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Impact of climate variability on pineapple production in Ghana

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Abstract

Background: Climate variations have a considerable impact on crop production. For pineapple, variable temperatures and rainfall patterns are implicated, yet there is limited knowledge of the conditions and consequences of such variations. Pineapple production plays a major role in Ghana, primarily via socioeconomic impacts and the export economy. The aims of this study were to assess the impact of current climatic trends and variations in four pineapple growing districts in Ghana to provide stakeholders, particularly farmers, with improved knowledge for guidance in adapting to changing climate.

Results: Trend analysis, standardized anomaly, correlation analysis as well as focus group discussions were employed to describe climate and yields as well as assess the relationship between climate and pineapple production from 1995 to 2014. The results revealed that, relative to Ga district, temperature (minimum and maximum) in the study areas was increasing over this period at a rate of up to 0.05 °C. Rainfall trends increased in all but Nsawam Adoagyiri district. Rainfall and temperature had different impacts on production, and pineapple was particularly sensitive to minimum temperature as accounting for up to 82% of yield variability. Despite consistent report of rainfall impact on growth stages later affecting quantity and quality of fruits, minimal statistical significance was found between rainfall and yield.

Conclusions: With continuously increasing stresses imposed by a changing climate, the sustainability of pineapple production in Ghana is challenged. This subsequently has detrimental impacts on national employment and exports capacity resulting in increased poverty. Further research to explore short- and long-term adaption options in response to challenging conditions in the pineapple industry in Ghana is suggested.

Keywords: Pineapple, Yield sensitivity, Temperature and rainfall variability, Ghana

Background

Globally, pineapple (*Ananas comosus*) is an important traded crop and is a popular and nutritious fruit grown in many tropical and subtropical countries [16]. It is a rich source of vitamins (C, A and E) and minerals in the human diet (e.g. 10–25 mg vit C) [16]. Pineapple is grown in developing countries where two-thirds of the rural population lives on small-scale farms of less than two hectares [22]. The Ghana Living Standards Survey indicates that about 2% of all Ghanaian households grow pineapple [17]. Due to its high labour requirements, cultivation of pineapple plays a vital role in improving income as well as generating employment. The Ghana pineapple industry grew from 1994 to 2004 at a cumulative annual rate of 172%, resulting in increased European Union (EU) market share of fresh Ghanaian pineapples from 2 to 10% between 1999 and 2004. Concurrently, it accounts for 40% of the total horticultural exports and is the most economically developed horticultural sector in the Ghanaian economy [10]. After 2004, the export market was characterized by rapid changes and slow uptake due to changing regulations and the shift of international demand from the formerly dominant "Smooth Cayenne" variety to the MD2 variety [25]. As a consequence, Ghanaian shares declined and retained only 4% of EU market shares in 2013 [14]. However, in response to this, farmers

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and other stakeholders have now intensified production to gain back market shares. The crop also remains important for local consumption both in the fresh market and as a raw material for local processing industries.

Global future climate projections suggest a rise in surface temperature and more intense and frequent extreme precipitation events with sea level rise in most regions including the tropics [23]. Crop production, particularly rainfed, is sensitive to climate variability and change which mostly impact negatively on horticultural crop productivity [26]. Deuter [13] suggests that a rise in temperatures up to 4 °C will challenge the horticulture industry, yet acknowledges that the effect of climate variability and change on most horticultural crops is not readily available. Regional changes in rainfall and temperatures are expected to have negative consequences for horticultural production. For example, untimely rains during drought stress periods or above normal temperatures during flowering and fruit growth reduce yields and can cause physiological disorders [11]. In Uganda, pineapple farmers reported reduced yields and increased pest and disease outbreaks in 2012 which were attributed to prolonged drought and hot temperature [29]. In Ghana, a recent study revealed that over the last two decades high rainfall variation coupled with increased temperatures resulted in lower tomato yields [19].

The most important climatic factors for pineapple production in Ghana are rainfall and temperature [28]. Currently, most regions in Ghana already seasonally vary outside from optimal climatic conditions. Recent studies emphasized the importance of long-term rising temperature and rainfall changes (towards a longer dry season) in Ghana [4, 31, 37]. Pineapple's Crassulacean acid metabolism (CAM) restricts CO_2 uptake to the dark periods of low transpiration (due to stomatal closure) and low evapotranspiration. This makes the pineapple plant highly water use efficient and therefore well adapted to arid conditions although the growth is sensitive to climate [9]. Lack of water at any stage of crop development can, however, result in low productivity [12]. These conditions are more likely to occur in the absence of supplementary irrigation, as is the case for most of Ghana's smallholder pineapple production. Pineapple is also sensitive to soil waterlogging which impacts fruit quality [12]. Various studies have identified minimum temperature as a critical climate variable in determining pineapple yields as well as fruit quality [6, 30, 34]. Predicted mean annual temperature is shown to increase in most regions of Ghana combined with increasing annual rainfall variability. It is predicted that these changes will continue and that extreme weather events resulting in floods and droughts will become more frequent and intense [3]. Olesen et al. [31] showed that the range of changes in temperature and rainfall will vary within Ghana. This consequently would affect pineapple productivity in terms of quantity and quality and seriously challenge farmer's investments and livelihood security.

There is very little scholarly work that has attempted to relate climate to pineapple production. Previous study focused on impact of climate variability on pineapple farming [29]. Less effort was attempted to understand the impacts of climate variability on production and more especially during the growth stages of production. In Ghana, this gap proves a major challenge when providing guidance to stakeholders, particularly farmers, who want to prepare and adapt to current and future climate variability. It is undeniable that rising temperatures and erratic rainfall distribution could result in reduction in soil moisture which could lead to water stress during production. This in effect could threaten pineapple productivity by decreasing potential yield and quality which would thwart the efforts of farmers and challenge livelihood security. This work aims at enhancing our understanding of pineapple production under current climate variability and offers evidence-based information to smallholder farmers relating pineapple sensitivity to climate variability in the future.

Methods

Description of study areas

Pineapple cultivation is mainly concentrated in the Greater Accra, Volta, Eastern and Central regions of Ghana. One district from each of these four regions was purposely selected since they are major pineapple growing areas in the respective regions. These were Ga West, Akatsi North, Nsawam Adoagyiri and Gomoa East districts representing Greater Accra, Volta, Eastern and Central regions, respectively. The LocClim Model developed by the Food and Agricultural Organization (FAO) was used to give a climatic description of the study areas as well as the length of the growing season and annual rainfall pattern (Fig. 1).

Figure 1 describes the annual growing seasons as the average period during which precipitation exceeds half the potential evapotranspiration [18]. The model output categorizes the dry, moist and humid seasons at each location. It presents the general growing seasons in Ga West (Fig. 1a), Akatsi North (Fig. 1b), Nsawam Adoagyiri (Fig. 1c) and Gomoa East (Fig. 1d) districts. All districts show bimodal rainfall pattern indicating two main growing seasons per year, that is, a major and a minor season. The major season rains last 3 to 5 months around the most humid May–June months, while the minor season rains last 1–4 months around October. There are dry periods in between ranging from 3 to 7 months

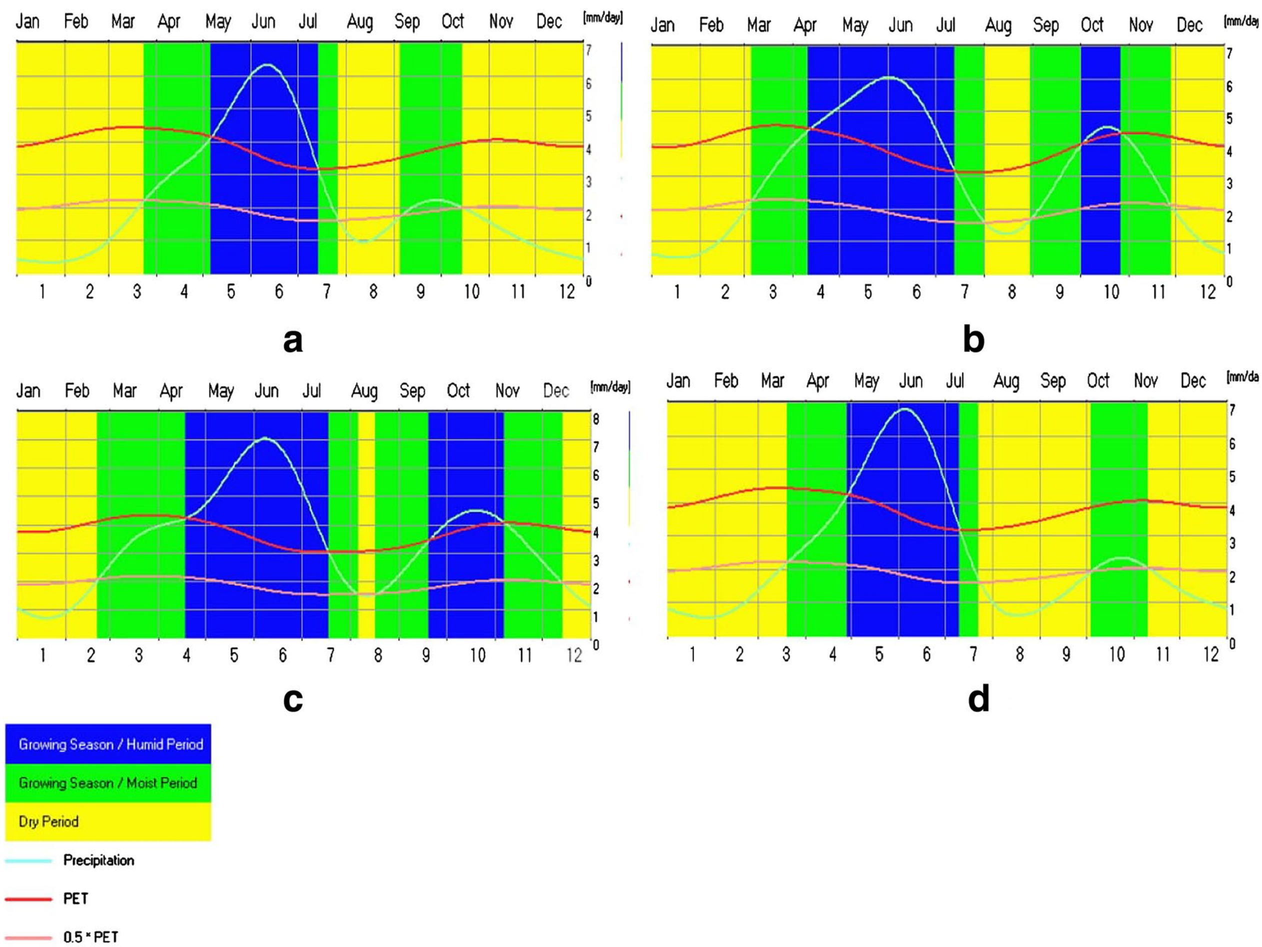

Fig. 1 Annual growing seasons in the study areas. **a** Ga West district growing season, **b** Akatsi North growing season, **c** Nsawam Adoagyiri growing season, **d** Gomoa East growing season

during which monthly rainfall is generally low across the four areas and precipitation mostly recorded in August, November to January (Fig. 1).

Pineapple production in Ghana

Temperatures in Ghana's pineapple growing regions range from 20 to 36 °C with annual rainfall of 600 mm to 4000 mm [28]. Smallholder pineapple farmers in Ghana cultivate between 1 and 10 acres of land, mostly without irrigation, hence highly dependent on rainfall [28]. Pineapple can be propagated from various vegetative parts such as suckers, slips and crowns. In Ghana, it is usually propagated from the suckers and harvest occurs 16–18 months after planting [33]. Pineapple growth to maturity is a sequence of vegetative, flowering and yield formation stages [15]. A schematic representation of pineapple cropping calendar in Ghana showing the various growth stages is depicted in Fig. 2. Main activities during the vegetative stage include planting, plant replacement and crop husbandry. Flowering primarily involves artificial flower induction (also called forcing) and sunburn protection. Yield formation stage mainly involves crop husbandry and harvesting. Labour is required by all activities making pineapple a labour-intensive production.

While flowering is timed to take place just before the minor rainfall season, harvesting takes place just before the major rainfall season onset but vegetative growth occurs throughout seasons. Flower induction during pineapple production optimally occurs 8 months after planting. Yield formation occurs primarily in the dry season between December and March irrespective of region. Flower induction to harvesting usually takes about 135 days. In Ghana, this can go beyond 160 days depending on the weather [33]. The final pineapple production depends on adequate climatic factors over 21 consecutive months from approximately 3 months before start until the end of the 18-month growing period. This implies

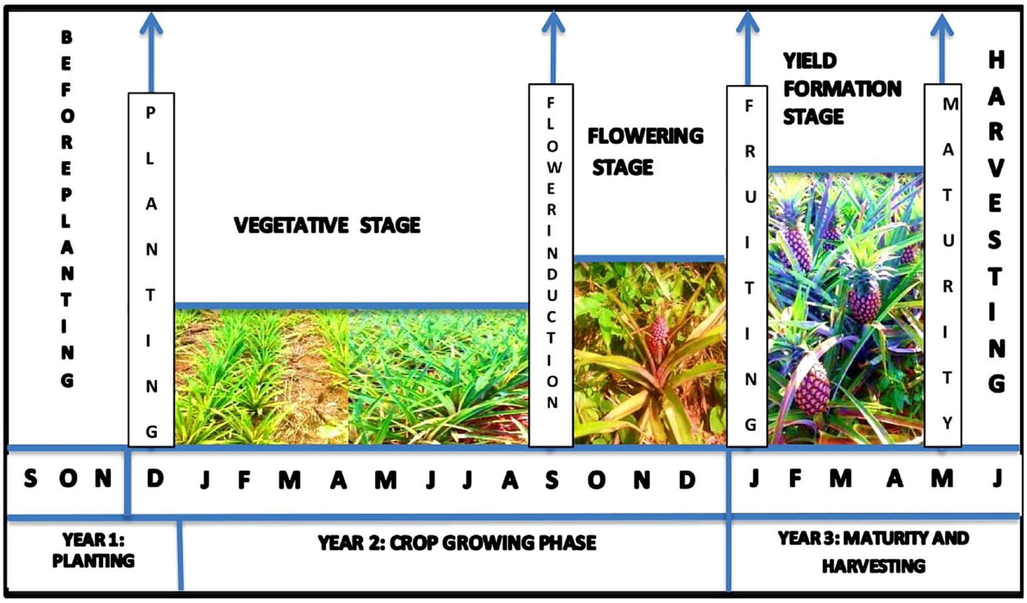

Fig. 2 Schematic representation of pineapple cropping calendar in Ghana

that pineapple yield in a subsequent year is as a consequence of climatic conditions of two preceding years and the first five months of the harvesting year as shown in Fig. 2. Importantly, because the growing cycle is longer than the annual cycle, our analysis relies on the running 21 consecutive months prior to the harvest. This period is also disaggregated according to the pineapple growth stages for further analysis.

Climate data and determination of trends and standardized anomaly

Climate data used for the four study regions include daily rainfall, maximum and minimum temperatures over the period 1984–2014 which were obtained from the Ghana Meteorological Services Agency (GMet). We used daily rainfall and temperature data at one representative synoptic weather station per district. We computed total annual rainfall and mean maximum and minimum temperatures. A linear model was fitted to the total annual rainfall and annual mean minimum and maximum temperatures to determine the trend of change over the period. Later standardized anomalies of rainfall and temperatures representing inter annual climate variability from 1995 to 2014 were used to assess the frequency and deviation of rainfall and temperature away from the long-term average amount for the 21-month growing period as described by [2]. The standardized climate anomaly was computed as the difference of long-term mean annual climate (temperature or rainfall) divided by the standard deviation.

Trends in pineapple yield and yield variation

Pineapple yield data were obtained from the districts and national offices of the Ministry of Food and Agriculture (MoFA). Data consist of 20-year annual pineapple yields from 1995 to 2014. Pineapple yield is measured in tons. We computed the standardized anomaly for each year. The number of standard deviations yield was above or below the long-term annual mean yield. It represents anomalies of interannual changes [1]. The standardized yield anomaly was computed as the difference in the long-term mean annual yields, divided by the standard deviation. A positive score indicated yield was above the mean, while a negative score indicated otherwise. Interannual yield anomalies were compared with rainfall/temperature anomalies.

Relationship between climate and pineapple production

We used a mixed approach including both quantitative and qualitative analysis for the exploration of the relationship between climate and pineapple production. Given the limited information available on pineapple in the context of climate variability, the multiplicity of sources and methods provided a broader perspective and understanding. Mixed method approaches are particularly relevant in concurring, complementing and building confidence from multiple analysis [8].

Focus group discussions/interviews

Two focus group discussions (FGDs) and an in-depth interview (IDI) with one key informant were conducted in each of the four districts. Purposive sampling technique was used to identify respondents for the FGD and IDI. In each district, the FGD constituted ten members of cooperative pineapple growers and marketing associations, and the IDI was also with a management member at the district MoFA. The respondents had expert knowledge of climate and its effect on pineapple production in Ghana and provided further information on pineapple growth stages and effects of climate variation. In connecting the impact of climate variability on the various crop development processes, the qualitative responses and views captured and explored were analysed using interpretational analysis into subthemes (effect on vegetative, flowering and yield formation stages).

Correlation analysis

Correlation analysis was used to quantitatively evaluate the effect of climate variables in determining the variation of pineapple yield. The independent variables were the 21-month growing period climate variables (temperature and rainfall) as well as disaggregated total pineapple growing period climate data over the period 1995–2014. The disaggregation reflected the various growth stages, that is, vegetative stage (September–August), flowering stage (September–December) and yield formation stage (January–May) within the 21 consecutive months prior to harvest. The correlation coefficient (r) was used to indicate pineapple yield sensitivity to climate variability.

Results

Climate trends

Trends in rainfall

The total annual rainfall in the pineapple growing districts in Ghana for the period 1984 to 2014 ranged from 450 mm to 1500 mm (Fig. 3).

The years 2000 and 1990 recorded the least rainfall and in Ga West and Gomoa East, respectively. The highest rainfall was recorded in 2006 at Nsawam Adoagyiri, the wettest district with total annual rainfall just about 1500 mm but a decreasing 3 mm/year trend. The driest district over the period was Gomoa district with the lowest total annual rainfall of 453 mm. Apart from Nsawam, there was evidence of increasing rainfall trend in all districts. Akatsi North showed the highest rate of about 6.7-mm increase per year (Fig. 3).

Trends in maximum temperature

Mean annual maximum temperature for the period 1984 to 2014 varied between 29 and 38 °C across the four pineapple growing districts (Fig. 4).

All districts show positive temperature trends at the rates of about 0.02, 0.05, 0.02 and 0.03 °C per year for Ga West, Akatsi North, Nsawam Adoagyiri and Gomoa East districts, respectively. The lowest mean annual maximum temperature over the period was recorded in 1986 in Gomoa East (29.1 °C), and the highest mean annual maximum temperature was recorded in 2004 at Ga West (38.0 °C).

Trends in minimum temperatures

Annual minimum temperature during the period 1984 to 2014 varied from 21 to 26 °C across the districts (Fig. 5). Trend analysis shows warming in all the districts, except Ga West which showed a marginal declining trend of about 0.001 °C/year. In Ga West, the highest increasing minimum temperature rate was observed at the rate of about 0.04 °C/year over the period (Fig. 5). The lowest mean annual minimum temperature was recorded in 1986 in Nsawam Adoagyiri district (21.4 °C), and the highest mean annual minimum

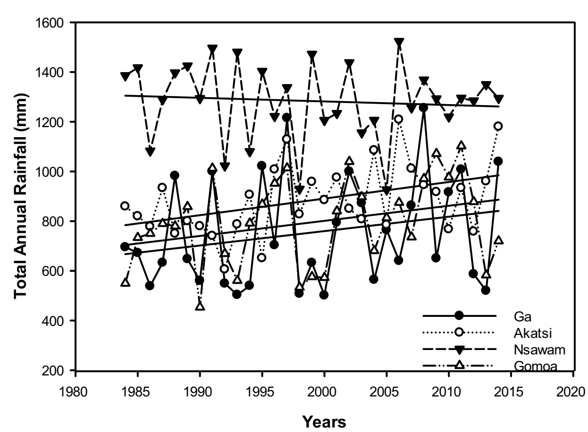

Fig. 3 Total annual rainfall for the study districts in Ghana

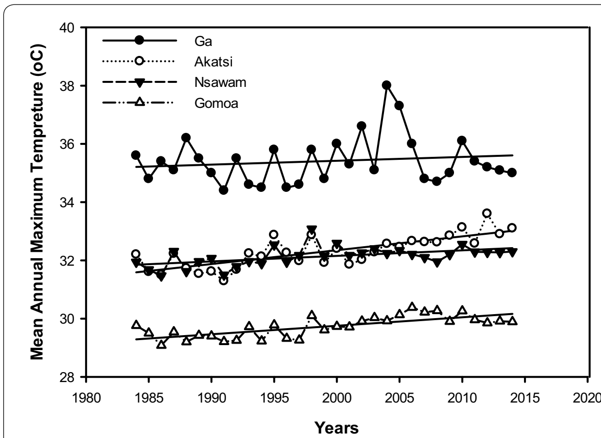

Fig. 4 Mean annual maximum temperature for the study districts in Ghana

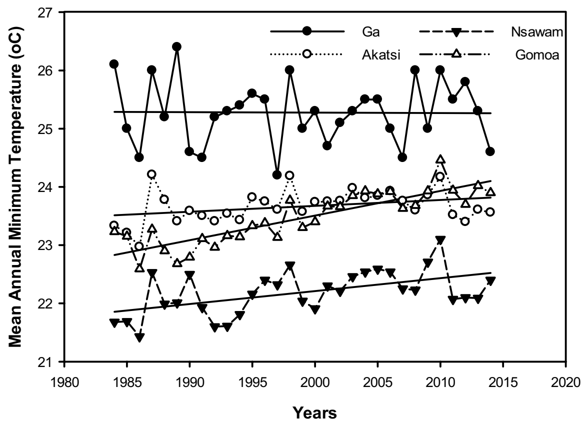

Fig. 5 Mean annual minimum temperature for the study districts in Ghana

temperature was recorded in 1989 in Ga West district (26.4 °C).

Trends in pineapple yields and variation

The highest mean yield for the study districts between 1995 and 2014 was 127,970 tons in Gomoa East followed by 86,779 tons in Nsawam Adoagyiri and 64,844 tons in Akatsi North and the lowest mean was 23,867 tons in Ga West (Table 1). Positive growth rate was observed in all the four districts during the study period (1995–2014).

Relating pineapple yield and climate anomalies

The standardized anomalies for pineapple yield and 21-month running growing period climate variables anomalies from 1995 to 2014 are shown in Figs. 6, 7 and 8 for rainfall, minimum and maximum temperatures, respectively. Positive anomalies indicate above average climate/yield variables, while negative anomalies indicate otherwise. Consistent high above average yields were observed after 2010 in all the districts, while below average were predominant over the whole period. Pineapple production in Ga district recorded negative yield anomalies in 13-year out of the 20-year study period. Akatsi district had 12 negative yield anomalies and 7 positive anomalies. In Nsawam, there were 14 negative yield anomaly cases and 6 positive cases. Likewise in Gomoa, there were cases of 13 negative yield anomalies and 7 positive anomalies (Figs. 6, 7, 8).

For rainfall and yield anomalies, up to about 54% of the negative yield anomaly cases were accompanied by negative rainfall anomalies. This was observed in Gomoa district where the least total annual rainfall for the study period was recorded. Positive yield anomaly was similarly accompanied by up to 71% cases of positive rainfall anomaly in the same district. The other districts also showed some cases of rainfall influences on yield (Fig. 6).

Table 1 Pineapple yield descriptive for the four growing districts (1995–2014) ***Source*** **MoFA (2015)**

District	Mean yield (t)	Standard deviation	Slope	R^2	Trend
Ga West	23,867	8249.60	1130.3	0.657	Increasing
Nsawam	86,779	25,525.70	4006.3	0.8622	Increasing
Gomoa	127,970	35,376.90	5512.5	0.8498	Increasing
Akatsi	64,844	17,041.14	2595.4	0.7713	Increasing

Standardized pineapple yield and minimum temperature anomalies

Standardized temperature anomaly showed more influences on yield anomaly cases for both maximum and minimum temperatures. For minimum temperature, recorded cases of negative yield anomalies were accompanied by negative temperature anomalies up to 69% with the highest cases observed in Gomoa and lowest cases in Akatsi. Seven positive yield anomaly cases in Gomoa district were accompanied by 6 (86%) positive anomalies and Akatsi had 57% of rainfall anomalies accompanying positive yield anomalies and Nsawam also showed similar pattern (Fig. 7).

Standardized pineapple yield and maximum temperature

Maximum temperature anomaly equally showed some influences on yield anomaly. The highest influences for negative yield anomaly were observed in Gomoa (69%) and the least in Ga (31%). The highest positive yield anomaly influences by positive maximum temperature were observed in both Akatsi and Gomoa (86%) districts (Fig. 8).

Relationship between climate, climate variability and pineapple production

Effect of temperature and rainfall on pineapple yield variation in Ghana

Correlation analysis of yield with climate variables (rainfall, minimum and maximum temperatures) from 1995 to 2014 for Ga West, Akatsi North, Nsawam Adoagyiri and Gomoa East is shown in Table 2. Climate variables for the annual 21-month running growing period and the disaggregated climate variables representing the pineapple growth stages (vegetative, flowering and yield formation) were correlated with annual pineapple yield. With the exception of total period of rainfall in Gomoa district and vegetative stage in Nsawam district which were significant, correlation values for rainfall were not significant in the remaining districts. Generally, minimum temperature during all the growth stages and the average 21-month growing period had

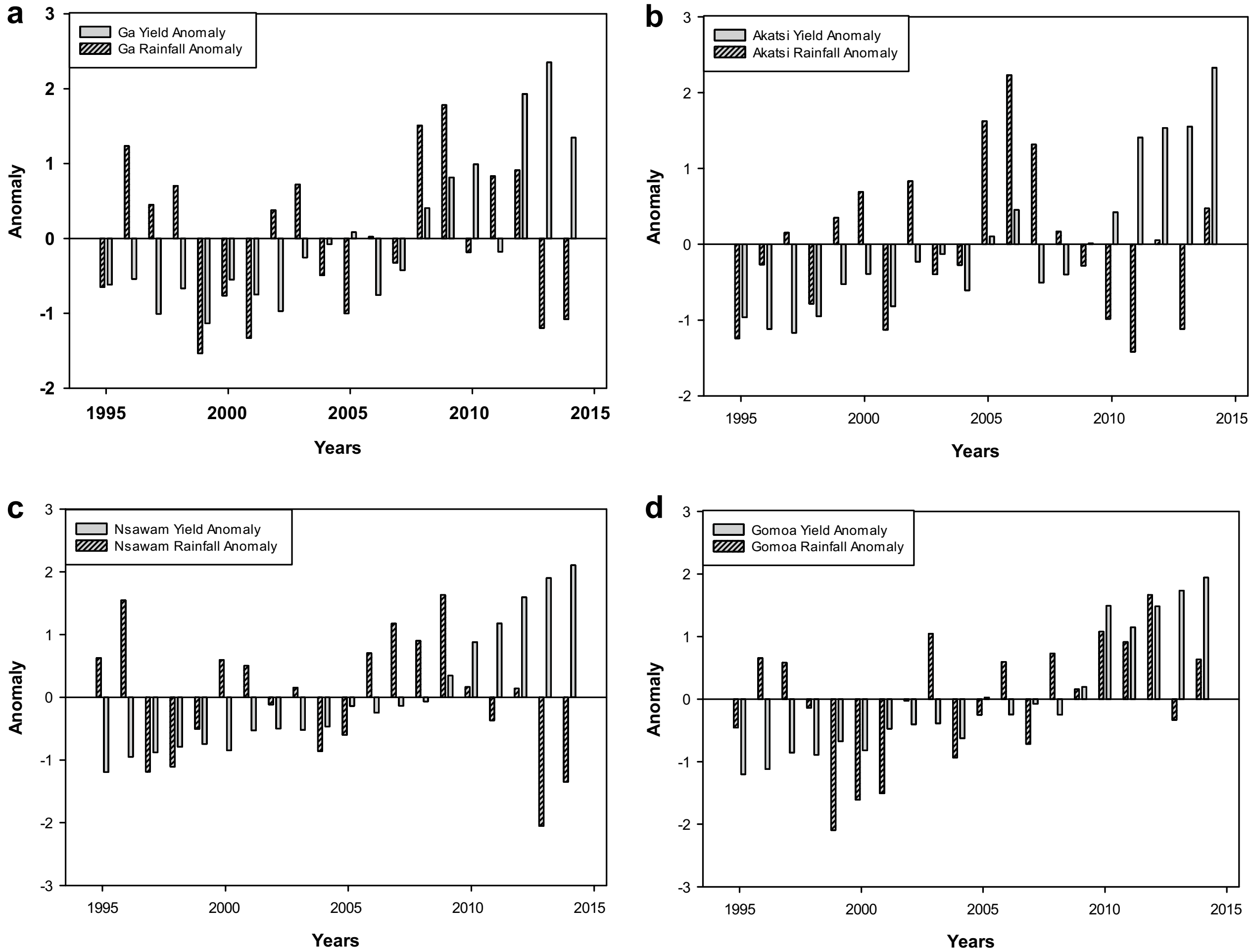

Fig. 6 Standard anomalies for pineapple yield and total growing period rainfall for the four study districts. **a** Ga yield and rainfall anomalies, **b** Akatsi yield and rainfall anomalies, **c** Nsawam yield and rainfall anomalies, **d** Gomoa yield and rainfall anomalies

significant correlation with pineapple yield in Nsawam and Gomoa district. Minimum temperature during flowering and yield formation stage periods in Ga district was also observed to be significant. For Akatsi district, however, the results showed that correlation between pineapple yield and minimum temperature was mostly not significant but negatively correlated. The correlation between maximum temperature and yield also showed that, apart from Nsawam, there was significant relationship between growing period (average 21 months) maximum temperature and yield in the districts. Significant correlation also existed between yield and periods corresponding to the vegetative and flowering stage maximum temperatures for Akatsi and Gomoa districts. Yield formation stage for Ga was also significant but was mostly negatively correlated in all the growth stages. The correlation between rainfall and yield shows that rainfall in the four districts did not contribute more than 45% to pineapple yields, while minimum and maximum temperatures contributed up to 82 and 50%, respectively (Table 2). Other influential factors apart from climate such as socioeconomic factors and soil conditions therefore may also contribute to the increased yield in the districts.

Perceptions on the effect of climatic variation on pineapple growth

In Ghana, climate variability is perceived as affecting pineapple growth stages from vegetative through to yield formation. The IDIs and FGDs highlighted perceptions of evidences of climate variability such as increasing temperature, unpredictable rainfall patterns and shorter duration of rains on the various growth stages in the four districts studied.

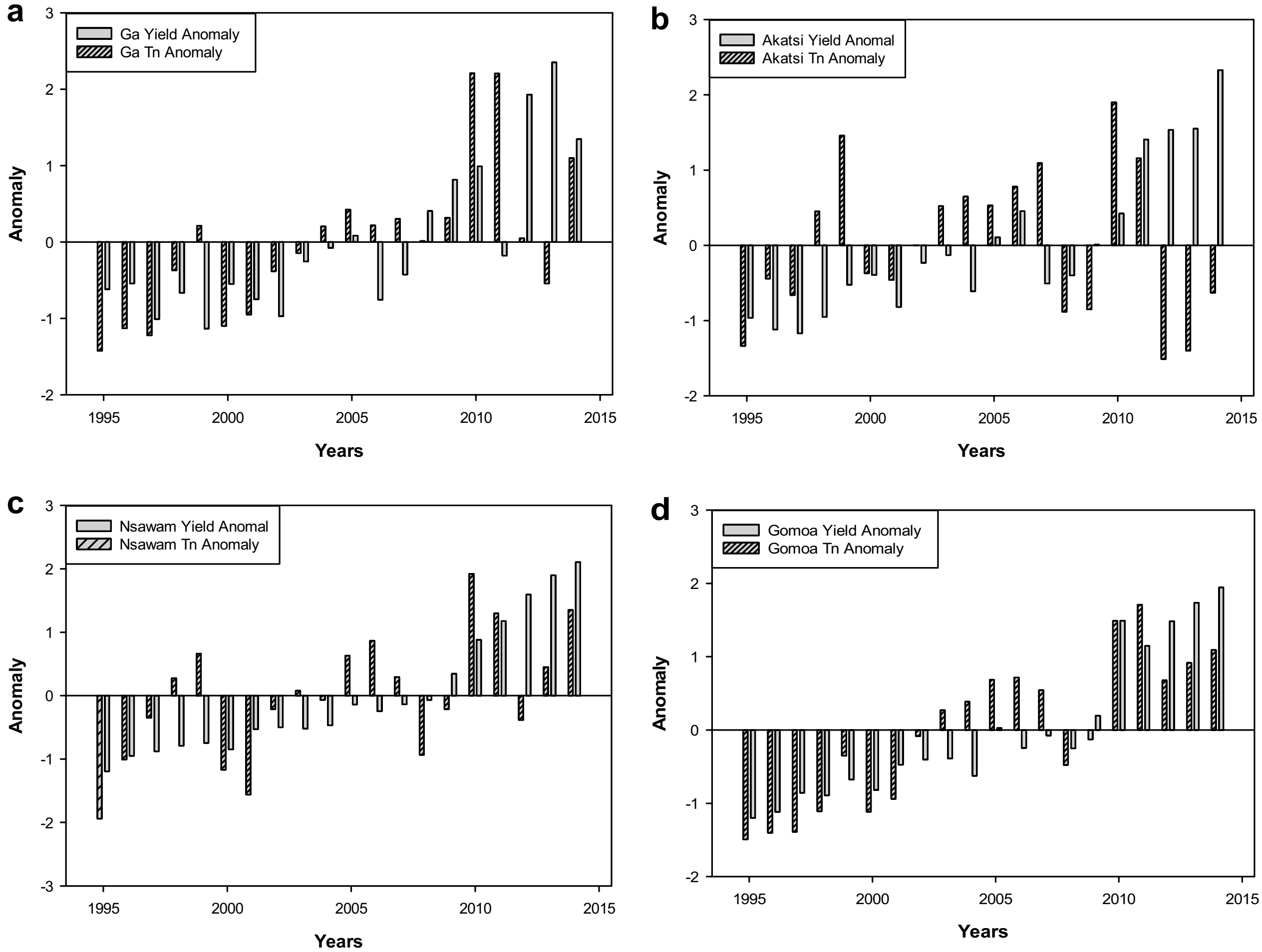

Fig. 7 Standard anomalies for pineapple yield and mean growing period minimum temperature for the four study districts. **a** Ga yield and minimum temperature anomalies, **b** Akatsi yield and minimum temperature anomalies, **c** Nsawam yield and minimum temperature anomalies, **d** Gomoa yield and minimum temperature anomalies

According to pineapple farmers, the first three months after planting pineapple do not require much rainfall; therefore, planting is done towards the end of the minor rainy season (November and December). However, inadequate rainfall after planting causes poor development of the plant, while continuous rains result in complete failure of the pineapple crop. Long dry or wet periods during sucker development which is mainly from April to May in all the four districts result in failure of suckers to develop. A farmer from Akatsi North shared his experience stating that "Rainfall at the beginning of the planting season was irregular in 2014 with extended duration and this affected the size of pineapples harvested in 2015". Another farmer also indicated that "From experience, no rainfall after planting affects shooting and development of the plant which produces small fruits with large crowns". The farmers therefore plant around December which corresponds to an early dry period for plants to obtain adequate rainfall needed to develop. When rainfall conditions vary from the above descriptions, farmers observe stunted growth which affects period for flower induction and subsequently prolonged maturity. Periods of considerable variation in rainfall increase cost of production as unestablished plants are replaced, new suckers must be bought for the next planting season, and prices of affected fruits are significantly reduced affecting pricing and revenue. Temperature changes in all the four districts, however, had no observed effect during the vegetative stage of production. Clearly, variation in rainfall amount, distribution and timing may delay vegetative growth stage.

Flowering stage was identified in all the districts as the critical stage in pineapple production process as successful flower induction leads to uniform flowering,

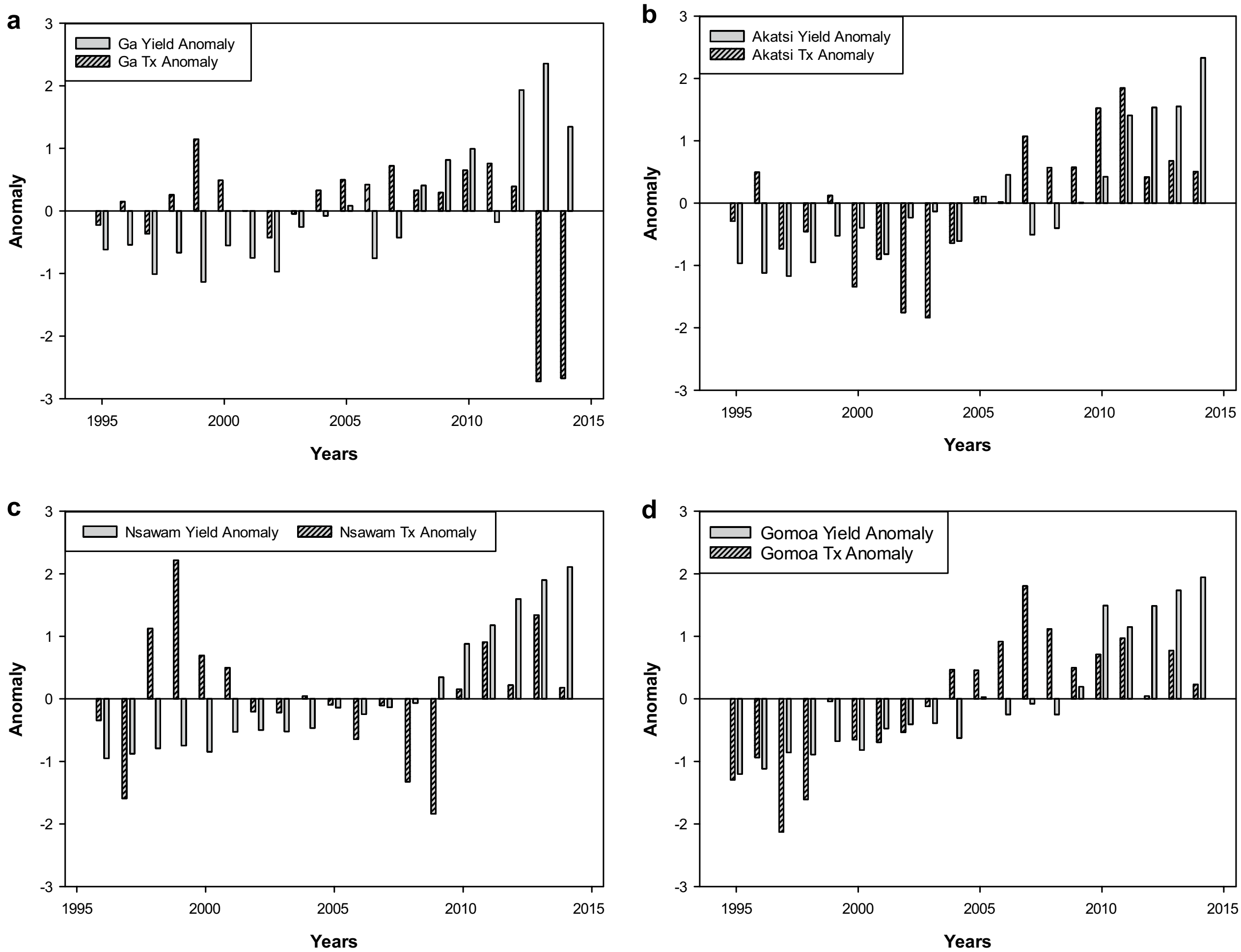

Fig. 8 Standard anomalies for pineapple yield and mean growing period maximum temperature for the four study districts. **a** Ga yield and minimum temperature anomalies, **b** Akatsi yield and minimum temperature anomalies, **c** Nsawam yield and minimum temperature anomalies, **d** Gomoa yield and minimum temperature anomalies

harvesting and ensuring regular supply of fruits for marketing. Pineapple farmers in all the districts explained that artificial flower induction was best done at night or early morning when temperature was relatively low. This relates to minimum temperature and its importance in pineapple production. According to a farmer from Nsawam Adoagyiri, "continuous rains after artificial flower induction result in ineffective application". This is described by farmers as ineffective as induction applications carried out during the day when temperature is high. Production is therefore planned such that flower induction coincides with the minor season rains. In years of irregular rainfall patterns, such as prolonged rainy or dry days, the application becomes ineffective and results in repeated applications with increased costs and non-uniform flowering later affecting maturity and marketing.

Yield formation stage is particularly sensitive to prolonged droughts or irregular rainfall. MoFA in Ga West links it to moisture stress, causing stunted growth, prolonged harvesting time hence increasing maintenance and general production costs. The MoFA officer further indicated that high rainfall variation during yield formation stage leads to nutrient deficit (apparent as yellowing of basal leaves), poor fruit taste, or increased pests and diseases resulting in smaller fruit. All district's farmers revealed that increases in temperature during yield formation result in fruit sunburn and marshy fruits with less juice, affecting fruit weight and quality.

It is important to note that it is difficult for farmers in the study areas to predict the rainfall pattern affecting planning of operations during the production cycle. This was confirmed by a pineapple farmer at Nsawam

Table 2 Correlation analysis of pineapple yield with climate variables

	Total	Rainfall (RR)		
	Vegetative stage RR	**Flowering stage RR**	**Yield formation stage RR**	**RR for total growing period**
Ga	0.144	0.183	−0.248	0.039
Akatsi	−0.146	0.149	0.084	0.003
Nsawam	0.379*	0.350	−0.334	0.361
Gomoa	0.217	0.189	0.275	0.454**
	Average	**Minimum**	**Temperature (Tn)**	
	Vegetative stage Tn	**Flowering stage Tn**	**Yield formation stage Tn**	**Tn for total growing period**
Ga	0.090	−0.410*	0.550**	0.358
Akatsi	−0.052	−0.064	−0.097	−0.002
Nsawam	0.436*	0.445**	0.403*	0.543**
Gomoa	0.733***	0.710***	0.595***	0.817***
	Average	**Maximum**	**Temperature (Tx)**	
	Vegetative stage Tx	**Flowering stage Tx**	**Yield formation stage Tx**	**Tx for total growing period**
Ga	−0.276	−0.294	−0.518**	−0.519**
Akatsi	0.435*	0.459**	0.060	0.453**
Nsawam	0.180	0.284	−0.690	0.146
Gomoa	0.459**	−0.536**	0.300	−0.552**

***, ** and * 1, 5 and 10% significance levels, respectively

who stated that "Planting of pineapple could have begun anytime within the year since it can tolerate some level of drought but now because of variations in climate, one has to strategically plan for the whole production activities which also seem unreliable". In summary, there is an indication from the IDIs and FGDs that rainfall and temperature variation produces delay in growth stages of pineapple plants as the various crop development phases were found to be affected and delayed. Similarly, increasing cost of production resulting in significant reduction in crop revenue was observed. Consequently, production schedules and marketing arrangements and timing are affected.

Discussion

Climatic trend and variation in Ghana

Total annual rainfall in the pineapple growing districts of Ghana exhibited an increasing trend in three of the four study districts and a decreasing trend in one (Nsawam Adoagyiri district). The results concur with rainfall observations in West Africa, suggesting that most of the regions since the 1990s are wetter and have recovered from the Sahel drought and dryness during the 1980s [21]. The study further indicated that while there has been a recovery of rains in West Africa, some parts of the region particularly southern Ghana where Nsawam Adoagyiri district is located among other areas are relatively dry and vary considerably agreeing with the trend observed in Nsawam.

Mean annual temperature (minimum and maximum) trends were also found to be increasing in three of the study districts except Ga West where minimum temperature is relatively stable. These concur with warming trends in West Africa as mean annual temperature over the period 1963–2012 has increased by 1 °C with the exception of some localized cooling in some parts of Ghana, Burkina Faso and Cote D'Ivoire [21]. Similarly in Ghana, there has been reported mean annual temperature rise in most locations [27, 37] which conforms to the results of the pineapple growing districts studied as well. Overall, Ghana is projected to become hotter but wetter during the wet season and drier during the dry season [4, 31, 37]. Interannual variations in rainfall are likewise expected to continue to be the dominant influence on future rainfall. Climatic variations have potential implications for challenging agricultural production. Evidently, the observed patterns of decreasing rainfall trend with increasing temperature trends in Nsawam district could affect current production in the district. Increasing rainfall trend with increasing temperature in the remaining districts could likely also be affected by climate variation and future change in ways that could have increased risk on agricultural production particularly for Gomoa and Ga districts which were the driest and hottest districts, respectively.

Effect of climate on pineapple yield

The pattern of pineapple yield between 1995 and 2014 in the four study districts depicted increasing trends in all districts. Results from anomalies in annual yield and total growing period climate, correlation analysis as well as the qualitative responses explored, explain climate-pineapple yield and production relationship during the study period. Generally, the contributions of climate (rainfall and temperature) to yield variations suggest that, in addition to climate, other influential factors such as introduction of new variety, agriculture technology, market accessibility and better crop management practices may also contribute to the increased yield in the districts.

The observed relationship between temperature and yield implies pineapple production is highly sensitive to temperature and is a major climatic factor to consider for pineapple production in Ghana as statistically significant relationships were observed in most cases between temperature (minimum and maximum) and yield variation during the total growing period and most of the growth stages in all the four districts studied. The results also revealed that standardized temperature anomalies had higher influences on standardized yield anomalies particularly for Gomoa district. Furthermore, pineapple farmers during the FGD perceived temperature as an important climatic factor affecting flowering stage (critical pineapple growing stage) where temperature increases result in poor production as the quantity and quality of fruits produced are affected. The contribution of minimum temperature to yield variations was up to 82%, showing the relationship was the greatest which supports the view of Rainha et al. [34] that minimum temperature is a critical climate variable in pineapple production. Increases in minimum temperature above 26 °C are known to hinder flower induction and this contributes to loss of yield and quality [9]. Even moderate elevation of temperatures poses possibly significant reduction in flowering of crops [35]. This implies that if the observed minimum temperature trend increase in around 0.04 °C per annum in the study districts should continue or accelerate, then in line with Hulme et al. [20], there would be a 4 °C increase as predicted for Africa over the next 100 years which has been cautioned to be a real challenge to the horticulture industry as impacts on cropping systems are not readily available [13]. Ga district that is the hottest among the four study districts appears to be the one to suffer the most from this impact but had an almost stable minimum temperature trend. Therefore, the observed increasing trend in the remaining pineapple growing districts of Ghana has increased risk of negatively affecting pineapple productivity as indicated in other studies [24, 29]. This is particularly so for Akatsi and Gomoa districts where negative correlation between minimum temperature and yield was observed in all the growth stages and higher influences of standardized yield and minimum temperature anomalies were observed respectively. Pineapple farmers clearly need to be made aware of farming techniques and improved adaptation strategies to minimize adverse impacts from temperature.

The results corresponding to rainfall on the other hand statistically showed less significant relationships with yield in most cases in the study districts except total growing period and vegetative stage in Gomoa and Nsawam districts, respectively. Given the statistical insignificance of rainfall to yield in most of the study districts, the result appears to be in line with the agronomic characteristics of pineapple plants which has high water use efficiency (WUE) hence can fairly tolerate dry conditions though not erratic rainfall conditions [7]. Results from the correlation analysis suggest the contribution of rainfall to yield variations was up to 45% though comparison between standardized yield anomalies and rainfall anomalies indicated influences of rainfall on yield with the highest frequency observed in Gomoa, the driest district among the study districts. Gomoa district relatively had the lowest amount of total annual rainfall and had the strongest correlation with pineapple yield. This implies that the negative yield anomalies which resulted from negative rainfall anomalies may mainly be due to insufficient rainfall because of dry periods during production which has the tendency to affect yield. Rainfall influences on yield have also been attributed to the interaction between the cumulative growing period rainfall variations and rainfall during various growth stages [32]. In addition, other studies have also indicated that dry periods during a growing season especially when accompanied by high temperature have the tendency to affect production [5, 36]. Pineapple farmers in Ghana are generally reported to experience poor pineapple production under long dry periods [33]. The decreasing rainfall trend in Nsawam Adoagyiri district with significant increase in temperature is therefore of concern as future climatic variations and change is likely to further exacerbate this condition with implications for soil moisture which consequently can negatively impact on pineapple yields in the district. It will be reasonable for rainfed pineapple farmers in Ghana to consider supplementary irrigation especially during the dry months of the growing periods where rainfall is generally low. However, future studies considering thresholds and looking at decadal variability and its effect on pineapple yield may be particularly relevant for clearer future projections as the increasing rainfall trend in the other districts could challenge pineapple production and sustainable production under wetter future projections. Findings from the study have shown that both high and low rainfall variation influences the growth stages of pineapple production in Ghana particularly the vegetative and yield formation stages where higher correlation values were observed and was qualitatively supported by farmers experiences. Mugambwa [29] similarly identified influences of variation in rainfall amount, distribution and timing on the quantity and quality of pineapple outputs causing delay in the growth stages and increases cost of production under rainfed productions. This implies that there is the need for improved access to climate information particularly forecasting to enable pineapple farmers to effectively plan and organize their farming activities. This would serve as a guide for appropriate dates and times for all farming operations.

Impact of climate on pineapple production

The implication of the impact of climate on pineapple yield indicates that threats from future climatic variations and climate change will challenge pineapple productivity in Ghana. It is important to note that the consequences of poor-quality fruits and fluctuation of yield surrounding pineapple production as a result of climate variability and future change generally have reaching impacts on livelihoods and sustainability of pineapple and the horticultural industry in Ghana. There is increasing interest in health conscious nutritional trends based on consumption of more fruits and vegetables globally which has resulted in steady demand for tropical fruits with developing countries accounting for 98% of the production of fruit imports [35]. This indicates that Ghana still has more potential for growth of the pineapple industry even in the export market for improved foreign exchange earnings and economic development while reducing poverty and improving incomes of farmers. To ensure sustainable production, there is the need for adaptation strategies to respond to the changing climate as well as improved access to reliable climate information particularly forecasting to enable pineapple farmers cope with climate impacts and build on their adaptive capacities. Omoyo et al. [32] suggested technological changes (such as more drought-tolerant varieties), managerial changes (such as increase/decrease farm size) and policy changes (such as planning regulations and infrastructural development) as options of possible adaptive responses to deal with climate variability. Future studies should be encouraged to look into some adaptive strategies that will reduce the adverse effects of climate variability in the pineapple industry of Ghana.

Conclusions

The impact of climatic trends and variation on pineapple production and development of Ga West, Akatsi North, Nsawam Adoagyiri and Gomoa East districts of Ghana was analysed using variations in rainfall, maximum and minimum temperatures. The study revealed that total annual rainfall exhibited an increasing trend in Ga, Akatsi and Gomoa districts and a decreasing trend in Nsawam district. Both mean minimum and maximum temperature trends were also increasing in Akatsi, Gomoa and Nsawam districts except Ga where minimum temperature trend was stable. Pineapple production was more sensitive to temperature of which minimum temperature impacts the most pineapple flowering stage with critical production consequences affecting quality of fruits and production costs. Our results also suggest that the increasing trend in temperature further increases the risk on pineapple production in all but Ga district where minimum temperature is stationary.

Rainfall variation, however, showed less significant correlation with yield variation. The relationship between standardized yield and rainfall anomalies indicated rainfall influence on yield and Gomoa district emerged with the highest frequency reflecting the largest sensitivity to rainfall in an otherwise dry district. Rainfall trends increase in all but Nsawam Adoagyiri district which directly challenges rainfed pineapple production in the district. The study shows that high and low rainfall variations influence particularly the vegetative and yield formation stages of pineapple production stretching the growth stages, increasing the production costs, affecting the quantity and quality of fruits produced and ultimately reducing fruit productivity.

Climate variability is clearly impacting pineapple production in Ghana, with consequences for both fruit quality and quantity produced. The trends observed for the different districts vary and lead to more or less challenging conditions under an average change, but all districts are exposed to large climate variations with direct economic consequences in a competitive exporting pineapple market. At governance level, the promotion of—and investment in—water supply systems (irrigation) in all pineapple production districts would ensure continued optimal production under the effect of climate variability. At institutional level, production and dissemination of improved and reliable climate information including seasonal forecasts would further improve farmer's capacity to plan and organize farm operations effectively. At extension level, further sensitization of pineapple farmers about climate variability, its impacts on growth stages and the various strategies at hand would further inform and facilitate the uptake of coping and adaptive strategies to be put in place to minimize adverse impacts. At a research level, we can foresee benefits in further investigating short-term economic assessed impact of climate variability, or projecting long-term consequences and potential adaptations for a sustainable pineapple production in Ghana under our changing climate.

Abbreviations
EU: European Union; CAM: Crassulacean acid metabolism; WUE: Water use efficiency; FAO: Food and Agricultural Organization; GMET: Ghana Meteorological Services Agency; MoFA: Ministry of Food and Agriculture; FGD: focus group discussions; IDI: in-depth interview.

Authors' contributions
PAW was responsible for developing the initial content of the manuscript, including literature search, data collection and analysis. OC was the supervisor for the research and provided guidance in terms of the article structure and directed the retrieval of relevant literature and finalization of the manuscript. CJA and GE were also responsible for the write-up and finalization of the manuscript. All authors played equal roles in terms of having the article completed. All authors read and approved the final manuscript.

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Competing interests
The authors declare that they have no financial or personal relationships which may have inappropriately influenced them in writing this article.

Availability of data and materials
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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