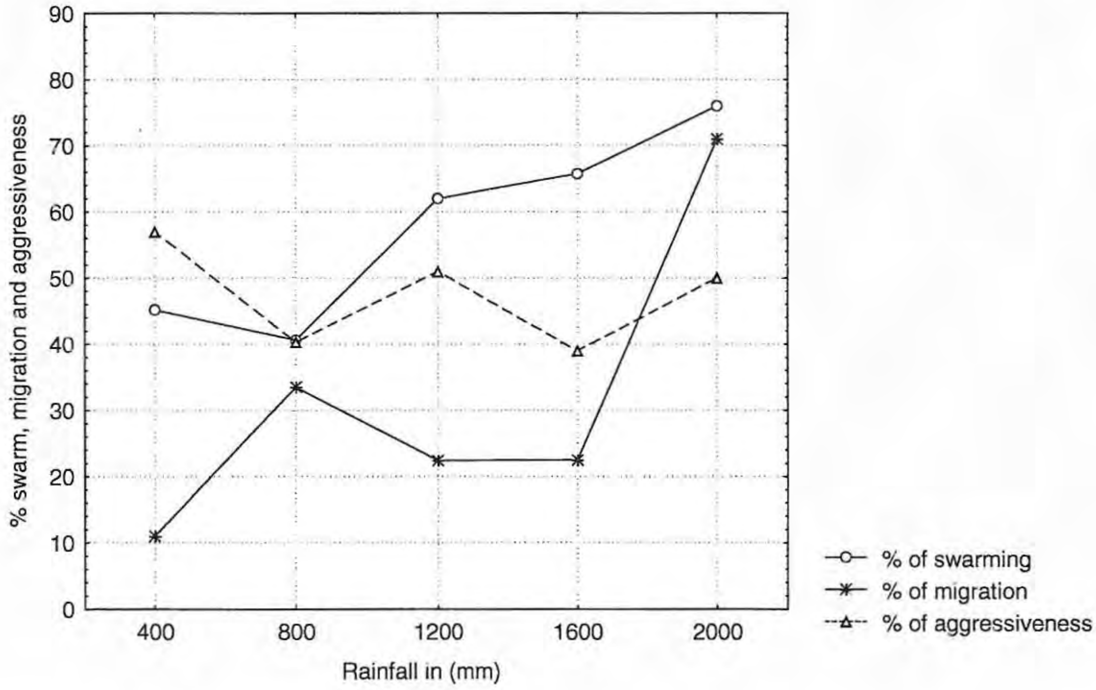
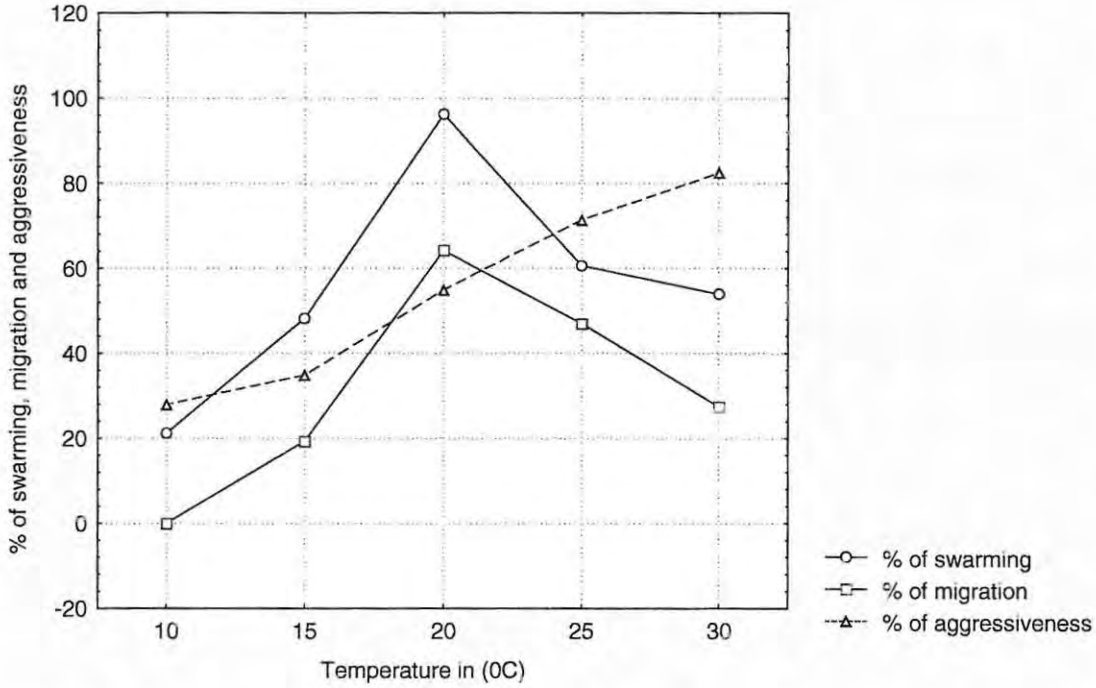


Figure 51 The effect of temperature on swarming, migration and aggressiveness.



5.7 Honeybee plants

Generally, the flowering patterns of bee plants vary depending to the ecological conditions and rainfall pattern of the area. In arid and semi-arid lowlands the majority of bee plants adapt to flower as soon as the rain starts while in midland and high altitude areas the majority of flowering of bee plants occur soon after rain. However, there are exceptional bee plants such as *Vernonia* spp., *Echinops* spp. and *Caylusea abyssicica*, which adapt to flower in a very dry period. Moreover, the various pulse crops, which are growing in vertisoil (after the raining period) are mostly start to flower much after the major flowering period and are very important for extending flowering periods in dry season and serve as a good source of honeys. Besides this, many natural trees and *Eucalyptus* species flower between March to June during small raining period. Since these trees are deep rooted, their flowering conditions and periods are not much influenced by rainfall distribution. Generally, places with different species of bee plants with successive flowering pattern throughout the year would be favourable for the maintenances of bees. However, presences of distinctive peak flowering conditions are very important for surplus nectar collection and better honey production.

5.7.1 Poisonous bee plants pollen grains

The pollen grains of *Justicia schimperiana* (Plate 3) are easily recognizable by their prolate shape and dicolporate apertures and also differ from other pollen grains of the genus *Justicia* like, *J. striata, J. heterocarpa*, and *J. cufodontii* by their larger size. The pollen grains of Ranunculaceae species: *Clematis simensis* and *C. hirsuta* (Plate 1) are morphologically very similar each other under both light and scanning electron microscopy observations; however, they vary in polar axis, equatorial and colpi diameters. The surface pattern of *Ranunculus multifidus* (Plate 3) shares similarities with the *Clematis* species, however differ much in shape, aperture type and dimensions. The surface pattern and aperture types of *Phytolacca dodecandra* (Plate 1) pollen grains are similar to *Clematis* species but larger in size. The pollen grains of *C. simensis, C. hirsuta*, and *Phytolacca dodecandra* are prolate in SEM preparations and change to spheroidal when they are treated with ether and glycerine jelly for light microscope observations while the pollen grains of *J. schimperiana* remain more or less similar in both preparations. The pollen grains of *Croton macrostachys* are peculiar in that they do not have apertures and the surface is covered with dense warts (gemae).

Honey from *Justicia schimperiana* is well known in Ethiopia for its toxicity to man; even the nectar of this plant causes vomiting and diarrhoea when sipped by children (Nuru, 1996). The author is also a victim of the toxic effects of this honey, but a poisonous effect on bees has not been reported. The other plant species presented here are reported to be poisonous to honeybees. *Phytolacca dodecandra* is also reported to be poisonous to humans and animals (Fichtl *et al.,* 1994). On the other hand these same plants are also widely used for different medications in traditional healing (Gelahun *et al.,* 1976), which indicates that the plants may produce some active ingredients, which could be toxic when consumed in large amounts. Moreover, *Justicia shimperiana* honey is used as a purgative substance. From the pollen morphological analyses of these plants it is possible to pinpoint the botanical origin of poisoning cases of bees and humans. However, besides the pollen grain analyses of these plants, identifying the chemical substances, which are responsible for the toxicity, would help to support the confirmation of poisoning cases. In areas where plant poisoning cases are serious, some of the possible recommendation would be avoiding of beekeeping in such areas and planting of different non poisonous bee plants which have the same flowering period with the toxic plants to dilute the poisoning effects of nectars of such plants.

5.8 Conclusions and recommendations

5.8.1 Conclusions

The study revealed the existence of four statistically distinct morphoclusters or geographical races, which occur in different ecological regions of the study area. The high inter and intracolonial variances at the edges of ecological and biological transition zones indicate the occurrence of gene flow in zones of natural hybridisation among these distinct morphoclusters as a result of the natural movements of bees during swarming and migration. The behavioural characteristics (swarming, migration and temperament) of these bees also distinctively varied among morphoclusters. Both morphological and behavioural variations seems the result of long adaptations to the various interrelated environmental factors in their respective ecological areas.

Since these morphoclusters or geographical races occur as contiguous populations without geographical barriers, the changes in morphological and behavioural characters are gradual and continuous from one race to the other. Moreover, the diversification of the physiographic and climatic conditions of the regions and their intermingling in very close proximity resulted in more complexity in the honeybee populations of the area, which makes difficult to match the honeybee populations of the region with established tropical Africa honeybee races. However, the general trend of morphological and behavioural variations show that, bigger, darker and gentle honeybee populations with less inclination to swarm and migrate occur towards the higher altitudes and small, lighter and more defensive bees with a high tendency to swarm and migrate occur at lower altitudes. The ecological variations create considerable time shifts in reproductive swarming periods among these honeybee subspecies, which is believed to play a major role in the partial reproductive isolation among these honeybee groups.

5.8.2 Recommendations

Migration: the seasonally based migration conditions of honeybees seems highly restricted to certain ecological areas and to a given honeybee population. In such areas most beekeepers believe that colonies usually migrate when the flowering season is over, so that after the honey harvest beekeepers shake away the bees and collect their hives to be hung for the next flowering period. Such a management system has been suggested as one of alternatives options to manage bees with a migratory tendency instead of maintaining them throughout dearth periods (Chandler, 1976). However at present, due to various factors the populations of honeybee colonies are certainly in the state of continuous decrease. As a result, it is becoming more difficult to obtain many swarms every year to be occupied by bait hives as in the past. Moreover, in most cases these new swarms are small and may not be able to produce honey in the same season, and even if they able to produce the yield could be very small.

Although, migrations of honeybees are considered as means of a survival strategy to escape the harsh periods, and as means of exploiting resources found in different seasons and areas, from the beekeeping point of view (for better honey production), maintaining colonies throughout the year would be more productive than starting from new swarms every season. As it has been observed, within highly migratory areas, some honeybee colonies stay without migrating, which indicates the possibilities of minimising the migratory tendency of these honeybees by applying a better management system such as leaving some honey during harvesting, providing provisions and water during dearth periods and sheltering them from harsh weather conditions.

Reproductive swarming: in areas where the reproductive swarming tendency is low (in *A. m. monticola* and *A. m. bandasii* areas) one of the major problem of apiculture is obtaining swarms, either to start beekeeping or to increase the existing stock. As a result, in these areas the price of a honeybee colony is very high and selling colonies becomes a good source of income to beekeepers. So in these areas developing skills in a simple way of colony multiplication system such as over crowding in a small volume traditional or box hive and a simple splitting technique (which have been proven to be efficient for local honeybee population (Nuru and Dereje, 1999)) would be highly recommended to multiply honeybee colonies. On the other hand, in the lowland and mid-altitude parts of the study areas where *A. m. scutellata* and *A. m. jemenitica* occur, a high reproductive swarming tendency and subsequent low honey production are major problems of beekeeping. So in these areas keeping colonies in relatively large volume hives, removing queen cells and limiting the egg laying of a queen (after a certain population build-up using queen excluders) could minimise the high brood rearing and subsequent swarming tendency of these honeybee colonies.

Colony management: it has been noted that the types of honeybee populations, their behavioural characteristics and their ecologies are different. Moreover, the phenology of the bee plants and the colony seasonal cycles are more localized. So the honeybee management system should be designed according to their behavioural and biological characters in their respective ecological regions. However, transferring of better traditional beekeeping skills of one area (leaving provisions during harvesting; feeding and watering during dearth periods; sheltering and protecting from enemies) to the other should be encouraged.

Future research areas: due to the occurrence of highly contrasting ecological areas within the geographical distribution of these subspecies, some localities require further investigation to confirm the continuous occurrence of these subspecies within delineated areas. These include areas between Shiraro and Berahile to confirm the continuous distribution of *A. m. jementica* population of the eastern lowlands to the western lowlands and areas between north Wollo and north Gonder to confirm the continuation of *A. m. monticola* population between these areas.

Based on this study, distinctive honeybee populations and their geographical delineation were noted both in morphology and behaviour. However, further detailed studies are required to assess the merits and demerits of these honeybee populations from the productivity and manageability points of view. To improve the productivity and manageability of these honeybees, appropriate selection and breeding programmes have to be employed using the wide range of morphological and behavioural diversity of local honeybees. During selection important qualitative characters such as gentleness, less inclination to swarm, migration and absconding, high tendency to store honey, the ability to easily synchronise to the change of environmental conditions and fast colony build-up ability have to be considered. Moreover, quantitative morphological characters, which are important for honey production and which meet the local situation, have to be included.

The survey information on swarming, migration and temperament gave very important clues on the behavioural aspects of these bees. However, the information have its own limitations due to the differences in the experiences, cultural backgrounds and subjectivities of different beekeepers in assessing their colonies which might have interfered with the actual behavioural difference evaluation of the bees. However, the information will still be valuable to synthesize various hypotheses for further investigation to substantiate the findings based on controlled experiments and close observations to critically evaluate the behavioural and biological differences of the bees and to fully understand the various attributable factors. Controlled experiments are very important to determine whether the reported behavioural characters are genetically fixed and remain persistent under different ecological conditions or not.

CHAPTER 6

Appendices

Appendix I

6.1 Beekeeping activities of the study area

Traditional knowledge about bees and methods of handling them are very different within the country. In some areas traditional skill is very advanced while in others it still remains very elementary. The problem of beekeeping is also different depending on the ecology and behaviours of the bees. So knowledge about beekeeping activities of each area and understanding the inherent problem of that area is very important to envisage an appropriate beekeeping development plan suitable to the particular area. Moreover, transferring of a better traditional knowledge of one area to the other would be very desirable before introducing box hive beekeeping to such areas.

6.1.1 Beekeeping in the Amhara and Tigray Regions

In this region, large areas of inaccessible lands for cultivation and livestock grazing (along escarpments, hills and mountainous) are very potential for beekeeping. Besides this, the beekeeping potentiality of the regions is partly attributable to the various cultivated oil and pulse crops, which are very important to bee forage and honey production. Farmer beekeepers of the area have well developed traditional beekeeping skills. In this area beekeeping is very fascinating and mostly practiced at a backyard level by keeping beehives either under separate shelters or around the house wall or even inside the house (Figure 52), with domestic animals and family members with out any problems. Many farmer beekeepers hang their beehives inside their living rooms and provide bee entrances on the sides of the walls.

Interestingly it was also observed that in the Tigray region bee colonies are kept inside living rooms and bees were sharing the same doors with members of the family. Those honeybee colonies kept inside the house are not subjected to the external ambient weather such as direct sun heat, cold and rain. Beekeepers believe that honeybee colonies kept inside the house are more productive. This might be because the energy and time required to regulate their nest temperature is very minimal. Besides this, bees kept inside the house is very convenient to the beekeepers and protect them from various honeybee enemies and also theft.

Beekeepers construct different sizes of traditional hives for different purposes; small hives to induce reproductive swarming and big hives for honey production. In these regions when the population of their colonies increases, beekeepers add extra space by appending another traditional hive horizontally to the mother hives. Unlike other areas, beekeepers of the regions practice feeding, watering and moving their colonies for better forage. In some places like Gojjam, beekeepers move their colonies to other places not only for better forage but also to protect them from certain diseases, which occur on a seasonal basis in mid-altitudes at some localities. The causes of the diseases are not known. In the experiences of the beekeepers, such disease occurs in the moist season but not in highland areas. The major problems of beekeeping of the area are obtaining of colonies/swarms/ to start or to expand beekeeping, limited bee forage and the occurrence of complete death of colonies, which is reported in many parts of Amhara region.

6.1.1.1 Marketing honeybee colonies

In these regions a very fascinating part of beekeeping is the practice of beekeepers selling their honeybee colonies in the market (Figure 53). Beekeepers bring well-established bee colonies in traditional hives to the market. They carry colonies on their heads up to a two days journey, distances of nearly 60 km on foot. In one market day, for example during the selling season at Inticho, it was reported that about 300 bee colonies were gathered for selling. The price of one established bee colony in a traditional hive ranges from 250–300 Ethiopian Birr (US$ 30–35). The municipality of the town collects a tax of 1 Eth. Birr per colony. When selling colonies, beekeepers open one end of the hive to show the population strength of their colonies. In these areas multiplication and selling of bee colonies is a good source of cash income for beekeepers. They utilise the money to purchase food, cloths and other needs of their family members.

In areas where honey production is not attractive, beekeepers specialise in multiplication and selling of colonies by keeping their bees in small hives to induce reproductive swarming by over-crowding. In areas where honey production is attractive, beekeepers are not interested in the reproductive swarming of their colonies and try to control swarming by keeping them in relatively large volume traditional hives and by removing a certain amount of brood and queen pupae during swarming periods

6.1.2 Beekeeping practices in western parts of the study areas (Wollega)

This area is one of the beekeeping potential areas in the country. The better natural vegetation coverage and the presence of cultivated crops, coupled with suitable weather conditions make the area very conducive for beekeeping. Large honeybee populations are found as wild. Even though the area has a very high potential for beekeeping, the way beekeepers manage their colonies and handle their products still requires much improvement.

In the area beekeeping is mostly practiced in the forest by hanging hives on very big trees (Figure 54). In swarming season beekeepers prepare their hives and hang them on trees to be occupied by a new swarm. Up to fifty colonies are common in one tree. During honey harvesting beekeepers mostly use a very long rope to bring down the beehives from tall trees and remove all the contents of the hive: honey, brood and pollen without taking care of the bees. After the honey harvest they shake away the bees and collect and store the empty hives in a shelter to be hung for the next swarming season.

When beekeepers were interviewed about the reasons why they shake away the bees and collect their hives, they said that bees of the area have a high migratory tendency and, once the colony is disturbed during honey harvesting it will abscond eventually even leaving some combs and brood behind. So they want to collect and store their hives against wear due to heavy rain. However, it was observed that some beekeepers in the same area still keep their bees under shelter in their farmyards. These beekeepers reported that if the necessary precautions are taken during honey harvesting, the colonies could remain in their hives without migration.

The major problems of beekeeping of the area are: (1) hanging and honey harvesting in such a very big trees is a very difficult task and it has a high risk of losing lives; (2) forest beekeeping by hanging hives in big trees can be difficult if done by women, old men and very young people; (3) such a brutal way of harvesting and shaking away whole colonies results in the loss of thousands of colonies every year; (4) the "nomadic" nature of the bees; (5) forest fires in dry seasons; (6) excessive swarming and (7) lack of knowledge on better handling methods of bees.

6.1.3 Beekeeping activities in Afar Region

The Afar region is one of the arid zones of the country. The vegetation coverage of the area is very minimal. The annual rainfall and its distribution are very limited and the monthly average temperature of the area is very high. Because of such factors generally most areas of the region do not have a potential for beekeeping. However during the rainy season in July and August it was observed that the whole of the Afar plains are covered with various fast growing and fast flowering plants (Figure 42). In addition to this, areas along the river Awash basin and the large irrigated lands along the river remain green throughout the year. This particular part of the region still retains a high potential for beekeeping. As a result of this, quite a large number of wild honeybee colonies occur in the area. Since the area is very hot, most wild colonies dwell in various cavities in the ground like crevices of stones, caves and hollow trunks of trees.

Most of the indigenous Afar communities follow a nomadic way of life, moving from place to place looking for better grazing areas and water for their livestock. As a result of this, beekeeping is not a common practice and does not seem convenient to such communities. But honey hunting is not uncommon. It was also observed that some people who came from highland parts of the country with some beekeeping background are able keep bees very successfully along the Awash River basin.

6.1.4 Beekeeping activities in the Benshangul and Gumuz Region

This region has a high beekeeping potential. The vegetation coverage of the region still remains intact and the annual rainfall and distribution are adequate to support the growth and flowering of various honeybee plants. As a result of this, quite a large number of honeybee colonies are found, and a large proportion of these colonies exist as wild colonies. In the area, backyard, forest beekeeping and honey hunting are widely practiced simultaneously.

Backyard beekeeping is not well developed in the area. It is only practiced by people who came to the area from the central highlands during the government resettlement programs. These people have a well-developed beekeeping tradition. Forest beekeeping by hanging a number of beehives in a tree is very common. In this area, during honey harvesting beekeepers also remove all the contents of the hive and shake away the whole colonies and collect their hives to be used in the next flowering season.

Beekeepers prefer to hang their hives in trees far away from their homes because places away from man's interference are more productive than areas closer to settlements. Secondly, due to the aggressive nature of the bees, it is difficult to keep bees around farmyards and near the villages. In this region beekeepers reported that due to the high aggressive nature of the bees, it is difficult to carry out farm activities in the presence of honeybee colonies even those in a very tall trees about 20 m above the ground. The major problems of beekeeping of this area are: (1) the occurrence of forest fires that clear thousands of km^2 forest areas and destroy thousands of honeybee colonies every year; (2) aggressive nature of the bees; (3) migratory tendency of the bees; (4) excessive swarming and (5) lack of knowledge on management of bees and their products.

Although forest beekeeping is widely practiced in the country and it is believed to be important to exploit resources far away from settlement areas, backyard beekeeping has to be encouraged and promoted simultaneously for many of its practical advantages, such as for easily monitoring and managing colonies, protecting them from various enemies and better utilisation of the honeybees for pollination of cultivated food and cash crops around farm and home yard areas. Moreover, unlike forest beekeeping, backyard beekeeping can be exercised irrespective of age and sex and is easy to apply better management system.

Figures legends (52, 53 and 54)

Figure 52 Backyard beekeeping (Gojjam area).

A and B, Traditional beehives kept inside the house.

C, Traditional beehives at backyard in separate shelter.

D, Beehives hung around the wall and beekeeper with self-made grass woven bee veil.

Figure 53 Selling honeybee colonies in the market (Tigray Inticho).

A and C, Beekeepers carrying beehives toward the market for selling.

B, Beekeeper having break after long journey carrying colony toward the market.

D, Young beekeepers selling their bee colonies in the market by leaving one end of the beehives open.

E, Honeybee colony market place in one side of the Inticho town.

Figure 54 Forest beekeeping (in western parts of the country (Wollega area))

A and B, Beekeepers how to climb on and come down from a big trees using long rope during hanging beehives and honey harvesting.

C, Beekeeper carrying empty hives to be hung in the forest.

D, Traditional beehives hanged on tree.

Figure 52 Backyard beekeeping (Gojjam area)

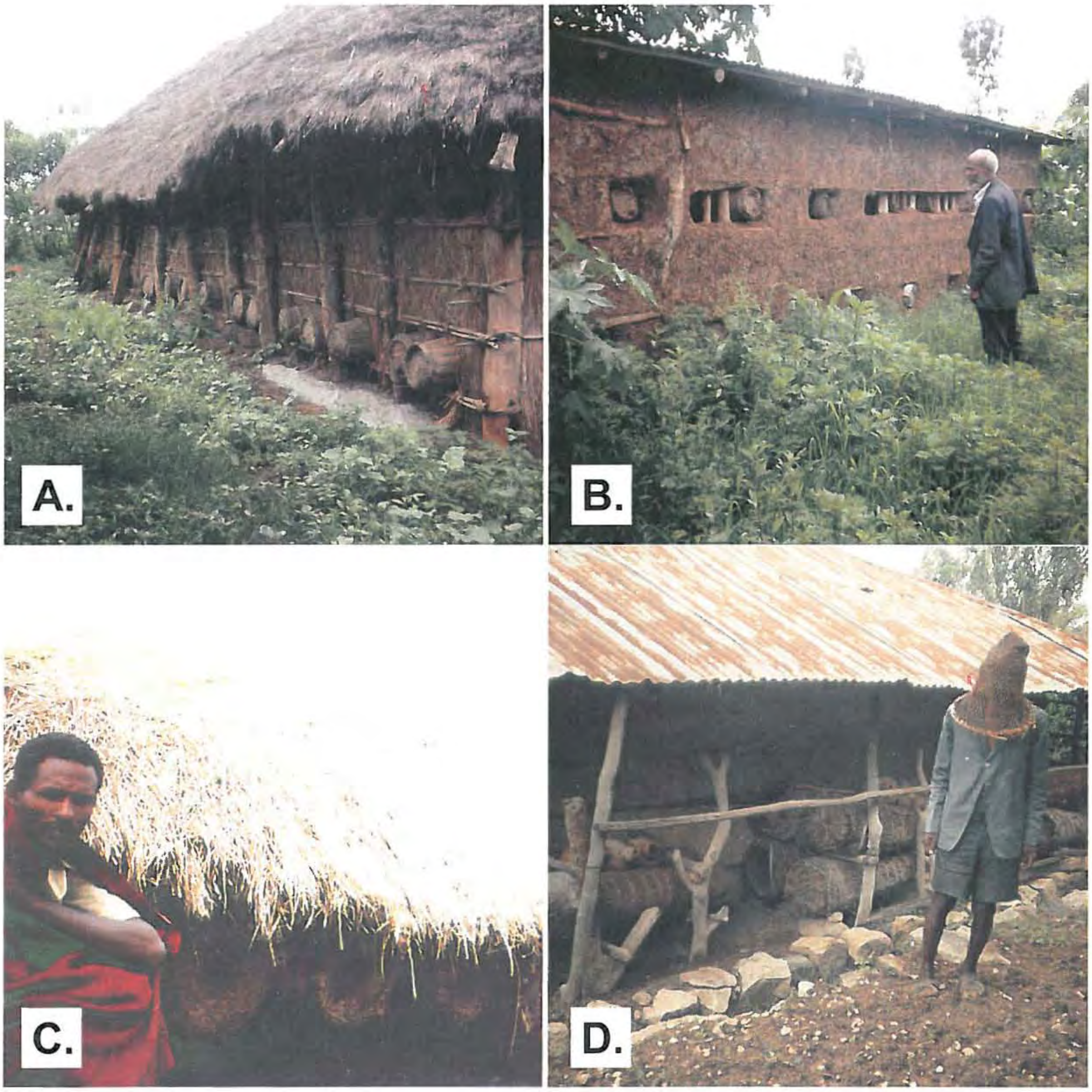


Figure 53 Selling honeybee colonies in the market (at Inticho)

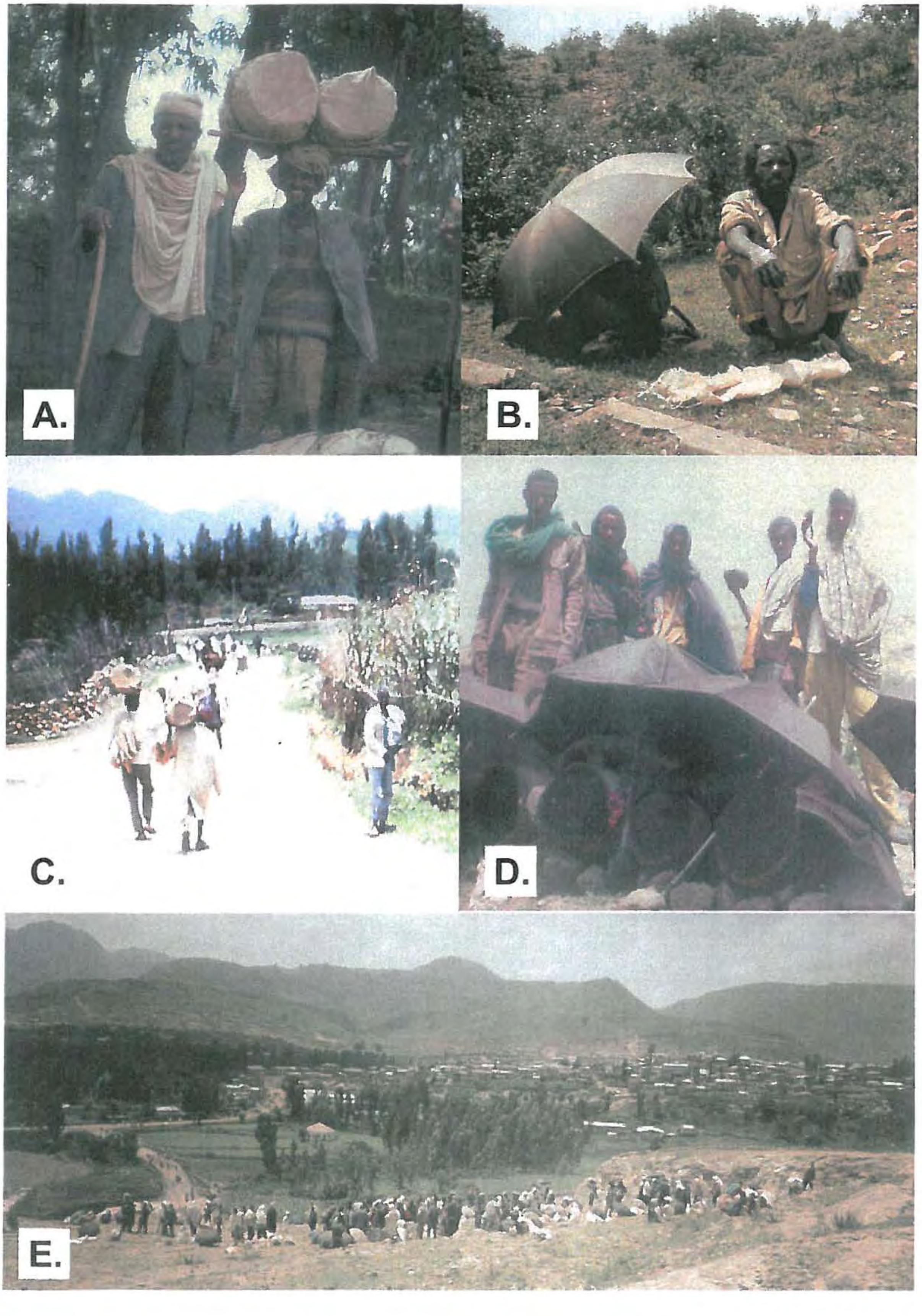
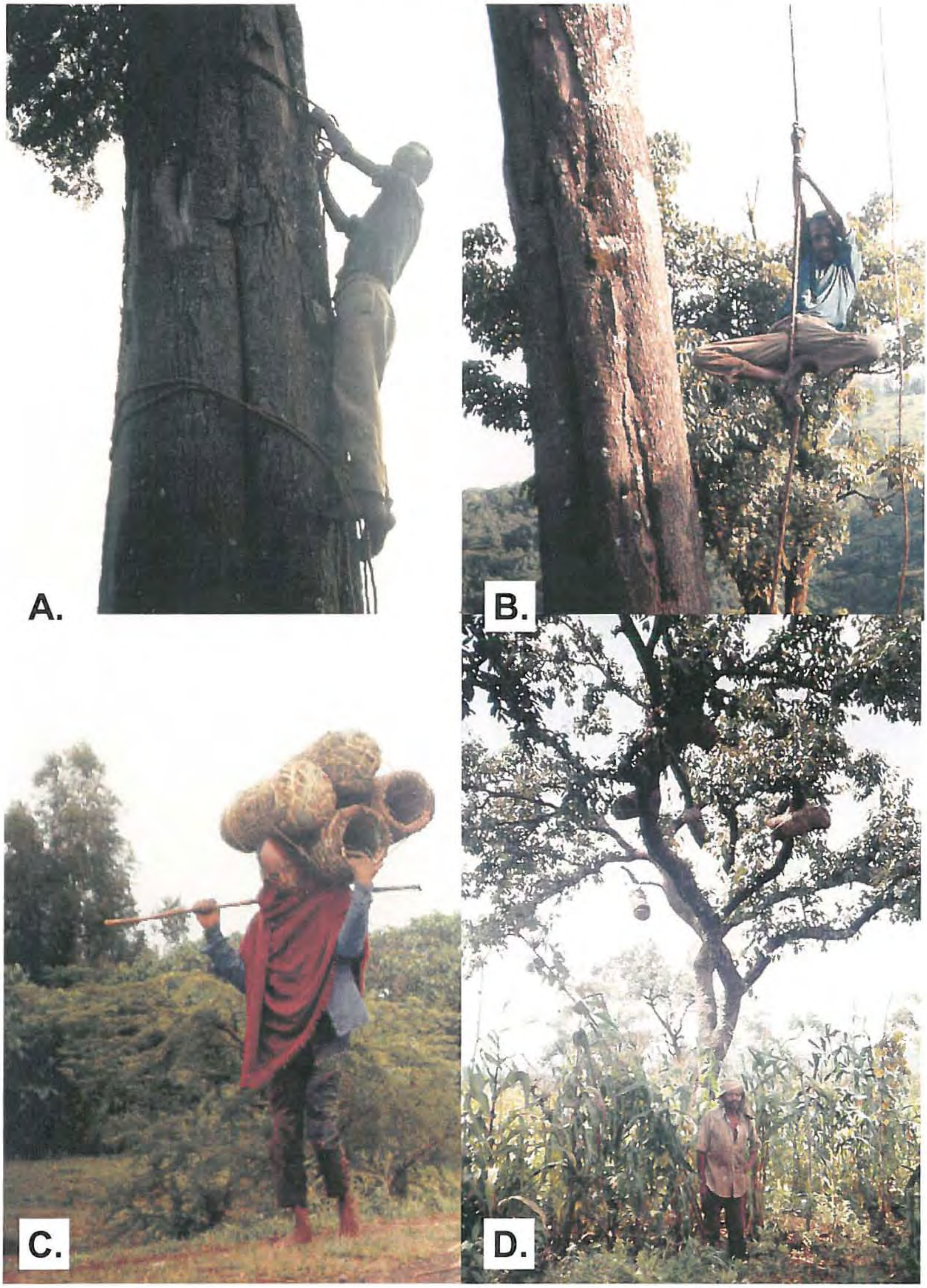


Figure 54 Forest beekeeping in western parts of the country (Wollega area)



Appendix II

Some of the major honeybee plants of the study areas.

Botanical name	Families	Plant type	Growing altitudes in (mm)	Flowering periods
Acacia abyssinica	Fabaceae	Tree	1500-2900	Jan. – May
Acacia albida	Fabaceae	Tree	500-2600	July – Dec.
Acacia pilispina	Fabaceae	Tree	1800-2800	July – Dec.
Acacia polyacantha	Fabaceae	Tree	500-1800	Apr. – June
Acacia seyal	Fabaceae	Tree	500-2300	Sep. – Jan.
Acanthus sennii	Acanthaceae	Herb	500-3200	Oct. – Jan.
Achyranthes aspera	Amaranthaceae	Herb	1000-3000	Aug. – Feb.
Albizia gummifera	Fabaceae	Tree	1500-2100	Jan. – Apr.
Albizia lebbek	Fabaceae	Tree	500-2000	Jan. – May
Albizia schimperiana	Fabaceae	Tree	1500-2800	Jan. – May
Aloe berhana	Aloeaceae	Herb	2000-2700	Nov. – May
Andropogon abyssinicus	Poaceae	Herb	1800-2900	Sep. – Nov.
Anthemis tigreensis	Asteraceae	Herb	1200-4000	Jan. –Apr.
Azadirachta inidca	Meliaceae	Tree	500-2000	July –Mar.
Balanites aegyptica	Balanitaceae	Tree	500-1800	Jan. – Aug.

Bersama abyssinica	Melianthaceae	Tree	1300-2800	Sep. – May
Bidens macroptera	Asteraceae	Herb	1800-3700	Sep. – Dec.
Bidens ghedoensis	Asteraceae	Herb	1300-2600	Aug. – Nov.
Bidens pachyloma	Asteraceae	Herb	2200-3000	Sep. – Oct.
Bidens prestinaria	Asteraceae	Herb	1300-2900	Sept. – Oct.
Bothriocline Shcimperi	Asteraceae	Herb	1500-2800	Oct. – Apr.
Brassica carinata	Brassicaceae	Herb	1350-2600	Sep. – Nov.
Brassica nigra	Brassicaceae	Herb	2000-2600	Sep. Nov.
Buddleja polystachya	Buddlejaceae	Tree	1000-3300	Jan. – July
Caesalpina decapetala	Fabaceae	Shrub	1700-2400	Oct. – Jan.
Capsicum annuum	Solanaceae	Herb	1000-2500	Aug. – Oct.
Carduus nyassanus	Asteraceae	Herb	2000-3500	Sept. – Nov.
Carissa edulis	Apocynaceae	Shrub	600-2600	Nov. – Mar.
Caylusea abyssinica	Resedaceae	Herb	1600-2400	Oct. – Feb.
Celosia argentea	Amaranthaceae	Herb	600-1900	Oct. – Apr.
Cicer arientinum	Fabaceae	Herb	1000-2100	Oct. – Nov.
Cirsium schimperi	Asteraceae	Herb	2000-3100	Aug. – Dec.
Clematis hirsuta	Ranunculaceae	Climber	1000-3200	Oct. – Jan.
Clematis simensis	Ranunculaceae	Climber	1500-3300	Sep. – Jan.
Clerodendrun cordifolium	Verbenaceae	Shrub	1300-2100	May – Nov.
Coffea arabica	Rubiaceae	Shrub	1700-2100	May – Aug.
Combretum paniculatum	Combretaceae	Woody climber	1400-2000	Sept. – Feb.

Cordia africana	Boraginaceae	Tree	550-2600	Sept. – Nov.
Coriandrum sativum	Apiaceae	Herb	1500-2500	Aug. – Sep.
Crinum abyssinicum	Amaryllidaceae	Herb	1600-3000	Jun. – Sep.
Croton macrostachys	Euphorbiaceae	Tree	1300-2700	Apr. – July
Cynoglossum coeruleum	Boraginaceae	Herb	1700-3500	Oct. – Dec.
Cynotis barbata	Commelinaceae	Herb	1700-2800	Sept. – Nov.
Datura stramonium	Solanaceae	Herb	1250-2400	Aug. – Feb.
Dichrostachys cinera	Fabaceae	Shrub	500-2000	Feb. – Aug.
Dipsacus pinnatifdus	Dipsaccaeae	Herb	1900-3600	Sep. – Mar.
Discopodium penninervium	Solanaceae	Shrub	2100-2600	Sep. – Apr.
Dombeya aetheopica	Sterculiaceae	Tree	2000-3300	Oct. – Dec.
Dombeya torrida	Sterculiaceae	Tree	1800-3300	Oct. – Dec.
Echinops hispidus	Asteraceae	Herb	1600-2700	Oct. – Feb.
Echinops longisetus	Asteraceae	Herb	2000-4000	Sept. – Jan.
Echinops macrochaetus	Asteraceae	Herb	1400-3500	Oct. – Mar.
Ehretia cymosa	Boraginaceae	Tree	500-2700	July – Oct.
Ekebergia capensis	Meliaceae	Tree	1500-2700	Nov. – May
Erica arborea	Ericaceae	Shrub	2500-4000	Sep. – Nov.
Erythrina abyssinica	Fabaceae	Tree	1000-2800	Sep. – Apr.
Erythrina brucei	Fabaceae	Tree	1600-2800	Nov. – Feb.
Eucalyptus camaldulensis	Myrtaceae	Tree	1000-2400	Sep. – Nov.
Eucalyptus globulus	Myrtaceae	Tree	1800-3200	Apr.– Jun.

Euphorbia abyssinica	Euphorbiaceae	Tree	1400-2400	Sep. – Nov.
Euphorbia candelabrum	Euphorbiaceae	Tree	1200-2000	Oct. – Jan.
Gossypium hirsutum	Malvaceae	Herb	500-1500	Sep. – Nov.
Guizotia abyssinica	Asteraceae	Herb	1500-2450	Sep. – Oct.
Guizotia scabra	Asteraceae	Herb	1300-2900	Sep. – Nov.
Hagenia abyssinica	Rosaceae	Tree	1800-3500	Oct. – Dec.
Hebenstretia dentata	Scrophulariaceae	Shrub	2100-4200	Aug. – Dec.
Helianthus annus	Asteraceae	Herb	1700-2400	Sept. – Oct.
Helminthotheca echioides	Asteraceae	Herb	2000-2500	Nov. – Feb.
Hypericum quartinianum	Hypericaceae	Shrub	2000-3000	Sept. – Feb.
Hypericum revolutum	Hypericaceae	Shrub	2300-4000	Sep. – Oct.
Hypoestes forskaolii	Acanthaceae	Herb	500-2700	All year round
Hypoestes triflora	Acanthaceae	Herb	1200-2500	Jul. – Jan.
Impatiens rothii	Balsaminaceae	Herb	1500-3000	Aug. – May
Jasminum abyssinicum	Oleaceae	Climber	2000-3000	Aug. – Dec.
Justicia heterocarpa	Acanthaceae	Herb	500-1900	Sep. – Jan.
Justicia ladanoides	Acanthaceae	Herb	500-2800	Jul. – Oct.
Justicia schimperiana	Acanthaceae	Shrub	1400-2600	Sep. – Jan.
Kinphofia foliosa	Liliaceae	Herb	2000- 4000	Apr. – Jul.
Kinphofia insignis	Liliaceae	Herb	2400-2800	Jun. – Aug.
Lathyrus sativus	Fabaceae	Herb	1500-2500	Sep. – Jan.
Lens culinaris	Fabaceae	Herb	1500-2600	Sep. – Oct.

Linum usitatissimum	Linaceae	Herb	2000-3000	Sep. – Oct.
Lippea adoensis	Verbenaceae	Shrub	1700-2500	May – Sep.
Maesa lanceolata	Myrsinacea	Shrub	1500-3000	Sep. – Dec.
Mangifera indica	Anacardiaceae	Tree	500-1800	Oct. – Feb.
Maytenus arbutifolia	Celastraceae	Shrub	1500-2500	Sep. – Nov.
Maytenus obscura	Celastraceae	Shrub	1700-3000	Oct. – Dec.
Maytenus senegalensis	Celastraceae	Shrub	500-2400	Oct. – May
Melia azedarach	Meliaceae	Tree	500-2000	June – Nov.
Melletia ferruginea	Fabaceae	Tree	1000-2800	Nov. – Apr.
Musa x paradisiaca	Musaceae	Herb	450-2000	All year round
Ocimum uriticifolium	Lamiaceae	Herb	1000-2200	All year round
Olea europea	Oleaceae	Tree	1500-3000	Oct. – Dec.
Opuntia ficus-indica	Cactaceae	Herb	1500-2500	May – July
Otostegia integrifolia	Lamiaceae	Shrub	1700-2500	Aug. – Oct.
Parkinsonia aculeata	Fabaceae	Shrub	500-2000	Jan. – Aug.
Persicaria nepalense	Polygonaceae	Herb	1350-3200	Aug. – Oct.
Phytolacca dodecandra	Phytolaccaceae	Shrub	1500-3000	Oct. – Apr.
Pisum sativum	Fabaceae	Herb	2000-3000	Sep. – Oct.
Plantago lanceolata	Plantaginaceae	Herb	1500-3000	All year round
Plectocephalus varians	Asteraceae	Herb	1900-3600	Sep. – Dec.
Plectranthus barbatus	Lamiaceae	Herb	1000-2700	Oct. – Nov.
Pterolobium stellatum	Fabaceae	Shrub	1200-2500	Sep. – Apr.

Pycnostachys abyssinica	Lamiaceae	Herb	1000-2700	Aug. – Feb.
Ranunculus multifidus	Ranunculaceae	Herb	1500-3500	All year round
Raphanus raphanistrum	Brassicaceae	Herb	1900-2800	Aug. – Oct.
Ricinus communis	Euphorbiaceae	Shrub	500-2500	Sep. – Nov.
Rosa abyssinica	Rosaceae	Shrub	1900-3300	Sep. – Dec.
Rubus apetalus	Rosaceae	Shrub	1500-3200	Oct. – Dec.
Rubus steudneri	Rosaceae	Shrub	1500-3000	Aug. – Jan.
Rumex nepalensis	Polygonaceae	Herb	1500-3500	Sep. – Nov.
Rumex nervosus	Polygonaceae	Shrub	500-3500	All year round
Salvia leucantha	Lamiaceae	Herb	1500-2600	All year round
Salvia merjamie	Lamiaceae	Herb	2200-4200	Aug. – Nov.
Salvia nilotica	Lamiaceae	Herb	1800-3800	Jun. – Nov.
Satureja paradoxa	Lamiaceae	Herb	1400-3200	Aug. – Oct.
Schefflera abyssinica	Araliaceae	Tree	1500-3500	Mar. – May
Schinus molle	Anacardiaceae	Tree	500-2400	Jun. – Nov.
Senecio myriocephalum	Asteraceae	Herb	2200-3300	Sep. – Nov.
Senecio ochrocarpus	Asteraceae	Herb	2400-3000	Aug. – Nov.
Sesanum indicum	Pedaliaceae	Herb	600-1700	Aug. – Oct.
Silybum marianum	Asteraceae	Herb	2400-2500	Aug. – Dec.
Sorghum bicolor	Poaceae	Herb	500-2400	Sep. – Dec.
Sparrmannia ricinocarpa	Tiliaceae	Shrub	2300-3300	Aug. – Feb.
Sphaeranthus suaveolens	Asteraceae	Herb	1000-2500	Sep. – May

Stereospermum kunthianum	Bignoniaceae	Tree	700-2000	Apr. – May
Syzygium guineense	Myrtaceae	Tree	1400-3200	Jan. – Apr.
Thymus schimperi	Lamiaceae	Herb	2300-3800	Mar. – Sep.
Trifolium decorum	Fabaceae	Herb	1800-3000	Sep. – Oct.
Trifolium rueppellianum	Fabaceae	Herb	1700-3650	Jul. – Nov.
Trifolium semiplosum	Fabaceae	Herb	1800-3100	Aug. – Nov.
Urtica simensis	Urticaceae	Herb	1500-3400	All year round
Vernonia amygdalina	Asteraceae	Shrub	500-2800	Dec. – Feb.
Vernonia auriculifera	Asteraceae	Shrub	1600-2800	Nov. – Apr.
Vernonia leopoldii	Asteraceae	Shrub	2300-2900	Oct. – Jan.
Vernonia rueppellii	Asteraceae	Shrub	1700-3000	Oct. – Mar.
Vernonia urticifolia	Asteraceae	Shrub	1600-2600	Oct. – Mar.
Vicia faba	Fabaceae	Herb	2000-3000	Aug. – Oct.
Veronica abyssinica	Scrophulariaceae	Herb	1500-3200	Aug. – Nov.
Ximenia american	Olacaceae	Tree	500-2100	Dec. – Apr.
Zantedeschia aethiopica	Araceae	Herb	1500-3000	Sep. – Dec.
Zea mays	Poaceae	Herb	500-2400	Aug. – Sep.

Appendix III

The colony means of each morphometric character (numbers in parenthesis are Ruttner, (1988) character numbers).

No	Locality Code	colony	(35)	(36)	(1)	(32)	(33)	(34)	(9)	(10)	(11)	(13)	(22)	(30)	(31)	No of Bees
1	N16	1	3.25	1.45	0.19	5.30	5.35	4.05	2.09	2.03	2.61	2.16	105.32	90.66	34.23	20
2	N16	2	1.60	0.30	0.17	3.75	3.60	2.75	2.13	2.07	2.63	2.18	105.80	93.37	38.24	20
3	N16	3	4.40	2.55	0.19	8.25	8.25	4.45	2.04	1.98	2.50	2.05	110.69	90.29	37.19	20
4	N16	4	1.85	1.70	0.18	3.00	2.95	1.30	2.04	1.97	2.47	2.02	101.71	89.76	35.43	20
5	N16	5	2.35	0.70	0.19	7.25	7.25	3.95	2.10	2.05	2.61	2.20	101.78	86.60	35.26	20
6	N11	1	2.15	1.80	0.19	3.60	3.45	2.00	2.02	1.95	2.48	2.11	102.22	90.73	36.02	20
7	N11	2	4.15	1.00	0.18	8.80	8.75	7.65	1.95	1.92	2.44	2.00	104.57	88.88	40.03	20
8	N11	3	3.20	0.65	0.19	5.85	5.70	3.60	1.97	1.90	2.46	2.04	105.19	93.75	36.70	20
9	N11	4	4.00	0.30	0.19	8.30	8.20	5.80	2.01	1.97	2.53	2.05	106.19	89.49	34.56	20
10	N11	5	3.60	0.95	0.19	6.30	6.20	4.45	1.98	1.93	2.47	2.05	104.27	89.97	36.74	20
11	N10	1	2.50	1.35	0.20	3.95	3.90	1.95	2.06	2.01	2.57	2.13	104.04	90.04	36.38	20
12	N10	2	3.30	0.95	0.20	5.75	5.60	3.95	2.08	2.02	2.58	2.15	108.19	87.91	33.17	20
13	N10	3	3.20	1.20	0.19	6.00	5.90	3.15	2.07	2.03	2.61	2.18	110.15	89.83	37.62	20
14	N10	4	2.95	0.25	0.18	4.50	4.40	3.50	2.03	1.98	2.57	2.12	100.25	87.21	35.70	20
15	N10	5	3.00	1.50	0.20	3.65	3.60	2.30	2.03	1.98	2.49	2.10	103.25	88.81	38.23	20

No	Locality Code	Colony	(35)	(36)	(1)	(32)	(33)	(34)	(9)	(10)	(11)	(13)	(22)	(30)	(31)	No of Bees
16	N25	1	1.65	0.20	0.17	2.45	2.60	1.65	2.00	1.97	2.53	2.13	101.18	86.28	37.06	20
17	N25	2	0.70	0.45	0.19	0.80	0.80	0.55	1.97	1.93	2.47	2.07	104.14	92.38	37.47	20
18	N25	3	1.70	1.60	0.16	2.50	2.70	4.30	1.96	1.90	2.47	2.06	105.79	87.91	38.73	20
19	N25	4	1.50	1.10	0.15	1.60	1.55	0.95	2.02	1.98	2.46	2.04	105.53	90.25	36.95	20
20	N25	5	1.80	1.80	0.17	1.15	1.10	0.75	2.04	1.97	2.46	2.12	104.72	90.98	39.60	20
21	N04	1	0.80	0.00	0.19	2.00	2.00	0.70	2.03	1.95	2.50	2.06	109.03	89.13	36.49	20
22	N04	2	0.85	0.00	0.18	1.60	1.60	1.05	2.02	1.92	2.46	2.05	101.64	89.83	37.10	20
23	N04	3	0.80	0.05	0.20	1.20	1.20	0.85	2.04	1.98	2.53	2.08	101.20	90.27	37.64	20
24	N04	4	0.25	0.00	0.17	0.40	0.40	0.25	1.99	1.92	2.48	2.06	101.88	89.57	33.97	20
25	N04	5	1.05	0.00	0.19	2.00	1.95	1.15	1.99	1.93	2.49	2.07	110.82	90.79	36.02	20
26	N07	1	1.80	0.35	0.19	0.80	3.50	2.25	2.08	2.02	2.55	2.14	108.03	86.80	38.15	20
27	N07	2	0.40	0.10	0.19	0.80	0.80	0.50	2.06	1.98	2.56	2.13	97.03	89.94	35.51	20
28	N07	3	1.75	0.80	0.17	1.95	1.90	1.05	2.16	2.06	2.62	2.17	107.14	90.14	36.40	20
29	N07	4	2.70	0.40	0.18	5.05	4.95	3.35	2.11	2.03	2.67	2.25	101.37	89.41	36.83	20
30	N07	5	1.55	0.00	0.19	2.55	2.55	1.85	2.24	2.15	2.61	2.21	103.35	85.09	38.69	20

No	Locality Code	Colony	(35)	(36)	(1)	(32)	(33)	(34)	(9)	(10)	(11)	(13)	(22)	(30)	(31)	No of Bees
31	N14	1	0.75	0.40	0.22	1.10	1.25	0.80	2.13	2.15	2.68	2.25	107.68	86.80	37.05	20
32	N14	2	0.35	0.20	0.21	0.50	0.45	0.25	2.13	2.15	2.66	2.21	106.46	88.94	39.17	20
33	N14	3	0.75	0.40	0.22	0.00	0.00	0.00	2.19	2.10	2.70	2.22	103.67	87.46	35.93	20
34	N14	4	1.50	1.00	0.21	2.65	2.85	1.25	2.14	2.14	2.72	2.19	107.60	89.75	34.16	20
35	N14	5	0.35	0.35	0.20	0.15	0.15	0.05	2.13	2.14	2.67	2.24	104.54	90.23	37.77	20
36	N02	1	0.15	0.25	0.24	0.00	0.00	0.00	2.10	2.03	2.69	2.19	106.55	86.96	35.10	20
37	N02	2	0.10	0.00	0.21	0.00	0.00	0.00	2.07	1.98	2.56	2.13	101.61	87.31	35.50	20
38	N02	3	0.20	0.20	0.22	0.00	0.00	0.00	2.10	2.03	2.62	2.23	100.94	88.88	38.47	20
39	N02	4	0.55	0.75	0.21	0.00	0.00	0.00	2.08	2.01	2.58	2.10	105.74	89.84	38.93	20
40	N02	5	0.10	0.20	0.21	0.00	0.00	0.00	2.08	2.01	2.61	2.17	105.47	87.29	36.26	20
41	N29	1	0.00	0.00	0.20	0.00	0.00	0.00	2.14	2.06	2.66	2.21	104.35	86.68	35.49	20
42	N29	2	0.00	0.00	0.22	0.00	0.00	0.00	2.10	2.06	2.63	2.15	103.31	92.31	36.23	20
43	N29	3	0.25	0.00	0.23	0.70	0.70	0.40	2.07	2.00	2.63	2.17	103.06	90.35	38.51	20
44	N29	4	0.00	0.00	0.21	0.00	0.00	0.00	2.12	2.06	2.59	2.16	106.43	89.43	38.59	20
45	N29	5	0.00	0.00	0.21	0.00	0.00	0.00	2.08	2.02	2.62	2.19	105.89	91.92	39.14	20

No	Locality Code	Colony	(35)	(36)	(1)	(32)	(33)	(34)	(9)	(10)	(11)	(13)	(22)	(30)	(31)	No of Bees
46	N12	1	3.50	0.00	0.17	8.35	8.25	6.70	2.07	2.01	2.46	2.09	103.54	88.80	39.21	20
47	N12	2	4.10	0.65	0.16	7.30	7.20	4.80	1.98	1.92	2.49	2.08	103.65	87.72	35.69	20
48	N12	3	4.85	0.80	0.15	8.50	8.50	7.00	2.11	2.05	2.61	2.25	108.48	90.45	36.06	20
49	N12	4	4.45	0.75	0.14	8.45	8.30	6.60	2.03	1.97	2.56	2.10	101.18	92.36	36.75	20
50	N12	5	4.40	0.10	0.14	8.35	8.25	6.15	1.98	1.93	2.45	2.04	105.11	91.34	39.13	20
51	N30	1	0.65	0.00	0.24	0.10	0.05	0.10	2.10	2.02	2.57	2.09	110.17	90.99	38.57	20
52	N30	2	0.65	0.90	0.24	0.20	0.55	0.45	2.11	2.01	2.62	2.21	104.47	85.54	39.73	20
53	N30	3	0.35	0.05	0.24	0.00	0.10	0.15	2.03	1.94	2.52	2.15	102.54	82.25	38.88	20
54	N30	4	0.80	0.35	0.23	0.15	0.00	0.00	2.07	1.96	2.56	2.11	106.14	86.64	38.96	20
55	N30	5	0.95	0.35	0.24	0.00	0.00	0.00	2.08	2.00	2.52	2.15	104.71	87.32	39.81	20
56	N18	1	1.45	0.35	0.19	1.80	1.80	1.60	2.17	2.10	2.69	2.16	106.90	86.49	36.87	20
57	N18	2	1.15	0.30	0.21	1.60	1.55	0.85	2.11	2.07	2.70	2.23	107.71	90.72	38.50	20
58	N18	3	1.05	0.05	0.20	2.30	2.70	1.00	2.13	2.07	2.68	2.20	107.03	90.58	38.28	20
59	N18	4	1.20	0.05	0.20	1.50	1.50	0.75	2.14	2.08	2.71	2.17	102.44	88.40	36.40	20
60	N18	5	0.30	0.10	0.20	0.00	0.00	0.00	2.14	2.08	2.69	2.18	105.67	90.22	41.23	20

No	Locality Code	Colony	(35)	(36)	(1)	(32)	(33)	(34)	(9)	(10)	(11)	(13)	(22)	(30)	(31)	No of Bees
61	N06	1	4.30	1.85	0.16	6.15	6.05	4.60	2.01	1.96	2.44	2.00	100.89	87.64	38.87	20
62	N06	2	3.00	2.80	0.16	4.00	3.95	2.60	1.98	1.93	2.47	2.06	107.73	88.24	39.62	20
63	N06	3	2.75	0.30	0.14	4.70	4.70	2.85	2.03	1.97	2.50	2.01	109.06	88.84	37.72	20
64	N06	4	3.65	3.05	0.17	6.20	6.05	4.15	2.02	1.94	2.47	2.01	108.63	88.52	35.61	20
65	N06	5	4.45	3.10	0.16	8.00	7.95	5.85	1.99	1.91	2.50	2.01	110.94	88.16	37.13	20
66	N22	1	5.05	2.85	0.18	6.15	6.05	5.40	1.99	1.92	2.44	1.98	106.00	85.69	40.45	20
67	N22	2	5.70	3.00	0.16	6.25	6.30	4.60	1.95	1.86	2.43	2.01	104.55	85.92	37.20	20
68	N22	3	5.65	3.15	0.18	6.95	7.00	6.15	1.99	1.91	2.46	2.03	98.24	89.57	39.92	20
69	N22	4	5.35	3.45	0.15	7.90	7.75	7.00	1.95	1.87	2.40	2.00	109.35	89.68	36.71	20
70	N22	5	4.95	1.05	0.16	7.65	7.65	7.05	1.97	1.90	2.39	1.98	105.74	86.73	37.66	20
71	N27	1	0.15	0.15	0.21	1.00	1.05	0.40	2.07	2.03	2.63	2.12	102.93	90.50	39.01	20
72	N27	2	0.05	0.00	0.22	0.00	0.00	0.00	2.11	2.02	2.62	2.21	106.42	91.83	35.55	20
73	N27	3	0.05	0.05	0.22	0.00	0.00	0.00	2.06	1.99	2.60	2.16	105.42	91.97	37.25	20
74	N27	4	0.60	0.20	0.21	0.75	0.75	0.60	2.01	1.94	2.51	2.07	106.56	90.30	38.65	20
75	N27	5	0.20	0.05	0.20	0.95	0.95	0.35	2.07	2.01	2.63	2.18	105.19	91.31	39.95	20

No	Locality Code	Colony	(35)	(36)	(1)	(32)	(33)	(34)	(9)	(10)	(11)	(13)	(22)	(30)	(31)	No of Bees
76	N03	1	0.60	0.70	0.22	0.40	0.40	0.25	2.13	2.07	2.64	2.26	106.17	88.78	40.02	20
77	N03	2	0.80	1.50	0.24	0.00	0.00	0.00	2.08	2.04	2.62	2.18	104.81	91.24	36.77	20
78	N03	3	1.25	2.35	0.21	0.00	0.00	0.00	2.08	2.00	2.63	2.22	106.14	93.16	34.42	20
79	N03	4	0.85	0.95	0.22	0.00	0.00	0.00	2.11	2.04	2.63	2.20	106.24	91.50	38.19	20
80	N03	5	1.30	1.50	0.24	0.00	0.00	0.00	2.09	2.03	2.57	2.18	105.15	90.16	38.15	20
81	N21	1	6.60	3.70	0.14	9.00	9.00	7.80	2.04	1.97	2.45	2.11	106.04	91.82	34.46	20
82	N21	2	4.35	1.25	0.15	9.00	9.00	7.80	2.00	1.92	2.51	2.05	103.39	86.84	36.12	20
83	N21	3	5.70	3.45	0.14	9.00	8.95	7.55	2.04	1.96	2.51	2.13	105.88	91.22	35.77	20
84	N21	4	4.25	0.60	0.15	8.25	7.80	6.90	1.97	1.93	2.43	1.95	101.26	90.22	39.99	20
85	N21	5	4.85	1.65	0.14	8.85	8.05	7.15	1.96	1.88	2.42	1.97	103.01	85.28	38.61	20
86	N15	1	3.15	0.55	0.18	6.05	6.05	4.30	2.08	2.03	2.53	2.11	103.35	90.31	39.69	20
87	N15	2	3.40	0.25	0.20	6.50	6.50	3.70	2.08	2.02	2.60	2.14	110.24	88.95	38.21	20
88	N15	3	4.05	1.20	0.18	8.05	8.00	6.30	2.05	1.97	2.53	2.12	103.97	89.71	38.80	20
89	N15	4	7.40	3.65	0.17	8.35	8.30	5.45	2.07	2.02	2.56	2.09	108.13	90.04	36.68	20
90	N15	5	2.85	0.10	0.19	5.90	5.85	3.70	2.03	1.95	2.52	2.09	110.04	89.65	36.47	20

No	Locality Code	Colony	(35)	(36)	(1)	(32)	(33)	(34)	(9)	(10)	(11)	(13)	(22)	(30)	(31)	No of Bees
91	N19	1	1.90	1.35	0.25	3.10	3.10	2.70	2.21	2.11	2.77	2.30	106.54	91.07	36.71	20
92	N19	2	1.00	1.80	0.23	0.00	0.00	0.00	2.17	2.15	2.71	2.17	103.03	89.05	38.68	20
93	N19	3	1.15	2.45	0.23	0.00	0.00	0.00	2.17	2.10	2.70	2.17	103.84	88.80	35.44	20
94	N19	4	0.85	1.80	0.28	0.00	0.00	0.00	2.17	2.10	2.71	2.32	104.46	89.39	36.83	20
95	N19	5	0.80	2.10	0.25	0.00	0.00	0.00	2.17	2.09	2.69	2.16	108.79	92.61	36.85	20
96	N17	1	3.10	2.75	0.21	3.80	3.80	2.25	2.16	2.14	2.70	2.24	104.72	90.88	36.22	20
97	N17	2	2.20	0.85	0.20	3.75	3.75	2.45	2.10	2.06	2.60	2.20	106.63	91.40	37.88	20
98	N17	3	2.75	1.30	0.20	6.90	6.70	5.45	2.13	2.09	2.63	2.21	105.32	89.71	37.63	20
99	N17	4	2.85	1.35	0.20	7.30	7.15	3.80	2.10	2.05	2.57	2.15	104.10	89.87	36.70	20
100	N17	5	1.30	1.35	0.20	0.80	0.80	0.55	2.12	2.08	2.59	2.20	109.45	89.41	41.05	20
101	N26	1	0.90	1.40	0.22	0.40	0.40	0.15	2.02	1.95	2.53	2.06	100.11	93.00	39.01	20
102	N26	2	1.10	0.50	0.23	2.00	1.95	1.25	2.03	1.98	2.56	2.10	106.61	89.75	37.30	20
103	N26	3	0.10	0.15	0.23	0.00	0.00	0.00	2.01	1.94	2.53	2.10	108.31	93.96	40.31	20
104	N26	4	0.65	0.45	0.21	0.40	0.40	0.30	2.04	1.98	2.54	2.10	103.96	91.09	39.42	20
105	N26	5	0.25	0.45	0.20	0.00	0.00	0.00	2.01	1.95	2.51	2.10	102.78	90.99	37.76	20

No	Locality Code	Colony	(35)	(36)	(1)	(32)	(33)	(34)	(9)	(10)	(11)	(13)	(22)	(30)	(31)	No of Bees
106	N05	1	0.95	0.75	0.22	1.20	1.20	0.95	2.05	2.00	2.51	2.09	99.19	90.88	35.82	20
107	N05	2	1.25	0.95	0.20	1.70	1.65	1.30	2.05	2.00	2.49	2.06	105.15	88.96	36.35	20
108	N05	3	2.45	2.35	0.23	3.00	2.90	2.30	2.07	2.02	2.54	2.12	106.18	88.56	40.86	20
109	N05	4	0.25	0.25	0.22	0.00	0.00	0.00	2.06	2.02	2.59	2.13	106.91	89.92	37.21	20
110	N05	5	0.95	2.00	0.22	0.75	0.75	0.55	2.00	1.94	2.49	2.06	101.02	88.18	37.94	20
111	N23	1	1.45	1.15	0.21	1.95	1.95	1.25	2.00	1.97	2.54	2.12	104.35	90.19	34.63	20
112	N23	2	2.05	1.95	0.22	2.00	2.00	1.30	2.05	2.02	2.58	2.13	101.20	92.44	37.37	20
113	N23	3	0.75	0.85	0.20	0.40	0.40	0.30	2.04	2.00	2.52	2.10	106.40	89.54	36.58	20
114	N23	4	0.60	0.00	0.22	1.35	1.35	0.65	2.04	1.99	2.57	2.12	108.59	92.45	39.12	20
115	N23	5	1.45	1.90	0.17	1.15	1.15	0.60	2.00	1.95	2.46	2.04	104.98	89.18	39.99	20
116	N31	1	0.00	0.00	0.25	0.00	0.00	0.00	2.16	2.08	2.62	2.18	104.77	92.52	39.99	20
117	N31	2	0.00	0.00	0.25	0.00	0.00	0.00	2.17	2.08	2.63	2.10	105.14	91.71	36.87	20
118	N31	3	0.15	0.10	0.24	0.00	0.00	0.00	2.18	2.10	2.62	2.21	104.38	92.27	38.23	20
119	N31	4	0.05	0.00	0.23	0.00	0.00	0.00	2.13	2.05	2.61	2.20	104.39	93.28	37.95	20
120	N31	5	0.00	0.00	0.22	0.00	0.00	0.00	2.14	2.07	2.62	2.19	104.73	90.50	38.84	20

No	Locality Code	Colony	(35)	(36)	(1)	(32)	(33)	(34)	(9)	(10)	(11)	(13)	(22)	(30)	(31)	No of Bees
121	N09	1	1.95	0.05	0.19	4.75	5.40	5.40	2.08	2.02	2.51	2.08	110.51	86.56	32.15	20
122	N09	2	2.20	0.10	0.19	5.75	5.40	5.90	2.10	2.04	2.53	2.15	107.90	88.02	32.87	20
123	N09	3	6.50	3.30	0.18	8.70	8.55	7.30	2.01	1.97	2.46	2.01	106.06	93.83	38.99	20
124	N09	4	5.40	2.25	0.19	7.90	7.55	6.00	2.04	1.98	2.51	2.08	105.61	92.98	38.69	20
125	N09	5	3.65	1.60	0.20	5.80	5.80	3.50	2.06	1.99	2.51	2.03	99.95	89.82	37.29	20
126	N28	1	0.00	0.05	0.20	0.00	0.00	0.00	2.08	2.00	2.61	2.21	95.54	92.55	36.15	20
127	N28	2	0.05	0.05	0.22	0.00	0.00	0.00	2.05	1.99	2.54	2.08	101.69	93.19	37.23	20
128	N28	3	0.50	0.90	0.21	0.00	0.00	0.00	2.05	1.99	2.58	2.15	102.97	90.86	38.50	20
129	N28	4	0.55	0.30	0.22	0.40	0.40	0.20	2.09	2.03	2.60	2.15	104.87	93.21	37.39	20
130	N28	5	0.15	0.20	0.22	0.25	0.25	0.00	2.11	2.06	2.62	2.11	103.04	92.23	37.25	20
131	N08	1	0.00	0.00	0.23	0.00	0.00	0.00	2.10	2.04	2.62	2.15	101.76	88.92	39.28	20
132	N08	2	0.50	0.55	0.25	0.00	0.00	0.00	2.08	2.01	2.60	2.13	100.95	89.61	37.18	20
133	N08	3	0.50	0.65	0.22	0.00	0.00	0.00	2.08	2.01	2.59	2.13	103.81	87.81	39.67	20
134	N08	4	0.10	0.00	0.23	0.35	0.35	0.10	2.12	2.06	2.63	2.15	106.51	90.33	41.03	20
135	N08	5	0.00	0.00	0.24	0.00	0.00	0.00	2.08	2.02	2.60	2.13	102.06	89.26	39.92	20

No	Locality Code	Colony	(35)	(36)	(1)	(32)	(33)	(34)	(9)	(10)	(11)	(13)	(22)	(30)	(31)	No of Bees
136	N24	1	4.50	0.00	0.23	8.40	8.15	5.00	2.03	1.96	2.52	2.11	107.11	91.39	37.69	20
137	N24	2	3.15	0.00	0.22	5.15	5.15	3.00	2.05	1.97	2.49	2.06	97.66	92.89	39.43	20
138	N24	3	2.15	0.00	0.22	2.75	2.75	1.70	2.01	1.96	2.48	2.06	104.20	90.00	41.15	20
139	N24	4	3.95	0.00	0.20	8.05	8.05	5.50	2.05	1.97	2.57	2.08	100.09	92.34	36.56	20
140	N24	5	3.10	0.25	0.23	5.55	5.55	3.40	2.04	1.98	2.47	2.02	110.63	93.02	34.62	20
141	N13	1	2.00	1.30	0.21	2.40	2.40	1.30	2.07	2.00	2.55	2.09	104.67	92.48	39.85	20
142	N13	2	1.20	0.00	0.21	3.30	3.30	1.95	2.09	2.01	2.59	2.17	97.54	93.54	39.00	20
143	N13	3	0.40	0.40	0.23	0.40	0.40	0.15	2.07	2.01	2.59	2.10	103.71	92.59	33.29	20
144	N13	4	0.75	0.45	0.20	0.80	0.80	0.35	2.18	2.11	2.66	2.19	106.23	93.22	38.66	20
145	N13	5	0.45	0.50	0.21	0.80	0.80	0.80	2.11	2.06	2.63	2.18	109.08	88.32	35.23	20
146	N20	1	0.00	0.00	0.26	0.00	0.00	0.00	2.23	2.17	2.75	2.33	100.19	93.74	40.10	20
147	N20	2	0.00	0.00	0.25	0.00	0.00	0.00	2.19	2.11	2.71	2.26	105.47	94.09	38.78	20
148	N20	3	0.00	0.00	0.25	0.00	0.00	0.00	2.15	2.17	2.70	2.21	103.35	91.41	38.73	20
149	N20	4	0.00	0.00	0.27	0.00	0.00	0.00	2.27	2.19	2.74	2.33	106.81	93.67	37.75	20
150	N20	5	0.00	0.00	0.25	0.00	0.00	0.00	2.22	2.16	2.71	2.30	101.85	93.62	39.15	20

No	Locality Code	Colony	(35)	(36)	(1)	(32)	(33)	(34)	(9)	(10)	(11)	(13)	(22)	(30)	(31)	No of Bees
151	N01	1	0.70	1.20	0.24	0.00	0.00	0.00	2.07	2.00	2.64	2.16	110.70	87.83	36.70	20
152	N01	2	0.25	0.20	0.23	0.00	0.00	0.00	2.08	2.00	2.61	2.15	107.57	88.76	38.92	20
153	N01	3	0.25	0.55	0.22	0.00	0.00	0.00	2.07	2.01	2.64	2.16	111.09	89.93	37.06	20
154	N01	4	0.65	1.40	0.22	0.00	0.00	0.00	2.08	2.03	2.58	2.18	110.14	89.29	36.81	20
155	N01	5	0.20	0.25	0.25	0.00	0.00	0.00	2.13	2.07	2.65	2.23	100.58	89.40	38.10	20

Appendix IV

Questionnaire

Questionnaire on survey of characterization of the Northern Ethiopian honeybees (*Apis mellifera* L.)

Remark: Use " X" mark where necessary

Date of interview --------------------

1. Data about District/Woreda

1.1 General information

1.1.1 Region: -----------------------------------

1.1.2 Zone: -----------------------------------

1.1.3 Woreda: ----------------------------------- Code of locality:-----------

1.1.4 Geographical Co-ordinates: -----------

1.1.5 Altitude (m): -----------------------------

1.1.6 Temperature (^{0}C): Max.---------------- Min. -------------- Mean -------

1.1.7 Rainfall (mm): Max. ---------------- Min.-------------- Mean -------

1.1.8 Rainy seasons (mark X):

	Remark	
	Small	Big
1.1.8.1 September–November	-------	---
1.1.8.2 December–February	--------	----------
1.1.8.3 March–May	--------	----------

1.1.8.4 June–August --------- ---------

1.1.8.5 Others, specify:

------------ to -------- -------- ----------

1.2 Land utilisation (hectares)

1.2.1 Total area: ---------------------

1.2.2 Cultivated land: ---------------------

1.2.3 Forest land: ---------------------

1.2.4 Bush land: ---------------------

1.2.5 Grazing land: ---------------------

1.2.6 Open land: ---------------------

1.2.7 Agro–climatical zone (in percent): Highland ------ Midland ------ lowland ------

1.3 Beekeeping activities in district/woreda/

1.3.1 Number of farmer households: ---------------------

1.3.2 Number of beekeepers in woreda: ---------------------

1.3.3 Number of honeybee colonies in woreda: ---------------------

1.3.4 Number of bee colonies owned by farmer beekeepers:

1.3.4.1 Basket hives Min. ------- Max. ---------------

1.3.4.2 Movable frame hives Min. ------- Max.---------------

1.3.5 Annual honey production (kg.)

1.3.5.1 Basket hive Min. -------- Max. ----------

1.3.5.2 Movable frame hive Min. -------- Max. ----------

1.3.6 Where do beekeepers keep their bee colonies?

1.3.6.1 At backyard -------------

1.3.6.2 Hanging on trees near homestead ------------

1.3.6.3 Hanging on trees in forests -------------

1.3.6.4 1and 2 ------------

1.3.6.5 1and 3 ------------

1.3.6.6 2 and 3 ------------

1.3.7 Is there any honey hunting in the district? yes -------- no --------

1.4 What are the major honeybee plants in the woreda:

1.4.1	Bee plants (common or Botanical names)	Flowering times
1.4.1.1	---------------------------------	-------------------------------
1.4.1.2	---------------------------------	-------------------------------
1.4.1.3	--------------------------------	-------------------------------
1.4.1.4	---------------------------------	--------------------------------
1.4.1.5	---------------------------------	--------------------------------
1.4.1.6	---------------------------------	--------------------------------
1.4.1.7	---------------------------------	--------------------------------
1.4.1.8	---------------------------------	--------------------------------
1.4.1.9	---------------------------------	--------------------------------
1.4.1.10	--------------------------------	---------------------------------
1.4.1.11	--------------------------------	---------------------------------
1.4.1.12	--------------------------------	---------------------------------

1.4.1.13 ------------------------------ --------------------------------

1.4.1.14 ------------------------------ --------------------------------

1.4.1.15 ------------------------------ --------------------------------

1.4.1.16 ------------------------------ --------------------------------

1.4.1.17 ------------------------------ --------------------------------

1.4.1.18 ------------------------------- --------------------------------

1.4.1.19 ------------------------------ --------------------------------

1.4.1.20 ------------------------------ --------------------------------

1.4.2 Is there any poisonous bee plants

1.4.2.1 ------------------------------ --------------------------------

1.4.2.2 ------------------------------ ----------------------------------

2 Information on sample site

2.1 Information on beekeepers and locality

2.1.1 Locality name: ---------------

2.1.2 Code of locality: ----------------

2.1.3 Altitude (m): ----------------- Geographical co-ordinates: -------------

2.1.4 Name of the beekeeper: ------------------ Experience (years): -----------

2.1.5 Marital status Single: -------- Married:----------

2.1.6 If married, the size of his/her family: --------------

2.1.7 Occupation: ---------------------------------

2.2 Beekeeping practise

2.2.1 Types of traditional bee hive used (mark “X”, one or more when necessary)

2.2.1.1 Log hive ----------

2.2.1.2 Straw hive --------

2.2.1.3 Clay pot --------

2.2.1.4 Bamboo hive --------

2.2.1.5 Mud hive --------

2.2.1.6 False banana hive --------

2.2.1.7 Bark hive --------

2.2.1.8 Climber --------

2.2.1.9 Others --------

2.2.2 Movable frame hive: -------------- Top bar hive ----------

2.2.3 How many hives do you have? ----------------

2.2.4 Occupied hives box hive --------- traditional -----------

2.2.5 Non-occupied hives box hive --------- traditional ------------

2.2.6 How do you characterise your colony? (mark one from each category)

2.2.6.1 Colour: Black------- Red/yellow --------

2.2.6.2 Size: Big ------- Medium--------- Small -----

2.2.6.3 Defensive behaviour: High----- Medium------ Low -----

2.2.6.4 Others, specify----------------------

2.2.7 When do bees become more aggressive? (mark One or more)

2.2.7.1 During honey flow -----------

2.2.7.2 During harvest -----------

2.2.7.3 During dearth period -----------

2.2.7.4 During rainy season -----------

2.2.7.5 When being attacked by enemies ------------

2.2.7.6 During high temperatures -------------

2.2.7.7 brood rearing -------------

2.2.7.8. Others, specify -------------

2.2.8 How do you get new colonies? (mark one or more)

2.2.8.1 Catching swarms ------------

2.2.8.2 Buying ------------

2.2.8.3 Other, specify -------------

2.2.9 How many bee hives did you hang for catching swarms:

this year -------- last year -----------

2.2.9 How many of them were occupied by swarms:

this year ---------- last year -----------

2.2.11 When do you think many swarms could be obtained? (mark one or more)

2.2.11.1 September–November ----------------------

2.2.11.2 December–February ----------------------

2.2.11.3 March–May ----------------------

2.2.11.4 June–August -----------------------

2.2.11.5 Others: specify ----------- to ---------

2.2.12 When is the honey flow season	Major	Minor
2.2.12.1 September–November	--------	-------
2.2.12.2 December–February	--------	-------
2.2.12.3 March–May	--------	-------

2.2.12.4 June–August -------- -------

2.2.12.5 Other, specify -------- -------

2.2.13 What is honey yield/year/colony in kg.

2.2.13.1 Traditional hive -------------------

2.2.13. 2 Movable frame hive --------------------

2.2.14 How do you harvest honey?

2.2.14.1 Do you remove all combs and brood yes ----- no ----

2.2.14.2 Do you remove all honey combs and leave brood yes ----- no ----

2.2.14.3 Do you leave some honey for your colony yes ---- no ----

2.2.15 Do your bees evacuate immediately after honey harvest? Yes ---- no ----

3. Behaviour of honeybees

3.1 Swarming

3.1.1 Is swarming a problem? Yes ----------- no -------

3.1.2 When does swarming occur? (mark one or more)

3.1.2.1 September–November -----------

3.1.2.2 December–February -----------

3.1.2.3 March–May ------------

3.1.2.4 June–August ------------

3.1.2.5 Others, specify ------------- to -------- ------------

3.1.3 If swarming occurred in two seasons of a year, in which season is swarming more frequent ------------- ---------to----------------------

3.1.4 How many of your colonies swarmed: this year ----------- last year ----------

3.1.5 Number of swarms per colony per swarming season: min. --------max. --------

3.1.6 Does swarming occur

3.1.6.1 Every year? Yes -------- no ----------

3.1.6.2 Once in two years? yes -------- no ----------

3.1.6.3 Once in three years? Yes -------- no ---------

3.1.6.4. Every season yes -------- no ---------

3.1.6.5 Others, specify? -----------------------------

3.1.6.6 Give reasons for your response above ---

3.1.7 Which type of your colonies swarm frequently?

3.1.7.1 Colour: black ones ----------- red ones -------- grey ones---------

3.1.8 Do you think the swarming of your colonies is advantageous ----------- or disadvantageous -------------

3.1.9 If advantageous why?

3.1.9.1 Is it to increase your number of colonies yes --------- no ----------

3.1.9.2 Is it to sell and get income yes --------- no ----------

3.1.9.3 Both 1 and 2 yes --------- no -----------

3.1.9.4 Other, specify ---------------------------------------

3.1.10 If your answer above is 2, Is it more advantageous than honey? yes ---- no---

3.1.11 Colony seasonal cycles

3.1.11.1 When do brood rearing periods occur?

3.1.11.2 September–November -----------

3.1.11.3 December–February -----------

3.1.11.4 March–May ------------

3.1.11.5 June–August ------------

3.1.11.6 Others, specify ------------- to -------- ------------

3.1.12 When does dearth period occur?

3.1.12.1 September–November -----------

3.1.12.2 December–February -----------

3.1.12.3 March–May ------------

3.1.12.4 June–August ------------

3.1.12.5 Others, specify ------------- to -------- ------------

3.2 Migration

3.2.1 Does migration occurs in your apiary? yes -------- no ------

3.2.2 If yes, when does it occur?

3.2.2.1 September–November yes ---------- no ---------

3.2.2.2 December–February yes ----------- no ---------

3.2.2.3 March–May yes ----------- no ---------

3.2.2.4 June–August yes ---------- no ----------

3.2.2.5 Other, specify --------------- to ------------------

3.2.3 Did all or parts of your colony migrate? all --------- part -----------

3.2.4 How many of your bee colonies migrated this year? ------- last year? -------

3.2.5 Does migration occur

3.2.5.1 Every year yes -------- no --------

3.2.5.2 Once in two years yes -------- no --------

3.2.5.3 Once in three years yes -------- no --------

3.2.5.4 Others, specify --

3.2.5.5 Give reasons for your response above ---

3.2.6 Where did the bee colonies migrate?

3.2.6.1 To highlands yes -------------- no --------

3.2.6.2 To midlands yes -------------- no ---------

3.2.6.3 To lowlands yes -------------- no ---------

3.2.6.4 Others, specify ---

3.2.7 Give reasons for your answer above ---

3.2.8 Do the migrated bee colonies come back again? yes ------- no ---------

3.2.9 If yes, when do they come back?

3.2.9.1 September–November yes ------------- no -----------

3.2.9.2 December–February yes ------------- no -----------

3.2.9.3 March–May yes------------- no -----------

3.2.9.4 June–August yes ------------- no -------------

3.2.9.5 Others, specify -------------------to --------------

3.2.9.6 Why do you think honeybee colonies come back? -----------------------------------

----

3.2.10 What do you think are the causes for migration?

3.2.10.1 Shortage of forage yes -------------- no --------

3.2.10.2 Shortage of water yes ------------- no ---------

3.2.10.3 High temperature yes -------------- no ---------

3.2.10.4 High wind yes -------------- no --------

3.2.10.5 High rainfall yes ------------- no --------

3.2.10.6 Drought yes ------------- no --------

3.2.10.7 Pests and predators yes ------------- no --------

3.2.10.8 Pesticides yes ------------- no --------

3.2.10.9 Forest fires yes ------------- no -------

3.2.10.10 Management problems yes ------------- no -------

Others specify ---

3.3 Defence

3.3.1 Are your honeybee colonies: docile ----- aggressive------very aggressive ------?

3.3.2 How many of your honeybee colonies are aggressive? --------------

3.3.3 Are there unprovoked attacks? yes --------- no ----------

3.3.4 Which of your honeybee colonies are very aggressive?

3.3.4.1 Size: big ------ medium --------- large --------

3.3.4.2 Colour: yellow -------- black -------------

3.3.5 When do honeybees become more aggressive?

3.3.5.1 During honey harvest yes ------- no --------

3.3.5.2 During honey flow yes -------- no --------

3.3.5.3 During dearth period yes ------- no ---------

3.3.5.4 During being attacked by pest & predator yes ------ no -------

3.3.5.5 During swarming yes --------- no --------

3.3.5.6 During brood rearing yes -------- no --------

3.3.5.7 During September–November yes -------- no ---------

3.3.5.8 During December–February yes - ------ no --------

3.3.5.9 During March–May yes -------- no --------

3.3.5.10 During June–August yes -------- no ---------

3.3.6 Are there any incident of attacking domestic animals yes ------ no -------

Are there any death? yes------- no -------

3.3.7 Are there any incident of attacking neighbours yes ----- no ----

family members yes ----- no --------

3.3.9 Are there any deaths of humans yes ----- no ----

4. Pests and predators

4.1 What are the major pests and predators of honeybee colony in the locality?

Pests and predators	Incidence time	Damage caused
1. Ants	1. --------------------	1 ---------------
2. Birds	2.---------------------	2 ---------------
3. Wax moths	3.---------------------	3 ---------------

4. Honey badger	4. -------------------	4-------------
5. Bee lice	5.--------------------	5 ------------
6. Spiders	6.--------------------	6 -----------
7. Beetles	7. -------------------	7 -----------
8. Others, specify	8.-------------------	8 -----------

4.2 Put the above mentioned pests and predators in order of importance

1. ------------------
2. ------------------
3. ------------------
4. ------------------

5. Problems of beekeeping in the area

5.1 What are the major problems of beekeeping in the locality?

Put in order of importance	Rank (put No.)
1. Shortage of forage	----------
2. Shortage of water	----------
3. High temperature	----------
4. High wind	----------
5. High rainfall	-----------
6. Drought	---------
7. Pests and predators	---------
8. Pesticides	---------

9. Defensive behaviour of bees ---------
10. Migration ---------
11. Swarming ---------
12. Inadequate honeybee colony ----------
13. Marketing ----------
14. Beekeeping equipment ----------
15. Lack of knowledge ----------
16. Others, specify ----------

6 Information on bee products

6.1 Price of honey per kg.

During harvesting crude honey ------------- strained honey -----------

During dearth periods crude honey ------------- strained honey -----------

6.2 For what purpose do you use the honey

Consumption as food yes------ no ----- for medicament yes----- no ------

For selling ---------------

What is the annual income from honey selling minimum -------- maximum-------?

6.3 Do you collect and sell beeswax? Yes ----- no -------

If no, what are the reasons?

Lack of market yes ------- no ---------- lack of awareness ye -------- no -------

Lack of processing skills yes ------ no --------

Lack of processing technologies yes ------ no --------

CHAPTER 7

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