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Original Paper

Evaluation of the Pollen Production Potential of Local Honeybee Races in Waghimra, Ethiopia

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***Abstract*—Bee pollen is an essential protein source for honeybee (Apis mellifera) colonies and a valuable nutritionally rich product for human consumption. This study evaluated the pollen production potential of local honeybee races and examined the effects of pollen harvesting on colony resources across three agro-ecological zones (highland, midland, and lowland) in Waghimra, Ethiopia. Thirty healthy colonies were selected in each agro-ecological zone and divided into pollen-trapped and non-trapped (control) groups. Pollen was collected weekly during peak flowering periods, and colony performance parameters, including adult bee population, brood area, nectar stores, and pollen stores, were measured using standard estimation methods. The results showed that colonies in the highland produced significantly higher mean pollen yields (102.81 ± 11.17 g/month/hive) than those in the midland (72.80 ± 5.84 g/month/hive) and lowland (69.68 ± 7.21 g/month/hive) agro-ecologies ($p < 0.05$). Pollen yield was also significantly higher in the first study year compared to the second year ($p < 0.05$). Pollen harvesting significantly reduced stored pollen area but did not significantly affect adult bee population, brood development, or nectar stores. The findings indicate that moderate pollen harvesting during peak flowering periods can be practiced without compromising colony performance. Highland agro-ecological conditions provide favorable environments for sustainable pollen production and improved apiculture productivity in Waghimra, Ethiopia.**

Keywords— Apis mellifera; agro-ecology; colony performance; pollen yield; Ethiopia

I. INTRODUCTION

The pollen, produced by bee often referred to as “the life-giving dust,” is a natural mixture of flower pollen, nectar, and bee salivary secretions [1][2]. Honeybees collect pollen from flowers using specialized structures called pollen baskets[3]. Pollen is important for source of protein and amino acids for honeybee colonies and is vital for brood rearing, colony development, and overall hive productivity [4]. There is floral scarcity, such as early spring or late fall, and stored pollen provides essential nutrients to sustain bee populations. Beyond its importance for bees, pollen is also consumed by humans as a health supplement due to its high nutritional value. It contains proteins, vitamins, minerals, lipids, and antioxidants, making it one of nature’s most complete foods [5]. Pollen is available commercially in various forms, such as granules, capsules, and tablets, and is incorporated into health foods and cosmetic products [6].

In the Globe, countries such as Australia, Argentina, Brazil, China, Spain, and Vietnam are recognized producers and exporters of bee pollen [5]. Because of its bioactive compounds, bee pollen has been linked to numerous health benefits, including enhanced immunity, cardiovascular protection, and improved vitality [5]. In Africa, beekeeping and pollination services similarly underpin both ecosystem stability and rural livelihoods [7].Traditional farming systems depend on pollinator mediated crop yields, especially for fruits, vegetables, and oilseed crops that are highly responsive to effective pollen transfer [8]. African continent hosts extensive floral diversity and supports large numbers of wild and managed honey bee colonies, although detailed continent wide pollen production data remain sparse relative to Europe and North America [9].

Ethiopia, in particular, stands out within Africa for its rich floral resources and long standing beekeeping heritage [10]. The country’s diverse climates and ecosystems support thousands of flowering plant species that offer abundant pollen and nectar for honey bee forage [11]. Ethiopia ranks among the top honey producers in Africa and globally, with millions of managed colonies sustained in varied agro ecologies [12]. Pollen studies in Ethiopian contexts reveal substantial seasonal and botanical variation in pollen availability and composition[13]. Moreover, it is increasingly utilized in pharmaceuticals and the cosmetics industry for its antioxidant and skin-regenerating effects [3],[14].The commercial pollen market provides growing economic opportunities for beekeepers, farmers, processors, and rural communities. Integrating pollen harvesting with honey production and pollination services contributes to the sustainability and profitability of apiculture enterprises [15]. Therefore, this study was designed to evaluate the pollen production potential of local honeybee races in Waghimra, Ethiopia, and to assess the effects of pollen harvesting on hive resources and colony performance.

II. MATERIAL AND METHOD

A. Study Area Description

The study was conducted between 2020 and 2023 across three agro-ecological zones of the Wag-Himra Zone, northern Ethiopia (Fig.1). Experimental apiary sites included Gazgibla (highland), Jinkaba in Sekota Zuria (midland), and Zequala (lowland). The districts represent different agro- ecological gradients in altitude, vegetation cover, and climatic conditions. The study areas are geographically situated between approximately 12°30′–13°15′ N latitude and 38° 45 – 39° 20 ′ E longitude, with altitudes ranging from 1400 to 2600 m above sea level[16]. The mean annual rainfall varies from 350 to 650 mm, and temperatures range from 18°C to 42°C, with the main rainy season occurring between June and September. In the area Beekeeping is an important livelihood activity, contributing to household income through honey, and wax production[17]. However, environmental challenges such as deforestation, soil erosion, and periodic droughts affect floral resources and honeybee productivity [16]. Pollen sampling was conducted from mid-August to mid-September, coinciding with the peak flowering period of major bee forage plants and prior to the honey harvesting season[2].

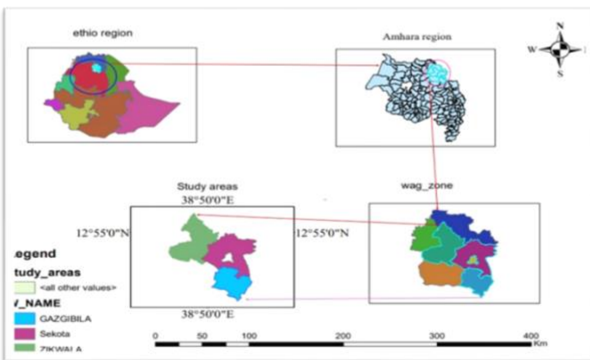

Fig. 1. Maps of study area

B. Experimental Management

Thirty (30) healthy and queen-right colonies of Apis mellifera were selected for the experiment; all are in movable frame hives of uniform strength and age of the queen. The colonies were randomly assigned into two groups:

- Treatment group (T1): Five colonies equipped with pollen traps
- Control group (T2): Five colonies without pollen traps for each district sites

All colonies were managed under uniform management conditions, including feeding, inspection intervals, and disease control. The experimental hives were arranged 2 meters apart to avoid foraging overlap. To be easy installation, durability, minimal interference Pollen traps were selected based on compatibility with standard management practices. Weekly hive inspections was incorporated to ensure colony health and to prevent disturbances from trap use.

C. Pollen Collection

Pollen trap was installed at the hive entrances of the five treatment colonies. After installation Pollen was harvested once per week from August to September in two years across agro-ecological sites. Each hive was labeled, the collected pollen was cleaned, and then dried to moisture content below 10% in a forced-air oven at ≤45° C to preserve nutritional quality and prevent microbial growth. The dried pollen was stored in airtight, dark containers under ambient conditions to avoid contamination and degradation (Fig.2).

Fig. 2. Pollen trap installation and Pollen drying

D. Data Collection

Two main types of data were recorded

- Pollen yield (g/hive/week)
- Other Hive resource parameters measured

The Hive resource parameters included adult bee population, open brood area, sealed brood area, stored pollen, and stored nectar. Data collection was performed based on Liebefelder estimation method, where a 10 cm × 10 cm unit area was assumed to contain approximately 125 bees or 400 brood cells. Each hive frame (20 cm × 40 cm) was divided into 16 unit areas (8 on each side), and observations were expressed as unit area equivalents. An adult bee population was counted visually, while brood, pollen, and nectar stores were estimated as occupied unit areas.

E. Data Analysis

Data were analyzed using a General Linear Model (GLM) in SAS version 9.4. Mean comparisons were performed using Least Significant Difference (LSD) at $p < 0.05$. The model used for the analysis was:

Yijk= u+Ai+Yj+(A+Y)ij+eijkY_{ijk} =μ+ai+yj+_{ij} +e_{ijk}yijk=u+ai+yj+(a+y)ij+eijk (1)

Where:
Yijk-{ijk}Yijk = Observation of pollen yield or hive resource variable,
U = Overall mean
Ai = Effect of the ith agro-ecology (highland, midland, lowland),
Yj = effect of the jth year (2020, 2023),
(A×Y)ij)_{ij}(A×Y)ij = Interaction effect of agro-ecology and year,
eij〖k〗_{ijk}eijk= random error term

The relation between treatments means were pursued using Least Significant Difference (LSD) at a 5% probability level ($p < 0.05$). The Independent t-tests in SPSS software (version 26) were used to compare mean differences between colonies with and without pollen traps. The Post-hoc analyses (Tukey's HSD) were performed for multi-category comparisons.

F. Ethical Considerations

The procedures followed the Ethiopian National Apicultural Research Guidelines (2020) and cared out that honeybee colonies were handled ethically and safely. There is No any harmful chemicals applied, and the pollen harvesting did not exceed recommended limits to prevent stress on bee colonies.

III. RESULTS

A. Hive Resource Metrics

Adult bee population, sealed brood, open brood, nectar yield, and pollen yield across the three agro-ecological zones and two study years (2020 and 2023) (Table 1). Generally, colonies found in the highland districts higher mean values for all measured variables except nectar yield, compared to the midland and lowland zones. In 2020, the adult bee population was greatest in the highland (10,996.21 ± 4,815.45), followed by the midland (6,919.72 ± 2,818.00) and lowland (6,370.70 ± 3,136.00). At 2023, there is similar trend also observed with slightly reduced overall means. The parameter in sealed brood and open brood followed the same geographical pattern, being consistently higher in the highland across both years. Although numerical differences were evident, the variations in sealed brood across locations were not statistically significant ($p > 0.05$), while open brood varied significantly between the two years ($p < 0.05$). The Pollen and nectar yields also difference between in location and production years, with the highest mean values consistently recorded in the highlands. The findings indicate that colony strength, in terms of adult bee population and brood area, was generally greater in the highland environment (Fig.3).

TABLE I. MEAN (±SD) COLONY PERFORMANCE ACROSS YEARS AND LOCATIONS

Year	Variable	Highland (Mean ± SD)	Midland (Mean ± SD)	Lowland (Mean ± SD)	Overall Mean	F-value	Sig.
2020	AB	10996.21±4815.45	6919.72±2818.00	6370.70±3136.00	8095.50	2.36	.02
	SB	16.12±4.70	12.97±14.29	13.17±16.36	10.74	3.88	.06
	OB	7.00±6.36	3.06±3.28	2.19±2.83	4.08	3.29	.03
	NY	36.21±31.07	37.72±35.80	40.13±42.69	36.06	5.63	.06
	PY	11.88±10.76	5.35±4.74	6.63±8.42	7.95	0.17	.03
2023	AB	9358.40±27.43	7133.10±3680.30	6592.60±3276.00	7694.70	2.36	.03
	SB	14.65±6.73	13.00±8.40	15.25±7.08	6.30	3.88	.05
	OB	6.50±1.18	3.50±4.58	3.55±4.21	2.90	3.29	.04
	NY	44.30±50.09	44.55±44.18	42.85±36.26	41.90	5.63	.07
	PY	8.85±6.12	4.45±4.48	5.45±7.21	5.25	0.17	.03

AB=adult bee, SB=sealed brood, OB=open brood, NY= nectar yield, PY= pollen yield

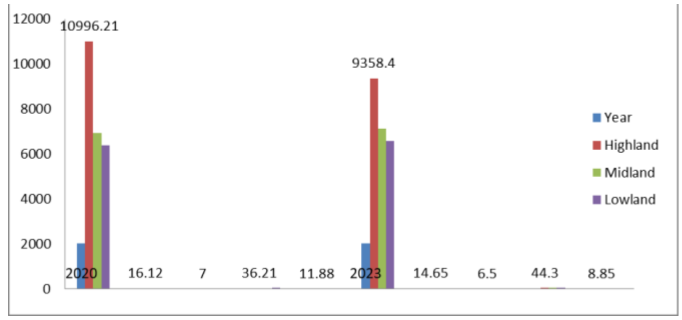

Fig. 3. Comparison of Hive Resource Parameters between Pollen-Harvested and Non-Harvested

B. Poolen Yield

Average pollen yield varied significantly among the three location ($F = 4.76$; $p < 0.05$). Colonies in the highland produced the highest average pollen yield (102.81 ± 11.17 g/month/hive), followed by the midland (72.8 ± 5.84 g) and lowland (69.68 ± 7.21 g).Table 2 below indicted that, statistical result revealed that pollen yield in the highland was significantly higher than both midland and lowland, while the latter two did not differ significantly. The comparison of the two study years indicated that pollen production was statistically higher in first year (93.99 ± 8.66 g/month) than in the second (69.53 ± 5.08 g/month) ($F = 5.93$; $p = 0.021$). The overall mean for both years was 81.76 ± 5.43 g/month. This difference between years indicates that temporal environmental differences, such as rainfall distribution and flowering intensity, likely influenced pollen availability and collection rates.

TABLE II. MEAN (±SD) POLLEN YIELD (G/MONTH) IN 2020 AND 2023

Year	N	Pollen yield (g/month)	F value	Sig.
2020 (Year 1)	15	93.99±8.66[a]	5.93	.021
2023 (Year 2)	15	69.53±5.08[b]		
Grand Mean		81.76±5.43		

C. Post Hoc Analysis of Pollen Yield

The difference between location based comparison analyses of pollen yield is presented in (Table 3). The mean difference between Highland and Midland was 30.01 g/month, which was statistically significant ($p = 0.003$). The mean difference between Highland and Lowland was 33.13 g/month, also statistically significant ($p = 0.001$) (Fig.4). In contrast, the difference between Midland and Lowland was 3.12 g/month, which was not statistically significant ($p = 0.730$). These results indicate that pollen yield in the highland was significantly higher than in both midland and lowland, while no significant difference was observed between the midland and lowland locations.

TABLE III. POST HOC COMPARISON OF MEAN POLLEN YIELD BETWEEN LOCATIONS

(I) Location	(J) Location	Mean Difference (I-J)	Sig.
Highland	Midland	30.01*	.003
	Lowland	33.13*	.001
Midland	Highland	-30.01*	.003
	Lowland	3.12	.730
Lowland	Highland	-33.13*	.001
	Midland	-3.12	.730

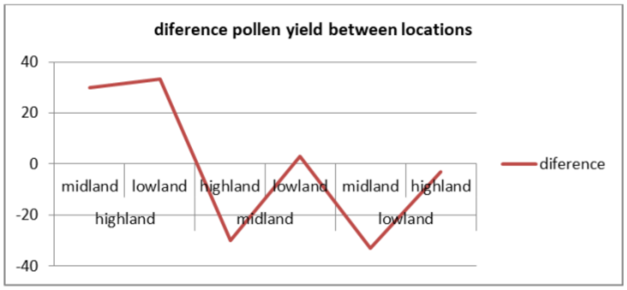

Fig. 4. Post hoc comparison of pollen yield between locations

D. *Effect of pollen harvesting on hive resources*

The comparison between pollen-harvested and non-harvested colonies is presented in (Table 4).Colonies subjected to pollen harvesting showed slightly lower mean values for adult bee population (6,766.78 ± 563.44) and sealed brood area (1.58 ± 0.33) than non-harvested colonies (8,090.32 ± 710.38 and 2.66 ± 0.44, respectively) (fig.5). However, these differences were not statistically significant ($p > 0.05$). The pollen store area was the only parameter showing a significant difference ($F = 5.63$; $p = 0.02$), with non-harvested colonies having higher values than harvested ones. Open brood and nectar store values also followed a similar pattern, though the differences were not significant.

TABLE IV. EFFECT OF POLLEN HARVESTING ON HIVE RESOURCE PARAMETERS

Parameter	Pollen Harvested Colonies (Mean ± SEM)	Colonies Not pollen Harvested (Mean ± SEM)	F-value	Sig.
Adult bee population	6766.78±563.44	8090.32±710.38	2.36	.13
Sealed brood (unit area)	1.58±0.33	2.66±0.44	3.88	.06
Open brood (unit area)	0.80±0.19	1.45±0.30	3.29	.08
Pollen store (unit area)	1.32±0.25	2.27±0.33	5.63	.02
Nectar store (unit area)	71.37±5.60	74.38±4.49	.17	.68

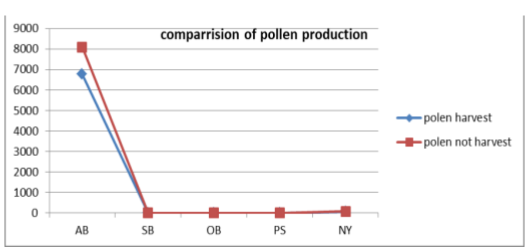

Fig. 5. Effect of Pollen Harvesting on Hive Resources

IV. DISCUSSION

The present study demonstrated clear spatial and temporal variation in pollen production and colony performance of local honeybee (Apis mellifera) races across different agro-ecological zones in Waghimra, Ethiopia (Table1). Colonies located in the highland agro-ecology consistently produced higher pollen yields and exhibited stronger adult bee populations and brood development than those in midland and lowland areas (Fig.3). This finding is in strong agreement with earlier studies conducted in Ethiopia and other tropical regions, which reported that higher altitude environments generally support better colony performance due to favorable climatic conditions and richer floral resources [18].

The higher pollen yield observed in highland colonies can be attributed to greater floral diversity, prolonged flowering periods, and moderate temperatures, which collectively enhance pollen availability and foraging efficiency. Similar altitudinal effects on pollen and nectar collection have been documented in Ethiopia, Tanzania, and Nepal, where colonies in cooler and more humid environments collected significantly more pollen than those in hotter, drier lowland zones [1], [19]. Studies by [20]and [21],further emphasized that pollen diversity and abundance are critical determinants of colony strength, brood rearing capacity, and overall hive productivity.

Although sealed brood area did not differ significantly among agro-ecological zones, open brood area showed significant variation between study years, indicating the influence of temporal environmental factors on colony reproductive dynamics. Year-to-year differences in rainfall patterns, flowering phenology, and forage continuity are known to affect brood production by altering pollen availability and nutritional intake of nurse bees [22], [23]. Similar inter-annual variability in brood development has been reported in Ethiopian honeybee populations, where fluctuations in rainfall and vegetation cover directly influenced colony growth cycles [23][24].

Pollen yield differed significantly between the two studies years, with higher production recorded in 2020 than in 2023 (Table 2). This temporal variation aligns with previous findings showing that pollen production is highly sensitive to climatic variability, particularly rainfall distribution and flowering intensity [18][19][25]. Reduced or irregular rainfall can shorten flowering periods and limit pollen availability, thereby decreasing pollen collection rates. Despite this variation, the overall pollen yield recorded in the present study remained substantial, demonstrating the inherent potential of the study area for pollen production under suitable environmental conditions.

The comparison between pollen-harvested and non-harvested colonies revealed that moderate pollen harvesting had limited effects on most hive resource parameters. Adult bee population, sealed brood, open brood, and nectar stores were not significantly affected by pollen trapping, indicating that colonies were able to compensate for pollen removal during peak flowering periods. This finding is consistent with earlier studies reporting that partial pollen trapping does not significantly impair colony strength when floral resources are abundant [19], [26]. Colonies can respond to pollen removal by increasing foraging activity and reallocating labor to pollen collection, thereby maintaining internal nutritional balance [27][28].

However, the significant reduction in stored pollen area in harvested colonies reflects the direct removal of pollen reserves and highlights pollen's central role as the primary protein source for honeybee colonies. Pollen is essential for hypo-pharyngeal gland development in nurse bees and for larval nutrition, and reduced pollen stores may temporarily affect internal colony resource allocation [27], [29]. Similar reductions in pollen reserves following trapping have been reported in controlled studies, although such effects were often short-term and reversible under favorable forage conditions [26][30].

The absence of significant negative effects of pollen harvesting on brood and adult bee populations in the present study suggests that the timing of pollen collection during peak flowering periods is critical. Previous research has shown that excessive pollen removal during dearth periods can negatively affect brood rearing and colony survival, whereas harvesting during periods of abundant forage poses minimal risk to colony health [1]. This highlights the importance of aligning pollen harvesting practices with seasonal floral availability. Generally, the findings of this study are consistent with existing literature and provide empirical evidence that agro-ecological conditions strongly influence pollen production and colony performance. The superior performance of highland colonies underscores the importance of environmental factors such as altitude, climate, and floral diversity in shaping honeybee productivity. At the same time, the limited impact of moderate pollen harvesting on colony resources supports its feasibility under favorable ecological conditions. These results contribute valuable insights into pollen production dynamics in Ethiopian beekeeping systems and enhance understanding of how environmental variability and management practices interact to influence honeybee colony performance.

V. CONCLUSION AND RECOMMENDATION

This finding implied that, clear variation in the pollen production potential of local honeybee colonies across different locations in Waghimra, Ethiopia. Colonies found in the highland consistently produced higher pollen yields and exhibited stronger adult bee populations and brood areas compared to those in the midland and lowland zones. The production of pollen also differ between the two study years, indicated differences in climatic conditions and floral resource availability; however, overall pollen yield remained substantial across years, indicating strong potential for pollen production in the study area. Modest pollen harvesting significantly reduced stored pollen reserves but did not significantly affect adult bee population, brood development, or nectar stores, suggesting that colony performance was not adversely compromised during peak flowering periods. These findings highlight the ecological and economic importance of bee pollen production and confirm that highland agro-ecological conditions are particularly favorable for sustainable pollen production and apiculture development in Waghimra, Ethiopia.

DECLARATION OF INTERESTS' STATEMENT

The authors declare no conflict of interest.

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