MELLIFERA RESEARCH ARTICLE

SW Nigeria Experience of Impacts of Agricultural Intensification and Climate Change on *Apis mellifera adansonii* Colony Establishment and Health

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A B S T R A C T

Declines of wild bees together with unsustainably high losses of managed colonies and worsening bee health have become global issues. Southwest Nigeria is a tropical rainforest biome. It is one of the most biologically diverse ecosystems, with the changing agricultural development and climate overwhelmingly impacting it. The impact is also significant on beekeeping vis: colony establishment, health and productivity of the native bees the West African honeybees, *Apis mellifera adansonii* Latreille (Hymenoptera: Apidae). This bee was once described as strongly adaptive to the tropical rainforest, productive, hygienic and immuned to pathogenic infections. This study was carried out between December, 2015 to December, 2018 to determine the stress factors associated with colony establishment, health and productivity of the bee colonies. Four states were purposively selected in the Southwest Nigeria. Some beekeepers were selected, sampling and colony observations were made in selected apiaries and laboratory investigations were conducted. Results indicated decline in colony numbers and honey production from 2016 to 2018. Out of 96 inspected colonies, 16 (16.67%) colonies have become weakened or lost due to bee pests and diseases this is greater than losses recorded due to other factors. Similarly, infestation with small hive beetles (SHB) across the region is 82(85.43 ± 0.01%) greater than 67(69.93 ± 2.08) (Mean ± SD) recorded for Galleria mellonella infestation. SHB infestation were significantly different across the states ($P = 0.005$, $p < 0.05$). The mean levels of Gluthathion-S-Transferase (GST) detoxifier chemical signal in the tissues of bees tested in the colonies for the three years were higher than the normal value for bees. The climate change, and the adaptation policy and development such as agricultural intensification programme adopted is a relevant and sustainable mitigation tool but with a pervasive influence on beekeeping, honeybee health, population and productivity.

Keywords: Colony establishment, decline, productivity, pests, climate change, forest

Introduction

The tropical rainforest has been described as the most biologically diverse ecosystem [1]. This biome covers the geographical zone of SW Nigeria that is predominantly modern beekeepers' enclave in Nigeria. The beekeepers use modern hives often than the traditional hives. However, knowledge and practice of modern beekeeping is deficient among the beekeepers [2, 3], honey and beeswax processing remained traditional as generally in the tropics [2, 4]. The bees

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respond to changes in human apicultural practices, environment [5], ecological and climatic factors [6] in Nigeria [7]. The declined populations of honeybees and honey production recorded in many countries are of widespread concern [8, 9], no single factor has been found to account for the incidence, but pesticides and pathogens are known to play important roles [10, 11]. The modern beekeeping methods were supposed to improve colony establishment, sustenance, and honey production because colonies could be managed and manipulated, hives could be opened and examined without undue disturbance; this best described the concept ‘modern beekeeping’ [8, 9]. But contrary reports from USDA-ARS [12], Watanabe [13], Johansen and Mayer [14] claimed bee colonies were continuously weakened to the point where they succumb to pests and diseases that would otherwise have only minor impacts on their health. The beekeeping practices that agitated the bees are regular colony inspection (without any disturbance), artificial feeding, queen rearing, colony division/splitting, manipulation of colony for pollination, chemotherapy and other treatment of bee diseases, honey harvesting, and some changes in agricultural practices [15]. Although, some of these activities are practice in the tropics despite the wide acceptance of modern beekeeping [16]. Again, climate change and human activities have greatly influenced beekeeping, climate change had resulted in declining floral development, nectar and pollen production affecting colony foraging and development [17]; altering the quality and quantity of the nutrients for honey bees [18]; influencing the honeybee development cycle [5, 19]; the frequency of occurrence and diversity of pests and parasites of the bees [7]; development of migration strategy to escape predation and starvation [5] and; later the same colony returns to recolonize same hive [20, 21]. Similarly, human activities had greatly disturbed the ecosystem. Agricultural practises have resulted in clearing of forest resources for crop production and logging of woods for construction [22]. Dry season bush burning [23] to clear land for farming and cattle grazing had contributed to decline of natural forest and considerably reducing the wild bee population. Agricultural intensification to boost cash and food crop productivity with increasing application of chemical to control insect pests had resulted in poisoning of honeybees [24] and decline of swarms. Similarly, continuous exposure of honeybee to agrochemical applications

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might induce physiological impairment that could affect the bees' health [25], immunity against infections and detoxification of harmful substances they inject [26]. Acetylcholinesterase (AChE) and GSTs are among the enzymes the bees use as biomarkers of chemical toxicity in the environment [27]. GSTs are members of a significant intracellular and multifunctional antioxidant enzyme superfamily that detoxify and protect against oxidative damage caused by reactive oxygen species [28] and catalyse nucleophilic attack in order to bring about detoxification of xenobiotics. Similarly, acetylcholinesterase represents a biomarker of neurotoxicity to chemicals such as pyrethroids [29, 30] organophosphates and carbamate insecticides [28, 31, 32]. Honey bees use these active detoxifying enzyme systems for eliminating harmful substances they come in contact [17, 33, 34]. There is a need to mitigate the effect of xenobiotic exposure on honey bee health and productivity with activities of beekeepers, growers, manufacturers and regulators of agrochemical. In view of multiple factors of environmental conditioning risks, beekeeping management practices, agricultural development, climate change and anthropogenic factors; colonies are continuously exposed to a broad spectrum and highly pathogenic pests, parasites and pathogens that were initially taken as insignificant or non-native to the local bee (Apis mellifera adansonii Latrielle). In Kwara State, Nigeria, pest insurgence had resulted in 15% decline in colony establishment in some Local Government areas [35]. The incidence of Varroa destructor (Acari: Varroidae), ‘Korean hypotype’ reported by Akinwande et al. [36] in South West Nigeria, recorded an average mite load of 0.01 to 0.055 mites/adult bee. Although, there was no established link between regular complaints of decline in colony establishment in the area and mite festations. The mites feed on bee haemolymph [37, 38] and fat body [39], vector numerous viral pathogens between individual bees and colonies. Although, Shen et al. [40] adjudged Korean haplotype Varroa mites were virulent mostly to the native host, the Eastern honeybee. This race lacks the natural defence mechanism and the mite is capable of wiping off the entire colony within few years of infestation [41, 42]. Wax moths: the greater wax moth *Galleria mellonella* L. and smaller wax moth *Achroia grisella* F. (Lepidoptera: Pyralidae) have been identified as common natural enemies that

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enter the bees' nests in South West Nigeria [7, 35, 43]. Although, these pests, according to May [44] may not affect a strong colony but a weak one that cannot protect its comb, they become susceptible and collapse or abscond. Other terrestrial enemies associated with the honey bees in the tropics are ants (Hymenoptera: Formicidae) and termites (Blattodea: Termitoidea [7, 45]. Harvester ants *Pheidole barbata* and termites *Macrotermes nigeriense* were identified in some colonies in SW Nigeria [7]. Again, the small hive beetle (SHB), *Aethina tumida* Murray (Coleoptera: Nitidulidae), is a pest [46, 47]; and kleptoparasite [48] of bee colonies, it transmits pathogenic viruses [49]. SHBs are mostly recorded in the forest region in SW Nigeria [50] while large African hive beetles *Oplostomus haroldi* and *Oplostomus fuligineus* (Coleoptera, Scarabideae, Cetoniinae) are associated with the savannah in northern Nigeria [51]. Various economic losses have been incurred by beekeepers in Nigeria due to infestation of SHB, these include significantly reduction in colony establishment and productivity [36], and possibly colony collapse [50]. Hence, the objectives of this study are to provide a baseline information on colony loss which is lacking in Nigeria and to determine the stress factors such as climate change, agricultural intensification and detrimental beekeeping practices (anthropogenic factors) associated with the colony loss, health and productivity of the native West African honey bee colonies *Apis mellifera adansonii.*

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Materials and Methods

Study Site

The study area covered the Southwest geographical zone of Nigeria which consists of Lagos, Ogun, Oyo, Osun, Ondo and Ekiti states (Figure 1). The region lies between longitude 2°311 and 6°001 East and Latitude 6°211 and 8° 371 North [52].

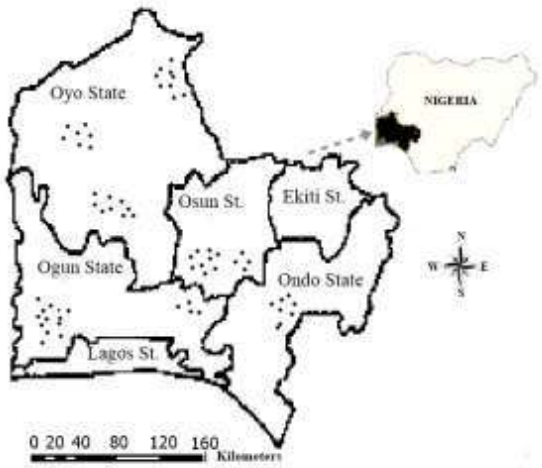

Figure 1. Map of Southwest Nigeria showing areas of study

It is a tropical rain forest biome. Expected temperature throughout the year ranges from 29 ± 5Oº C, relatively high humidity of 70 - 85% and rainfall varies from 2,000 mm [53]. This study was carried out between December, 2015 to December, 2018 to determine the stress factors associated with *Apis m. adansonii* establishment, health and productivity of their colonies. 4 states were purposively selected in the region because of accessibility to information from the large number of beekeepers in the states.

Sample Collection

Sampling and sample collections were carried out in 48 apiaries (n =12/state) randomly selected among the apiaries owned by 179 beekeepers that responded to our requests. In each apiary, 2 framedbar colonies were randomly inspected (n = 96 colonies (24 colonies/state) and sample collections were carried out. Honeybee and brood samples were collected from each colony. The bees were shaken into zip lock bag and sealed, while about 5 x 10 cm pieces of brood combs were cut neatly with knife and wrapped in an absorbent tissue paper. The sampled combs were ensured not containing honey and not wrapped in airtight containers/plastics to prevent condensation which might cause fungi and moulds to grow, thereby, making it difficult to identify the bee pathogens. The knife used was washed thoroughly with water and detergent before reused to avoid cross infestation.Also, each sample in zip lock bag from colony was labelled and immediately placed in ice cubes to inactivate the bees and also preserves the pathogens. The samples collected were taken to the laboratory for analysis.

Colony Observation

Visits and observations were made to therandomly selected colonies early in the morning between the hours of 9:00 am and 12 noon and twice per season in the year (wet and dry seasons) for the three years of study. The colonies selected were those in standard framed bar hives with good top covers, placed in protected shade where rainfall impact is minimal and the quadruped stands supporting the hives immersed in 4 containers of used oil to protect the colonies from predators like lizards and geckos climbing the hives to feed on live and dead bees:

i.Presence of large clusters of dead bees

Observations of large clusters of dead bees

[54] in the hive hollows, in and around the hive entrances and in the hive surroundings within 5 metres radius were conducted in the selected colonies (classified as strong or weak colonies) in the apiaries. Regular observation (once per month) and feedback were sought from the (owner) beekeepers while the researcher visited and conduct similar observation twice per season in the year. Inquiries (through the questionnaire administered) were made of cases of application of agrochemicals in the cultivated land within or nearby the apiary before or during the planting season. The presence of large cluster of dead bees (>1000) was used to confirm pesticide poisoning according to Akratanakul [54].

ii. Presence of pests and parasites

The colonies were opened, pests and parasites present in the hives were collected, identified and recorded, while the bee samples were examined for ectoparasites and pathogens. The hive surroundings were also examined for the presence of pests and predators. This exercise was carried out twice per season in the year (wet and dry seasons) for the 3-year period of study.

Beekeepers' Activities, Colony Establishment and Productivity

Random cluster sampling procedure was used in selecting the professional beekeepers and farmers keeping bees for the study. Each state selected for the study has clusters of local associations of beekeepers and farmers keeping bees (Figure 1). Multiple choice survey questionnaires were administered during the state and cluster groups' meetings, to focus group and on social media (WhatsApp) platform. Extensive interviews, contact discussion and seminars were organised. 220 (n =55/state) questionnaires were administered out of which 199 respondents were returned, information received from 179 (81.36%) of the respondents were treated on the following semantic areas: Ecological problems of beekeeping, management practices, pest and diseases management, pesticide poisoning, colony behaviour, colony number and loss, honey and wax production, brood rearing, brood pattern and harvesting. The questionnaire surveys were repeatedly conducted twice annually for the 3-year period (2016 -2018) on the same respondents and subject, to update the information on the semantic areas. The information collected were reviewed and compared to justify the reliability of the instrument used.

Laboratory Analyses of pathogens

i. Microbial test

Bacteriological and mycological examinations of brood comb/bee samples collected from the apiaries were carried out on the same day in the Federal University of Technology, Akure (FUTA) Laboratory. 1.0 gram of the brood/bee samples collected were crushed and sample extracts were made in 10ml sterile distilled water, centrifuged and the extracts obtained were serially diluted in ten tubes. 1ml of aliquot of dilution factors 10-2, 10-4 and 10-6 each were inoculated into molten potato dextrose agar (PDA) containing tetracycline (inhibit bacteria growth), while nutrient agar (NA) and De Ma Ro (MRS) agar were inoculated for bacteria growth. PDA plates were incubated at 30oC for 3 days while NA and MRS were incubated at 37^{o}C for 3 days. The plates were prepared in duplicates and were examined daily for growth. These media were prepared following the manufacturer instructions. Each different colony was subcultured to obtain pure culture and was identified using morphological and biochemical methods as described by Idowu et al. [55]. Colony forming unit (CFU) growth on PDA were counted, sub-cultured on new PDA using streak plate method and identified using staining techniques (Gram's staining techniques) and biochemical tests methods [56]. The cultural characteristics of the isolates were done based on colour, shape, pigmentation and opacity of the colonies. The examination helped to detect the presence of bacteria and not to identify the type.

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ii. Viral test

For the viral analysis, bee samples collected in the selected colonies in all the 48 apiaries visited were labeled accordingly. The bees were crashed while still alive into falcon tubes containing about 20 ml RNA-later. The samples were labelled showing date and place of collection. RNA-later was prepared by: 935 ml of autoclaved, MilliQ water; 700 g Ammonium Sulfate; Stir until dissolved; 25 ml of 1 M Sodium Citrate added; 40 ml of 0.5 M EDTA added; adjusted to pH 5.2 using concentrated H2SO4 (about 20 drops = 1 ml); They were stored at room temperature before the samples were sent to the Microbiology Department, FUTA for analyses to detect the presence of viral pathogens.

Tissue homogenate for biochemical analyses

250mg of freshly collected honey bees per sample were weighed with a scale (JS600H-A & GULF) from each sampling bags and placed in a clean thoroughly washed mortar and pestle. The weighed samples were homogenized in 900µl of phosphate buffer (pH 6.5), and centrifuged at 1000rpm for 10 mins with a centrifuge (MSE-MINOR35). All cellular debris were discarded while the supernatants obtained were kept in a refrigerator at 4^{o}C.

Test on levels of detoxification enzymes (Glutathione-S-transferases)

Glutathione-S-transferases (GSTs) levels were estimated using CDNB (1-chloro-2, 4-dinitrobenzene) as substrate [57] in a reaction mixture containing 100 µl of 25mM of (1-chloro-2, 4-dinitrobenzene), 150µl of 20mM reduced glutathione, 500µl of 40mM Phosphate buffer (pH6.5 and 30µl of enzyme). These mixtures were incubated at 20^{o}C for 3 mins and the absorbance was recorded after 3mins at 340nm using UV Visible Spectrophotometer (Jenway 6850). The level of GSTs was reported in (µmol/ml/min). The experiments were replicated three times for each sample. Freshly colonized and healthy colonies from the University Research Farm were used as control against the colonies sampled from the beekeepers.

Statistical Analysis

Differential and inferential statistics were used to process the data. Descriptive analysis was used to process information obtained from questionnaire, factors responsible for decline, and

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pest/parasite/disease infestation/infections in order to make inference on their impacts while inferential statistics of one-way analysis of variance (ANOVA) were used to establish relationship between GSTs data, percentage infestation, colony and honey production decline across the states and where significant differences existed, the means were compared at $P < 0.05$ significant level established using the New Duncan's Multiple Range Test.

Results and Discussion

Colony Loss and Honey Productivity Decline

Three years (2016-2018) collated information from responses to questionnaires obtained from 160 beekeepers (n = 40/state) selected out of 179 consistent respondents revealed the following: In 2018, the total number of hives owned by the selected beekeepers were 9,371 and number with established colonies inside were 4,513 (48.16%) (Table 1). Annual loss in the region increased from 36.22 ± 6.73% ; 43.32 ± 9.60%; 49.44 ± 8.42% (Mean ± SD) in 2016, 2017, 2018 respectively (Table 1). Colony establishment declined over the years. The decline was significantly different between and within the states in the region ($F_{2,8} = 7.012$, $p = 0.015$ ($p < 0.05$).

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Table 1. Colony establishment and honey yield

	2016			2017			2018			Cumulative (2016 - 2018)	
State	No of hives	Established colonies No.(%)	Estd honey yield (Lt/ colony/year)	No. of hives	Established colonies (%)	Estd honey yield (Lt/ colony/year)	No of hives	Established colonies (%)	Estd honey yield (Lt/ colony/yr)	colony loss (%)	decline in honey yield /colony
Osun	684	443 (64.76)	860 (1.94)	897	564 (62.87)	788 (1.39)	1440	802 (55.69)	860(1.07)	35.24; 36.31; 40.12	1.94; 1.39; 1.07
Ondo	712	507 (71.20)	712 (1.40)	1001	571 (57.06)	809 (1.42)	2001	1081 (54.02)	1448(1.34)	28.80; 42.94; 45.98	1.40; 1.42; 1.34
Ogun	908	584 (64.31)	922 (1.57)	1540	970 (62.98)	1314(1.35)	3090	1490 (48.22)	1622(1.09)	35.69; 37.02; 51.78	1.57; 1.35; 1.09
Oyo	1108	698 (54.87)	1229 (1.76)	1689	726 (42.98)	1214(1.67)	2840	1140 (40.14)	1509(1.32)	45.13; 57.02; 59.86	1.76; 1.67; 1.32
Total	3412	2232 (65.41)	3723 (1.67)	5127	2831(55.31)	4125(1.46)	9371	4513 (48.16)	5439(1.21)	36.22; 43.32; 49.44	1.67; 1.46; 1.21

Note : Hives are colonized/colony established by swarms. Number of beekeepers sampled (n = 40/state).

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Similarly, the region experienced an average decline in honey production by 1.66 ± 0.23; 1.46 ± 0.144; 1.21 ± 0.144 kg/colony/year (Mean ± SD) in 2016, 2017, 2018 respectively (Table 1).This decline was not significantly different ($F_{2,8}$ = 3.336, p= 0.082 ($p < 0.05$). There was a weak positive correlation (r = 0.047) between the percentage of colony established and honey yield/colony in all the states (Figure 2).

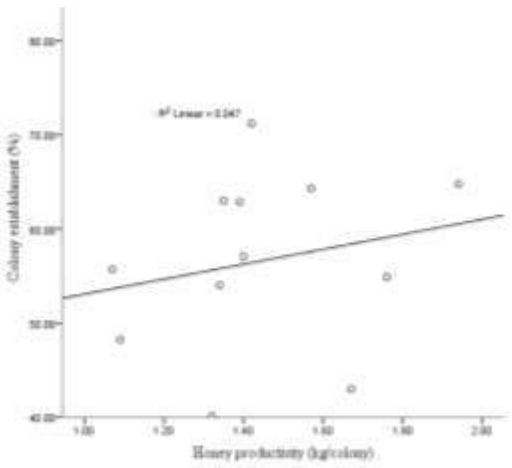

Figure 2 . Correlation between colony loss (%) and decline in honey productivity (kg/colony)

Climate and Agricultural Development Factors

Information obtained on climate change from Nigeria Meteorological Centre (NIMET) and observation reports by the beekeepers during the period of the study included the following: dryness, heat waves and bush fires following the heat waves, late and heavy rainfall, preceded with unusual flooding. These changes impacted beekeeping activities with loss of some plants identified as foraging plants and high infestation levels of pests/parasites/diseases pathogens. Again, during the period, climate change adaptation facilitated modification and intensification of agriculture as different agricultural programmes aimed at improving food production and rural development were embarked upon. Loans were provided exclusively for crop farming with many open lands cultivated. Therefore, 128 (71.5%) out of 179 beekeepers were engaged in agricultural programme of cassava and maize planting that linked agricultural intensification to extensive cultivation of natural wild forest. Decline in number and percentages of colony loss out of 4,513 established colonies of the beekeepers were 25 (0.55%) due to clearing of vegetation; 108 (2.4 %) due to land disputes and 65 (1.45%) damaged by cattle herds, as a result of herdsmen migration to south west in search of greener pasture from drought ravaged savannah north.

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Anthropogenic and Influence of Local Beekeeping Practices

The study revealed the following colony loss due to some human activities reported by the selected beekeepers. Out of total of 4,513 established colonies recorded by the beekeepers, 90 (2.0%) and 29 (0.64%) were lost to theft and damaged through land dispute respectively and 71(1.58%) colonies were lost to poor management. Some beekeeping practices were linked to colony loss and production decline such include traditional placing of hives under shade to reduce the bee aggressiveness and baiting with honey to attract swarms, both practices were observed to attract pests and pathogens, contributing to high infestation and infection levels respectively. Hence, the inspection conducted by the researchers on 96 colonies revealed 16 (16.67%) have become very weak, almost or been lost due to pests and pathogens. Other bad beekeeping practices include: harvesting of all the honey combs and removing the brood and pollen combs, cutting off any part of the brood comb with little store of honey and sharing of equipment were indicted to have negatively affected the established colonies.

Agrochemicals in Use and GST Activation Levels of Bees in Selected Colonies

Beekeepers admitted intentional use of agrochemicals in the surrounding farmland. Agrochemicals indicted include endosulfan (24%), methyl parathion (21%), mevinphos (20%), trithion (16%) and tedion/tetradifon (12%). 7(8.5%) out of 96 colonies observed by the researchers had large clusters of dead bees in the hive hollows, around the entrances and within 5m radius. These colonies were very weak colonies and few later absconded. The mean activation levels of GST in all the tested bee samples in the 96 colonies within and across the 4 states (Figure 3) in 2016 range from 0.074 - 0.087 μmol/min/ml, the activation levels were not significantly different ($F_{3,11} = 1.168$, Sig = 0.363, $p > 0.05$) (Table 3), in 2017, the GSTs activation levels range from 0.082 - 0.094 and also were not significant different in all the colonies within and across the states in the region ($F_{3,11} = 0.201$, Sig = 0.894, $p > 0.05$). Similarly, in 2018, GSTs activation levels range from 0.082 - 0.094 and they were also not significant different ($F_{3,11} = 0.267$, Sig = 0.848, $p > 0.05$). There was a significant difference in rise of GST activation levels ($P < 0.05$) annually in tissues of tested

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bees in colonies within and across the four states (Figure 3). These results indicated the formation and build-up of glutathione conjugate in the bees.

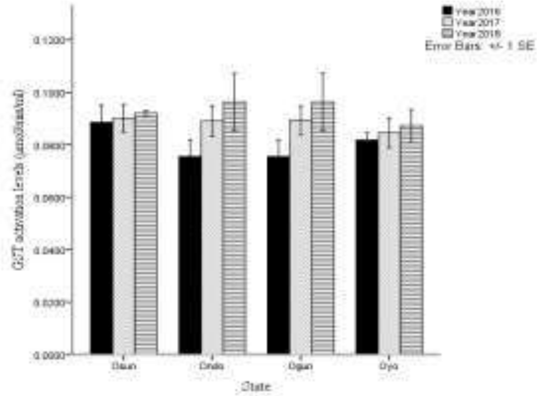

Figure 3. GST levels of sampled colonies from 2016 -2018.

Table 3. Mean GST activation levels for all sampled bees across all the colonies .

Period	Mean GST levels	*S.E*	*F*	*Sig*
Year 2016	.080	.003	1.168	.363
Year 2017	.088	.003	.201	.894
Year 2018	.093	.004	.267	.848

Pests and Disease Pathogens

There were persistent problems of insect pests, predators and parasites in the 96 colonies inspected during the period in all the states (Table 2). 16 (16.67%) colonies out of 96 inspected have become very weak, almost or been lost to pests and diseases. The percentage colonyinfestation for the following insect pestswere recorded: ants (Companotus pennsylvanicus) 62.50 ± 6.25%, greaterwax moth (GWM) (Galleria mellonella) 69.93 ± 2.08%, lesser wax moth (LWM), (Achroia grisella) 61.45 ± 1.82%, spider (Lactrodectus mactan) 34.50 ± 1.47%, termite (Macrotermes militaris) 62.50 ±1.63%, crickets and wasp (Polistes fuscatus) 62.50 ± 1.34%, large hive beetle(LHB) (Hoplostomus fuligenius) 45.98 ± 3.12%, and small hive beetle (SHB) (Aethina tumida) 85.43 ± 0.01% (Table 2). SHB infestation is highly prevalent (χ = 14.15, p = 0.001 (p>0.05) when compared to others (Figure 4). Also, the beekeepers claimed the presence of vertebrates' pests that included rodents, reptiles (e.g. lizards (Agama agama), and amphibians (e.g. toad (Bufo regularis), some birds e.g. woodpeckers and mammals moving around the colonies.

Table 2. Average number and percentage of colonies infested and infected for 3years in each state

States	**Oyo**	**Ogun**	**Osun**	**Ondo**	**Total**
No. colonies inspected	24	24	24	24	96
Pests	Average No. (%) of colonies infested for 3years				Total No. (%)
Ants	13(54.2)	15(62.5)	18(75.0)	14(58.3)	60 (62.5 ± 6.25)
SHB	20(83.3)	16(66.7)	24(100)	22(91.67)	82 (85.43 ± 0.01)
LHB	10(41.7)	12(50.0)	13(54.7)	9(37.5)	43 (45.98 ± 3.12)
GWN	15(62.5)	15(62.5)	19(79.7)	18(75.0)	67 (69.93 ± 2.08)
LWN	14(58.3)	15(62.5)	14(58.3)	16(66.7)	59 (61.45 ± 1.82)
Termites	16(66.7)	18(75.0)	12(50)	14(58.3)	61 (62.50 ± 1.63)
Spiders	7(29.7)	8(33.3)	9(37.5)	9(37.5)	33 (34.50 ± 1.47)
Crickets/Wasps	12(50)	14(58.3)	16(66.7)	18(75.0)	60 (62.50 ± 1.34)
Pathogens	Average No. (%) of colonies infected for 3years				Av/ Total No. (%)
Fungi	19(79.17)	16(66.67)	20(83.33)	18(75.0)	73 (76.04 ± 5.21)
Bacteria	21(87.5)	23(95.8)	22(91.67)	23(95.8)	89 (92.69 ± 0.01)
Virus	23(95.83)	24(100)	22(91.67)	22(91.67)	91 (94.79 ± 2.6)

Note : 24 colonies were inspected every year from 2016 to 2018, average of percentage colonies infested/infected for the 3 years were as shown

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Viral pathogens were detected in 94.79 ± 2.6% of colonies inspected, colony forming units (CFU) of moulds and bacteria were observed in 76.04 ± 5.21% and 92.70± 0.01% respectively in samplesacross all the states. Percentage colony infestation with pests were significantly different across the states ($F_{3,7} = 14.228$, Sig = 0.033, $p < 0.05$). The decline in colony establishment and honey productivity were unexpected despite the annual increase in the number of hives and colonies possessed by the beekeepers during the survey. The average annual yield of honey per colony plummeted to extremely low level compared to values obtained from other African countries.

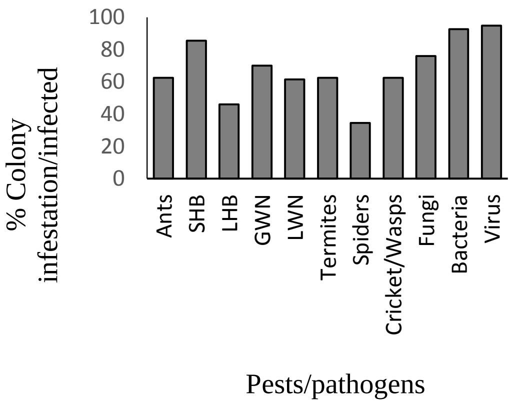

Figure 4. Percentage colony infestation/infected with pests/pathogens in the sampled colonies in the area

Nuru et al. [58] reported in Saudi Arabia, the average annual productivities of colonies to be 6.64 ±5.64 kg and 3.69 ± 2.62 kg honey/colony/annum for box and traditional hives respectively which were still considered low compared to the honey yield (>10kg/colony/annum) recorded in many other countries. In Tanzania, base line survey revealed 15kg of honey per hive annually [59] while Michael [60] recorded colony yields between 30-35 kg/hive/year. When honey production/hive falls below these recommended average productions per year [61], the area is termed unsuitable and many factors including climate change could be posing worrisome implications on the bees and beekeeping. This might be the possible contributors to the decline in honey production, colony establishment, pollination, and a loss of synchronization between pollinator activity and flowering [6, 62]. Although, the West African honey bee species, *Apis mellifera adansonii* has shown adaptive potentials to the tropical climate [43].

Climate change constraints/factors such as decreased precipitation, shift in seasonal rainfall, heat waves, flooding etc due to rising temperatures and heat waves have impacted colony health, survival and colony density [63, 64, 65], reduced plant vigour, delayed and fluctuations in greening, flowering and aging periods, and an overall shortening of the growth [66].

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These might have hampered the livelihood of bee population. Annual temperature of 28 +/- 3°C for colony survival is desirable in the tropics [67]. Temperatures above this threshold constrain foraging capacity, reduce colony density and high rate of mortality [63, 64, 65]. The heat wave have produced temperatures that hindered plants growth, reduced foraging, increased colony temperature and swarming tendencies. Rainfall 350 - 700mm [68] wil spur brood production which determines bee foraging and forage availability for nectar and pollen. Late and excessive rainfall with characteristic flooding reported during the period must have increased the colonies vulnerability to diseases and plagues and the flooded or washed away bees reduced the colony population [68]. In the Southwest Nigeria, the yearly short time drought witnessed in the three years of investigation affected bees forage crops and the later appearance of heavy rainfalls characterized by heavy flooding might have also resulted in loss of arable land and wild forage plants.

To reduce the impacts of climate change, it requires adaptation. Adaptation is a phenomenon of reducing vulnerability and increase resilience, limiting the risk of climate impacts on life forms, and seizing the opportunities posed by the climat change. The loss encountered by the beekeepers due to climate change was because of lack of adaptation. Adaptation would have helped the beekeepers to maintain their trade despite the changing climatic conditions. Ozor et al. [69] noted that poor climate change information and farmers' lack of access to weather forecast technologies are major barriers to climate change adaptation among farmers in Southern Nigeria.

Therefore, in Nigeria, vulnerability to climate change is high because adaptation is low and because climate change affected food production and water resources, mitigation effort is tailored towards massive agricultural development or intensification. Agricultural development unlike climate change has short and reversible effects when it is limited only to large scale mono-cropping and absence of pesticides and land degradation. However, reported use of various grower pesticides detected through the heavy presence of GST biomarkers, poison the bees, impair their reproduction, eliminate nectar sources and deplete bees' nesting materials [70], chronic herbicide use may be driving the loss or reduce foraging [71]. With chronic or sub-lethal exposure of bees to these agricultural chemicals, the bee's immune system might be weakened and flight impaired, vulnerability to various pathogens and damage to colony health become obvious [9]. Therefore, pesticides are environmental stress on the honeybees, and the bees come into contact with it on the field. According to Gilbert and Wilkinson [33]; Yu [34]; Smirle and Winston [17] the bees actively detoxify and eliminate these chemicals with the enzyme systems which formed the biomarkers in their system when exposed to the chemicals in the environment. Acetylcholinesterase (AChE) and GSTs enzyme activities are among the biomarkers [27]. Therefore, the significant increase in GST activation levels in the tissues of bees in sampled colonies within and across the four states indicated the formation and build-up of glutathione conjugate in the bees. According to Kostaropoulos et al.[72] GST activity i induced by various substances (food quality and certain insecticides). The activity level of this biomarker in the larval and adult stages of honey bees is an evidence of exposure to toxic stress especially synthetic agrochemicals [73, 74].

Changes in land-use and landscape structure from agricultural intensification in addition to climate change, human activities have all impacted seriously on beekeeping activities in the region. Human activities have impacted the landscape through fragmentation, degradation and destruction of natural habitats with key adverse changes for beekeeping and bee population [75]. Mono-cropping has made it increasingly difficult for pollinators to obtain sufficient pollen sources for all their essential amino acids hampering successful larva development. Government empowerment programme in the cultivation of grains and cereals which are staple food of the people might have negatively impacted colony health, these crops have great propensity for pest infestations, facilitating increase in the application of pesticides in farmlands around the apiaries.

The persistent problems of insect pests, Small hive beetles, Large hive beetles, Lesser wax moth, Greater wax moth, Ants; parasites which includes bacteria, fungal spores and predators such as crickets experienced in all the apiaries appeared similar to that experienced elsewhere, Kugonza et al, [76] reported high infestation of greater wax moth, *Galleria mellonella* in all hives placed under shades, however, he had a contrary view on the infestation and distribution of the Small hive beetles, *Aethina tumida* Murray (Coleoptera: Nitidulidae) with respect to shades. Pests and pathogens' infestation that are emerging and increasing in the colonies were due to climate change and host shift as a result of natural habitat destruction.

Conclusion

The dwindling colony establishment, honey production and worsening colony health are connected with environmental and anthropogenic factors. These factors were borne from climate variability and adaptation policies and development. The agricultural intensification and development policy adopted by the government as a relevant and sustainable mitigation tool to climate change, rather than ameliorate the situation, negatively impacted beekeeping and the pollination industries.

Author's contributions

AKL conceived the research, analysed the data and wrote the scripts, AEO carried out the experiment under the supervision of AKL.

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Conflict of interest

None.

Güneybatı Nijerya'da Yoğun Tarımsal Uygulamaların ve İklim Değişikliğinin *Apis mellifera adansonii* Kolonilerinin Gelişimi ve Sağlığı Üzerindeki Etkileri

Öz: Yabani arıların azalması, bal arısı kolonilerinin kayıpları ve bal arılarının kötüleşen sağlığı küresel sorunlar haline gelmiştir. Güneybatı Nijerya, biyolojik olarak en çeşitli ekosistemlere sahip bölgelerden bir tanesidir. Ancak bu bölge, farklılaşan tarımsal uygulamalar ve iklim değişiminin etkileri altındadır. Bu etkiler aynı zamanda *Apis mellifera adansonii* Latreille (Hymenoptera: Apidae)(doğal olarak yayılış gösteren Batı Afrika bal arıları)'nin koloni kurulumu, sağlık ve üretkenliği gibi arıcılık faaliyetleri üzerinde de etki göstermektedir. Bu çalışma, arı kolonilerinin koloni oluşumu, sağlığı ve üretkenliği ile ilgili stres faktörlerini belirlemek amacıyla Aralık 2015 - Aralık 2018 tarihleri arasında gerçekleştirilmiştir. Güneybatı Nijerya'da belirlenen dört eyalette, seçilen arılıklarda örnekleme, koloni gözlemleri ve laboratuvar incelemeleri yapılmıştır. Sonuçlar, koloni sayılarında ve bal üretiminde düşüş olduğunu göstermiştir; kolonilerin arı zararlıları ve hastalıkları nedeniyle kayıpları, diğer faktörlere kıyasla daha yüksektir. Bölgedeki küçük kovan böcekleri (SHB) ile istila, Galleria mellonella istilası için kaydedilen 67'den (69,93 ± 2,08) (Ortalama ± SS) daha büyüktür. Kolonilerde üç yıl boyunca test edilen arıların dokularındaki ortalama Gluthathion-S-Transferase (GST) detoksifiye edici kimyasal sinyal seviyeleri, arıların normal değerlerinden daha yüksek bulunmuştur. İklim değişikliği, uyum politikaları ve tarımsal uygulamalardaki farklılaşmaya paralel gerçekleştirilen programlar arıcılık, bal arısı sağlığı, populasyonu ve üretkenliği açısından da oldukça önemlidir.

Anahtar kelimeler: Koloni kuruluşu; düşüş; verimlilik; zararlılar; iklimdeğişikliği; orman

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