



Contents lists available at ScienceDirect

Saudi Journal of Biological Sciences

journal homepage: www.sciencedirect.com

Original article

Comparative study on the dynamics and performances of *Apis mellifera jemenitica* and imported hybrid honeybee colonies in southwestern Saudi Arabia

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ARTICLE INFO

Article history:

Received 7 April 2016

Revised 7 December 2016

Accepted 1 January 2017

Available online 9 January 2017

Keywords:

Adaptation

Brood population dynamics

Exotic honey bee

Hive resource

Local race

Saudi Arabia

ABSTRACT

The aims of this study were to assess the seasonal population dynamics and evaluate the performance of *Apis mellifera jemenitica* (local bee) and introduced hybrid honeybee colonies in the lowlands and highlands of southwestern Saudi Arabia. Data regarding the performance and population dynamics parameters such as brood and adult bee population, amounts of stored pollen and nectar were gathered from the two races (25 colonies of each) for one year (April 2013 through March 2014), and statistically tested. The results indicated that at low lands, local bee colonies maintained relatively high brood and adult bee populations ($P < 0.05$) than introduced honeybee colonies and produced more ($P < 0.05$) honey. The local bee colonies were able to hoard three times more ($P < 0.05$) pollen and built more ($P < 0.05$) queen cells than introduced bees in both the low and highland areas. The annual survival rate of local bee colonies was almost double ($P < 0.05$) than that of introduced honeybee colonies. Moreover, local bees had greater ($P < 0.05$) adult bee and brood populations than imported, throughout the year. The relatively good performance of local colonies could be due to their long year's adaptation to cope with resource scarcity and unpredictable environmental conditions of the regions. The possible reasons for the dwindling of the imported hybrid colonies could be due to continuing to exhibit adaptive characteristics of their original that might not fit well with the new environment.

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1. Introduction

The beekeeping industry of the Saudi Arabia depends mainly on two races: the local honey bees (*Apis mellifera jemenitica*) and the exotic hybrid honey bees (*A. m. carnica* x *A. m. lamarki*) from Egypt. The local bees are preferred for their better adaptation to the local arid climatic conditions of the country (Al-Ghamdi et al., 2013a,b; Abou-Shaara, 2014). However, the local bees are too scarce and productivity per hive is relatively low to satisfy the increasing demand for honey in Saudi Arabia. Moreover, the price of one local bee colony is double compared to the exotic bees (Al-Ghamdi and Nuru, 2013). As a result, the importation of exotic bee colonies is

steadily increasing from time to time and currently reaches up to 200,000 package bee per annum (MoEP, 2012). The importation of exotic bees is taking place without considering the long term negative effects on the diversity of the local bees and survivability of the exotic bees. In relation to this, Meixner et al. (2014) reported that the current beekeepers' demand for high economic performance of bee colonies resulted in mass importations, queen trade and colony movement that contribute to changing the natural diversity of local bees across the world. Such practices are mostly occurring without evaluating the performances and the adaptation level of the local bees in comparison to the exotic ones, which has remained as important information gaps in our honey bee knowledge (Meixner et al., 2014).

Currently, large scale of colony losses as a result of using a genetic stock with insufficient vitality, or using stock that is not well adapted to locally prevailing environmental conditions become one of the great challenges to beekeeping (Costa et al., 2012b). Moreover, the loss of genetic character of local honey bee ecotypes due to importation and genetic introgression become a great concern (Strange et al., 2007).

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Peer review under responsibility of King Saud University.



Beekeepers of Saudi Arabia are not fully utilizing the comparative advantages of beekeeping and the existing bee products' market opportunities (Nuru et al., 2014) because of certain environmental challenges and low performances of bee colonies. Generally, the average annual productivities of colonies are reported to be 6.64 ± 5.64 kg and 3.69 ± 2.62 kg honey/colony/annum for box and traditional hives, respectively (Nuru et al., 2014) which is generally low compared to the honey yield records (>10 kg/colony/annum) of many other countries. The performances of honey bee colonies are reported to be affected by several internal factors, such as types of bee race, queen fecundity, colony size, stored food and management practices, in addition to external factors such as temperature, humidity and nectar and pollen sources (Alqarni et al., 2014). Recently, evaluation of the performances of local bees in comparison with non-local ones has become an important global research topic to investigate the vitality of colonies, survival rate, and the role of genotype–environment interactions in the health and performances of honey bees colonies (Falconer and Mackay, 1996; Costa et al., 2012a,b; Büchler et al., 2014; Meixner et al., 2014, 2015; Hatjina et al., 2014).

In Saudi Arabia, high temperature, low humidity, low and erratic rainfall and the associated shortage of bee forages are the major challenges encountering the beekeeping subsector (Abou-Shaara et al., 2012). In accordance with this, success in beekeeping is mainly due to utilization of improved beekeeping knowledge and skills suitable to local bee types and conditions coupled with synchronized management of bee colonies according to seasonal changes in internal colony population's dynamics and external environmental conditions (Hepburn and Radloff, 1998). Thus, a better understanding of the potentials and seasonal population dynamics of the existing honey bee races would enable identification of appropriate technological amendments and management options to improve the honeybees' productivity and to cope with the environmental challenges. Adaptation to regional environmental factors such as climate, vegetation, and agricultural practices, has been identified as an important prerequisite for understanding problems in health and performances of honey bee colonies (Büchler et al., 2014). Environment has an immense effect on the performance differences among honey bee races, but the genetic makeup of a colony can also affect the characteristics that define a particular honey bee group (Louveaux et al., 1966; Strange et al., 2007).

Some beekeepers argue that the low honey hoarding capacities of local bees and the tendency for exotic colonies to have low survival rates and quick deterioration in colony strength contributed to the low productivity of the subsector. In addition, it has been argued that the limited availability of bee flora (Champetier et al., 2014) and the low dissemination of improved beekeeping practices (Nuru et al., 2014) have been considered as major factors that contribute to the low performances of honeybees in the region. However, the suggested reasons for the low productivity of the subsector and low performances of colonies so far are not well substantiated based on experimental results. Hence, efforts to evaluate the performances and population dynamics of both the local and exotic honey bee races under different conditions, giving due consideration to environmental and genetic variations, may narrow the existing information gaps.

Based on this framework, Alqarni et al. (2014) tried to compare the performances, of the local and exotic honey bee colonies in the Asir Region of Saudi Arabia in terms of their activities, such as foraging ability, brood production, and storage of pollen and honey. However, the study was limited to certain months of the year and did not consider multiple locations and important parameters such as, brood and adult bee population dynamics across all seasons of the studied years; and their survival rate trends left undressed. In highly variable and harsh environmental conditions

such as those in Saudi Arabia, performance evaluations and related assessments of honey bee colonies characters should be conducted throughout the year in different localities to assess the effects of seasonal and altitudinal variations. Such studies would better represent the actual migratory beekeeping practices of the region, in which colonies are moved on average five times per year according to the availabilities of floral rewards at different seasons and ecologies (Nuru et al., 2014).

Parameters such as number of adult bees; amount of brood, pollen storage; honey yield and dearth period survival rate were considered as important variables for evaluation of productivity and performances honey bee colonies (Louveaux et al., 1966; Harris, 2010; Costa et al., 2012b; Hatjina et al., 2014). Thus in this study, these factors are considered to be the most important parameters for evaluating the performances of the local and exotic honey bee colonies.

Information regarding the seasonal population dynamics of the honey bee races can be an important indicator of how honey bee colonies of different genetic and environment origins respond to changes in external environmental factors and can be prerequisite for refinement of efficient year-round colony management practices. Given this background, the objectives of this study were to evaluate the performance of local and exotic honey bee colonies across different seasons in the lowlands and highlands of southwestern Saudi Arabia.

2. Materials and methods

2.1. Study sites and races

This study was conducted in the highlands and lowlands of the Al-Baha region in Southwestern Saudi Arabia. The highlands have an altitudinal range of 1995.5–2048.0 masl, with a mean annual temperature of 22.9 °C and a mean annual rainfall of 361.1 mm (El Karemy and Zayed, 1992). In contrast, the altitude ranges in the lowlands vary from 137 to 800 masl, with average minimum and maximum annual temperatures of 16.9 and 29.7 °C, respectively and an average annual rainfall of 53.8 mm (El Karemy and Zayed, 1992). The major pollen and nectar source plants of the study areas are: *Dipterygium glaucum* "arfaj", *Acacia tortilis* "sumira", *A. ehrenbergiana* "selam", *Ziziphus spina-christi* "sidir", in the lowlands and *A. origina* and *A. gerrardii* "telih", *Lavandula dentata* and *L. pubescens* "Thorma", *Otostegia fruticosa* "Sharm/Shakab", *Nepeta deflersiana* "Abel", and other annual and perennial plant species in the highlands.

To assess the effects of environmental factors on the performances of the two races during the study period (April 2013 through March 2014), the experimental colonies were occasionally moved between the highlands and lowlands (depending to the availability of recurrent honey bee resource rewards), thereby representing the migratory mode of beekeeping, which is a common honey production system in the area. Baljurashi (1995.5–2048.0 masl) was the highland to which the experimental colonies were kept, whereas Betat (375 masl), Soqoma (449 masl), Muzaylif (137 masl), Wadi As (233 masl), and Hazina (785 masl) were the lowlands that were used as temporary apiaries with some bee forages at different seasons. The experimental honey bee colonies were composed of two races, *Apis mellifera jementica* (the local bees) and the exotic bees, which is known as a hybrid between two honey bee races *Apis mellifera lamarckii*, of African origin, and *Apis mellifera carnica*, of European evolved bees. *A. m. jementica* is native to the Arabian Peninsula and the Sahel climatic zone of Africa (Ruttner, 1988; Al-Ghamdi et al., 2013a,b). *A. m. lamarckii* is indigenous to Egypt. The original homeland of *A. m. carnica* is cen-

tral Europe, and this race is a gentle European honey bee subspecies, adapted to a very different climate (Ruttner, 1988).

2.2. Colony selection and management

At the beginning of the experiment, 50 colonies (25 colonies of each race) in frame hives with equal estimated colony strengths were selected. The maternity of the queens was monitored for a month before commencing of data recording. During this period, efforts were made to keep all of the tested colonies homogenous by employing balancing techniques to begin with relatively similar adult bee population, broods, and pollen stores. The common migratory beekeeping practice was used to manage the experimental colonies through moving the honey bee colonies regularly to temporary experimental sites according to the seasonal availability of floral rewards (pollen and nectar). Migrating of experimental colonies applied because bee colonies cannot survive the harsh environmental conditions and scarcity of forage in one permanent apiary site.

The colonies were provided with nectar and pollen supplements for stimulation of early brood rearing at the commencement of flowering season and at the times of depletion of the natural nectar and pollen sources during long dearth periods. The swarming tendency was monitored through inspection and abortion of newly initiated queen cells. All of the experimental colonies were kept under uniform environmental conditions. Moreover, all of the necessary management practices, such as provision of clean water, shelter and protection from bee enemies, were applied whenever necessary.

2.3. Population dynamics and performance evaluation of the races

To assess the population dynamics and performances of the two honey bee races, parameters such as the adult honey bee and brood populations and the amount of nectar and pollen stores were considered and measured using a grid frame following the procedures of Jeffree (1958) with some modifications. One unit grid cell (25 cm²) represented 118.0 ± 5.9 worker brood cells used for brood rearing and nectar or pollen hoarding and an average of 45.1 ± 5.3 adult bees. The number of adult bees per 25 cm² was counted by taking the photos of the combs along with the bees overlapping the grid frame which is useful to avoid flying and movements of the adult bees. In the brood measurement, both open and sealed broods were considered, which was recorded every 21 days for a period of one year. The reproductive swarming tendencies of the races were assessed through counting the number of initiated queen cells followed by aborting them to avoid recounting in the subsequent data collection time and also to avoid the effect of swarming on colony performance. The relative productivities of the races were assessed based on the average estimated honey yields for the major honey flow seasons by weighing frames that contained ripened honey and nectar. The survival rate of the race was calculated as the ratio of total colonies died during the experimental period to the total number of initial colonies. Every time data were recorded, all of the existing colonies were counted to compute the annual and monthly survival and death rates.

2.4. Statistical analysis

Comparisons were made to identify any variations in the performances and seasonal population dynamics between the two honey bee races both in the highlands and lowlands. One-way analyses (*t*-tests) were used to analyze the differences between the two honey bee colony types in their performance parameters. Correlations between the performance parameters in each type of colony were examined to determine their relationships. Descrip-

tive statistics were also used to evaluate variations in the performance and seasonal population dynamics between the two races that were associated with the highland and lowland beekeeping landscapes. For all of the computations, the JMP-5 statistical software package (SAS Institute Inc, 2002) was employed, and a 95% ($\alpha = 0.05$) level of significance was used.

3. Results

3.1. Performances of local and exotic honeybees in lowlands and highlands

3.1.1. Colony maintenance

Results regarding the colony's adult bee population and brood rearing performance of local and exotic honey bee colonies in both the lowland and highland areas are presented in Table 1. In both areas, the local bees had higher values for the adult bee population than exotic honey bee colonies; though, a significant ($P < 0.05$) difference was observed only in the lowland ecosystem.

The brood populations of local bees were greater than twice those of exotic honey bee colonies in the lowlands; this difference was significant ($P < 0.05$). There was no significant difference in the highland area. For each two unit cells of adult bees, the local bee colonies reared almost one unit cell of brood, whereas this ratio was far less than a unit in the case of exotic honey bee colonies in the lowlands. However, both types of colonies reared a single unit area of brood (118.0 ± 5.9 brood) to replace almost every four adult bee unit areas (4 * 45.1 ± 5.3 adult bees) in the highland area.

3.1.2. Honey production

The honey production abilities of the races were estimated during two harvesting seasons in the lowland and highland areas when the major honey source plants *Acacia tortilis* (sumra) and *A. origena* (telih) were flowering in the lowland and highland, respectively. The results for the honey production potentials of the two races are presented in Table 2.

During the *A. tortilis* honey flow season, the average amount of honey collected per colony from the local bees was significantly ($P < 0.05$) greater than that of harvested from exotic bees. In contrast, no significant difference in honey yield was observed during the *A. origena* honey flow season, except that the exotic bee colonies hoarded slightly more.

3.1.3. Pollen hoarding capacity

The results presented in Table 3 indicated the presence of significant variation ($P < 0.05$) in the average amount of pollen hoarded per colony both in the lowland and highland production landscapes.

Colonies of the local bees were able to store on average three times more ($P < 0.05$) pollen than the exotic bee colonies in both the lowland and highland areas. Regarding the proportion of pollen stored to the number of unit brood area reared, both races were observed to hoard one unit cell of pollen for every 4–5 unit areas of brood reared in the lowlands. However, in the highland areas, the local bee colonies were able to store one unit cell of pollen for every three unit areas of brood reared, whereas the exotic bee colonies hoarded only one unit area of pollen for almost every ten unit areas of brood reared. The result may indicate that the local bees despite high brood rearing activity they were hoarding more reserve pollen than the exotic bees.

3.1.4. Reproductive swarming tendencies

According to the observations made during the experimental period, the colonies did not engage in reproductive swarming, except for one case observed in the local bee colony. However, both

Table 1

Average colony strength (population) of local and exotic honeybees in terms of adult bee and brood population in lowland and highlands.

Types of colonies	N		Colony replenishing performance					
			Adult bees in unit areas (Mean ± SE)		Brood unit areas (Mean ± SE)		Proportion of broods to adults (Mean ± SE)	
	Low land	High land	Lowland	Highland	Lowland	Highland	Lowland	Highland
Local	133	173	214.5 ± 9.6 ^a	(237.7 ± 7.9) ^a	103.9 ± 5.4 ^a	63.1 ± 3.8 ^a	0.47 ± 0.02 ^a	0.26 ± 0.01 ^a
Exotic	114	164	149.6 ± 10.4 ^b	(228.2 ± 8.1) ^a	49.5 ± 5.9 ^b	56.2 ± 3.9 ^a	0.34 ± 0.02 ^b	0.24 ± 0.01 ^a
P-value			0.000	0.401	0.000	0.200	0.000	0.257

Values with different superscripted letters within a column are significantly ($P < 0.05$) different.N = number of records; one unit area (25 cm²) represents an average of 118.0 ± 5.9 adult bees and 45.1 ± 5.3 worker broods.

Local colonies as indicated in Fig. 1 constructed a very large number of queen cells. The average numbers of queen cells per colony per 21-day period were found to be 2.7 ± 0.3 (standard error (SE)) and 2.4 ± 0.3 (SE) for local and exotic honey bee colonies, respectively.

The studied colonies of both races exhibited similar trends of constructing queen cells, which indicates their tendencies toward reproductive swarming. As indicated in Fig. 1, the local bee colonies built a higher average number of queen cells for seven consecutive months (October through April) compared with the exotic honey bee colonies. However, during June through August, the exotic colonies built a higher average number of queen cells, whereas in May and September, both races had almost equal average numbers of queen cells. Higher numbers of queen cells and peak reproductive swarming tendencies were recorded during December through March and June through July for the local bees, whereas the exotic honey bee colonies had higher values in June through August and December.

3.2. Survival rate, seasonal population and hoarding dynamics of local and exotic bee colonies

3.2.1. Survival rates of colonies

Out of the 25 initial colonies from each type of honey bee colony, 13 local bee and 7 exotic bee colonies survived one full year without any therapeutic treatment. The monthly survival and death rates are presented in Fig. 2.

According to the results, more than 50% of the local bee colonies were able to survive throughout the year, which is almost double the number of exotic colonies that survived, only 28%. Sharp declines in the colonies of both races were observed after October until mid of December, although the rate of decline varied significantly. The average monthly death rate (9.4%) and maximum monthly death rate (28%) of exotic colonies, occurred in December, and were considerably greater than the local bee colonies' average monthly death rate (5.1%) and maximum monthly death rate (17.6%).

3.2.2. Seasonal dynamics of the adult bee and brood populations

Fig. 3 shows the seasonal population dynamics of adult bees and broods throughout the year for both honey bee races. Both

the adult bee and brood population curves for the local colonies are conspicuously above the corresponding curves of the exotic honey bee colonies. Hence, a higher number of adult bees and broods was recorded in the local bee colonies than in the exotic, except in June.

However, except for slight variations, the races exhibited similar trends in terms of the adult bee and brood population dynamics throughout the year. Higher values for the adult bee population occurred from early March to the end of June and for the brood population from February to June. It was also observed that the brood population steadily increased from late August through the end of December in local bees, whereas it remained constant in exotic honey bee colonies (Fig. 3).

The nectar and pollen stockpiles measured in the hives in the different months for the two races are shown in Fig. 4. In most months, the exotic bees had higher nectar stores and lower pollen stores in their honeycombs than the local bees. In both races, nectar hoarding was observed to decrease in late February but started to increase in early March.

Relatively high levels of stored pollen were observed in the hives of local bees in early April through early June. However, in the case of exotic bee colonies, pollen stockpiles remained almost constant, except for extreme depletion in July and August.

4. Discussion

In the lowland landscapes, with relatively high ambient temperatures, local bee colonies tended to sustain their strength through brood rearing and maintaining adult bee populations better than the exotic bees did. This result is in agreement with the findings of Alqarni et al. (2014), who reported the higher brood rearing abilities of local bee race compared to exotic bee colonies. This difference might be due to long-developed adaptive traits of the local races that enable coping with harsh environmental influences. Moreover Harris (2010) indicated that population growth is the best indicator of a colony's potentials to withstand unfavorable seasons (Harris, 2010). In addition, Hatjina et al. (2014) reported that local genotypes had higher adult bee populations in their area of origin than outside, and the adaptation allows individual bees to survive longer and build larger colony population. The better per-

Table 2

Honey producing abilities of the local and exotic honeybees in the lowland and highlands.

Races	Estimated honey amounts					
	N	Lowland (<i>Acacia tortilis</i> season) (mean ± SE)		N	Highland (<i>A. origina</i> season) (mean ± SE)	
		In unit areas	In kg per harvest		In unit areas	In kg per harvest
Local	20	117.4 ± 7.4 ^a	1.8 ± 0.1 ^a	28	87.4 ± 9.7 ^a	1.4 ± 0.2 ^a
Exotic	20	80.7 ± 7.4 ^b	1.3 ± 0.1 ^b	30	103.6 ± 9.4 ^a	1.6 ± 0.1 ^a
P-values		0.001	0.001		0.232	0.232

Values with different superscripted letters within a column are significantly ($P < 0.05$) different; one unit area = 25 cm².

Table 3
Pollen hoarding capacities of local and exotic honeybees in lowland and highlands.

Types of colonies	Pollen hoarding capabilities							
	Pollen unit areas				Proportion of pollen to brood unit areas			
	Lowland		Highland		Lowland		Highland	
	N	(Mean ± SE)	N	(Mean ± SE)	N	(Mean ± SE)	N	(Mean ± SE)
Local (<i>Amj</i>)	133	20.3 ± 1.2 ^a	173	22.0 ± 1.1 ^a	122	0.24 ± 0.03 ^a	151	0.37 ± 0.02 ^a
Exotic (IH)	114	6.5 ± 1.3 ^b	163	5.9 ± 1.1 ^b	107	0.20 ± 0.03 ^a	153	0.11 ± 0.02 ^b
P-values	0.000		0.000		0.374		0.000	

Values with different superscripted letters within a column are significantly ($P < 0.05$) different; N = number of records, one unit area = 25 cm².

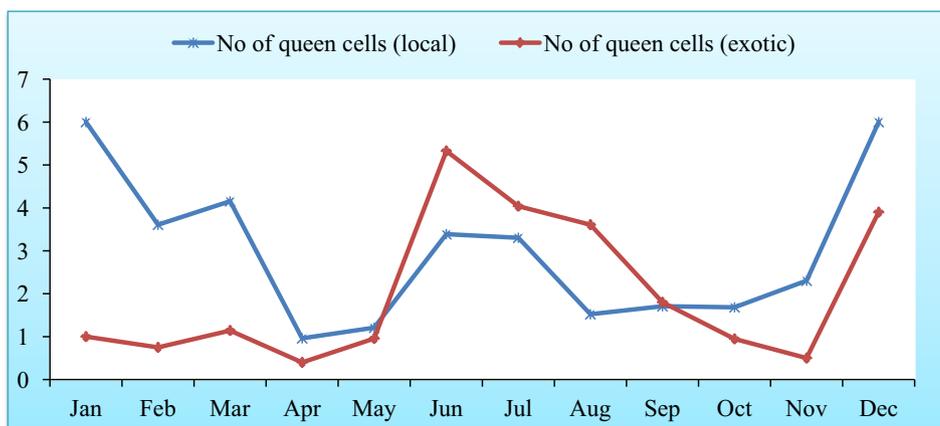


Figure 1. Seasonal distribution of the average number of queen cells for both races.

performances of local bees than non-local ones have been well documented for different European honey bee races and ecotypes (Louveaux et al., 1966; Costa et al., 2012a,b; Büchler et al., 2014).

In this regard, the local race is well known to adapt to high temperatures of 27–40 °C and irregular and low yearly rainfall of 50–300 mm in the semi-desert parts of its distribution (Ruttner, 1988). Having a relatively large work force in the local bee colonies (Table 1), especially during honey flow seasons, might be one of the adaptive strategies used by the local race to rapidly build its population to cope with the short flowering periods of the study areas. In this regard, the local race is reported to increase its population quickly during the flowering season, which is an important adaptive feature in semi-arid habitats, where the rainfall and flowering periods are very short (Chandler, 1976). Moreover, the local race is well known to maintain relatively small adult and brood populations during the dearth period, thereby matching with the availability of forage resources (Ruttner, 1988) which is a mechanism of minimizing the risk of long dry seasons to survive better.

The local bee race hoarded a higher amount of honey per colony in the lowland ecosystem than the exotic race, most likely could be due to the better adaptation of the race in hot environment. Likewise, Harbo (1993) documented that honey bee colonies with high population sizes hoarded more honey than less populous colonies. The better adaptation of the local bees could be due to efficient yearly rhythmic activities that synchronize well their population dynamics with the flowering periods of the local plants. Similarly, Louveaux et al. (1966) observed the adaptation of local honey bee (Landes honey bees of France) to the local floral phenology. The low performances of the exotic bees in this study could be due to the lack of adaptation to the new environment which agrees with the above authors who experimentally demonstrated that when bees of one region are transported to new environment they are observed to perform worse as a result of continuing to exhibiting

their prior adaptive characters, which might not fit well in the new environment. Later, Strange et al. (2007) observed similar brood cycle trends following the local floral phenology as reported by Louveaux et al. (1966) for the same bee ecotypes.

Comparing the pollen hoarding capacities of the races, the local bees hoarded three times more pollen than the exotic bees did. A stronger tendency to hoard pollen might be related to the more brood rearing potentials of the local bees, which require much pollen, thereby triggering bees to collect more. A similar result was reported by Alqarni et al. (2014) in Assir, a region that neighbors the current study area. This relationship agreed with the results of Keller et al. (2005), who reported that protein-rich larval food is secreted from the hypopharyngeal glands, whose development is induced by the consumption of high-quality pollen, thus implying a direct relationship between pollen supply and brood rearing. Even if honey bees prefer to consume fresh pollen stored less than 72 h (Anderson et al., 2014); pollen collection is a continuous process and by principle, the stronger the colony, the higher the brood rearing activity hence it collects and temporarily hoards more pollen than weak colonies. Hence, the current study revealed that local bees exhibit higher pollen collection, hoarding and brooding activity than exotic honey bee colonies.

The gradual dwindling of the performances of exotic honey bee colonies in terms of brood rearing, adult bee population and pollen hoarding abilities could be due to the effect of shifting of the colonies into completely different environment and their continuation to follow the behavioral rhythm similar to their original homeland which may not match well to the new environment. The presence of continuation of behavioral rhythms similar to the original homeland and its critical effect on adaptability of the shifted honey bee colonies in the new environment as a result of the residual effect of prior environment experience have been well documented (Mârza, 1965; Johansson and Johansson, 1979). Moreover, Louveaux et al.

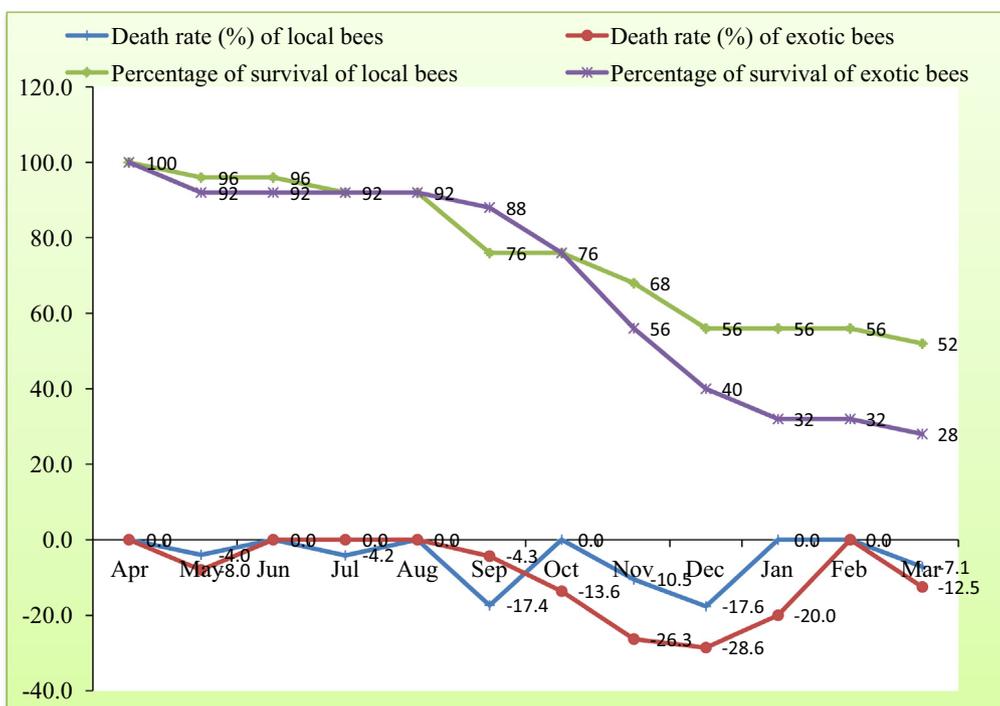


Figure 2. Monthly survival and death rates of local and imported honeybee colonies.

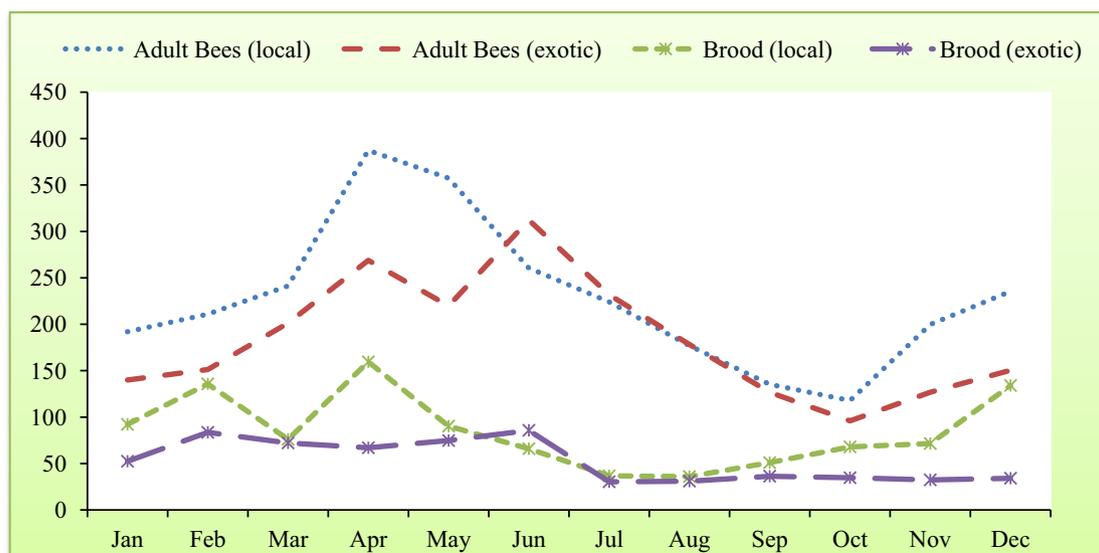


Figure 3. Adult bee and brood population dynamics of local and exotic honeybee colonies.

(1966) and Meixner et al. (2015) reported that a given genotype of certain habitat origin that is well known for its most performances, survival rate and resistance disease and such adaptive traits were not observed when the genotype is moved to the new environment. The contributing factors for the low adaptation of exotic honey bee colonies could be related to their clustering and nest microclimate regulation and foraging behaviors and their morphological traits such as larger body size that may not fit well in the new environment.

Morphological factors coupled with behavioral characteristics and climatic conditions have been used to predict the distribution limit of tropical evolved Africanized honeybees in North America not to be exceeded beyond Isoline temperatures regions, 10 °C dur-

ing winter (Southwick et al., 1990). The reverse could be true in that the importation of the temperate evolved exotic honey bee colonies to Saudi Arabia climate conditions could be beyond its distribution limit, which requires further detailed investigations to determine the adaptability range or phenotypic plasticity of the race.

The proportion of pollen hoarded in the hive to the number of broods reared was different in the lowlands and highlands. In the lowlands, for every 4–5 unit cells of brood reared, one unit cell of pollen was hoarded in both races. In the highlands, this proportion decreased by half in the case of exotic honey bee colonies but increased in local bee colonies. This phenomenon might imply that the brood rearing tendencies of local bee are reduced when it is

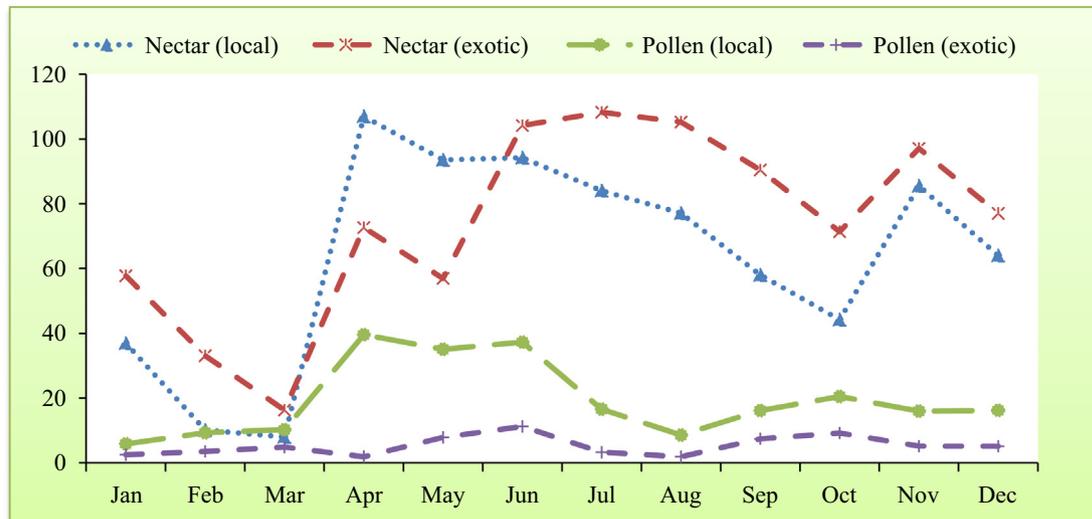


Figure 4. Nectar and pollen hoarding dynamics of local and bees.

moved from lowlands to highlands, but those of exotic honey bee colonies are increased. This result perhaps indicates a difference in the races' responses to different altitudes, i.e., local bee responds better in the lowlands than exotic does.

The low reproductive swarming tendencies of both races might be due to the limitation of the honey bee resources in both the highlands and lowlands of the beekeeping landscapes. Moreover, aborting new queen cells during inspection might also have discouraged colonies from undergoing reproductive swarming. In fact, honeybees wisely optimize their reproductive tendencies according to the available floral rewards. In the current study, the higher number of queen cells formed by local bee compared with exotic honey bee colonies could perhaps imply that local bee rear broods more actively than exotic bees.

Peak numbers of queen cells were recorded for local bee from December through March, which was associated with the flowering of plants such as *Dypterigeum glaucum* (arfaj), which is a chief source of pollen and thus could cause the colonies to increase their activities and hence reproduce better. Alqarni et al. (2011) noted the association of enhanced colony performance with the flowering of some honey bee plant species in similar regions of Saudi Arabia.

Unlike the local bees the peak reproductive swarming period of exotic honeybees interestingly match with the original homelands (Mediterranean region) reproductive seasons (June to August). This could be related to the Avetisyan's hypothesis that honey bee colonies moved from one region to another may continue to follow behavioral rhythm similar to the original homeland (Johansson and Johansson, 1979).

Regarding the annual survival rate, exotic bee colonies, which were imported as packaged bees from abroad, were worse survivors than the local bee race. The current situation may be explained by the poor responses of the exotic bees to the seasonal environmental conditions of the new environment. However, the local bees withstood the unpredictable and limited floral resources and had a lower death rate, most likely because of their long-developed coping mechanisms. This result is in agreement with Alqarni et al. (2011), who reported that the local bees appear better suited than other races for survival and activity (e.g., foraging) in the extremes harsh Saudi environment. In addition, tolerance of extreme conditions, high temperature or low humidity by the local races has been documented (Abou-Shaara et al., 2012). Similarly,

under European conditions colonies with queens from local origin reported to survive better than non-local origins (Büchler et al., 2014). The authors explained that the strong interaction between genotype and environment may play significant role in survival rate of colonies.

Sharp declines in colony strength and the highest rate of colony losses observed during October through December in both races, which might be due to the winter season stresses and cool weather conditions in the study area. Similar findings were presented by Riessberger and Crailsheim (1997), who reported that even a relatively short duration of bad weather has significant effects on the survival rate of honey bee colonies.

The dynamics of adult bees and the broods of both races exhibited wide fluctuations throughout the year. The increases in both the adult bee and brood populations from March through June and subsequent decreases from June through September may be related to the floral dynamics of the potential honey bee plants that are used as pollen and nectar sources in the area. In agreement with this result, Keller et al. (2005) reported that the availability of pollen is likely to be a dominant parameter that influences the development of honey bee colonies. The increases in the bee populations coincided with the flowering time of *Dypterigeum glaucum* "arfaj", *A. tortilis* "sumira" and *A. ehrenbergiana* "selam", which are considered to be major sources of floral rewards (pollen and nectar) in the study areas during this period. The flowering periods of these species start in March in the mid-altitude and lowland areas near the study areas. The hive resources, particularly pollen and nectar, exhibit very similar dynamics throughout the year, most likely because of the latter phenomenon.

Moreover, the positive correlations between all of the internal activities of the colonies of both races in the current study support the latter idea. However, the adult bee and brood population fluctuations were more pronounced in local bees than imported, which might reflect the long-developed sharp responses of the local race to the local floral resource dynamics. This result may indicate a better ability of local bees to synchronize its population dynamics with the highly variable resources (pollen and nectar) and unpredictable climate. This study agrees with the findings of Alqarni et al. (2011), who reported that local bees appear better adapted to the unique climatic conditions and their variations in the Kingdom of Saudi Arabia than other races.

5. Conclusions

In a year-round performance evaluation, local bee colonies thrive effectively in the harsh environmental and limited resource conditions of southwestern Saudi Arabia compared with exotic honey bee colonies. Furthermore, local bees because of their better survival and lower death rate, remained superior to exotic honey bee colonies in withstanding and producing in the very dynamic and seasonal environmental conditions of the study area. Although exotic bee colonies are seen to behave hording nectar quickly and are economical for production in resource-rich areas, the race survives poorly and depletes its stocks quickly compared with local bees.

Mass importation of exotic colonies besides carrying various pathogens may gradually dilute the genetic resources of the indigenous bees and in the long term will affect the beekeeping industry of the country. Therefore, it would be wise to design how to improve and conserve the local bees instead of focusing on importation of exotic bees.

Acknowledgements

The authors are grateful to King Saud University, Vice Deanship of Research Chairs for providing research support.

References

- Abou-Shaara, H.F., 2014. Biological and Ecological Studies on Honey Bee (*Apis Mellifera Colonies*) Under Harsh Environmental Conditions PhD thesis. King Saud University, Riyadh, Saudi Arabia, p. 130.
- Abou-Shaara, H.F., Al-Ghamdi, A.A., Mohamed, A.A., 2012. Tolerance of two honeybee races to various temperature and relative humidity gradients. *Environ. Exp. Biol.* 10, 133–138.
- Al-Ghamdi, A., Nuru, A., 2013. Beekeeping in kingdoms of Saudi Arabia: opportunities and challenges. *Bee World* 90 (3), 54–57.
- Al-Ghamdi, A.A., Nuru, A., Khanbash, M.S., Smith, D.R., 2013a. Geographical distribution and population variation of *Apis mellifera jemenitica* (Ruttner). *J. Apic. Res.* 52 (3), 124–133. <http://dx.doi.org/10.3896/IBRA.1.52.3.03>.
- Al-Ghamdi, A.A., Nuru, A., Khanbash, M.S., Smith, D.R., 2013b. Geographical distribution and population variation of *Apis mellifera jemenitica* (Ruttner). *J. Apic. Res.* 52 (3), 124–133.
- Alqarni, A.S., Hannan, M.A., Owayss, A.A., Engel, M.S., 2011. The indigenous honeybees of Saudi Arabia (Hymenoptera, Apidae, *Apis mellifera jemenitica* Ruttner): their natural history and role in beekeeping. *ZooKeys* 134, 83–98.
- Alqarni, A.S., Balhareth, H.M., Owayss, A.A., 2014. Performance evaluation of indigenous and exotic honey bee (*Apis mellifera* L.) races in Assir region, southwestern Saudi Arabia. *Saudi J. Biol. Sci.* 21 (3), 256–264. <http://dx.doi.org/10.1016/j.sjbs.2013.10.007>.
- Anderson, K.E., Carroll, M.J., Sheehan, T., Mott, B.M., Maes, P., Corby-Harris, V., 2014. Hive-stored pollen of honey bees: many lines of evidence are consistent with pollen preservation, not nutrient conversion. *Mol. Ecol.* 23, 5904–5917. <http://dx.doi.org/10.1111/mec.12966>.
- Büchler, R., Costa, C., Hatjina, F., Andonov, S., Meixner, M.D., Le Conte, Y., Uzunov, A., Berg, S., Bienkowska, M., Bouga, M., Drazic, M., Dyrba, W., Kryger, P., Panasiuk, B., Pechhacker, H., Petrov, P., Kezić, N., Korpela, S., Wilde, J., 2014. The influence of genetic origin and its interaction with environmental effects on the survival of *Apis mellifera* L. colonies in Europe. *J. Apic. Res.* 53 (2), 205–214. <http://dx.doi.org/10.3896/IBRA.1.53.2.03>.
- Champetier, A., Sumne, D.A., Wilen, J.E., 2014. The Bioeconomics of Honey Bees and Pollination. Working paper, Dept. of Agric. Econ., University of California, Davis.
- Chandler, M.T., 1976. Apiculture in madagascar. *Bee World* 56, 149–153.
- Costa, C., Lodesani, M., Bieneffld, K., 2012a. Differences in colony phenotypes across different origins and locations: evidence for genotype by environment interactions in the Italian honey bee (*Apis mellifera ligustica*). *Apidologie* 43 (6), 634–642. <http://dx.doi.org/10.1007/s13592-012-0138-9>.
- Costa, C., Büchler, R., Berg, S., Bienkowska, M., Bouga, M., Bubalo, D., Charistos, L., Le Conte, Y., Drazic, M., Dyrba, W., Fillipi, J., Hatjina, F., Ivanova, E., Kezić, N., Kiprijanovska, H., Kokinis, M., Korpela, S., kryager, P., Lodesan, M., Meixner, M., Panasiuk, B., Pechhacker, H., Petrov, P., Oliveri, E., Ruottinen, I., Uzunov, A., Vaccari, H., Wilde, J., 2012b. A Europe-wide experiment for assessing the impact of genotype-environment interactions on the vitality and performance of honey bee colonies: experimental design and trait evaluation. *J. Apic. Sci.* 56 (1), 147–158. <http://dx.doi.org/10.2478/v10289-012-0015-9>.
- El Karemy, Z.A.R., Zayed, K.M., 1992. Distribution of plant communities across Al Abna escarpment, SW Saudi Arabia. *Phyton (Horn, Austria)* 32 (1), 79–101.
- Falconer, D.S., Mackay, T.F.C., 1996. Introduction to Quantitative Genetics. Longmans Green, Harlow, Essex, UK.
- Harbo, J.R., 1993. Worker-bee crowding affects brood production, honey production, and longevity of honeybees (Hymenoptera: Apidae). *J. Econ. Entomol.* 86, 1672–1678.
- Harris, J.L., 2010. The effect of re-queening in late July on honey bee colony development on the northern great plains of north America after removal from an indoor winter storage facility. *J. Apic. Res.* 49 (2), 159–169. <http://dx.doi.org/10.3896/IBRA.1.49.2.04>.
- Hatjina, F., Costa, C., Büchler, R., Uzunov, A., Drazic, M., Filipi, J., Charistos, L., Ruottinen, L., Andonov, S., Meixner, M.D., Bienkowska, M., Dariusz, G., Panasiuk, B., Le Conte, Y., Wilde, J., Berg, S., Bouga, M., Dyrba, W., Kiprijanovska, H., Korpela, S., Kryger, P., Lodesani, M., Pechhacker, H., Petrov, P., Kezić, N., 2014. Population dynamics of European honey bee genotypes under different environmental conditions. *J. Apic. Res.* 53 (2), 233–247. <http://dx.doi.org/10.3896/IBRA.1.53.2.05>.
- Hepburn, H.R., Radloff, S.E., 1998. Honeybees of Africa. Springer, Germany, p. 370.
- Jeffrey, E.P., 1958. A shaped wire grid for estimating quantities of brood and pollen in combs. *Bee World* 39 (5), 115–118.
- Johansson, T.S.K., Johansson, M.P., 1979. The honeybee colony in winter. *Bee World* 60 (4), 155–170. International Bee Research Association reprint.
- Keller, I., Fluri, P., Imdorf, A., 2005. Pollen nutrition and colony development in honeybees—Part II. *Bee World* 86 (2), 27–34.
- Louveau, J., Albisetti, M., Delangue, M., Theurkuff, M., 1966. Les modalités de l'adaptation des abeilles (*Apis mellifera* L.) au milieu naturel. *Ann. Abeille* 9 (4), 323–350. <http://dx.doi.org/10.1051/apido:19660402>.
- Märza, E., 1965. Comparative data on the performances of steppe and montane honeybee populations. *Lucr. Stunt. Stat. Cent. Seri. Apic.* 6, 23–31.
- Meixner, M.D., Büchler, R., Costa, C., Francis, R.M., Hatjina, F., Kryger, P., Uzunov, A., Carreck, N.L., 2014. Honey bee genotypes and the environment. *J. Apic. Res.* 53 (2), 183–187. <http://dx.doi.org/10.3896/IBRA.1.53.2.01>.
- Meixner, M.D., Kryger, P., Costa, C., 2015. Effects of genotype, environment, and their interactions on honey bee health in Europe. *Curr. Opin. Insect Sci.* 10, 177–184.
- MoEP, 2012. Import Data on Honeybees from Different Sources. Central Department of statistics and Information, Ministry of Economics and Plane (MoEP).
- Nuru, Adgaba, Shenkute, Awraris G., Al-Ghamdi, Ahmed A., Ismaiel, Sobhy, Al-kahtani, Safar, Tadesse, Yilma, Abebe, Workneh, 2014. Socio-economic analysis of beekeeping and determinants of box hive technology adoption in the Kingdom of Saudi Arabia. *J. Anim. Plant Sci.* 24 (6).
- Riessberger, U., Crailsheim, K., 1997. Short-term effect of different weather conditions upon the behavior of forager and nurse honeybees (*Apis mellifera carnica* Pollmann). *Apidologie* 28, 411–426.
- Ruttner, F., 1988. Biogeography and Taxonomy of Honey Bees. Springer-Verlag, Berlin, Germany, p. 284.
- SAS Institute Inc, 2002. JMP-5 Statistical Software, Version 5. Cary, NC, USA.
- Southwick, E.E., Roubik, D.W., Williams, J.M., 1990. Comparative energy balance in groups of africanized and european honey bees: ecological implications. *Comp. Biochem. Physiol. A Physiol.* 97 (1), 1–7.
- Strange, J.P., Garnery, L., Sheppard, W.S., 2007. Persistence of the Landes ecotype of *Apis mellifera mellifera* in southwest France: confirmation of a locally adaptive annual brood cycle trait. *Apidologie* 38, 259–267. <http://dx.doi.org/10.1051/apido:2007012>.