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Assessing Impacts of Climatic Parameters on Beekeeping Productivity in the North of Côte d'Ivoire

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Abstract

In many parts of the world, beekeeping, a pillar of agricultural production and biodiversity conservation, is subject to the harmful effects of climate change and climate variability. In Côte d'Ivoire, no scientific study has examined the impact of climatic variations on beekeeping production. This study aimed to assess the impact of climatic parameters on beekeeping in the Poro region, a bastion of beekeeping in Côte d'Ivoire, using the annual production of 11 available beekeepers. The beekeepers' perceptions of the impact of climatic variability on their productivity were collected from semi-structured surveys using a questionnaire. Snowball sampling was used to interview 162 beekeepers who responded to the questionnaire. The results showed that there has been an increase in average temperature over the years, with an average of 27.29˚C, and a deficit in rainfall since 1999. There is a downward trend in production for 2 beekeepers, while there is no significant trend for the other 9 producers. The correlation between certain climatic variables and honey production showed that the average temperature (26˚C and 27˚C) over the last seven years of production had no significant impact on beekeeping in the region (r = 0.02; $p > 0.05$). On the other hand, rainfall had a significant impact on honey production (r = 0.078; $p < 0.05$). Beekeepers have a good knowledge of the impacts of climate variability and recognize that it affects their activities. some adaptation strategies will be proposed to beekeepers to cope with climate impacts like the use of water tanks, transhumance, reforestation and changes in management practices. It is necessary to take into account the other climatic factors, all the environmental parameters and beekeeping management practices.

Keywords

Climatic Variability, Honey Production, Beekeeping, Poro, Impacts

1. Introduction

Climate change and variability are a global issue and their impacts vary across space, geography and time (Akala, 2019). Climate change has affected people's livelihoods, impacting development, economic stability, biodiversity and ecosystems (Thornton et al., 2011). Africa, like all other continents, is sensitive to the impacts of climate variability and change. The continent could face increased poverty, higher food prices, high inequality, food insecurity, higher energy prices, a barrier to development and a high incidence of disasters (Parry et al., 2007). According to Sylla et al., (2016), analysis of the climate in West Africa has shown that climate parameters have changed over the last few decades. As a result, agriculture, mainly rain-fed, has emerged as the major economic sector most vulnerable to climate change (Roudier et al., 2011).

In this context, beekeeping is one of the branches of agriculture that raises bees to produce honey other hive products (Masuku, 2013). It is also impacted by the effects of climate change and variability. Beekeeping plays an important role in socio-economic development and environmental conservation (Etxegarai-Legarreta & Sanchez-Famoso, 2022; Papa et al., 2022; Aryal et al., 2020). It increases the monetary income of stakeholders limits the destruction of forests and generates a large population of pollinating agents for the plant environment (Ahouandjinou et al., 2017). Bees are essential to the global environmental balance as pollinators of many plants species (Adjlane et al., 2012). Bees contribute to food security by increasing yields and the availability of food diversity and their behavior reflects the impacts of disturbances (Bogdanov, 2006; Chauzat et al., 2006; Le Conte & Navajas, 2008).

Despite the many benefits of beekeeping, particularly in improving people's livelihoods in rural areas (Masuku, 2013). Beekeepers have reported a fall in production in recent years (Van Espen et al., 2023; Nyunza, 2018), leading to consumer complaints about the scarcity of products and rising prices. There are several reasons why beekeepers have reported a fall in productivity, and climate variability and change are some of the most frequently mentioned factors (Gajardo-Rojas et al., 2022; Ijigbade, 2017), given the current context of climate change in the countries of West Africa. Over the last decade, several scientific publications have reported an unusual weakening and mortality of bee colonies especially *Apis mellifera* in several countries around the world (Faucon & Colin, 1983; Rafalimanana, 2003; van Engelsdorp et al, 2010; Adjlane et al., 2012; van der Zee et al., 2012; Pirk et al., 2014; Van Der Zee et al., 2014; Brodschneider et al., 2016; Kulhanek et al., 2017; Brodschneider et al., 2018). Indeed, numerous research studies have shown that climate change is one of the current threats to pollinators (Hegland et al., 2009; Schweiger et al., 2010; IPBES, 2016; Flores et al., 2019). This loss of colonies, in addition to causing damage to bees, could be a threat to food security.

However, there is a lack of information in the literature on the effects of climate change on the ecosystem services provided by bees and on beekeeping productivity in Côte d'Ivoire. This article aims to assess the impact of climate variability on honey production in the Poro region, a beekeeping basin in Côte d'Ivoire. Specifically, the aim is to: 1) Assess beekeepers' perceptions of climatic parameters and their impacts on productivity; 2) assess trends in climatic variability from 1982 to 2022 and the temporal evolution of honey production in the Poro region, and 3) to assess the relationship between trends in climatic variability and honey production.

2. Materials and Methods

2.1. Study Area

The Poro region is located in the north of Côte d'Ivoire. It covers an area of 12,550 km^2 and includes the departments of Dikodougou, M'Bengué, Sinematiali, and Korhogo, which is the departmental capital (Figure 1).

A tropical Sudanese climate influences the region. It is characterized by two types of seasons: the rainy season and the dry season. The dry season includes the Harmattan period from December to February (Figure 2).

The average relative humidity of the Poro region varies between 35% and 79% (Soro et al., 2013) it has the lowest humidity in the country. The average monthly temperature over the period 1980-2022 was 26˚C. The area has experienced two

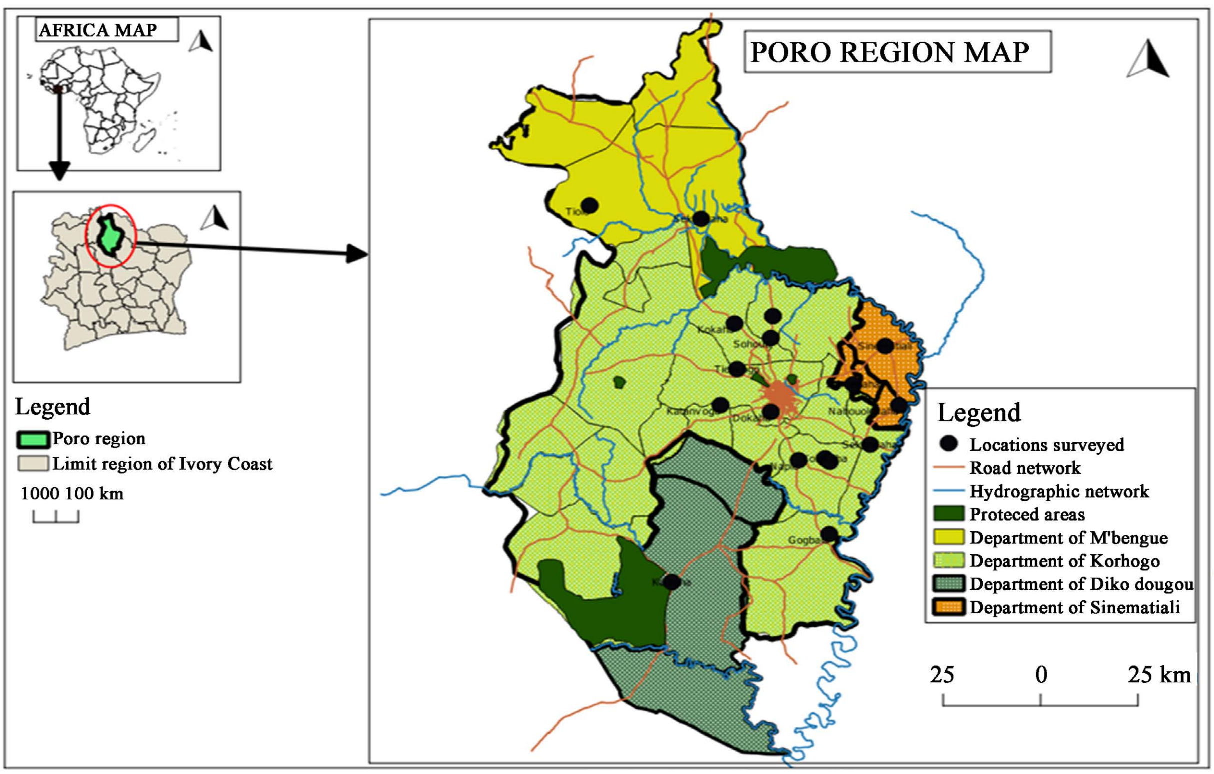

Figure 1. Map of Poro region.

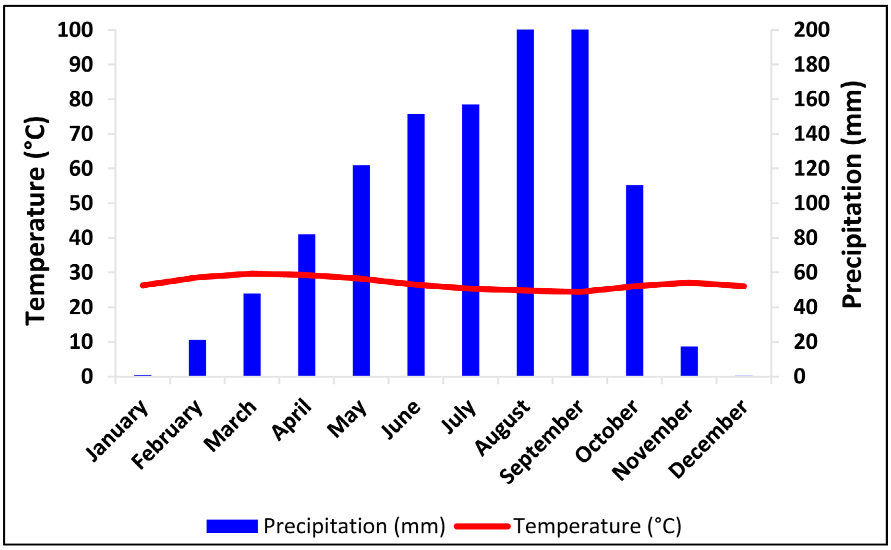

Figure 2. Umbrothermal diagram of Korhogo (2012-2022).

extreme climatic events: a period of drought (2000-2005) followed by flooding (2006-2007) (Koné et al., 2009; M'Bra et al., 2018). The study site is a savannah zone comprising tree, shrub and grass savannah, with the presence of a few gallery forests (Guillaumet & Adjanohoun, 1971). The economy of the Poro region is based on agriculture, livestock farming and trade. Cash crops include mango, cashew nuts and cotton, and food crops such as rice, maize and groundnuts. The choice of the study area was based on the following criteria: The department of Korhogo is known as a major honey-producing area, where both modern and traditional beekeeping is practiced, and its honey is the most prized by the Ivorian population, who claim that they are of good quality. According to Douhet (1980), Kouassi et al., (2018) beekeeping is practiced in all regions of Côte d'Ivoire but is more intense in the North and Centre of the country. On the other hand, this region is facing a collapse in bee colonies (Ohoueu et al., 2017) due to hive desertions. These regions benefit from a favorable climate and a variety of crops (Ouattara et al., 2023) for the development of beekeeping. The Ivorian state recognizes beekeepers' cooperatives (Kouassi et al., 2018).

2.2. Surveys of Beekeepers Using Questionnaires

A pre-survey was carried out in December 2022 to test the questionnaire and gauge beekeepers' understanding. Snowball sampling (Naderifar et al., 2017) was used in the semi-structured interviews added to the questionnaire and focus group discussion, which included 162 beekeepers.

First, after a meeting with the National Federation of Beekeepers of Côte d'Ivoire (FENAPCI), we were given a list of beekeepers. Then after meeting these beekeepers, we obtained a complementary list of other beekeepers in the region. The questionnaire aimed to assess the impact of climatic variability on beekeeping activity and honey production. It was carried out to obtain statistics on honey production and the number of hives used, using Kobotoolbox software. The questionnaire covered the following main areas: 1) the social situation and economic activity of beekeepers, 2) bee management, 3) beekeepers' perception of climate variability, 4) climate variability and honey production. These interviews were conducted in the presence of the beekeepers and only two of them completed the questionnaire by e-mail.

2.3. Honey Production

The data has been collected from 3 to 7 years and is different from one beekeeper to another in 2023. Unfortunately, due to a lack of records, only eleven (11) beekeepers (Bkp) were able to report on their production. The beekeepers had several years of experience but were unable to record all their production. The fact is that they encountered some challenges and did not know that it is important to record production.

2.4. Climatic Data

Temperature and rainfall data for the period 1982 to 2022 were collected from the national meteorological services (SODEXAM) with interpolation of missing data (ERA5 climate models). The climatic data has been adjusted to correspond to the specific periods of honey production data available. The values of the temperature and precipitation parameters were used over 10 years to calculate the correlation with honey production (3 to 7 years). This analysis precedes the qualitative analysis of beekeepers' perceptions of the impact of climatic parameters on their production.

2.5. Data Analysis and Processing

Xlstat (2019 edition) software was used to carry out the following tests. The Pettitt, Buishand and Homogeneity tests were used to assess climate variability through the annual climatic parameters. These tests examine time series and identify breakpoints, which correspond to a change in the distribution of the parameters within the series (Bougara et al., 2020). Validation of the results is based on the p-values and the consistency of the results between the three tests. Descriptive statistics were used to analyze the information gathered from the questionnaire and interviews. Trends in honey production were assessed using the Mann-Kendall test and the Sen's slope with thresholds of $p < 0.05$ and $p < 0.1$. Mann-Kendall test is a non-parametric test developed by (Mann, 1945) and (Kendall, 1948) to detect trends in time series. Sen's slope method (Sen, 1968) is a non-parametric approach frequently used to accurately determine the slope corresponding to the trend present in the data of a time series. To assess the relationship between climate and honey production, Pearson's correlation was used. According to (Sedgwick, 2012), Pearson's correlation measures the strength of the linear relationship between two variables. To calculate the correlation, the values of the Bkp2, Bkp5, and Bkp9 productions that have the highest values in honey production (2016-2022) were combined and used to evaluate the relationship of climate parameters on honey production. The analysis highlighted the climatic factors that could directly impact optimum production. So, the beekeepers representing those with the most significant production performance were considered. The mean values of the temperature and precipitation parameters were used for ten years to calculate the correlation.

3. Results

3.1. Assessing Beekeepers' Perception of Honey Production Trends and Climatic Parameters

3.1.1. Beekeeping Characteristics

Table 1 shows that the majority of beekeepers in the Poro region are men (87.65%). Those aged from 31 to 40 are the most common. Concerning the educational level, Beekeepers with no education (37.65%) followed by those with primary education (33.95%) are the most represented. Among beekeepers, 55.56%

Table 1. Beekeeping characteristics.

Variables types	Variables	Frequency (number)	Percentage (%)
Gender	Female	20	12.35
	Male	142	87.65
Age (Years)	20 - 30	4	2.47
	31 - 40	62	38.27
	41 - 50	54	33.33
	Over 50	42	25.93
Education	Higher degree	9	5.56
	No formal education	61	37.65
	Primary	55	33.95
	Secondary	37	22.84
Experience (Years)	[0 - 5]	90	55.56
	[6 - 10]	27	16.67
	[11 - 16]	21	12.96
	Over 16	24	14.82
Hives	Modern beehive	138	85.19
	Traditional beehive	24	14.81
Hive location	Farm	136	83.95
	Farm and Bush	5	3.09
	Protected area	4	2.47
	Protected area and Farm	2	1.23
	Protected area and bush	1	0.62

of them have between 0 to 5 years of experience. The modern hive is used by 85.19% and the majority of these hives are located on farms (83.95%).

3.1.2. Perception of Trend Production

Based on the quantities harvested, beekeepers have made some estimations. The beekeepers' perceptions showed that 67.90% of them think that their production has decreased over 10 years. For 22.22% of them, they have a good perception that their production has increased, while 9.88% think that their production varies. Variation here means that production decreases from one year to the next, increases the following year and vice-versa (**Figure 3**).

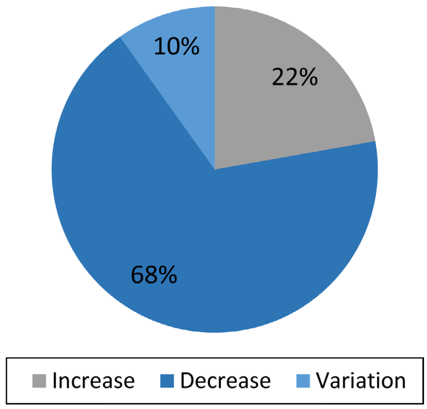

Figure 3. Beekeepers' perception of honey production trends.

3.1.3. Perception of Climatic Parameters

Beekeepers (129) say the temperature has increased, and they suggest (106) that the precipitation varies. They debate the dry season because some think it has been prolonged (78), while others think it varies according to rainfall (82) (**Figure 4**).

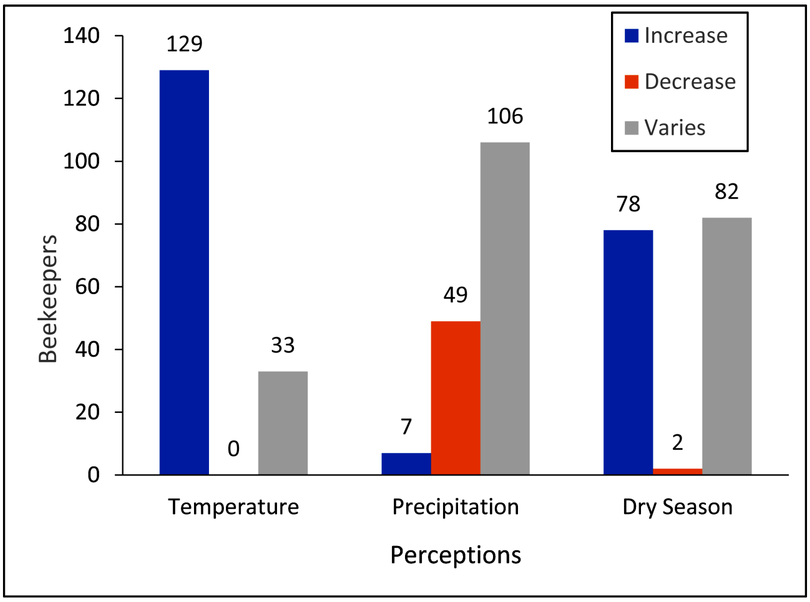

Figure 4. Perception of climatic parameters.

3.2. Analysis of Trend in Honey Production and Climatic Parameters

3.2.1. Temporal Variability of the Main Climatic Parameters

1) Temperature

The average temperatures observed increased over the years since 2002 (Figure 5). Temperature values ranged from 26.03˚C to 27.30˚C. In the time series, the Pettitt, homogeneity, and Buishand ($p < 0.0001$) tests showed a discontinuity in the data series, with a break in 2001 (Pettitt test) and 2002 (homogeneity and Buishand). The warmest year was 2010 with an average of 27.29˚C.

2) Precipitation

The results show that there has been a deficit in rainfall since 1998. Only the Pettitt and Buishand test showed a break in rainfall in 1998 while homogeneity showed a break in 2014 (Figure 6). Rainfall fell continuously in 2017, reaching a value of 184.04 mm, before increasing to reach a peak in 2019 with a value of 1621.3 mm.

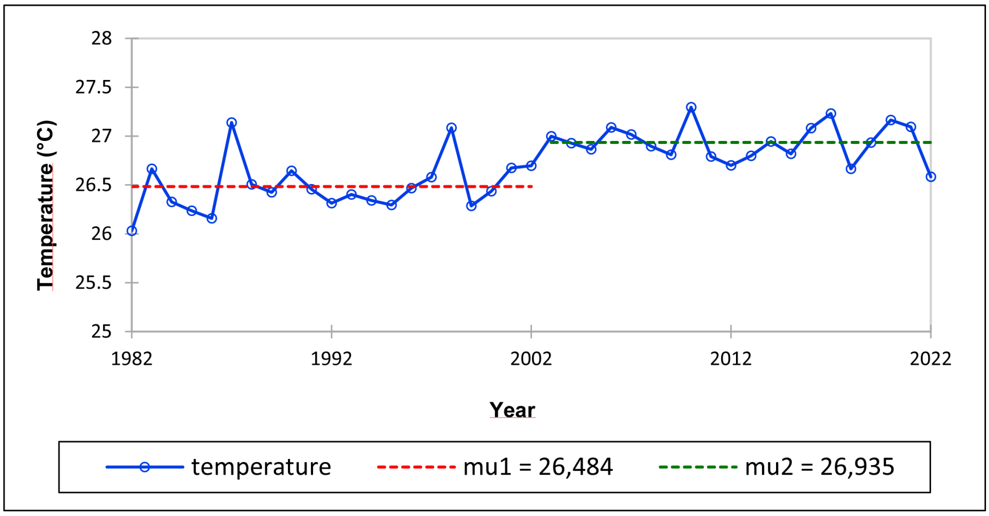

Figure 5. Annual mean temperature in Poro Region.

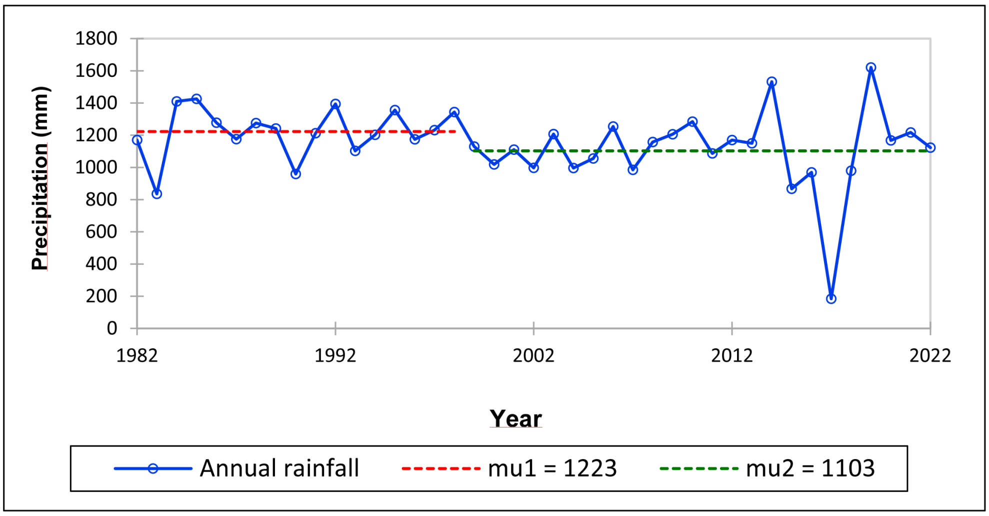

Figure 6. Annual mean precipitation in Poro region.

3.2.2. Annual Honey Production Trends

Among beekeepers, only 11 beekeepers were able to register their honey production (Table 2). Production averages ranged from 68.16 kg to 1579.293 kg. Mann Kendall and Sen's slope (Figure 7) showed that there is no significant difference between the p-values of observed production and the threshold p-values ($p < 0.05$ and $p < 0.1$), except for the values of Bkp8 (from 217.44 kg in 2019 to 31.06 kg in 2022) and Bkp9 (from 170.4 kg in 2022 to 28.968 kg in 2022). There is a downward trend for the productions (Bkp8 and Bkp9) whereas there is no trend for all the other productions. Sen's slope is made up of three types. An increasing slope (productions Bkp4, Bkp7, Bkp10, Bkp11 and Bkp) which shows a slight increase in honey production. A decreasing slope (productions Bkp3, Bkp5, Bkp6, Bkp8, Bkp9) which shows a decrease in honey production. A third zero slope (productions Bkp1 and Bkp2) indicates stable production (Figure 7).

Table 2. Annual honey production in the Poro region.

Beekeepers (Bkp)	Production year (kg)	Mean of production	Standard deviation
Bkp1	2015-2019	68.16	48.830
Bkp2	2016-2022	1328.71	526.09
Bkp3	2017-2022	262.917	86.163
Bkp4	2019-2022	83.425	18.673
Bkp5	2016-2022	149.607	50.055
Bkp6	2020-2022	175.133	35.7359
Bkp7	2018-2022	641.84	197.375
Bkp8	2019-2022	120.168	90.875
Bkp9	2016-2022	109.543	69.785
Bkp11	2019-2022	1121.703	335.800
Bkp (Bkp2 + Bkp5 + Bkp9)	2016-2022	1579.293	488.147

3.3. Relationship between Climate Variability and Honey Production

3.3.1. Temperature and Honey Production

Figure 8 shows that there is no correlation between temperature variability (10 years) and honey production of BKP ($r = 0.02$, $p = 0.96$ ($p < 0.05$)) whereas the graph showed a correlation between the two factors. Temperature is not the only factor directly influencing honey production.

3.3.2. Precipitation and Honey Production

There is a strong positive correlation between precipitation (10 years) and honey production (BKP) ($r = 0.78$, $p = 0.04$ ($p < 0.05$)) (Figure 9). When there is a drop in rainfall, a drop in honey production follows. An increase in rainfall is followed by an increase in honey production. The year 2019 recorded a record production

(2462.28 kg) correlated with high rainfall (1621.3 mm), whereas 2017 recorded low production (969.86 kg) with low rainfall (184.4 mm).

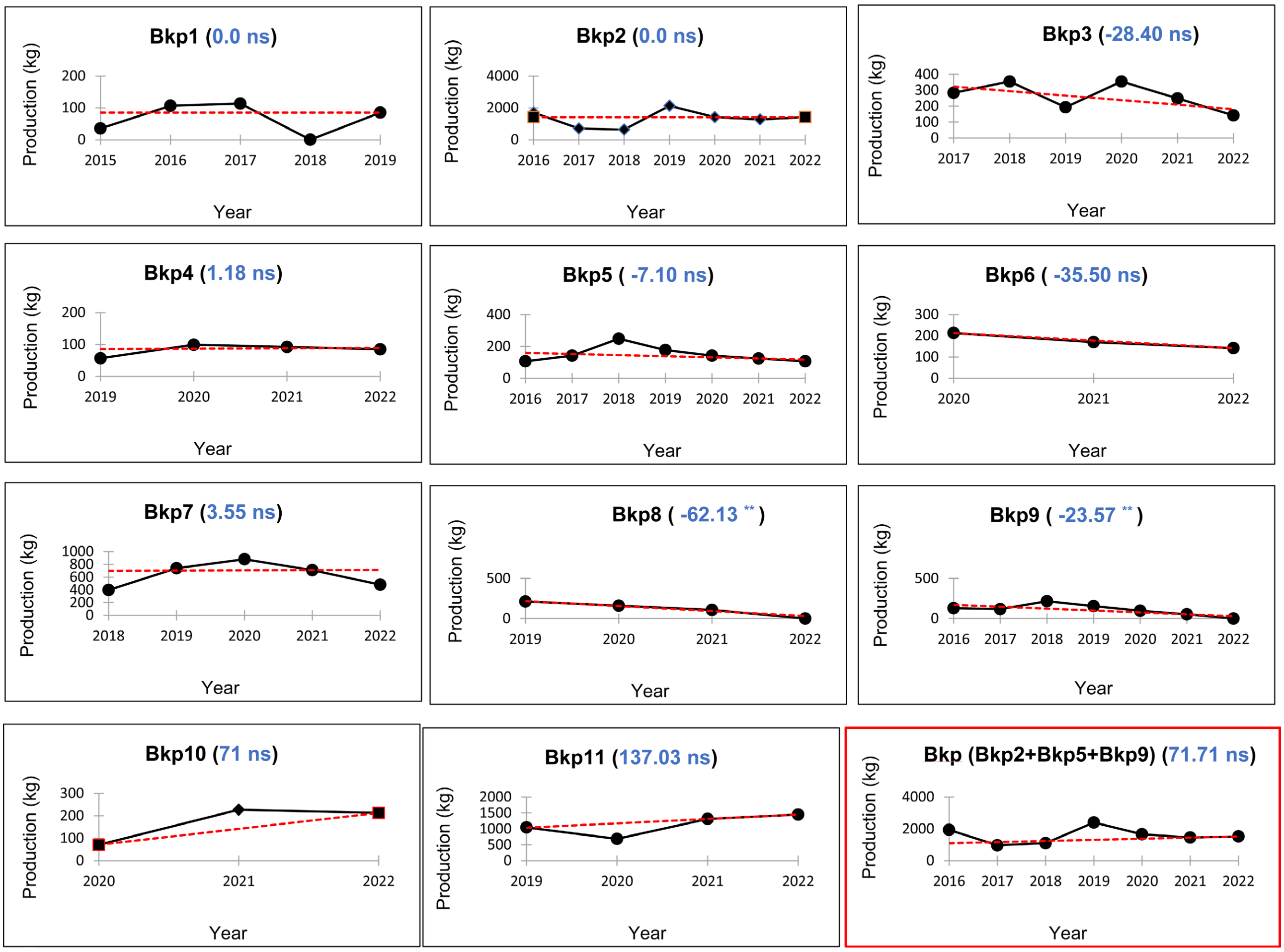

Figure 7. Temporal variation and trends in annual honey production between 2016 and 2022 in the Poro region. The parentheses values indicate the trend's Mann-Kendall slope and its statistical significance (*$p < 0.05$, **$p < 0.1$). The dotted lines (in red) represent the linear trends for the analyzed period.

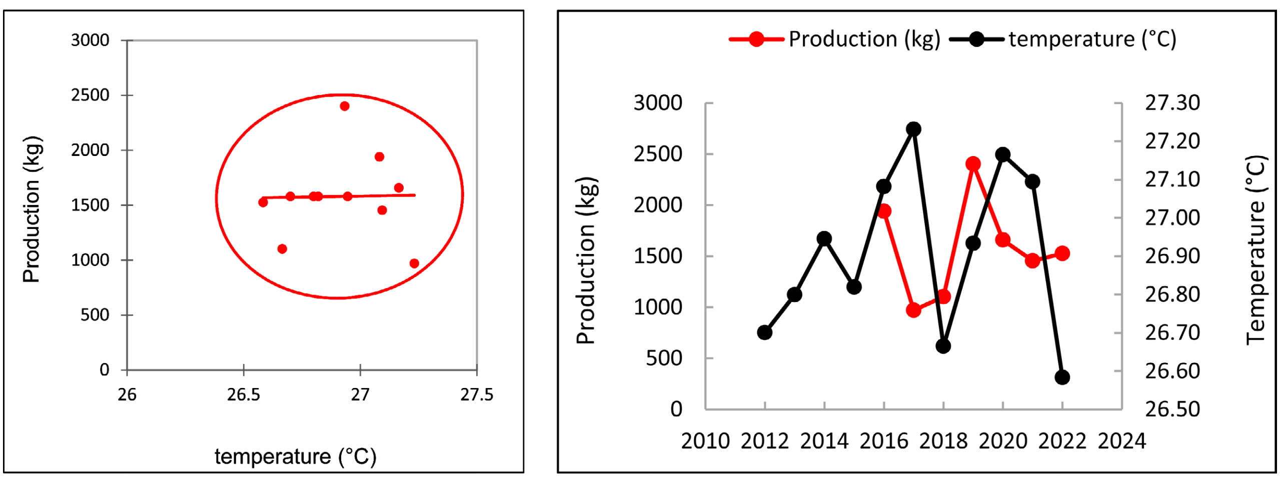

Figure 8. Annual mean temperature in Poro Region.

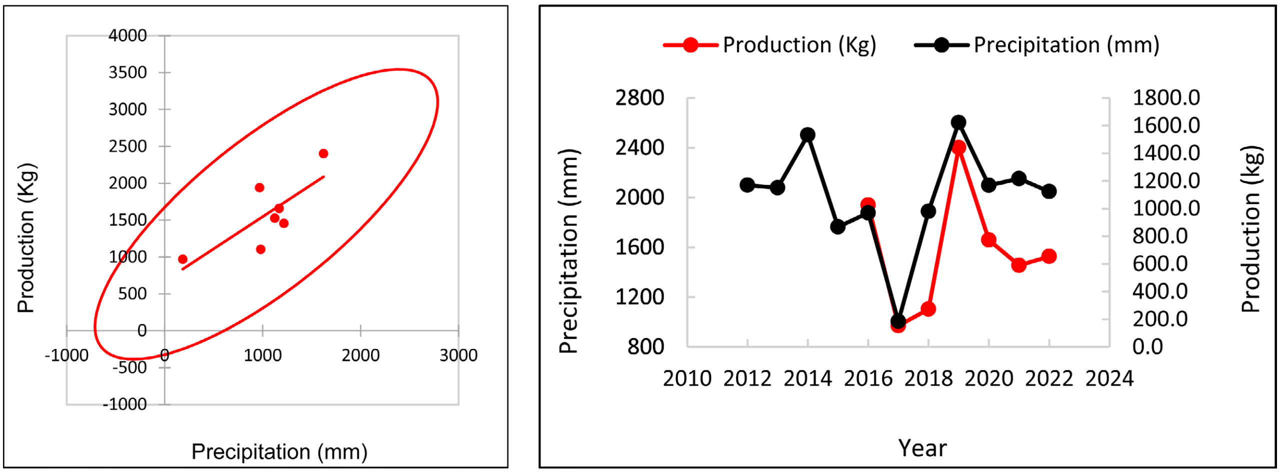

Figure 9. Correlation between precipitation and honey production (Bkp).

4. Discussion

The vulnerability of African populations to climate change (Roudier et al., 2011) Is a worrying phenomenon. Increased temperatures and variations in precipitation (Roudier et al., 2011) can alter the availability of crop yields. Studies on the impact of climatic parameters on bee productivity are limited in the Poro region. This study raised the question of the impact of climatic parameters on beekeeping productivity. It aimed to fill concerned assessing the impact of climatic parameters on honey productivity.

The results indicated that beekeepers observed an increase in temperature, variations in rainfall patterns, and a prolongation of the dry season. They reported that these climatic impacts adversely affected their beekeeping activities, particularly leading to a decrease in honey production. To understand the relationship between climatic factors and honey production, the study analyzed the combination of these parameters to predict beekeeping productivity in the region. This shows that precipitation is significantly correlated with productivity, with a correlation coefficient of r = 0.78 and a p-value of 0.04 ($p < 0.05$). On the other hand, temperature did not show any significant correlation with productivity, as illustrated in the accompanying **Figure 8**. However, this relationship was not statistically significant, with a Pearson correlation coefficient of r = 0.02 and a p-value of 0.96 ($p < 0.05$). The trend analysis of temperature and precipitation over 40 years has confirmed beekeepers' perception of climatic parameters concerning the changes. The result is confirmed by the IPCC AR5 report (IPCC, 2021) and (Switanek et al., 2017). This perception, particularly the decrease in precipitation, the increase in temperature leading to long dry seasons, and the decrease in watercourses is also reflected in their activities. They have a direct impact on the bees' food sources, such as the availability of water and floral resources (Landaverde et al., 2023), and the reduction in the production of nectar, pollen, and honey (Vercelli et al., 2021). Only the production of two beekeepers has decreased while there is no trend for other beekeepers. This could be due to the type and the number of hives used the beekeepers' experience, and the level of education in recording information. According to Nyunza, (2018) and Tarekegn and Ayele (2020), the level of education affects beekeepers' ability to record honey production statistics and manage beekeeping activity. The decreasing trends observed for the two beekeepers, BKP8 and BKP9, are comparable to the findings of Gajardo-Rojas et al., (2022), who documented a decline in honey production and exports from Chile. In the United States, there is no constant relationship between the number of colonies and honey production, which has decreased over time, according to Romero-Leiton et al. (2022). Some Ethiopian beekeepers have reported reduced honey production (Degu, 2021). Additionally, 80.9% of Tanzanian beekeepers surveyed indicated a decrease in honey production (Nyunza, 2018). Despite an increase in the number of hives, honey production has diminished due to several climatic factors in Nigeria (Ukamaka & Eberechukwu, 2018). Similarly, a decrease in honey production in Japan and South Korea has resulted in an increased reliance on imported honey (Kohsaka et al., 2017). On the other hand, the remaining production outcomes align with the research conducted by Shopova et al. (2022), which showed no significant trends in honey production from 2008 to 2020 in Bulgaria, suggesting a level of stability in the region. These differences can be explained by the type of methodology used and the climatic and environmental conditions. Indeed, beekeepers' perceptions via questionnaires and interviews are the most commonly used by the authors for impact analysis. The use of honey production statistics is difficult to obtain due to the lack of archives in the country (Ouattara et al., 2023). This difference could be related to management practices which can increase or decrease production. Especially, the socio-economic, technical and physical factors (Brodschneider et al., 2016; Jacques et al., 2017; Sperandio et al., 2019).

The strongest correlation between precipitation and honey production (Bkp) in our study area showed that it is an important factor for the productivity of beekeeping. It is in agreement with the study of (Gajardo-Rojas et al., 2022) who showed that rainfall influenced production during the 12 months preceding the beekeeping season. According to Schweitzer et al, (2013) and Akala et al, (2019), the decrease in honey production is due to the significant effect of rainfall on plant phenology, which modifies the flowering and foraging period of bees (Schweitzer et al., 2013). The effects of climate change and variability are harmful to beekeeping. Their impact on bees has a negative effect on honey production. Some of these impacts are desertion in the hives (Ohoueu et al., 2017); mortality (Brodschneider et al., 2018); and a decline in honey production (Gajardo-Rojas et al., 2022). Although the graph showed that there is a correlation between temperature and honey production, the Pearson correlation showed a lack of correlation. This could be explained by the interaction of temperature with other factors such as humidity, diseases and parasites, the types of flowers foraged by the bees and their sensitivity to pesticides. This may mask the impact on honey production (Gajardo-Rojas et al., 2022). This is why (Pătruică et al., 2021) state that the feeding of honey bees is strongly influenced by temperature and humidity We can also state that the temperature between 26˚C and 27˚C obtained in the Poro region could be ideal for good honey production. According to (Schweitzer et al., 2013) An optimal foraging temperature for bees is between 25˚C and 35˚C. This will allow the bees to take full advantage of the harvest of plant products. In addition to climatic factors, which play an important role in the survival of bees and their goods, other factors need to be taken into account such as anthropogenic factors. In other words, hives management and beekeeping management practices (Schouten, 2020) can cause damage to bees. Both can contribute to the reduction in the quantity of honey (Nyunza, 2018), because effective management has the potential to reduce stress, whereas inadequate management may exacerbate it (El Agrebi et al., 2022).

The use of Pearson correlation could not show the correlation between temperature and honey production. This implies the integration of other statistical analysis methods such as linear regression used by (Schweitzer et al., 2013) and Mann-Kendall and Sen's slope. The next analysis should take into consideration other climatic factors such as humidity, which could clarify the impact of temperature, and the number of hives associated with honey production.

5. Conclusion

The beekeepers' perception of climatic parameters and their beekeeping production, as well as the correlation between these factors, enabled us to understand the effect of climatic variables on beekeeping production in the region. From a statistical point of view, there is no trend in honey production except Bkp8 and Bkp9. There is no correlation between temperature and honey production even though we observe an effect on the graphic, while precipitation strongly correlated with honey production. Beekeepers have a good knowledge of the impacts of climate variability and recognize that it affects their activities; some adaptation strategies will be proposed to beekeepers to cope with climate impacts like the use of water tanks, transhumance, reforestation and changes in management practices.

We must urge the authorities, scientists and producers to be ever-vigilant and to take steps to anticipate the situation. It is necessary to take into account all the environmental parameters, the number of hives used, and the location of the apiary, beekeeping management practices, other climatic factors to improve productivity. This study will enable the implementation of adaptation strategies to be put in place to improve productivity.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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