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Investigating the Natural Bee Space and Comb Cell Dimensions of an Ethiopian Honeybee Race (*Apis Mellifera Scutellata*) in Borana Zone, Southern Ethiopia

Wayema Amano[1, *], Dereje Woltedji[2], Abebe Jenberie Wubie[3]

[1]Yabello Pastoral and Dry land Agriculture Research Center, Oromia Agricultural Research Institute, Yabello, Ethiopia

[2]Oromia Agricultural Research Institute, Addis Ababa, Ethiopia

[3]Department of Animal Production, College of Agriculture and Environmental Sciences, Bahir Dar University, Bahir Dar, Ethiopia

Email address:

wyemano@gmail.com (W. Amano), derejew2010@gmail.com (D. Woltedji), ajenberie@126.com (A. J. Wubie)

[*]Corresponding author

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Abstract: A study to determine bee space and comb cell dimensions for local honeybee race (*Apis mellifera scutellata*) was conducted in two districts of Borana zone, Oromia regional state, Southern part of Ethiopia during 2017. Data regarding bee space, worker bee comb cell dimensions, comb thickness and comb space were measured in traditional log hives using digital caliper. Comb length and comb width were measured and the number of worker bee cells per unit area were marked and counted from the combs. The collected data was fitted in GLM procedure of SAS version 9 to identify the effect of agro-ecology and comb type on the considered parameters. The race maintained an average 11.30±1.99mm bee space and 18.78±3.0mm comb thickness. The overall worker bee cell width and depth of the race were 4.65±0.30mm and 10.28±0.74mm respectively. It was observed that the race can construct a comb with an average of 44.80cm long and 20.51cm wide in their nest. The mean number of worker bee cells count per 100cm^2 is 539.44 cells (ranging from 441-621). This finding shows variations in bee space (11.30mm), cell diameter (4.65mm) and cell depth measurements (10.28mm) from other similar studies in the other parts of the country. Based on the analyzed data, it is understood that ecological differences (climate, vegetation type, altitudes, etc.) between the midland and lowland has got significant variation in biological diversity of the honeybee races of the study area compared to the other zones of the region/ country. Thus, it is suggested that further study on these measurements is required as parameters for the honeybee geographical races of the zone and the surrounding areas to come to a reliable recommendation to use this specification in improved hive construction.

Keywords: *Apis mellifera scutellata*, Bee Space, Comb Cell Dimensions, Comb Length, Comb Space, Comb Thickness, Comb Width, Traditional Log Hive

1. Introduction

Honeybees (*Apis mellifera*) are found all over the world covering a huge geographical area of the world. There are many different honeybee species varying in morphological and natural nest characteristics adapted to the specific conditions of their environment. Although the composition of a honeybee colony is basically the same all over the world, the management of bees must be adapted to the species and race, the climate and the vegetation [19].

In natural cavities honeybees build a series of parallel combs attaching to the upper part of the cavity from the top downwards leaving fixed distance between them called bee space, each comb consists of a mid- rib with the six sided cells attached to its lateral side. Bee space is a path or a corridor that bees need to move between the combs and around the nest. It is simply the crawl space needed by bees to pass easily between two structures (7.5mm+/ 1.5mm for the western bee hive, less for Eastern bee hives) [6]. The concept and usefulness of bee space was developed a century

and half ago by Lorenzo Langsthroth. This simple idea created a revolution in beekeeping. It is vital to allow the bees walk freely on the comb. If the space between any two surfaces in the hive is too small for a bee to pass through easily, the bees will seal it with propolis. If the space is larger than a bee needs to pass through easily, the bees will construct extra comb in the area which is known as brace comb [6]. When the space between two combs (top bars or frames) in the hive is with the right size, the bees will leave it free as a crawl space. Therefore, bee space is what dictates the distance at which the beekeepers space the frames in the box hives and the bars in top-bar hives. If bee space is considered and respected by beekeepers during hive construction, we are going to have a hive that allows hive inspections, division, honey harvesting and all hive manipulations without unduly disturbing the colony. Furthermore, this allows for the construction of hives which separate the brood nest from honey stores, permitting separate access to each area. Therefore, it is the critical dimension in the hive that need due attention during any type of hive construction particularly frame hives. In frame hives, bee space is needed between the outside end of each frame and the inner wall opposite it, between opposite surface of completed and sealed brood combs, and between the top frames in the lower box and the bottom of the frames in the upper box [5].

Different honeybee species and races in different areas of the world are believed to have a basic biological bee space requirement varying from 5-10mm for *Apis mellifera* races depending on their body sizes [5]. Beside bee space, the dimensions of the comb cell also vary among races. Worker bee brood cell diameters of *Apis mellifera* races vary greatly among races [16]. An average of 4.84mm worker brood cell diameter was recorded for Africanized bees [17] and 5.2mm for that of European Apis mellifera races [18]. The average depth of *Apis mellifera* species worker brood cells is 11mm [18]. In general, it can be said that the smaller the bee race (species) the smaller the bee space, comb spacing, cell size and nest volume will be [19].

Ethiopia is one of the most agro-climatically diversified countries of the world and is characterized by various climatic conditions, different types of land features (topography) and a wide range of altitude. The contrasting agro-climatic nature of the country creates good conditions, which are conducive for the growth of more than 7000 species of flowering plants and for beekeeping to sustain higher amount of honeybee colonies and a diversity of honeybee races [9].

The country has been reported to host five honeybee races distributed in different parts of the country [4]. These honeybee races have their own preferences in different regions as well as nests (example, they may need different bee spaces depending on their body sizes and other factor). Even though, each of the local honeybee race's color, size, and geographical distribution in the country are documented, not yet the appropriate bee space and comb cell dimensions in the wild nest (traditional hives) and the tolerable frame space in modern hives well organized and documented. But recently, different mean bee spaces were investigated at different parts of the country for different types of local honeybee races adapted to respective areas.

Currently the use of movable frame and top bar hives are recommended by researcher and development organizations for beekeeping to produce quality and quantity of honey crop. However, in many tropical and sub-tropical countries, it is common to directly adopt movable frame hives and accessories that have been designed for temperate evolved races. This might affect the performances of local honeybee colonies and the acceptance of the technology by beekeepers, because honeybees found in temperate regions are larger in size than the tropical and sub-tropical bee races and thus they need different bee space [20].

Similarly, in our country, even though there is standard for hive construction, there is less attention in consideration for the biology and ecology of the local bee races when constructing and adopting box hives and their accessories. The construction of hives is done simply by adopting the European dimensions which is not comparable with the size of local bees, as a result, so many problems have been observed during hive manipulations.

Moreover, the construction of poor designed improved bee hives which is unsuitable for the particular bee race of specific geographical area reduce of technology acceptances by users [15, 11]. In addition, weak extension services and poor knowledge of improved beekeeping management practices were also mentioned as factors. Leaving a bee space between parallel combs and between the outer comb and the hive wall is the basic principle of hive construction [10]. Such standard specification is very important to reduce disturbance of bee colonies during hive manipulation by beekeepers and may trigger halt absconding of the colony.

Based on the information provided, determination of natural bee spaces and cell dimensions for each of honeybee races in the country according to their agro-ecologies should be an immense task that every concerned body shall take. This will have its own positive contribution for appropriate potential utilization strategies targeting production maximization with very low disturbances during manipulations.

Besides, the casting mould introduced in the country was designed for European honeybee species or races and did not coincide with the biological comb cell dimension requirements of our local honeybee races. Consequently, this could have an effect on time and amount of wax used by the bees to construct cells and the use of this European casting mould has forced the local honeybees to construct larger worker cells than their normal sizes and thus slows down colony buildups [3]. Thus, in an attempt to make any type of frame or top-bar hives and casting moulds, everyone should make sure that the correct bee space and comb cell dimensions are maintained for the particular species or race to make the hive operation more efficient.

Bee space and cell dimension of any bee race can be determined from their natural nests or from combs constructed in fixed comb hives. Because bees have their

own preferences to these natural nest characteristics understanding and maintaining bee space and comb cell dimension, is very important to bees and beekeepers to manage bees properly.

According to [4], based on morphometric and geographical distribution analysis, honeybees of southern Ethiopia are classified as *Apis mellifera scutellata*. Though the color, size, and distribution of the race is documented in the country, no research have carried out to determinate bee space and comb cell dimension for eco type honeybee race of Borana zone. The investigation and determination of the natural honeybee space and comb cell dimensions of this local race (*Apis mellifera scutellata*) should be an important activity for provision of basic natural requirements targeting exploitation of the maximum potential from local bees in Borana zone of Oromia Region. Therefore, the study was carried out aiming to investigate natural size of hive bee space, comb space and worker comb cell dimension for Borana zone eco type honeybee race, and compare natural cell size with cell size of distributed casting moulds.

2. Materials and Methods

2.1. Study Site Selection

The study was conducted in two agro ecological zones of Borana zone of Oromia regional state were *Apis mellifera scutellata* is supposed to exist [4]. Accordingly Bule hora district from midland and Yabello district from lowland agro ecologies were selected purposively based on prior set parameters like potential of the area and accessibility.

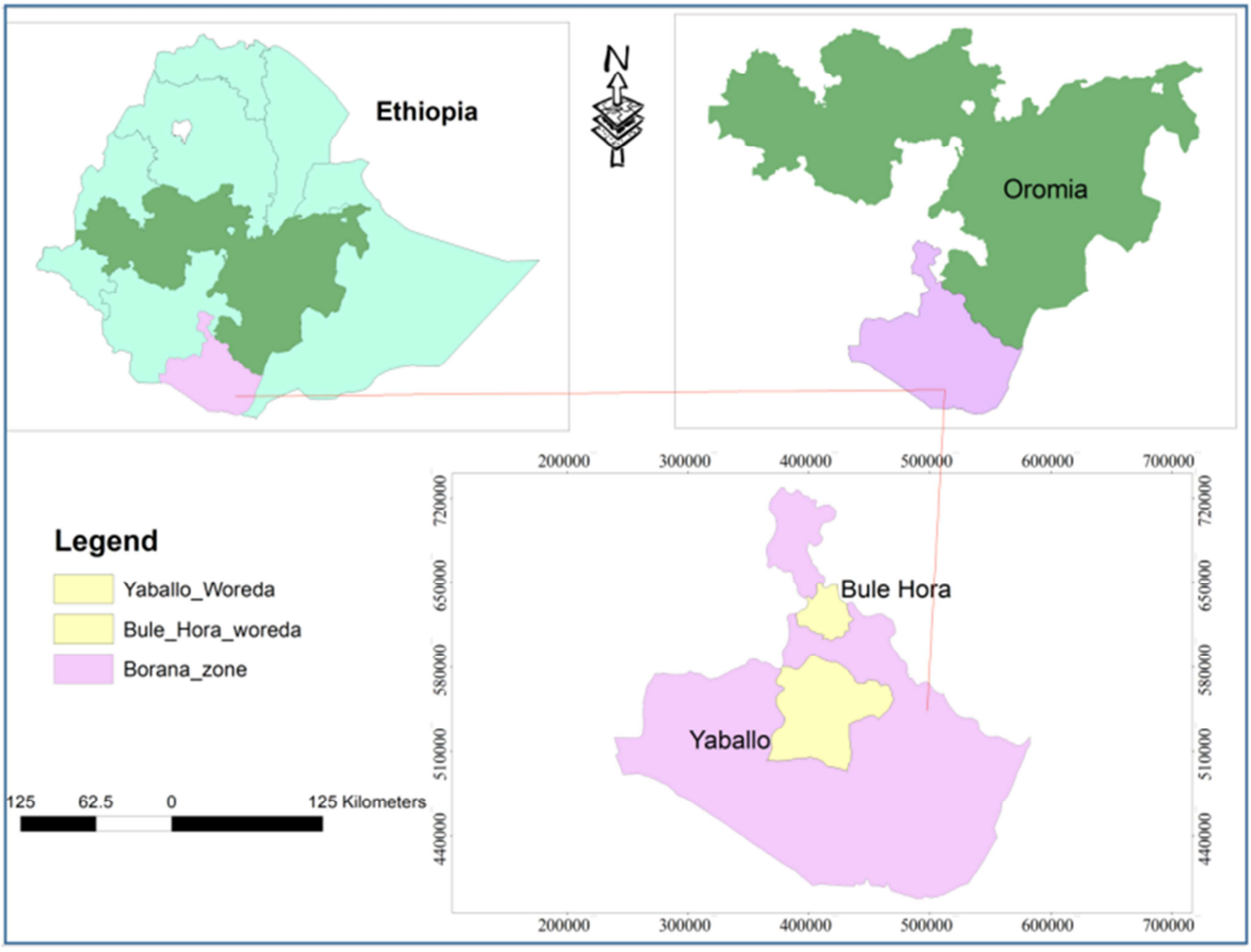

Figure 1. *Map showing location of the study.*

Further, in order to select the specific study sites which belongs to Agro-pastoral and Pastoral systems in the districts, kebeles were purposively selected in collaboration with zonal and district's development offices. Based on secondary information obtained of the respective districts, the beekeepers of the area are found to use log hives. Depending on the information and list obtained from Agro-pastoral and Pastoral development offices (APDO and PDOs) of both districts, purposive sampling was used to select beekeepers who have owned traditional log hives. Out of them ten beekeepers per districts (a total of twenty beekeepers) were selected randomly and twenty relatively strong honeybee colonies (colonies that have constructed combs at least to half of their hives) were purchased one colony from each of

the representative selected beekeepers.

2.2. Method of Data Collection

Field data measurements of various parameters such as bee space and comb space measurements and natural comb measurements (like comb thickness, worker bee brood cell width, worker bee brood cell depth, number of worker bee cells per unit comb area/100cm^2, comb length and comb width) were taken using digital caliper and ruler.

Bee space: - An average natural bee space of *Apis mellifera scutellata* was measured as the distance between two adjacent parallel combs built in a particular log hive. Accordingly, a total of 20 log hives (ten per district) with well-drawn combs were used to take measurements of the mentioned parameters. For each log hive, 5 (five) spaces between combs and 3 replication within the same space (mid and two ends; Figure 2A) of two adjacently built combs which is a total of 15 measurements per log hive was collected.

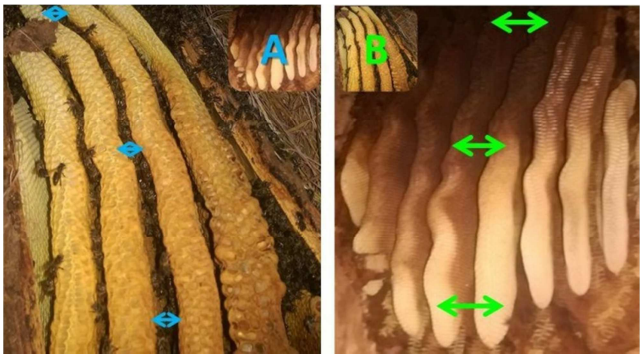

Figure 2. *Reference points at which measurements of bee space (A) and comb space (B) were taken.*

Comb space (mid rib to mid rib):- Comb space (mid-rib to mid-rib distance of two adjacent combs built) of *Apis mellifera scutellata* in log hives was measured. This measurement was taken from 20 different colonies and 5 midrib to midrib distances (Figure 2B) for each colony. The average midrib to midrib distances were also calculated from the number of combs built and the average spaces occupied by the combs on a given length in the log hive.

Comb thickness:-Brood comb and honey comb thicknesses were determined by measuring the thickness of both types of combs that had been used for brood rearing and nectar/honey storage. Combs were obtained from 20 different colonies; for each colony 5 and a total of 100 measurements were taken using digital caliber.

Worker bee brood cell width: Combs were obtained from sampled colonies from which the average cell width of worker bee brood cells and honey comb/storage cell were determined. The width of worker bee brood cells (inner wall to wall distance) was determined by measuring cross-sectioned 75 cells from each colony, a total of 1500 cell width measurements were taken.

Worker bee brood cell depth:- Combs from 20 representative colonies were used to determine the average worker bee brood and honey storage cell depths. The cell's depth measurements were taken from cell center at the crossing point of two diagonal directions downward between parallel walls (in mm) using digital caliper. For each colony the depth of 75 worker bee brood cells and honey storage cells and a total of 1500 cells were measured.

Comb length and comb width: For this, combs were obtained from the selected 20 colonies (hives) and all available combs were measured for their length and width using a ruler.

Number of worker bee cells per unit area: The average numbers of worker bee cells per unit area was determined as the number of worker bee brood cells in a 10 x10cm^2 area of built combs. For this, five naturally built combs were taken from each of 20 different colonies and combs with 10x10cm^2 areas with three counting replications were marked and recorded. The results were then compared with the number of cells built in an area of 10x10cm^2 embossed foundation sheets made by casting mould available at the study area.

2.3. Data Analysis

All data were collected, coded, entered, organized and managed for analysis using Microsoft Excel. Data were analyzed using SAS (statistical analysis software package) Version 9. GLM multivariate ANOVA procedures were used to compare means. For the significance level $P < 0.05$ LSD mean separation was done.

For determination **of** bee spacing, comb thicknesses and cell dimensions for *Apis mellifera scutellata* (the local honeybee race), the following statistical model was used:

$$Yij=\mu + Ai + Cj + \varepsilon ijk,$$

Where Yij=Measured parameter
μ=Over all mean
Ai=Effect of agro-ecology
Cj=effect of type of combs
(AC) ij=effect of interaction agro-ecology * type of combs
Ɛijk=random error

3. Results and Discussion

3.1. Bee Space and Comb Space Measurements (Mid Rib to Mid Rib)

The mean values of bee spaces and comb space are presented in table 1. According to the collected data, the average bee spaces measured in representative traditional log hives of the study areas were 10.67mm and 11.92mm for Midland (ML) and Lowland (LL) agro-ecologies respectively, with an overall mean of 11.30mm and greater mean bee space was from lowland representing colonies.

Accordingly, ANOVA demonstrated a significant difference ($P<0.05$) between agro-ecologies. Perhaps this could be related to the reason that higher temperature has forced the honeybee colonies to leave more space at warm areas to avoid overheating, while maintaining the optimum nest temperature. *Apis mellifera* colonies maintain their

brood nest temperature significantly higher than did *Apis cerana* [21]. On top of this, the result of present study is in line with previous research outputs for *Apis mellifera scutellata* at Sheka and Bench-Maji Zones, SNNPR of Southwest Ethiopia [7]; and *Apis mellifera monticola* at Amhara regional state honeybee races [12]; whereby honeybee colonies of lowland areas formed higher bee space when compared to their mid and highland counterparts. Similarly, [1] also reported that the mean bee spaces of local honeybee race along agro-ecology were 11.59mm, 12.62mm and 14.47mm respectively, for high, mid and lowlands showing larger mean bee space at lowland agro-ecology. On the other hand, in contrast to these studies, for an altitude range greater than 3000m.a.s.l larger bee space (12.48mm) and at lower altitude relatively lower bee space (8.92mm) were reported by [24] for *Apis mellifera bandasii* at Holeta Bee Research Center. This difference is may be variation of honeybee size where by honeybee at highland is larger than those at low land areas [4] and bee space vary based on size of bee race [19].

Likewise, a significant difference ($P<0.05$) was observed among the bee spaces left between two adjacent honey and sealed brood combs. The mean bee space between brood combs and stored honey combs were found to be 13.39mm and 9.79mm respectively. This could be due to the fact that as the colony ages, the combs which were used for rearing the worker bees might be used to store honey by increasing cell size. This change probably minimizes the space which is resulted from the formation of closely stocked combs. In the honey storing areas of the combs, the cells are often built deeper so that only one layer of bees can pass between. This result is in line with the results of [8] who reported the mean bee space between brood combs and space between honey combs were 5.67±0.10mm and 3.70±0.11mm respectively for Sudanese honeybees.

With regard to comb space measurements, the result showed that, there is no significant difference ($P>0.05$) between agro-ecologies. An average comb space of 31.45mm and 31.71mm were recorded from midland and lowland colonies respectively (Table 1). The overall mean midrib to midrib distance of *Apis mellifera scutellata* combs (31.58mm) was found to be much smaller than the space usually used for European races (35mm) [5]. *Apis mellifera* in Africa usually need 32millimetres while *Apis cerana* in Asia need 30millimetres. In this regard, [20] recommended 32mm comb spacing with 7mm bee spaces for tropical African honeybee races, which in our case does not seem appropriate for the local honeybee race of the study areas. The average midrib to midrib distances calculated from the number of combs occupied a given length in the log hive indicated that within the 40cm space that usually used to keep 10 frames in standard box hive, the race can naturally build an average of 12 combs in traditional log hives at study area. Moreover, [19] has mentioned that the smaller the bee race, the smaller the bee space, comb spacing, cell size and their nest volume.

Table 1. *Mean Apis mellifera scutellata natural bee space and comb space measurements.*

Items		Comb space (mm)	Bee space (mm)
Overall mean ± SD		31.58±2.42	11.30±1.99
Agro-ecology	Low land	31.71±2.27[a]	11.92±2.81[a]
	Mid land	31.45±2.55[a]	10.67±2.53[b]
Comb type	Brood	31.68±2.56[a]	13.39±1.83[a]
	Honey	31.50±2.30[a]	9.79±2.24[b]

N. B. Means with the same letter across column within the same factor are not significantly different ($p>0.05$)

3.2. Natural Comb Dimensions Measurements

3.2.1. Worker Bee Brood Cell and Honey Comb Cell Width Measurements

In this study, measurements revealed that 4.78±0.01mm and 4.53±0.01mm were an average natural comb cell width measured for the local honeybee race in the Midland and Lowland (LL) representative agro-ecologies respectively with an overall mean of 4.65±0.30mm (Table 2). In agreement with our measurements, an average cell width/diameter was found to be 4.7±0.29mm for *Apis mellifera bandasii* [3]; 5.09mm for *Apis mellifera scutellata* at Sheka and Bench-Maji Zones of southwest Ethiopia [7]; 3.60mm for local bee race [1]; and 4.89mm for *Apis mellifera monticola* [12]. This variation might be due to the body size differences of the bee races that are found in different regions and agro-ecologies. Moreover, ANOVA has shown that there was a significant difference ($P<0.05$) in natural comb cell width between Midland and Lowland agro-ecologies in which worker bee brood cell width at mid land (4.78±0.01mm) is greater than at lowland area (4.53±0.01mm).

In addition, mean honey comb cell width and worker bee brood cell width for *Apis mellifera scutellata* were found to be 4.80±0.02mm and 4.77±0.02mm in the Midland representation; and 4.54±0.02mm and 4.51±0.02mm in the Lowland study areas respectively. In this regard, worker bee brood cell width showed a significant difference ($P<0.05$) between the two agro-ecologies while honey comb cell width didn't show a significant difference ($P>0.05$) between the agro-ecologies represented. This further may explain that honeybees does have a standard cell dimensions for honey storage which afterwards might be modified for other purposes as time and biology requires.

The size of the cells of naturally built (i.e. without embossed foundation) worker bee comb is useful for distinguishing between species and some races of honeybees commonly kept in hives. The distance across ten cells of comb built by the eastern hive bee (*Apis cerana*) in the Philippines averages 4.1cm, and in southern India, the

distance is 4.3-4.4cm. The African races of the western hive bee build comb with measurements of 4.7-4.9cm across ten cells, while the distance in comb constructed by common European races is 5.2–5.6cm [22].

3.2.2. Worker Bee Brood Cell Depth

In this case, our data revealed that an average of natural comb cell depth were 10.25±0.03mm and 10.26±0.03mm for the Midland (ML) and Lowland (LL) agro-ecology representations respectively with an overall average of 10.28±0.74mm (Table 2). This result was found to be in agreement with [3] for *Apis mellifera bandasii* and [12] for *Apis mellifera monticola* who have reported an average cell depth of 10.80±1.35mm and 9.78mm respectively. In natural comb cell depths, our results demonstrated no significant difference (P>0.05) observed between mid-land and low land agro-ecologies.

In this study, 10.83±0.04mm and 9.67±0.04mm from mid-land representative colonies and 10.67±0.04mm and 9.87±0.04mm from those representing the low-land study area were found to be an average honey comb cell and worker bee brood cell depths respectively. This could explain that stored honey comb cells are deeper than the worker bee brood cells for *Apis mellifera scutellata* in the study area which could demonstrate that agro-ecology might have an effect on honey cell depths but not on brood cell depths. Furthermore, honey comb cell depth showed a significant difference (p<0.05) between the two agro-ecologies while worker bee brood cell depth measurements didn't show a significant difference between the two agro-ecologies.

Generally, the effect of agro-ecology on honey and brood comb cell depths was significant (P<0.05) which might be related to the biological behavior of the honeybees to adapt itself to the different environmental conditions. The result further demonstrated a significant effect (P<0.05) of agro-ecology on honey comb cell depth but didn't show a significant difference (P>0.05) effect on brood comb cell depth (Table 2).

3.2.3. Comb Thickness

Natural comb thickness measurements from Midland and Lowland agro-ecology representative colonies kept in traditional log hives has been presented in table 2. Accordingly, mean natural comb thickness measured for Midland and Lowland agro-ecology representative colonies were 17.78±0.34mm and 19.78±0.34mm respectively with an overall mean of 18.78±3.01mm. Even if our result demonstrated a significant difference (P<0.05) in natural comb thicknesses among the agro-ecologies, this average measurement was found less than average measurements reported to be 24.5mm for *Apis mellifera scutellata* in Sheka and Bench-Maji Zones of Southwest Ethiopia [7]; 23.05mm by for local honeybee race [1]; 20.01mm for *Apis mellifera monticola* [12], but comparable with that of *Apis mellifera jemenitica* (19.96±0.87) of the Sudanese bee race [15]. This may be attributed to the difference in the availability of diverse honeybee plants that force the honeybees the construction of thick honey combs to exploit and store the abundant nectar sources in the areas where the studies were carried out.

Similarly, mean honey and worker bee brood comb thickness measurements in the study area were found to be 19.35±0.49mm and 16.22±0.48mm for mid-land, and 21.15±0.47mm and 18.30±0.50mm for low land colonies respectively. In this case, while honey comb thickness demonstrated a significant difference (P<0.05) among agro-ecologies, worker bee brood comb thickness didn't show a significant difference (P>0.05).

The result of the study revealed that the average honey comb thickness was greater than that of the worker bee brood comb thicknesses in both agro-ecologies. This may be due to the fact that as the colony ages, combs which have been used for worker bee brood rearing might be modified and used for honey storage later. Consequently, honeybees might have modified worker bee brood cells to store honey which might brought comb thickness differences.

Table 2. *Mean measurement of worker brood cells and stored honey cells (natural combs).*

Factors		Diameter of cell (mm)	Depth of cell (mm)	Comb thickness (mm)	No cells/100cm^2
Overall mean ±SD		4.65±0.30	10.28±0.74	18.78±3.01	539.44
Agro-ecology	LL	4.53±0.01^b	10.26±0.03^a	19.78±0.34^a	-
	ML	4.78±0.01^a	10.25±0.03^a	17.78±0.34^b	-
Comb type	Brood	4.64±0.01^a	9.77±0.03^b	17.25±0.33^b	NA
	Honey	4.67±0.01^a	10.75±0.02^a	20.25±0.34^a	NA
Interaction	LL* BC	4.51±0.02^b	9.87±0.04^c	18.30±0.50^b	NA
	LL*HC	4.54±0.02^b	10.67±0.04^b	21.15±0.47^a	NA
	ML*BC	4.77±0.02^a	9.67±0.04^d	16.22±0.48^c	NA
	ML*HC	4.80±0.02^a	10.83±0.04^a	19.35±0.49^b	NA

LL=Lowland and ML=Midland NA=not applicable in the model.
Means across the same column under the same factor with different letter are significantly different at $p<0.05$.

3.2.4. Comb Length and Comb Width

In this study, it was observed that *Apis mellifera scutellata* colonies have constructed a comb with an average of 44.80cm long and 20.51cm wide in their nest (Table 3). The ANOVA indicates that there is significant difference of comb length and width between the study districts. This could tell us that when designing nests for this race, with similar agro-ecologies, we need to consider these parameters in order to exploit its potentials. Similarly, *Apis mellifera monticola* could construct up to 221.72mm long and 220.65mm wide comb in its nest [12]. The combs of *Apis mellifera* can be

more than one meter (1m) long in natural nest (hollow tree and wall) depending on the size of the space in the nest [13].

Table 3. *Mean Apis mellifera scutellata natural comb length and comb width measurements.*

Parameters		Comb length (cm)	Comb width (cm)
Overall mean ± SD		44.80±17.01	20.51±6.37
Agro-ecology	LL	48.43±16.99[a]	18.72±7.04[b]
	ML	41.18±16.45[b]	22.30±5.09[a]

Means with the same letter along column are not significantly different ($p<0.05$).

3.3. Number of Worker Bee Cells per Unit Area

Our data revealed that mean number of worker bee cells on a 100cm^2 area of a natural comb constructed by local honeybees and embossed comb foundation sheet made using a casting mould adopted from Europe were 539.44 (ranging from 441-621) and 433.62 (ranging from 418-460) respectively. According to this data, we found that local honeybees have constructed 105.82 cells/100cm^2 more than the number of cells counted on a foundation sheet made by the European casting mould which has been adopted in the country since long time ago. This, in turn, have demonstrated that the number of worker bee cells built per unit area (100 cm^2) by local honeybees on their natural combs was significantly higher than the number of cells counted from embossed foundation sheets (P<0.001).

Similarly, [3] have reported an average number of 436.4 cells/100cm^2 (ranging from 420 - 460) for the central highland Ethiopian honeybee race (*Apis mellifera bandasii*). Furthermore, [23] has reported a total number of 550 and 418 cells/100cm^2 of a naturally built combs and casting mould embossed foundation sheet respectively in Bahir Dar Zuria and Burie districts of Amhara National Regional state. This result, interestingly, has illustrated that the casting mould which have been adopted from Europe and distributed to beekeepers at different levels has been modified to make varied number of cells per unit area too.

In general, it is observed that average number of worker bee cells per unit area of a given naturally constructed comb was found to be higher than the number of cells counted on a unit area of an artificially moulded foundation sheet with the help of adopted casting mould distributed in the area. This generalization, could work for the lesser number of cells counted from a unit area of foundation sheet which is moulded by an adopted casting mould as a standard tool in the country. On the other hand, [14] have reported an average of 1124.5±54.94 cells/100cm^2 (both sides) from a naturally constructed comb by the Sudanese honeybee race (*Apis mellifera jemenitica),* in which the author found that their finding was relatively higher than reported for African *Apis mellifera* (1022 cells/100cm^2) in traditional hives. European races of *Apis mellifera* accept wax comb with 800 cells/100cm^2 cell numbers, which allows for cells with a diameter of 5.4mm.

Generally, the study indicated that the casting mould introduced and used throughout the country was designed for different honeybee species or races and did not coincide with the biological comb cell dimension requirements of our local honeybee races. As a result, the embossed comb foundation sheets made by European casting mould forced African honeybees including our races to construct larger worker bee cells than their normal size. Though our local bee races are still accepting and drawing out these cells embossed by European casting mould in accordance to their biological requirements, it is believed that this will have effect on biological requirements of the local bees. That means the bees should spend much more time, wax and energy to draw out cells. Interestingly, [3] have confirmed that honeybees draw out cells slower on embossed foundation sheets than plain foundation sheets (same to natural combs) and this may result in colony absconding (Consequently, some combs or foundation sheets left un drawn and this may lead to wastage of beeswax, poor building up of the newly transferred colonies, and little or no honey production from such colonies). Further, it may lead to less adaptation to the new hive.

Data analysis has revealed a significant difference in bee space, comb thickness, cell dimensions, comb length and comb width among the agro-ecologies tested. This means, these parameters are mostly affected by agro-ecology. Furthermore, this could tell us that *Apis mellifera scutellata* race has been forced to construct different sized nests according to the climates.

Thus, the bee space and comb thickness, which are the most important determinant factors to allow the honeybee species to act to their capacity, in the study area were ranges from 5.17- 15.74mm (11.30±1.99mm) and 11.59-25.10mm (18.78±3.01mm) respectively. The present result of the bee space of *Apis mellifera scutellata* is found to be slightly higher than the Ethiopian standard hive specification (2005) bee space (10mm) and western hive bee space (7.5 mm±1.5 mm) [6]. This may be due to biological diversity of the honeybee races found in different parts of the world. In line with this study, [7] also reported an overall mean bee space of 8.98 mm (ranges from 6.46-10.98 mm) for *Apis mellifera scuttelata* in Sheka and Bench-Maji Zones of southwest Ethiopia and an overall mean bee space of 8.4 for *Apis mellifera monticola* [12]. Other study, [6] reported the recommended range of bee spaces was between 6.5 to 10 mm. In line with this study, [2] also recommend that for Langstroth bee hives 7 mm and 10 mm than 14 mm bee space showed good performance on honey yield around lowland and highland areas of East and West Gojjam zone of Amhara regional state, Ethiopia.

The study has also confirmed that the overall cell diameter (4.65±0.33) constructed by the tested race (*Apis mellifera scutellata*) has been found to be lower than honey and brood

comb cells diameter of 5.48mm (range from 5.26-5.90mm) and 5.09mm (range from 4.94-5.22mm) respectively reported by [7] for *Apis mellifera scuttelata* at Sheka and Bench-Maji Zones of southwest Ethiopia and report by [12] for *Apis mellifera monticola*. Accordingly, the worker bee cell measurements of the Sudanese honeybee vary within the range of 4.46 to 5.0 mm for worker brood and stored honey cells respectively [8]. Besides to this, the Africanized comb cells were significantly smaller in width (4.84mm) than the European-sized comb cells (5.16 and 5.27mm for Italian and Carniolan cells, respectively) [17].

The study has also confirmed that the overall cell depth 10.28±0.89 constructed by the tested race was in the range of the honey and brood comb cell depth (with the range of 11.28-12.69 mm and 10.28-10.85 mm respectively) of *Apis mellifera scuttelata* reported by [7] in Sheka and Bench-Maji Zones of southwest Ethiopia. But it is slightly higher than the overall cell depth of *Apis mellifera monticola* (9.78±1.1mm) reported by [12].

4. Conclusions

The study generally revealed that most parameters recorded for the race were significantly affected by agro-ecologies. Accordingly bee space, comb thickness, cell dimension vary between the two agro-ecologies. The type of comb shows slightly significant difference on bee space and comb cell dimensions. In this regard honey comb may minimize the space left for the bees as it gets thicker during honey flow season. The overall mean of the bee space measured for the study areas honeybee race was 11.30±1.99mm. The average natural comb thickness in the traditional log hives in the study area was 18.78±3.01mm.

The race maintains an average of 4.65±0.30mm cell diameter and 10.28±0.74mm (8.11mm-15.00mm) cell depth depending on agro-ecologies and types of combs, and naturally builds 105.82cells/100cm^2 more comb worker cells per 100cm^2 than the number of cells constructed by casting mould. It is clear that cells sizes of printed wax foundation do not coincide with the cells sizes of natural built combs, therefore these results insured that manufactured and naturally built combs were not the same measurement which is indicating that we need to modify casting moulds that we are using (5.4-5.5mm of cell diameter).

The relationship between bee space and agro-ecology has clarified the different space requirements of the bees based on temperature differences and morphology of the bees. Comb thickness, in this study, has been observed to change with seasons of the year or availability of resources for the honeybees.

The variations in comb length and comb width have also explained the slight differences in the bee hives dimension used among the beekeepers in the study area. Moreover, as a general opinion, provision of bee nests out of the most important natural dimensions will trigger slower technology adoption from beekeepers due to less productivity from local bees.

Though honeybees have a tendency to tolerate a certain degree of bee space variations, however direct adopting of frames with 3.2cm wide comb spacing for *Apis mellifera scutellata* does not seem appropriate and it could be one of the reasons for frequent observing of brace combs between two standard frames.

Based on the analyzed data, it is understood that ecological differences (climate, vegetation type, altitudes, etc.) between the mid land and low land has got significant variation in biological diversity of the honeybee races of the study area compared to the other zones of the region/ country.

Beehive designs should consider the biological requirements of local honeybees. Thus introduction of foreign beekeeping equipment particularly hives and casting mould from outside Ethiopia with their different measurements proved seems unsuitable for beekeeping industry in Ethiopia.

The present study proved found out that the use of average bee space of 11.30mm and comb space of 31.58mm and the use of casting mould with 4.65mm base cell diameter or 539.44cells/100cm^2 were most convenient among the honeybee colonies of the study areas, and it is now suggested to undertake further study to realize this finding by increasing sample Woreda with different log hive length.

Furthermore, on farm evaluation of the suggested bee space in box frame hive in relation to the performance of the local honeybee race may be needed for further investigation through the experiment.

According to our field observation and assessments to the existing beekeeping equipment used in the study area, hive measurements should be checked and assessed in detail for further adjustments.

Conflict of Interests

All authors do not have any possible conflicts of interest.

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