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Profile of Pineapple (*Ananas comosus L.*) Adaptation to Climate Change in the Allada Municipality, Benin

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ABSTRACT
Pineapple is one of the main crops cultivated by farmers in the Commune of Allada. However, over the past decades, these producers have been increasingly exposed to intensified climatic constraints that negatively affect the productivity of this crop. This study analyzes the influence of climate change on pineapple cultivation in the Commune of Allada. Data were collected through literature review, field surveys, and direct observations. A sample of 377 producers distributed across the eleven rural districts of the commune was interviewed. The data were processed using statistical tools, including Principal Component Analysis (PCA) and multiple linear regression, to assess the impact of climatic variables. In addition, rainfall and temperature statistics were used to characterize local climatic variability. The analysis reveals three major phases in yield dynamics: (1) a period of moderate growth until the early 2000s; (2) a rapid increase between 2003 and 2012, likely linked to the adoption of new agricultural practices; and (3) stabilization after 2015, marked by high interannual variability attributable to climatic hazards. The sharp declines observed in 2009 and 2016 coincide with unfavorable climatic conditions. Cultivated areas increased from 96 ha in 1996 to 316 ha in 2006, before dropping to 110 ha in 2009, while production rose from 5,145 tons in 1996 to 20,540 tons in 2006, then fell to 6,600 tons in 2009. The recovery observed from 2009 onward reflects the adoption of adaptation strategies developed by producers in response to climatic disturbances.
***Keywords* -** Adaptation strategies, Allada Municipality, climatic hazards, cultivated areas, pineapple yield dynamics

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I. INTRODUCTION

Extreme climatic events affect approximately 230 million people worldwide and are associated with projected financial losses ranging from 290 to 580 billion USD by 2030 (OXFAM, 2022, [1]). These events have significant impacts on agricultural production, food prices, household incomes, and the overall quality of daily life (V. I. HUMURIZA, 2023, [2]). Agriculture therefore faces the dual challenge of meeting the food needs of a rapidly growing population -which is expected to double by 2050 and reach 9.1 billion people according to FAO (2004, [3]) - while continuing to ensure food security through the promotion of alternative, sustainable agricultural systems that integrate socioeconomic, environmental, and climatic dimensions (C. ANANI et *al.*, 2020, [4]).

In response to these realities, farmers on the Allada plateau diversify their production systems (Kouhoundji et *al.*, 2017, [5]). Owing to its favorable pedoclimatic conditions, this territory is particularly well suited for crop diversification, including pineapple cultivation (M. LUCAS, 2020, [6]). Agricultural statistics indicate that pineapple is the third-largest export crop in Benin—after cotton and cashew—supporting a value chain that generates numerous employment and commercial opportunities (DSA, 2018 [7]; INSAE, 2020, [8]).

Unfortunately, Benin's agricultural sector is highly vulnerable to climate change–related disturbances (C. S. U. Y. ALLE, 2014, [9]). Since the 1970s, the country has experienced recurrent droughts, floods, violent winds, extreme temperatures, and sea-level rise, all of which have led to negative outcomes such as disrupted agricultural calendars, declining yields, and crop losses (A-J Sawsan et *al.*, 2023, [10]; R. DIMON, 2008, [11]). Given that the pineapple sector represents a strategic development priority, and considering the societal demand for pesticide-free production, the sector is compelled to transform its practices and develop agroecological transition strategies to maintain its competitiveness (I. HOARAU et *al.*, 2019, [12]).

It is therefore essential to document the adaptive profile of this crop in the face of climate change. The Commune of Allada is the country's leading pineapple-producing area (INSAE, 2020, [8]) (Fig. 1), making it the logical starting point for this study. The objective of the present research is to analyze the extent to which variations in climatic parameters influence pineapple production, while also identifying the adaptation measures implemented by farmers.

II. DATA AND METHODS

The methodological approach adopted in this research can be summarized in three main steps: data collection, data processing and results analysis.

2.1. DATA COLLECTION

Several types of data were used in this study. These include the climatic data of the Allada Commune, particularly temperature and rainfall data. The climatological data used come from the Cotonou station, which is the closest station to the study area.

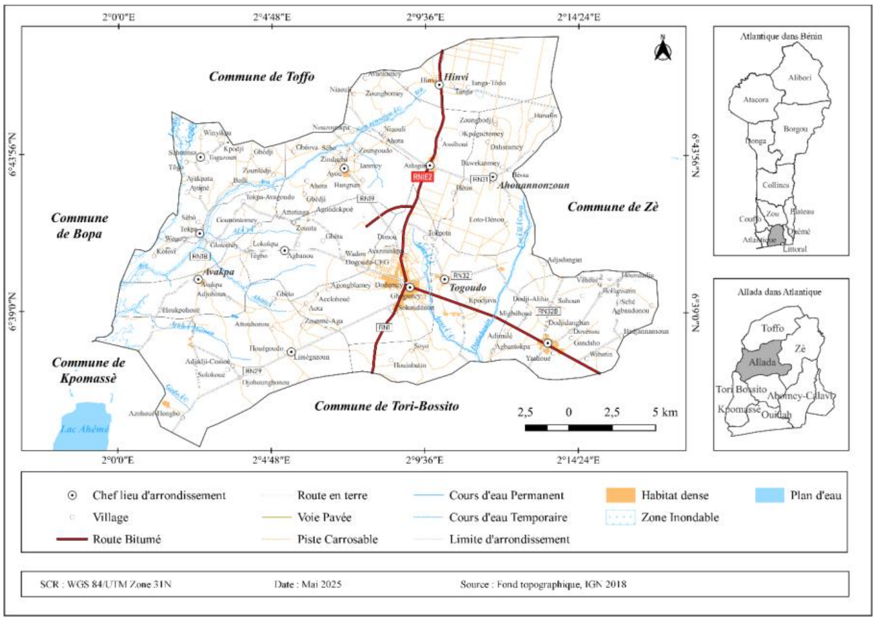

Figure 1: Geographical and Administrative situation of the Commune of Allada

In addition to climatic data, agricultural statistics were also used, covering the area, yield, and production of pineapples as well as the cultivation techniques employed in the Allada Commune. These data made it possible to analyze the constraints of climate change on pineapple production in the study area. These data were collected using some appropriate data collection techniques.

The data collection techniques employed include: (i) documentary research, (ii) surveys using questionnaires, (iii) interviews with key informants, (iv) and direct observations in the field.

The tools used were: (i) a questionnaire, (ii) an interview guide, and (ii) an observation checklist.

For the Sampling, The selection of respondents was based on the following criteria : (i) being a pineapple producer residing in the Allada Commune to ensure knowledge of local production ; (ii) having a farm located in one of the eleven (11) rural districts of the Commune to provide information representative of the study area; (iii) having at least thirty (30) years of experience in pineapple production in Allada to provide accurate information on climate variability and its effects on pineapple production.

The sample size was determined using the probabilistic method of D. Schwartz (2002, [13]) with the following formula:

$$N = \frac{Z_\alpha^2 \times P \times Q}{d^2}$$

Where:

- N= sample size
- $Z\alpha$ = 1.96, corresponding to a 95% confidence level
- P = proportion of agricultural households in the eleven rural districts of the Allada Commune
- Q=1−P
- d = margin of error set at 5%

Applying this formula, 377 pineapple producers were selected, including 227 heads of agricultural households. The distribution of the respondents by district is shown in the table 1.

Table 1: Distribution of surveyed farmers

District	Total number of farmers	Number of famers Surveyed
AGBANOU	1525	54
AHOUANNONZOUN	1 091	39
ATTOGON	438	16
AVAKPA	488	17
AYOU	927	33
HINVI	356	13
LISSEGAZOUN	2 136	76
LON AGONMEY	450	16
SEKOU	2 137	76
TOKPA AVAGOUDO	575	21
TOGOUDO	432	16
Total	**10 555**	**377**

Source: INSAE Data, 2015 [14], and field survey results, July 2025

The interviews with these key informants focused on the impacts of climate change on pineapple production in the Allada Municipality.

2.1. Data processing and results analysis

Data processing was carried out with digital tools. The information collected during the field surveys was coded and entered into a database management matrix using Excel 365. Text processing was done with Word 365, and cartographic processing was performed using ArcGIS 10.1.

The Principal Component Analysis (PCA) tool is used to identify temporal group years and marked contrasts between different periods.

A Shapiro–Wilk normality test was applied to each of the climatic variables considered in order to verify the validity of the normality assumption required for the analysis.

III. RESULTS AND DISCUSSION

The results obtained relate to the technical itinerary of pineapple cultivation, the climatic characteristics of the study area, and their influence on pineapple production.

3.1. TECHNICAL ITINERARY OF PINEAPPLE CULTIVATION

The technical itinerary used by pineapple producers begins with land preparation (clearing, burning, stump removal, cleaning), followed by planting, crop maintenance, and fruit harvesting. This process is scheduled in 4 steps (Fig. 2):

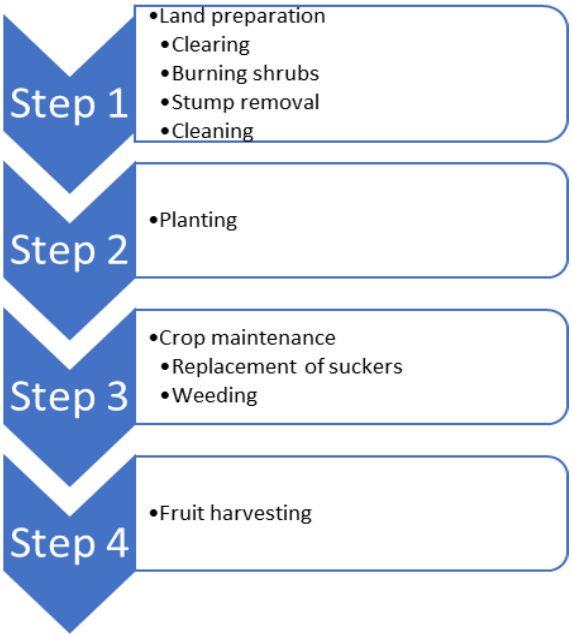

Figure 2: Technical itinerary of pineapple

Clearing: This operation is carried out using a cutlass, axe, or hoe and consists of cutting down large trees or forests to allow pineapple plants to receive sunlight.

Burning: Burning consists of gathering heaps of vegetation and setting them on fire in order to better detect the stumps that need to be removed. It is done using a rake and helps eliminate harmful insects (caterpillars, ants) that affect pineapple production.

Stump Removal: This operation involves removing stumps and roots and digging the soil to a depth of 40 to 50 centimeters. The tools used include the hoe and axe. To reduce the difficulty of this work, it is recommended to perform it after the first rains.

Cleaning: Cleaning consists of removing stumps and roots from the cleared land.

Planting of Suckers: After selecting good-quality suckers from the pile, they are sorted into homogeneous lots according to their weight. After staking the field, planting is done manually: digging holes with a mattock, placing the sucker inside, and compacting the soil around the planted sucker.

Plant Maintenance: Pineapple production requires a great deal of care from producers, like replacement of suckers, weeding, fertilization, floral induction treatment and fruit maturity control.

Replacement of suckers: This consists of replacing suckers that have died or have been attacked by ants or caterpillars with healthy ones. This work must be done no later than two months after planting.

Weeding/Hoed Weeding: This operation consists of eliminating weeds that grow between the rows of pineapple plants. It is done using a special hoe of medium width and sufficient handle length to avoid contact between the eyes and the spines of the pineapple plant (photo 1).

Photo 1: Pineapple plants weeded in Sekou district (*Photograph by Kouhoundji, July 2025*)

Photo 1 shows a well-maintained pineapple plantation in Sekou. Indeed, regular maintenance of the plantation allows pineapple plants to grow normally and ensures better yields.

Fertilization of Pineapple Plants: Fertilizer plays a very important role in plant nutrition and contributes to achieving good yields. Producers in the district have long understood the usefulness of fertilizers. More than 90% of the producers surveyed use fertilizers in pineapple production.

Floral induction treatment: This technique consists of treating pineapple plants with a chemical product, calcium carbide, which induces uniform flowering.

Control of Fruit Maturity: According to research, fruit maturity control takes place in three stages:

– Crown reduction: This operation is done 1 to 1.5 months before harvest, when the crown reaches approximately 8 cm. It contributes to fruit enlargement. It is performed using a 6-mm iron rod whose end is flattened with a hammer and anvil. The operation aims at destroying the central growing point of the plant to stop its development.

– Ethrel application ("ethrelage"): This aims to ensure good fruit coloration, as color is a determining quality criterion. To improve fruit coloration, ethrel is applied. Thanks to the acetylene it contains, ethrel has the ability to destroy chlorophyll. Eight (08) days before shipment, ethrel is diluted in water at a ratio of 250 g of ethrel to 15 liters of water, and the solution is sprayed on the fruits.

It should be noted that this operation is very rarely practiced in the district due to financial constraints and because fruits are sold mainly on local and national markets, which do not require strict color standards. According to surveys, only large producers and exporters perform this operation. Conversely, many producers in Allada protect the fruits against sunlight.

– Sun protection: This operation consists of tying the longest leaves above the fruit a few weeks before harvest—this is the traditional method. The entire plantation may also be covered with oil-palm branches. This is the most common protection method and is used during the dry season, from November to March.

Harvest and Post-Harvest Practices: At full maturity, pineapple fruits are harvested. There are two types of maturity: physiological maturity and morphological maturity. According to surveyed producers, when the fruit is immature, its skin is green. Maturity is indicated by a yellow color that gradually covers the entire fruit. Morphological maturity depends on fruit size and coloration.

After harvest, the fruits are grouped into piles based on size (large, medium, small) before being sent to commercial markets or processing units. Immediately after harvest, the field is treated again to produce suckers for the next production season.

3.2. Climatic Characteristics of the Study Area and Production of Pineapple

The figure below shows the evolution of rainfall in the study area between 1993 and 2023.

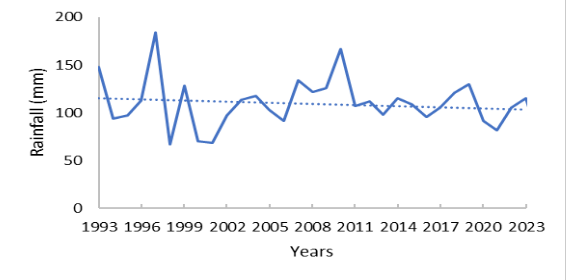

Figure 3: Evolution of average rainfall in the Municipality of Allada between 1993 and 2023
Source: Meteo Bénin, Cotonou station, 2025

The figure 3 presents the trends in annual average rainfall recorded from 1993 to 2023. A visual assessment reveals strong interannual variability, marked by significant peaks in 1997, 2000 and 2010, as well as notable troughs in 1998, 2006 and 2023. This irregularity suggests instability in rainfall patterns throughout the study period.

In addition to rainfall, the parameter of temperature was varying during the year Fig. 4).

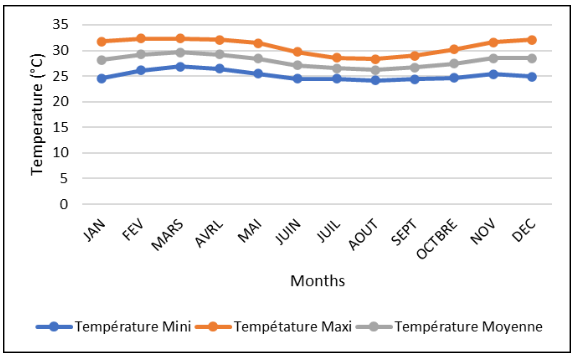

Figure 4: Average temperature in the Municipality of Allada between 1993 and 2023
Source: Meteo Bénin, Cotonou station, 2025

The figure 4 shows the monthly variability of average temperatures recorded in the Municipality of Allada between 1993 and 2023. The analysis shows that there is considerable variation between average temperatures from one month to another within the same year. The coolest months are June, July, August, September and October, with average temperatures ranging from 24.5°C to 29.71°C—still well above the normal average for the subequatorial climate—while the hottest months are February, March and April, during which temperatures reached up to 32.34°C. The lower average temperatures during the cooler months can be explained by the frequency of rainfall during these periods. Similarly, the rise in average temperatures during the hotter months can be attributed to the scarcity of rainfall.

From the above, it appears that temperature variation within a year also depends on rainfall patterns. Thus, the continuous decline in average temperatures from May to July corresponds to the major rainy season previously identified. Furthermore, the significant rise in average temperatures in February, March and early April coincides with part of the major dry season in southern Benin, where the Municipality of Allada is located. It should also be noted that the months experiencing the highest temperatures are those in which pineapple yields are lowest due to excessive heat. After this presentation of climatic characteristics, it is important to see how the production of pineapple was varying over years (Fig. 4).

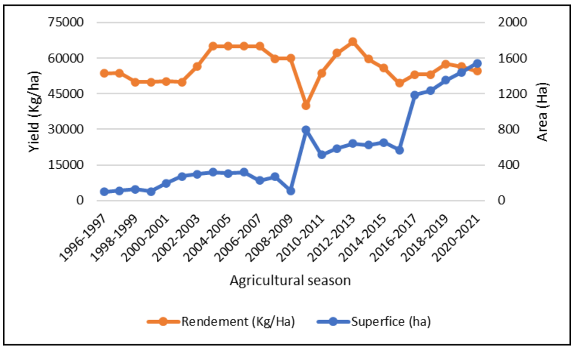

Figure 4: Evolution of pineapple cultivation areas and yields in the Municipality of Allada between 1996 and 2021 (*Source: CCATDA/Allada, 2025*)

The figure 4 presents the combined data for pineapple cultivation areas and yields in the Municipality of Allada between 1996 and 2021. It shows the dynamics of agricultural yield (per hectare). The analysis reveals three distinct phases: (i) moderate growth until the early 2000s; (ii) a notable acceleration between 2003 and 2012, likely linked to the adoption of new agricultural technologies or intensive practices, and (iii) stabilization after 2015 with increased interannual variability, possibly due to climatic uncertainties. The peaks observed in 2009 and 2016 suggest particularly unfavorable years. The overall positive trend likely reflects agricultural intensification, although the stagnation raises questions.

3.3. Influence of Climate Change on Pineapple Production

3.3.1. Effects of Rainfall Variability on Production

The combined data for average rainfall and pineapple production in the Municipality of Allada between 1997 and 2021 showed some relationship (Fig. 5).

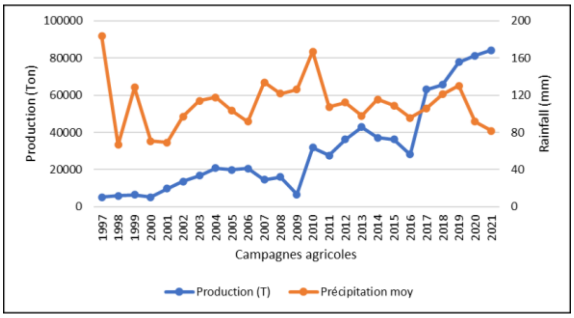

Figure 5: Evolution of average rainfall and pineapple production in the Municipality of Allada from 1997 to 2021 (*Source: Meteo Benin, Cotonou station, and CCATDA/Allada 2025*)

The figure 5 presents annual trends in production and average rainfall between 1996 and 2021, revealing several key patterns. The period shows overall growth in production, with interannual fluctuations typical of agricultural systems. There is a noticeable acceleration in growth from the mid-2000s, followed by a possible slowdown after 2015. Annual variations may be explained by conjunctural factors (economic demand, climatic conditions). The absence of abrupt breaks suggests relative stability in the production system over the period.

3.3.2. Principal Component Analysis (PCA) of Rainfall and its Influence on Pineapple Production

The evolution of pineapple production was analyzed over years (Fig. 6).

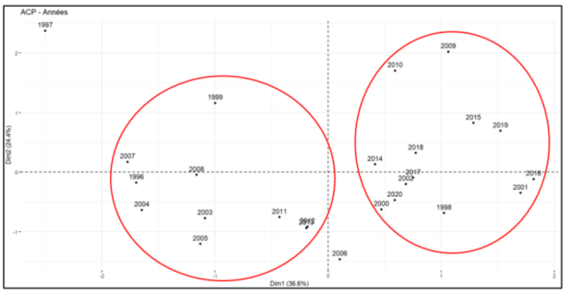

Figure 6: Principal Component Analysis (PCA) (*Source: Meteo Benin and field analysis results, July 2025*)

This report presents the results of a PCA conducted on a set of years to explore and visualize similarities or differences in their statistical profiles. The PCA identified temporal groupings and marked contrasts between different periods. The first two dimensions, explaining 61% of total variability, highlight a structural separation between the years 1996–2008 and those after 2000, as well as notable cyclical fluctuations. Some years, such as 1997, 2009 and 2010, stand out clearly, while others (2002, 2017, 2020) located near the center of the factor map show average profiles. Specific groupings, especially 2011–2013, indicate atypical years, potentially unfavorable for pineapple cultivation based on the variables studied. To deepen understanding of the influence of climate change on pineapple production, a linear regression analysis was conducted.

3.3.3. Multiple Linear Regression

A Shapiro–Wilk normality test was applied to each of the climatic variables considered to verify the normality assumption required for the analysis.

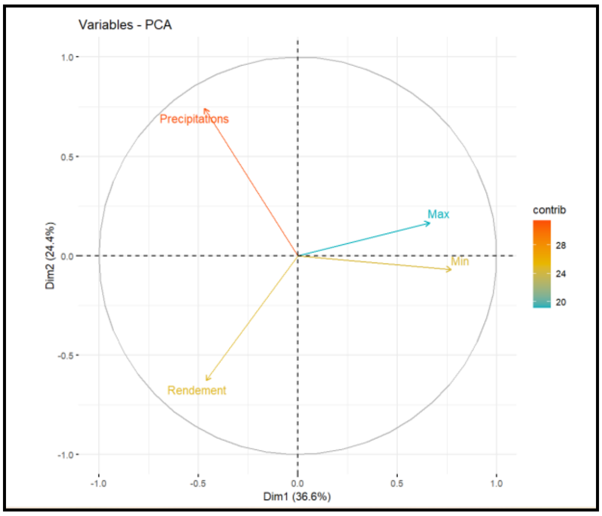

Figure 8: Results of multiple linear regression analysis (*Source: Field survey results, July 2025*)

The results indicate that all variables follow a normal distribution. A multivariate linear regression model was then built using stepwise forward selection. The results show that the climatic variables -rainfall, minimum, maximum, and average temperatures- have a statistically significant relationship with the dependent variable, namely yield per hectare. Indeed, the p-values associated with the explanatory variables are all well above the 5% significance threshold. It follows that, in this study, the climatic variables significantly explain the observed yield variations. Therefore, climatic conditions influence pineapple cultivation in the Municipality of Allada.

3.3.4. Summary of Climate Change Effects on Pineapple Production in the Municipality of Allada

High temperatures (above 32°C) lead to irregular fruit shape or plant mortality. When combined with high humidity, hot weather creates favorable conditions for pineapple pathogens. Higher nighttime temperatures can accelerate flowering and disrupt production and harvest schedules.

Intense solar radiation poses significant risks to fruit quality, including sunburn and severe fruit deformation. Direct exposure of pineapple plants to sunlight during flowering increases the number of fruits damaged by corky roots, reducing fruit quality and market value. Additionally, field workers' well-being and productivity are compromised due to risks such as dehydration, skin disorders and heat stress symptoms.

Excess rainfall directly impacts fruit quality and development, as well as pest and disease prevalence. Soil saturation reduces root development and vegetative growth, potentially causing loss of color, reduced sugar content and lower yield. Without proper drainage, waterlogging can cause developmental disorders and, when combined with high temperatures, increase the incidence of fungal diseases such as *Fusarium* and *E. carotovora*.

Strong winds severely damage all parts of the plant or uproot it entirely, leading to replanting costs. Violent winds also contribute to soil erosion, especially on bare soils.

Soil erosion is exacerbated by heavy rainfall and temperature changes. Combined with inadequate soil and land management practices, soil degradation—including pollution, fertility loss and salinization—can occur. This affects soil drainage and water retention capacities, thereby negatively affecting yield and product quality. Climate warming may also increase soil temperature, affecting moisture retention and soil structure.

3.4. Discussion

The results of this study show that climate change has negatively affected pineapple production in recent decades. These findings align with those of J. Bouffin (1991, [15]), who already stressed in 1991 that the problem was severe for Cayenne pineapple in South Africa. R. Dimon (2008, p.7) [11] also reported that farmers in the municipalities of Kandi and Banikoara, in northern Benin, have faced climate change impacts over the past 15 years. These results support those of M. Lawani (2016, [16]), who found that the period from 1973 to 2012 was marked by alternating rainfall surplus and deficit years, particularly 1974 (surplus) and 2002 (deficit). Such extreme rainfall years may lead to flooding and prolonged droughts, whose consequences include the submersion of pineapple crops in Allada.

IV. CONCLUSION

Climatic conditions in the Municipality of Allada have changed between 1993 and 2023. These changes negatively affect pineapple cultivation in the study area and compel producers to develop new cultivation strategies to sustain the value chain.

High temperatures cause irregular fruit shape or plant mortality; intense solar radiation poses significant risks to fruit quality; excess rainfall impacts fruit development and increases pest and disease prevalence; and strong winds cause severe plant damage and uprooting, incurring replanting costs. L. Adeagbo (2016, p.58) noted in his studies that climate change rapidly affects pineapple cultivation in Southern Benin due to the still traditional cultivation practices associated with this crop.

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