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Farmer-reported biometeorological hazards and their implications for banana production in Kyabugimbi subcounty, Bushenyi district, southwestern Uganda

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Abstract
Banana production in Uganda is increasingly exposed to environmental and biological stressors that affect productivity and livelihood stability among smallholder farmers. Despite growing attention to climate-sensitive agriculture, there remains limited localized evidence on how farmers experience and interpret environmental hazards within banana-based production systems. This study examined farmer-reported biometeorological hazards and their perceived implications for banana production in Kyabugimbi subcounty, Bushenyi district, southwestern Uganda. A cross-sectional mixed-methods design was employed, combining household surveys with key informant interviews and contextual climate observations. Data were collected from 172 banana farmers and six key informants and analyzed using descriptive statistics and thematic analysis to characterize reported hazards, perceived impacts, and local response patterns. The findings indicate that drought was the most frequently reported hazard, followed by rainfall irregularities, wind-related disturbances, pests, and diseases. Farmers associated these stressors with reduced plantation vigor, irregular yields, moisture stress, crop damage, and increased production uncertainty. Spatial differences in hazard reporting suggest that local environmental conditions and management practices influence how production risks are experienced across the study area. The study demonstrates the value of farmer-reported knowledge in understanding environmental stress within smallholder banana systems and highlights the importance of integrating localized experiences into agricultural risk management. The findings provide contextually grounded evidence that may inform extension services and support future research combining household observations with environmental monitoring to strengthen understanding of agricultural vulnerability under variable environmental conditions.

Keywords Biometeorological hazards, Banana production, Farmer perceptions, Environmental variability, Smallholder agriculture, Adaptation

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1 Introduction

Biometeorological hazards, arising from variations in atmospheric conditions such as rainfall, temperature, and humidity, significantly influence agricultural systems by affecting plant physiological processes, soil conditions, and ecosystem functioning [1]. These hazards are particularly important in rain-fed agricultural systems, where crop production is highly dependent on natural climatic variability. In sub-Saharan Africa, increasing climatic fluctuations have intensified risks to agricultural productivity, threatening food security and rural livelihoods [2]. Uganda, whose economy is largely dependent on rain-fed agriculture, has experienced increasing variability in rainfall patterns, rising temperatures, and more frequent extreme weather events, thereby increasing vulnerability among smallholder farming communities. Similar patterns have been reported across East Africa, where climate variability increasingly affects agricultural productivity, food systems, and livelihood security [22]. Agricultural systems respond to these environmental conditions through both direct and indirect pathways. Biometeorological hazards such as drought, excessive rainfall, temperature extremes, and associated pest and disease pressures can disrupt plant growth, reduce yield, and affect crop quality [3]. Perennial crops, including bananas, are particularly sensitive due to their continuous growth cycles and reliance on stable environmental conditions. Variations in moisture availability and temperature can influence physiological processes such as transpiration, nutrient uptake, and photosynthesis, ultimately affecting productivity [4].

The East African Highland Banana (AAA) is a major staple and cash crop in Uganda, playing a critical role in household food security and income generation for millions of smallholder farmers [5]. In southwestern Uganda, particularly in Bushenyi district, banana production is a dominant agricultural activity. However, farmers in this region increasingly report exposure to environmental stressors such as prolonged dry spells, erratic rainfall, and occasional extreme weather events. These conditions are associated with reduced soil moisture, declining yields, and increased incidence of pests and diseases such as Banana Bacterial Wilt and Black Sigatoka, as well as pests including banana weevils, thrips and nematodes. Kyabugimbi subcounty exemplifies these dynamics in that the area is historically characterized by favorable rainfall and fertile soils, has experienced shifts in rainfall distribution, prolonged dry periods, and occasional flooding in recent years [6]. These conditions, as reported by previous studies, are associated with soil moisture deficits, nutrient leaching, soil erosion, and reduced crop vigor. Such environmental stressors are also perceived to influence pest and disease dynamics, further affecting banana productivity and fruit quality. In addition, repeated exposure to these hazards may contribute to changes in soil properties and overall system resilience over time [7].

While extensive research addresses how climate variability impacts Ugandan agriculture, most studies focus on national or regional scales [8]. This macro-level focus overlooks localized farmer experiences and the precise ways environmental conditions interact with crop management at finer scales. Specifically, existing literature rarely integrates farmer-reported biometeorological hazards with objective climate records and observed crop impacts in banana-based farming systems. Although recent scholarship emphasizes combining local socio-ecological resilience with climate data, empirical evidence remains scarce for Uganda's perennial banana systems, where direct farmer insights are seldom documented alongside localized environmental metrics.

This study documents farmer-reported biometeorological hazards and their perceived implications for banana production in Kyabugimbi subcounty using household surveys, key informant interviews, and contextual climate observations. By integrating farmer experiences with descriptive climate observations, it provides locally grounded insights into hazard patterns and their implications for banana production systems. Rather than testing causal relationships between climate variables and agricultural outcomes, the study adopts a descriptive approach that emphasizes farmer-reported experiences and their contextual significance within a localized setting. Empirically, it contributes localized evidence on biometeorological hazards in banana systems, while theoretically engaging with broader scholarship on climate variability and smallholder agriculture, farmer perceptions and local knowledge, and socio-ecological understandings of vulnerability and adaptation, with particular emphasis on the role of experiential knowledge in shaping how environmental risks are interpreted and managed. The paper is structured into three main sections: the next section presents the methodology, describing sampling and analytical procedures; this is followed by the results section, which presents key empirical findings; and the discussion section, where the implications for practice are interpreted, followed by conclusions and recommendations.

2 Literature review and conceptual framework

Agricultural production systems are increasingly affected by environmental variability through changes in rainfall patterns, temperature conditions, and the occurrence of extreme events, with implications for productivity, livelihoods, and adaptation capacity [9]. However, environmental stress does not translate directly into production outcomes. Recent scholarship emphasizes that agricultural vulnerability and resilience emerge through interactions among ecological processes, farmer agency, and institutional conditions [10]. Within banana systems, environmental variability has been associated with moisture stress, changing pests and disease dynamics, and production uncertainty [11]. Banana production is particularly sensitive to water availability due to the crop's continuous growth requirements and dependence on relatively stable moisture conditions [5]. At the same time, adaptation outcomes are shaped not only by environmental conditions but also by socio-economic realities. Recent evidence shows that adaptation in banana systems remains constrained by socio-economic conditions even where environmental adaptation options exist [12].

Drawing on these insights, this study adopts a socio-ecological conceptual framework that explains banana production outcomes emerging from interactions among environmental variability, farmer-reported biometeorological hazards, socio-economic conditions, and farmer response strategies (Fig. 1). Environmental variability, including rainfall and temperature fluctuations, is associated with farmer-reported hazards such as drought, erratic rainfall, windstorms, pests, and diseases. These hazards are linked to perceived changes in plantation condition, yield stability, and overall production performance. The framework further recognizes socio-economic factors, including extension access, education, income, farm size, and cooperative membership, as conditions that shape adaptive capacity and influence how production risks are experienced and managed. Survey and interview data were therefore used to examine relationships among reported hazards, production outcomes, adaptation responses, and socio-economic characteristics within the study area.

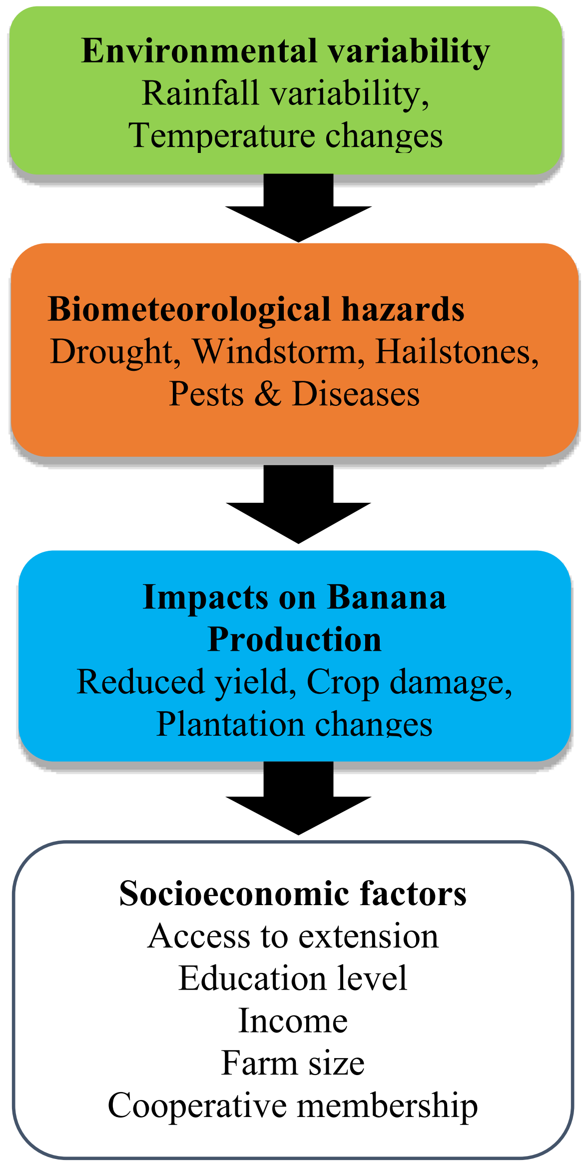

Fig. 1 Literature-informed conceptual framework illustrating the relationships among environmental variability, farmer-reported biometeorological hazards, adaptation responses, socio-economic conditions, and banana production outcomes

3 Methods

3.1 Study area

The study was conducted in Kyabugimbi subcounty, Bushenyi district in the southwestern part of Uganda (Fig. 2). Bushenyi district, located at 00°32′S, 30°11′E, spans altitudes of 910 to 2,500 m above sea level and covers a total area of 708 km^2, of which 698.6 km^2 is land. It is bordered by Rubirizi district to the northwest, Buhweju district to the northeast, Sheema district to the east, Mitooma district to the south, and Rukungiri district to the west. Ishaka, the district's main town, is situated 75 km northwest of Mbarara city, the largest urban center in the Ankole region, and approximately 337 km from Kampala, the national capital. The district experiences a tropical climate with moderate temperatures ranging from 17 °C to 27 °C and a bimodal rainfall pattern, with rainy seasons from

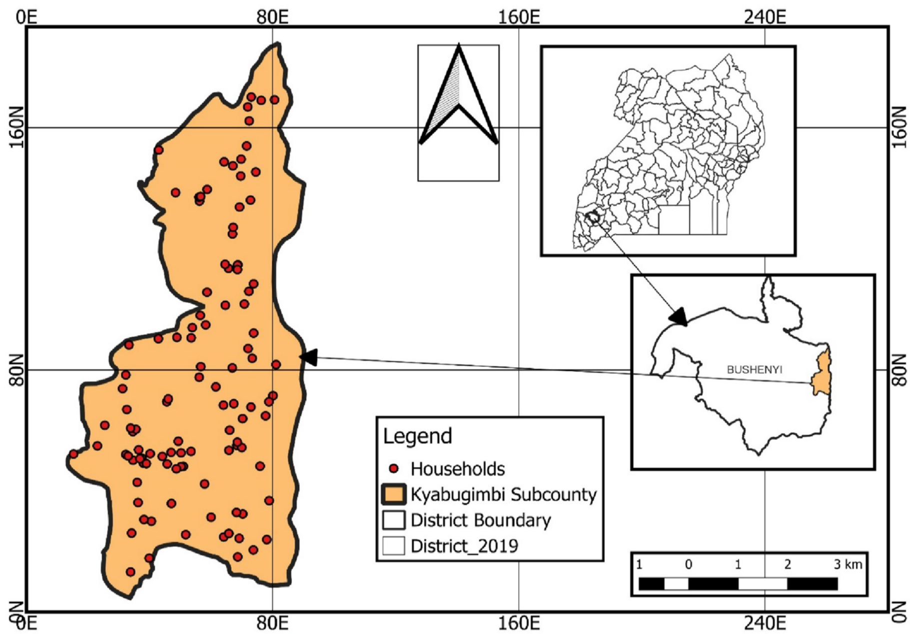

Fig. 2 Area map of Kyabugimbi subcounty, Bushenyi district

February to April and September to December. Annual rainfall ranges between 1,000 and 1,500 mm, and humidity remains moderately high throughout the year [13].

Bushenyi's soils are predominantly fertile, loamy to clay-loam in texture, and derived from volcanic parent material rich in organic matter, offering good water retention and favorable conditions for crop growth [14]. Nevertheless, soil fertility in some areas has declined due to continuous cultivation without adequate nutrient replenishment. The district supports diverse agricultural production, with banana, tea, and coffee being the principal crops grown on both smallholder and commercial scales. The combination of fertile soils, favorable climate, and reliable rainfall underpins the suitability of Bushenyi for high-value perennial crops and mixed farming systems.

3.2 Study scope and research design

This study examined farmer-reported biometeorological hazards and their impacts on banana production in Kyabugimbi subcounty over the period 2014–2024. The research focused on registered banana farmers, with a minimum of ten years of farming experienced, who represent the most consistently active producers within the subcounty and are engaged in sustained banana production. This selection ensured that respondents had adequate experience reporting on long-term hazard occurrence and reduced the inclusion of transient or marginal producers with limited production histories. A mixed-methods approach was employed, combining descriptive and analytical techniques [15]. Kyabugimbi subcounty in Bushenyi district was purposively selected, while participating farmers were randomly sampled using the lottery method of simple random sampling from a list of registered banana farmers across the three parishes.

Primary data were collected using household questionnaires, complemented by Key Informant Interviews with the District Agricultural Officer, the subcounty Extension Officer, Local Council Chairpersons, and the leader of the Kyabugimbi Empango Banana Cooperative Society. To reduce recall bias associated with reported hazard occurrence, respondents were asked to classify the frequency of major hazards using categorical scales (rarely, occasionally, frequently) rather than exact counts. In addition, meteorological data from the Bushenyi Weather Station (2014–2024) were analyzed to provide contextual information on rainfall and temperature variability. These data were used to describe observed climatic patterns alongside farmer-reported experiences. Key informant interviews provided further insights into banana production practices and local environmental conditions. Formal climate trend analyses such as the Mann-Kendall trend test, Sen's slope estimation, rainfall anomaly analysis, and the Standardized Precipitation Index (SPI) were not conducted because household survey responses were not temporally aligned with climate observations and the study objective was descriptive rather than predictive or causal.

3.3 Sampling procedure and sample size determination

The study employed purposive and simple random sampling techniques [16]. Bushenyi district was purposively selected due to its prominence in banana production in southwestern Uganda, while Kyabugimbi subcounty was chosen for its historical significance in banana cultivation and its exposure to climate-related hazards. Notably, heavy rains in 2015 and a variegated grasshopper outbreak in 2021 severely affected banana plantations already stressed by drought [6]. All the three parishes of Bijengye, Kajunju, and Kyeigombe, were purposively included. The target population consisted of banana farmers with at least ten years of experience and a minimum of one acre of plantations, regardless of cooperative membership. While members of organized groups benefit from collective support and access to training, non-members were included because they can adopt innovations through peer learning, and climate hazards affect all farmers equally [17].

Participants were selected using the lottery method of simple random sampling to ensure each farmer had an equal chance of selection. Farmers in each parish were assigned codes, which were written on papers, folded, mixed, and drawn randomly to match selected farmers. According to Kyabugimbi subcounty records, there were 211 registered banana farmers: 48 in Bijengye, 37 in Kyeigombe, and 126 in Kajunju. Using a 95% confidence level and 5% margin of error, the required sample size for each parish was determined using the Krejcie and Morgan (1970) formula [18].

$$S = \frac{\mathrm{X}^2.\ \mathrm{N}.\ \mathrm{p}.\ ((1\ -\ \mathrm{p})}{\mathrm{E}^2.\ ((\mathrm{N}\ -\ 1)\ +\ \mathrm{X}^2.\ \mathrm{p}.\ (1\ -\ \mathrm{p}))}$$

where; S =Required sample size. X^2 = The value from the chi-square distribution for 1 degree of freedom at the desired confidence level. N =Population size. p =Estimated proportion of the population. E =Desired margin of error.

Consequently, 43 farmers were randomly selected from Bijengye parish, 34 from Kyeigombe, and 95 from Kajunju, resulting in a total of 172 banana farmers. To gain deeper insights into banana production dynamics and climate variability in the area, six Key Informants were also interviewed, including the Bushenyi District Agricultural Officer, the Subcounty Extension Officer for Kyabugimbi, the Local Council Chairpersons of each parish, and the leader of a banana farmer group or cooperative. This brought the total number of study participants to 178.

3.4 Data collection and analysis

Data were collected using semi-structured household questionnaires administered to selected banana farmers to capture information on the types, frequency, and perceived severity of reported biometeorological hazards affecting banana production. The questionnaires combined structured questions with open-ended responses to allow flexibility and capture detailed farmer experiences [19]. To enrich and contextualize the findings, Key Informant Interviews were conducted with the Agricultural Officer, Extension Officer, Local Council Chairpersons from each parish, and the leader of the banana cooperative. These interviews provided additional insights into hazard experiences, agronomic practices, and institutional support dynamics.

The study also utilized secondary climate data. Meteorological records on rainfall and temperature for Bushenyi district (2014–2024) were obtained from the Bushenyi Automatic Weather Station in Nyaruzinga. These data were used to describe general climate patterns over the study period. Where applicable, these climate indicators were compared descriptively with farmer-reported hazard frequencies to provide contextual interpretation of observed patterns.

Quantitative data from questionnaires were coded and entered into IBM SPSS Version 25.0 for analysis. Descriptive statistics, including frequencies and percentages, were used to summarize reported hazard occurrence. Chi-square tests were applied to examine associations between parish location and reported hazard occurrence and impacts on banana production. Hazard prevalence was computed as the proportion of reported occurrences relative to the total number of respondents. Spatial variation in reported hazards and impacts was assessed through parish-level cross-tabulations and interpreted in relation to local environmental characteristics such as topography, land use, and drainage. Independent variables included farmer demographic characteristics and resource access, while dependent variables captured reported adaptation practices such as agroforestry, soil moisture conservation, altered planting dates, and pest and disease management. Qualitative data from Key Informants were transcribed and analyzed thematically using NVivo to identify recurring patterns in reported hazards, crop responses, and adaptation strategies. This study employs descriptive statistical techniques, including frequencies and cross-tabulations, to analyze farmer-reported hazards and impacts. Although climatic data were reviewed to provide contextual background, no formal time-series analysis, climate trend testing, or predictive modelling was conducted. The study does not attempt to statistically link climate metrics to hazard occurrence at the household level. Household-level data were not temporally aligned with specific climate observations, limiting the feasibility of causal or regression-based analyses.

Ethical approval for the study was obtained from the Mbarara University of Science and Technology Research Ethics Committee, and the study was registered with the Uganda National Council for Science and Technology (UNCST). Informed consent was obtained from all participants, with assurances of anonymity, confidentiality, voluntary participation, and the right to withdraw at any time. All data were securely stored and used solely for research purposes.

4 Results

The results presented are based on descriptive analyses of farmer-reported data and should be interpreted as indicative of local experiences rather than statistically modelled relationships between climate variables and hazard outcomes.

4.1 Demographic characteristics of participants

The study included 172 banana farmers. These included 95 male and 77 female respondents representing 55.2% and 44.8% respectively (Table 1). 87.8% of the participants were married, 1.7% had divorced, 8.1% were widowed and only 2.3% were still single. In addition, 34.9% of the participants were 55 years and above, 26.2% were aged between 45 and 54, 20.9% aged between 35 and 44, 15.1% aged between 25 and 34 while 2.9% of the participants were aged below 25 years. In terms of literacy levels, 23.8% of the participants had no formal education, 37.2% had only attained primary education, 27.3% had attained secondary education, 5.2% had technical education while only 6.4% had university education. On the other hand, only 20.9% of the participants belonged to a Co-operative society, while only 11% of the participants belonged to a farmer association or group (Table 1).

4.2 Prevalence and severity of biometeorological hazards in Kyabugimbi subcounty

Drought emerged as the most severe biometeorological hazard affecting banana production in Kyabugimbi subcounty, reported by 44.9% of respondents (144 responses). It was associated with soil moisture deficits, stunted growth, and early ripening, indicating its strong influence on banana crop performance. Most respondents identified 2023 as the most recent severe drought period, showing elevated temperatures exceeding 27 °C during August of that year (Fig. 3).

Other reported hazards included windstorms (19.6%), hailstorms (14.0%), and hailstones (14.0%), while flooding was the least reported at 1.2% (Fig. 4). This low percentage

Table 1 Demographic characteristics of respondents

Variable	Characteristic	Frequencies (n) = 172	Percentage (%)
Gender	Male	95	55.2
	Female	77	44.8
Age	Below 25	5	2.9
	25–34	26	15.1
	35–44	36	20.9
	45–54	45	26.2
	Above 55	60	34.9
Marital status	Single	4	2.3
	Married	151	87.8
	Divorced	3	1.7
	Widowed	14	8.1
Level of education	No formal education	41	23.8
	Primary school	64	37.2
	Secondary school	47	27.3
	Vocational/Technical Training	9	5.2
	Tertiary/University	11	6.4
Membership to Co-operative	Yes	36	20.9
	No	136	79.1
Membership to Farmer Associations	Yes	19	11.0
	No	153	89.0

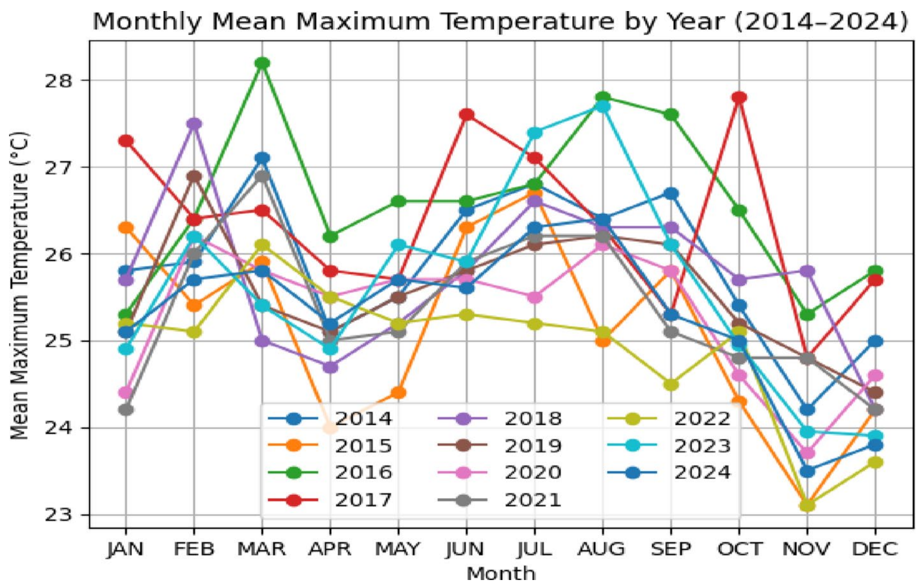

Fig. 3 Mean maximum temperatures for Bushenyi district (2014–2024)

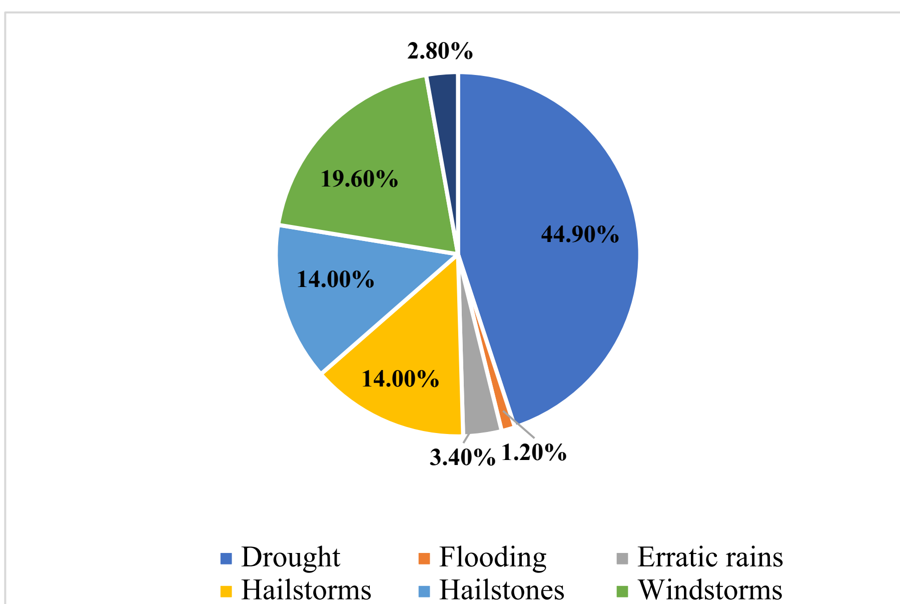

Fig. 4 Climate variability biometeorological hazards reported in Kyabugimbi

of reported flooding corresponds with the secondary rainfall data shown in Fig. 5, which indicate stable annual and seasonal rainfall totals relative to long-term averages and an absence of extreme rainfall events over the past decade. The bold values in Table 2 indicate the total number of times each biometeorological hazard was reported by the farmers.

The spatial distribution of reported hazards varied across the three parishes (Table 2). Drought was consistently the most frequently reported hazard in all parishes. Storm-related hazards, including windstorms, hailstorms, and hailstones, were more commonly reported in Kajunju Parish compared to Kyeigombe and Bijengye. In contrast, rainfall-related hazards such as flooding and erratic rainfall were less frequently reported across

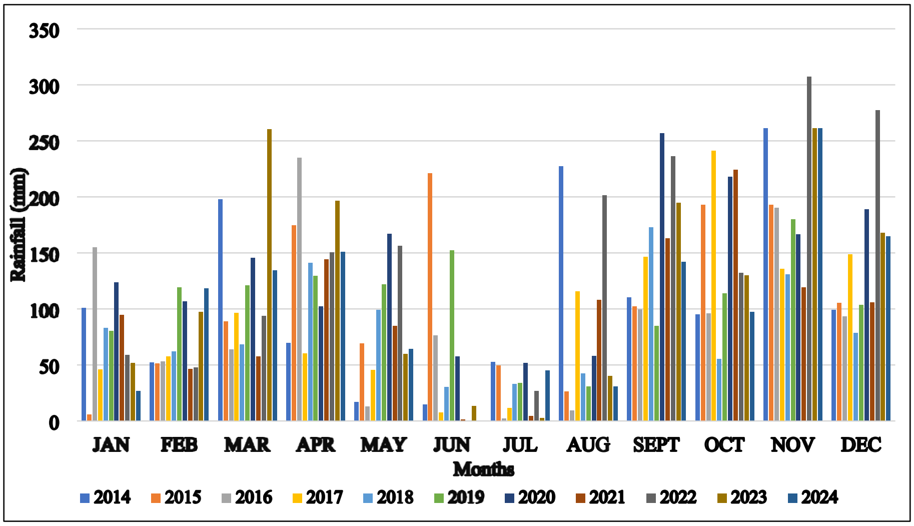

Fig. 5 Mean monthly rainfall for Bushenyi district (2014–2024)

Table 2 Association between biometeorological hazards' prevalence and parishes of Kyabugimbi (collapsed categories)

Parish	Drought	Rainfall-related hazards (flooding and erratic rains)	Storm-related hazards (hailstorms, hailstones, and windstorms)	Land degradation (soil erosion)	Row total	X^2	*p*-value
Kajunju	89	11	112	9	221	16.0	0.014
Kyeigombe	21	3	26	0	50		
Bijengye	34	1	15	0	50		
Column total	**144**	**15**	**153**	**9**	321		

Frequencies represent households reporting each hazard; multiple responses were allowed

Table 3 Farmer-reported frequency of occurrence of biometeorological hazards (% of respondents)

Frequency of occurrence	Drought (%)	Flooding (%)	Erratic rains (%)	Hailstorms (%)	Hailstones (%)	Windstorms (%)	Soil erosion (%)
Every season	56.0	18.1	37.5	55.1	59.3	53.3	52.2
Every year	30.0	9.1	18.8	28.4	25.8	31.3	32.2
Rarely occurs	24.2	8.1	16.9	26.4	24.4	25.4	25.6
Never occurs	1.0	0.0	0.6	1.1	2.0	1.0	2.2

Percentages are based on the number of respondents reporting each hazard type. Multiple responses were allowed because farmers reported perceived occurrence frequencies over the 10-year study period

all areas. Soil erosion was reported only in Kajunju Parish. A Chi-square test of independence revealed a statistically significant association between parish and the type of hazard reported (χ^2 = 16.0, df = 6, p = 0.014), indicating that the distribution of farmer-reported hazards differed across the study locations (Table 2).

4.2.1 Frequency of occurrence of biometeorological hazards in Kyabugimbi

Table 3 presents the farmer-reported frequency of occurrence of biometeorological hazards in Kyabugimbi subcounty. Drought was the most frequently reported hazard, with 56.0% of respondents indicating that it occurred every season and 30.0% reporting that it occurred every year. In this study, drought was defined based on

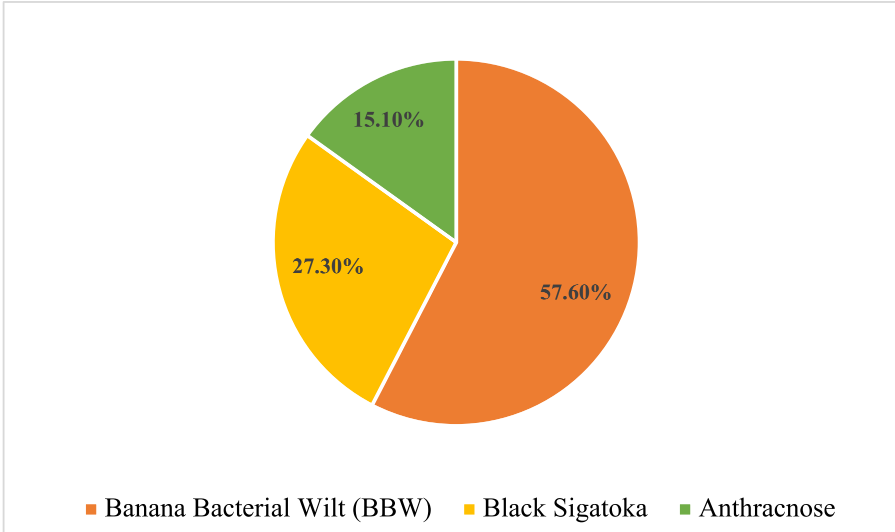

Fig. 6 Prevalence of banana diseases

Table 4 Relationship between prevalence of banana diseases and parishes

Parishes	Banana Bacterial Wilt (BBW)	Black Sigatoka	Anthracnose	X^2	*p*-value
Kajunju	60	19	18	14.847	0.005
Kyeigombe	16	16	0		
Bijengye	23	12	8		
Total	99	47	26		

farmer perception as periods of prolonged water scarcity that negatively affected banana growth, regardless of whether such periods coincided with the normal dry season. Windstorms, hailstorms, and hailstones were also commonly reported hazards. More than half of the respondents indicated that hailstones (59.3%), hailstorms (55.1%), and windstorms (53.3%) occurred every season. In contrast, flooding was the least frequently reported hazard, with only 18.1% of respondents indicating seasonal occurrence. Erratic rainfall and soil erosion were also reported less frequently compared to drought and storm-related hazards.

A considerable proportion of respondents further reported that drought, windstorms, and hail-related hazards occurred every year, while fewer respondents reported flooding and erratic rainfall on a regular basis. Reports under the "rarely occurs" and "never occurs" categories were generally low across all hazard types, indicating that most farmers had experienced at least one form of biometeorological hazard during the 10-year reference period. Generally, the findings demonstrate variation in the perceived frequency of occurrence of different biometeorological hazards within the study area as demonstrated in Table 3.

4.2.2 Prevalence of banana diseases in parishes of Kyabugimbi subcounty

Banana Bacterial Wilt (BBW) was the most prevalent disease overall at 57.6% ($n = 99$), followed by Black Sigatoka at 27.3% ($n = 47$) and Anthracnose at 15.1% ($n = 26$) (Fig. 6). Kajunju parish recorded the highest number of BBW cases ($n = 60$) and also exhibited relatively high occurrences of Black Sigatoka ($n = 19$) and Anthracnose ($n = 18$), indicating a comparatively diverse disease burden. In Kyeigombe, BBW ($n = 16$) and Black

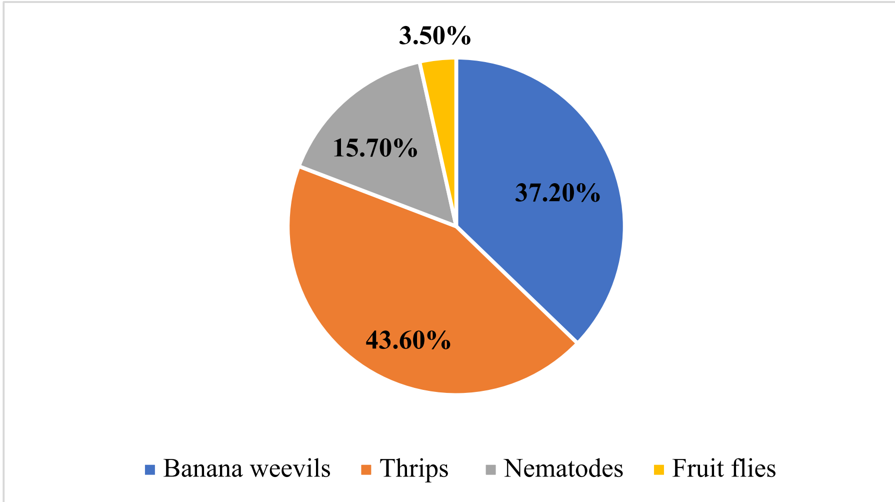

Fig. 7 Prevalence of banana pests in Kyabugimbi

Table 5 Association between banana pests and parishes of Kyabugimbi

Parishes	Banana weevils	Nematodes	Rust thrips	Fruit flies	X^2	*p*-value
Kajunju	36	17	38	6	11.174	0.083
Kyeigombe	8	7	17	0		
Bijengye	20	3	20	0		
Total	64	27	75	6		

Sigatoka ($n = 16$) were reported at similar levels, while Anthracnose was absent. Bijengye parish showed an intermediate pattern, with BBW remaining dominant ($n = 23$) alongside moderate occurrences of Black Sigatoka ($n = 12$) and Anthracnose ($n = 8$). Pearson's Chi-square test confirmed a statistically significant association between parish and banana disease occurrence ($\chi^2 = 14.847$, $p = 0.005$). This demonstrates that disease prevalence was not evenly distributed across the subcounty as illustrated in in Fig. 6 below.

4.2.3 Prevalence of banana pests in Kyabugimbi

The results in Fig. 7 below show that Thrips were the most dominant pest across all the three parishes (43.6%). Kajunju parish reported the highest number of cases ($n = 38$), followed by Bijengye ($n = 20$) and Kyeigombe ($n = 17$). Banana weevils were also widely reported (37.2%), particularly in Kajunju ($n = 36$) and Bijengye ($n = 20$), while nematode infestations were less common and unevenly distributed (15.7%), with higher occurrences in Kajunju ($n = 17$) compared to Kyeigombe ($n = 7$) and Bijengye ($n = 3$). Fruit flies were rare, reported only in Kajunju ($n = 6$, 3.5%). Pearson's Chi-square test was performed to establish whether the distribution of banana pests differed significantly across parishes. The analysis indicated no statistically significant association between parish and pest prevalence ($\chi^2 = 11.174$, $p = 0.083$), thus, the observed numerical differences are descriptive rather than statistically supported (Table 5).

4.2.4 Impacts of farmer-reported biometeorological hazards on banana production

Drought was identified as the most significant farmer-reported biometeorological hazard affecting banana production in Kyabugimbi subcounty, with multiple associated impacts (Table 6). Across all respondents ($n = 172$), the most frequently reported

Table 6 Association between the impacts of drought on banana and parishes

Parishes	Impact of drought on banana				Total	X²	*p*-value
	Cause stunted growth	Soil moisture loss	Early ripening of banana	Escalates spread of pests and diseases			
Kajunju	25	47	15	10	97	10.458	0.107
Kyeigombe	10	9	7	6	32		
Bijengye	10	27	4	2	43		
Total	45	83	26	18	172		
% Frequency	(26.2%)	(48.2%)	15.1%)	(10.5%)	(100%)		

Table 7 Association between impacts of erratic rains and parishes

Parishes	Impact of erratic rains on banana			Total	X²	*p*-value
	Disruption planting seasons	Causes stress (temperature fluctuation)	Causes irregular yields			
Kajunju	21	13	63	97	7.834	0.098
Kyeigombe	1	4	27	32		
Bijengye	8	9	26	43		
Total	30	26	116	172		
% Frequency	17.4%	15.1%	67.4%	100%		

effect was soil moisture loss (48.2%), followed by stunted growth (26.2%), early ripening (15.1%), and increased pest and disease incidence (10.5%). Disaggregated by parish, Kajunju recorded the highest counts of soil moisture loss ($n = 47$) and stunted growth ($n = 25$), while Kyeigombe and Bijengye reported lower frequencies, although the overall pattern was similar. A Chi-square test of independence (χ^2 = 10.458, $p = 0.107$) indicated no statistically significant differences in drought impacts across parishes.

Erratic rainfall was reported to affect banana production primarily through irregular yields, accounting for 67.4% of responses (Table 7). Other reported effects included disruption of planting seasons (17.4%) and plant stress associated with temperature and microclimate fluctuations (15.1%). Across the three parishes, respondents reported three main effects: disruption of planting seasons ($n = 30$), plant stress ($n = 26$), and irregular yields ($n = 116$) (Table 7). In Kajunju ($n = 97$), 21 respondents reported planting disruption, 13 reported plant stress, and 63 cited irregular yields. In Kyeigombe ($n = 32$), 1 respondent reported planting disruption, 4 reported plant stress, and 27 cited irregular yields. In Bijengye ($n = 43$), 8 respondents reported planting disruption, 9 reported plant stress, and 26 cited irregular yields. A Chi-square test (χ^2 = 7.834, $p = 0.098$) indicated no statistically significant differences in reported impacts across parishes.

Hailstorms were reported to affect banana production mainly through physical damage to leaves (82.6%). Uprooting of banana mats was reported by 12.8% of respondents, while 4.7% indicated fruit bruising affecting marketability. In Kajunju ($n = 97$), 79 respondents reported physical damage, 13 reported uprooting, and 5 reported bruising. In Kyeigombe ($n = 32$), 27 reported physical damage and 5 reported uprooting, with no reports of bruising. In Bijengye ($n = 43$), 36 respondents reported physical damage, 4 reported uprooting, and 3 reported bruising. A Chi-square test (χ^2 = 2.217, $p = 0.607$) indicated no statistically significant association between parish and reported hailstorm impacts (Table 8). Hailstones were similarly reported to cause physical damage to banana leaves (83.1%), while 16.9% of respondents associated them with fruit bruising that

Table 8 Association between the impacts of hailstorm and parishes

Parishes	Impact of hailstorms on banana			Total	X^2	*p*-value
	Physical damage of leaves and plant	Fruit bruising, limiting marketability	Uprooting the entire mat			
Kajunju	79	5	13	97	2.217	0.607
Kyeigombe	27	0	5	32		
Bijengye	36	3	4	43		
Total	142	8	22	172		
% Frequency	82.6%	4.7%	12.8%	100%		

Table 9 Association between the impacts of hailstones and parishes

Parishes	Impact of hailstones on banana		Total	X^2	*p*-value
	Physical damage of banana leaves	Fruit bruising, limiting marketability			
Kajunju	78	19	97	1.804	0.406
Kyeigombe	29	3	32		
Bijengye	36	7	43		
Total	143	29	172		
% Frequency	83.1%	16.9%	100%		

Table 10 Relationship between the impact of windstorms and parishes

Parishes	Impact of windstorms on banana			Total	X^2	*p*-value
	Uproots banana plants	Pseudostem and plant breakage	Leaf tearing and defoliation			
Kajunju	20	77	0	97	7.402	0.116
Kyeigombe	6	25	1	32		
Bijengye	11	29	3	43		
Total	37	131	4	172		
% Frequency	21.5%	76.2%	2.3%	100%		

reduced marketability. Overall, 143 respondents reported leaf damage and 29 reported bruising (Table 9). In Kajunju, 78 respondents reported physical damage and 19 reported bruising. In Kyeigombe, 29 reported physical damage and 3 reported bruising, while in Bijengye, 36 reported physical damage and 7 reported bruising. A Chi-square test (χ^2 = 1.804, $p = 0.406$) showed no statistically significant differences across parishes.

Windstorms were reported to affect banana production mainly through pseudostem and plant breakage (76.2%). Uprooting was reported by 21.5% of respondents, while 2.3% reported leaf tearing or defoliation (Table 10). Of the 172 respondents, 131 reported breakage, 37 reported uprooting, and 4 reported defoliations. In Kajunju ($n = 97$), 77 respondents reported breakage and 20 reported uprooting. In Kyeigombe ($n = 32$), 25 reported breakage, 6 reported uprooting, and 1 reported defoliation. In Bijengye ($n = 43$), 29 reported breakage, 11 reported uprooting, and 3 reported defoliations. A Chi-square test (χ^2 = 7.402, $p = 0.116$) indicated no statistically significant variation across parishes.

Regarding soil erosion, most respondents (89.5%) reported no noticeable effects. A smaller proportion (9.9%) indicated topsoil loss, while 0.6% reported mulch destruction. In Kajunju ($n = 97$), 13 respondents reported topsoil loss and 1 reported mulch loss, while 83 reported no effects. In Kyeigombe ($n = 32$), 3 reported topsoil loss and 29 reported no effects. In Bijengye ($n = 43$), 1 respondent reported topsoil loss and 42

Table 11 Relationship between the impact of soil erosion and parishes

Parishes	Impact of soil erosion on banana			Total	X^2	*p*-value
	Removes top soil	Removes/destroys mulch	No effect faced			
Kajunju	13	1	83	97	4.975	0.290
Kyeigombe	3	0	29	32		
Bijengye	1	0	42	43		
Total	17	1	154	172		
% Frequency	9.9%	0.6%	89.5%	100%		

Table 12 Association between impacts of rust thrips and parishes

Parishes	Impact of rust thrips		Total	X^2	*p*-value
	Damages fruit skin	Reduces quality and marketability of bananas			
Kajunju	52	45	97	3.848	0.146
Kyeigombe	11	21	32		
Bijengye	19	24	43		
Total	82	90	172		
% Frequency	47.7%	52.3%	100%		

Table 13 Association between the impact of nematodes on banana and parishes

Parishes	Impact of nematodes on banana			Total	X^2	*p*-value
	Attack and weaken banana roots	Cause yield loss	Cause premature plant death			
Kajunju	25	64	8	97	2.601	0.627
Kyeigombe	5	24	3	32		
Bijengye	7	31	5	43		
Total	37	119	16	172		
% Frequency	21.5%	69.2%	9.3%	100%		

reported no effects. A Chi-square test (χ^2 = 4.975, $p = 0.290$) indicated no statistically significant differences in soil erosion impacts across parishes (Table 11).

4.2.5 Impact of pests on banana

The results on the impacts of rust thrips indicate that farmers experienced two main challenges. Slightly more than half of the respondents (52.3%) reported reduced banana quality and marketability, while 47.7% indicated damage to the fruit skin. In total, 90 respondents reported reduced quality and marketability, while 82 reported fruit skin damage (Table 12). At parish level, Kajunju recorded 52 cases of fruit skin damage and 45 cases of reduced marketability. In Kyeigombe, 11 respondents reported fruit skin damage and 21 reported reduced marketability, while in Bijengye, 19 respondents reported skin damage and 24 reported reduced quality. A Chi-square test of independence (χ^2 = 3.848, $p = 0.146$) indicated no statistically significant association between parish and the type of rust thrips impact reported.

The impacts of nematodes on banana production were primarily reported as yield loss (69.2%). Other effects included root weakening (21.5%) and premature plant death (9.3%). Out of 172 respondents, 119 reported yield loss, 37 reported root damage, and 16 reported premature plant death (Table 13). In Kajunju ($n = 97$), 64 respondents reported yield loss, 25 reported root weakening, and 8 reported premature death. In Kyeigombe ($n = 32$), 24 reported yield loss, 5 reported root weakening, and 3 reported premature death. In Bijengye ($n = 43$), 31 respondents reported yield loss, 7 reported root damage,

Table 14 Association between impacts of weevils on banana and parishes

Parish	Impact of banana weevils			Total	X²	p-value
	Reduce yields	Creation of bores/holes in the corm	Increase susceptibility to lodging/falling			
Kajunju	87	6	4	97	2.886	0.577
Kyeigombe	29	1	2	32		
Bijengye	41	2	0	43		
Total	157	9	6	172		
% Frequency	91.3%	5.2%	3.5%	100%		

Table 15 Association between Black Sigatoka impact and parishes

Parishes	Impact of Black Sigatoka			Total	X²	p-value
	Damages leaves	Cause yield loss	Affects fruit filling			
Kajunju	29	68	0	97	5.586	0.232
Kyeigombe	6	26	0	32		
Bijengye	15	27	1	43		
Total	50	121	1	172		
% Frequency	29.1%	70.3%	0.6%	100%		

and 5 reported premature death. A Chi-square test (χ^2 = 2.601, $p = 0.627$) showed no statistically significant differences in reported nematode impacts across parishes. Banana weevils were also reported to significantly affect production, with yield reduction identified as the major impact by 91.3% of respondents. A smaller proportion reported corm damage through boreholes (5.2%) and increased susceptibility to lodging (3.5%). In Kajunju ($n = 97$), 87 respondents reported yield reduction, 6 reported corm damage, and 4 reported lodging. In Kyeigombe ($n = 32$), 29 reported yield reduction, 1 reported corm damage, and 2 reported lodging. In Bijengye ($n = 43$), 41 respondents reported yield reduction and 2 reported corm damage, with no reports of lodging. A Chi-square test (χ^2 = 2.886, $p = 0.577$) indicated no statistically significant differences in reported weevil impacts across the three parishes (Table 14).

4.2.6 Impact of disease on banana in Kyabugimbi

Regarding the impacts of Black Sigatoka on banana production, the results indicate that the disease was primarily associated with yield loss (70.3%). Other reported effects included damage to banana leaves (29.1%), while only 0.6% of respondents indicated an effect on fruit filling. At parish level, in Kajunju ($n = 97$), 68 respondents reported yield loss and 29 reported leaf damage, with no reports of fruit filling effects. In Kyeigombe ($n = 32$), 26 respondents reported yield loss and 6 reported leaf damage. In Bijengye ($n = 43$), 27 respondents reported yield loss, 15 reported leaf damage, and 1 reported an effect on fruit filling. Overall, 121 respondents reported yield loss, 50 reported leaf damage, and only 1 reported an effect on fruit filling (Table 15). A Chi-square test of independence (χ^2 = 5.586, $p = 0.232$) indicated no statistically significant association between parish and the reported impacts of Black Sigatoka.

The impacts of Banana Bacterial Wilt (BBW) were predominantly reported as yield loss and reduction (94.2%). A smaller proportion of respondents (5.8%) associated BBW with food security and economic challenges. In Kajunju ($n = 97$), 93 respondents reported yield loss and reduction, while 4 reported food security and economic impacts. In Kyeigombe ($n = 32$), 27 respondents reported yield loss and reduction, and 5 reported

Table 16 Association between the impact of Banana Bacterial Wilt (BBW) and parishes

Parish	Impact of BBW		Total	X^2	*p*-value
	Yield loss and reduction	Food security and economic loss			
Kajunju	93	4	97	7.087	0.029
Kyeigombe	27	5	32		
Bijengye	42	1	43		
Total	162	10	172		
% Frequency	94.2%	5.8%	100%		

food security and economic impacts. In Bijengye ($n = 43$), 42 respondents reported yield loss and reduction, while 1 reported food security and economic impacts. Overall, 162 respondents identified yield loss and reduction as the primary impact of BBW, while 10 reported food security and economic effects (Table 16). A Chi-square test of independence ($\chi^2 = 7.087$, $p = 0.029$) indicated a statistically significant association between parish and the reported impacts of BBW on banana production.

4.2.7 Thematic analysis of perceived biometeorological hazard impacts

The thematic analysis of key informant interview responses generated three major themes regarding the perceived nature and impacts of biometeorological hazards in Kyabugimbi subcounty: (1) increasing duration and severity of drought, (2) adverse effects on banana productivity, and (3) rising livelihood vulnerability and production risk. These themes complement the quantitative findings and provide deeper insight into farmers' lived experiences of climate variability.

Increasing duration and severity of drought

Respondents consistently described drought events as becoming more prolonged and intense, often extending beyond the traditionally expected dry months. This perception reflects changes in seasonal rainfall patterns and increasing climate unpredictability in the subcounty. As one key informant noted, *"Prolonged droughts, sometimes extending up to September, have become a serious problem, especially for those of us without irrigation systems"* (Female KI, Bijengye Parish, 25 February 2025). The reported extension of drought into September indicates delayed onset or early cessation of rains, which disrupts established cropping calendars and farm planning. This qualitative evidence aligns with the quantitative findings, where drought was reported by 44.9% of respondents and recorded as the most frequently cited hazard (806 instances).

Adverse effects on banana productivity

A second recurring theme concerned the negative impact of drought on banana growth and yield performance. Farmers frequently associated prolonged dry spells with visible physiological stress in banana gardens. Reported impacts included reduced bunch size, leaf wilting and premature drying, and slower sucker regeneration and ratoon development.

One key informant explained:

> *My banana plantation no longer produces bigger bunches compared to previous years. The plantation is moisture-stressed and the fingers are small. I used to sell banana suckers to other farmers and earn additional income, but now the plantation is struggling, and I cannot risk losing the few remaining suckers (Male KI, Kajunju Parish, 25 February 2025)*

These observations reflect farmer-perceived declines in productivity and income, reinforcing the quantitative evidence of yield-related challenges associated with drought conditions.

Rising livelihood vulnerability and production risk

Beyond agronomic impacts, respondents expressed concern about the increasing risks associated with reliance on banana farming under changing climatic conditions. Climate variability was perceived not only as an environmental issue but also as a livelihood threat. One key informant remarked:

> *It is now risky to rely solely on banana farming because bananas are easily affected by changing weather events that have become more frequent. I decided to convert part of my banana plantation into coffee so that in case bananas fail, I have an alternative source of income for my family (Male KI, Kyeigombe Parish, 26 February 2025)*

This perspective highlights adaptive behavior among farmers in response to perceived production risks, including crop diversification as a coping strategy to reduce vulnerability and enhance livelihood resilience.

4.2.8 Thematic analysis of the impacts of erratic rainfall on banana production in Kyabugimbi

The thematic analysis of farmer responses regarding erratic rainfall revealed two major themes: (1) irregular yields as a primary consequence and (2) disruption of planting seasons and associated crop stress.

Irregular yields as a primary consequence

The most frequently reported impact of erratic rainfall was irregular banana yields. Farmers consistently observed that unpredictable rainfall patterns disrupted flowering, fruit set, and bunch development, resulting in inconsistent harvests across seasons.

> *The rains have become increasingly unreliable these days. When we expect them in their normal seasons, they do not appear, and at times they come in June, which is supposed to be a dry month. This has made it difficult for us to know when to apply manure, and it has also caused fluctuations in banana harvests. We cannot commit to serious markets because we cannot predict the harvest (Male KI, Kajunju Parish, 22 February 2025)*

These observations highlight how rainfall variability affects not only crop development but also farm management decisions and market participation.

Disruption of planting seasons and microclimate stress

A second theme concerns the disruption of planting schedules. Farmers reported that irregular rainfall patterns often led to delays in planting or replanting, affecting crop establishment, growth synchronization, and overall productivity.

> *Last year, I wanted to expand my banana plantation, but because the rains were on and off, I feared that I could invest in planting and the banana stems dry. I dug the holes, and they have remained open to date, but I will plant when the March-May rains come (Male KI, Kajunju Parish, 22 February 2025)*

This response reflects how rainfall uncertainty influences farmer decision-making and contributes to delayed investment in production activities.

5 Discussion

This study examined farmer-reported biometeorological hazards and their perceived implications for banana production in Kyabugimbi subcounty, southwestern Uganda. The findings indicate that banana production challenges are experienced through interacting environmental, biological, and management-related processes rather than through isolated hazard events. Drought emerged as the most prominent reported hazard, followed by rainfall irregularities, wind-related disturbances, pest occurrence, and disease pressures. These findings provide localized insight into how environmental variability is interpreted and managed within smallholder farming systems.

The findings further demonstrate that farmer experiences provide an important perspective for understanding environmental change at local scales. Farmer-reported observations capture dimensions of agricultural stress that may not be fully represented through aggregated climatic indicators alone, particularly in production systems where outcomes are shaped by interactions among environmental conditions, landscape characteristics, and management practices. This supports broader arguments within adaptation and resilience scholarship that experiential knowledge contributes valuable evidence for understanding vulnerability and designing context-sensitive interventions [20].

5.1 Farmer-reported hazard patterns and environmental exposure in banana systems

The predominance of drought in farmer reports suggests that water availability remains one of the most important constraints affecting banana production in the study area. Farmers associated prolonged dry conditions with declining plantation performance, uneven crop development, and reduced production reliability. These observations indicate that environmental stress influences production not only through direct crop responses but also through disruptions in planning, labor allocation, and confidence in seasonal production cycles. These findings are consistent with previous studies showing that banana production depends heavily on relatively stable moisture conditions because of continuous growth requirements and substantial water demand [21]. Similar findings across East African agricultural systems indicate that drought and rainfall variability increasingly shape production stability and influence farmer perceptions of agricultural risk [22]. Research on climate-sensitive agricultural systems also suggests that moisture stress extends beyond immediate crop losses by influencing investment decisions and production planning processes [16].

The spatial variation observed in reported hazards further suggests that environmental exposure differs across local landscapes. Farmers linked greater exposure to windstorms and hail-related hazards with reduced vegetation cover and changing land-use conditions. Although these relationships were not directly assessed through land-use analysis, they reflect local interpretations of how landscape conditions shape production risks. Comparable observations have been documented in agroecological studies demonstrating that vegetation structure and land management practices contribute to buffering environmental disturbances and regulating local microclimates [23]. Socio-ecological resilience literature similarly emphasizes that vulnerability emerges through interactions between ecological processes and management systems rather than climatic conditions alone [24]. These findings imply that adaptation planning for banana systems should move beyond climate-focused interventions toward broader landscape and production management approaches. Supporting vegetation retention, ecological buffering functions, and locally responsive extension services may contribute to reducing environmental exposure while strengthening production resilience.

5.2 Moisture stress and rainfall variability as central constraints to banana production

Farmer reports indicate that moisture-related stress represents one of the most significant constraints affecting banana productivity in Kyabugimbi. Reported impacts including reduced vigor, irregular yields, slower plantation recovery, and premature ripening suggest that variability in water availability directly influences production performance and farmer decision-making. Importantly, farmers emphasized uncertainty in rainfall timing rather than rainfall absence alone. This distinction suggests that production challenges emerge not only from reduced rainfall quantities but also from changes in seasonal distribution and unpredictability in rainfall onset and duration. Such experiences indicate that farmers respond to broader shifts in production conditions rather than isolated climatic anomalies.

These findings align with evidence demonstrating that banana productivity is strongly influenced by stable moisture availability and that fluctuations in rainfall affect nutrient uptake, crop development, and physiological performance [22]. Climate-sensitive agriculture research increasingly recognizes that shifts in rainfall timing may produce stronger agricultural effects than changes in annual rainfall totals alone [25]. Similar observations have been reported among smallholder farming systems in Uganda and elsewhere in sub-Saharan Africa where rainfall uncertainty affects planting decisions, market participation, and investment behavior [16]. The consistency of these experiences across the study area suggests that interventions aimed at strengthening moisture management may have broad relevance across banana systems. Farmers identified practices including mulching, organic matter application, soil moisture conservation, and water retention as important mechanisms for reducing production risks. These findings, therefore, suggest that extension services should prioritize locally feasible adaptation measures rather than generalized recommendations. Agricultural advisory systems that incorporate local rainfall experiences, crop growth requirements, and farmer knowledge may improve both the effectiveness and uptake of adaptation practices.

5.3 Landscape conditions, biological stressors, and production resilience

The findings indicate that environmental hazards interact with biological stressors and management practices in shaping production outcomes. Farmers did not describe pests and diseases as isolated constraints but instead viewed them as interconnected with broader environmental conditions affecting plantation health and productivity. The concentration of Banana Bacterial Wilt in some locations suggests that management practices, planting material quality, and social coordination may influence disease occurrence and persistence. In contrast, the broader distribution of pests such as rust thrips and banana weevils may reflect continuous host availability and limitations in routine control measures.

These observations correspond with previous studies demonstrating that banana pests and diseases emerge through interactions among environmental conditions, crop management practices, and institutional coordination [26]. Agricultural resilience scholarship similarly emphasizes that ecological disturbances become production risks when combined with management limitations and reduced adaptive capacity [27]. Farmers also associated reduced tree cover with increased exposure to wind and storm-related damage. These observations reflect broader ecological relationships between vegetation cover, microclimate regulation, and crop protection that have been discussed within agroecological scholarship [28]. These findings suggest that strengthening production resilience requires integrated approaches combining disease sanitation, improved planting materials, agroforestry, soil conservation, and collective management practices. Interventions that address environmental and biological stressors simultaneously may generate greater benefits than approaches targeting individual hazards independently.

5.4 Implications for adaptation and agricultural policy

The findings indicate that adaptation within banana production systems is already occurring through incremental adjustments in farm management rather than through large-scale technological transformation. Farmers reported responses including moisture conservation, crop diversification, agroforestry, disease management, and adjustments in production decisions to reduce exposure to environmental stress. These findings align with adaptation scholarship showing that smallholder responses are embedded within socio-ecological contexts and shaped by environmental conditions, institutional support, and household decision-making [27]. Farmer-led adaptation practices increasingly emerge as important pathways for strengthening resilience under environmental variability [29]. However, recent studies also demonstrate that adaptation in banana systems remains constrained by socio-economic conditions even where environmental adaptation options exist [12]. This suggests that effective adaptation depends not only on technical solutions but also on farmers' ability to access knowledge, resources, and institutional support.

From a practical perspective, strengthening soil moisture conservation, coordinated pest and disease management, and agroforestry-based landscape approaches may improve production stability and reduce environmental exposure. Extension services may become more effective when they integrate farmer observations with locally relevant environmental information and support adaptation strategies that reflect local production realities. Localized hazard advisory systems that combine farmer experiences with environmental monitoring may further strengthen decision-making and contribute to more context-sensitive agricultural adaptation planning [30].

5.5 Contribution of the study

This study contributes to the growing literature on climate-sensitive agriculture by providing localized evidence on farmer-reported biometeorological hazards within banana production systems. By emphasizing farmer experiences rather than generalized climate narratives, the study demonstrates the value of documenting how environmental stress is interpreted and managed within specific socio-ecological contexts. The study further contributes by examining environmental hazards together with pest and disease pressures, offering a more integrated understanding of production challenges than approaches that examine these processes independently. The findings therefore provide contextually grounded evidence that may support agricultural extension, adaptation planning, and future research integrating farmer observations with environmental monitoring and longitudinal assessment.

6 Conclusion

This study examined farmer-reported biometeorological hazards and their perceived implications for banana production in Kyabugimbi subcounty, Bushenyi district, southwestern Uganda. The findings indicate that banana production is shaped by interacting with environmental, biological, and management-related stressors rather than by isolated hazard events. Drought emerged as the most prominent reported hazard, while rainfall irregularities, wind-related disturbances, pests, and diseases were also widely identified as influencing production conditions. Farmers reported that these stressors were associated with reduced plantation performance, variability in yields, increased production uncertainty, and challenges in maintaining stable banana production systems. The findings demonstrate that production risks in banana systems are experienced within broader socio-ecological contexts where environmental exposure, landscape conditions, farm management practices, and crop health interact. Farmer observations suggest that vulnerability is influenced not only by hazard occurrence but also by local capacity to respond through production decisions and adaptive management. The reported importance of moisture conservation, crop diversification, agroforestry, and disease management highlights the active role of farmers in responding to environmental pressures and maintaining production under changing conditions.

From a practical perspective, the findings suggest the need to strengthen locally grounded adaptation approaches that support moisture management, coordinated pest and disease control, and landscape-level practices that enhance ecological buffering. Agricultural extension and advisory services may become more effective when they integrate farmer observations with locally relevant environmental information and promote adaptation measures that align with existing farming realities and resource conditions. This study contributes localized evidence to discussions on climate-sensitive agriculture by demonstrating the value of farmer-reported knowledge in understanding environmental stress within banana production systems. Although the findings are specific to Kyabugimbi, they reflect broader challenges experienced across smallholder farming systems facing increasing environmental variability. Future research should build on these findings through longitudinal designs and greater integration of household observations with environmental and climate datasets to strengthen understanding of how interacting stressors influence production outcomes over time. There is also need for studies integrating environmental monitoring and household-level observations to provide stronger explanatory insights.

7 Limitations of the study

While this study provides important insights into the frequency of farmer-reported biometeorological hazards and their impacts on banana production in Kyabugimbi subcounty, certain limitations should be acknowledged. The assessment of hazard occurrence and impacts was based on farmer-reported experiences, which are widely used in agricultural research to capture localized and long-term conditions, but may reflect individual perceptions and recall biases. Additionally, the study largely focused on reported experiences rather than direct physiological or yield measurements, emphasizing farmer-level observations and adaptation patterns rather than biophysical quantification. The analysis was primarily descriptive and did not employ causal modeling, as the study aimed to document patterns and prevalence of reported hazards and associated impacts.

Furthermore, the use of a 10-year reference period may introduce some degree of recall variability; however, it also enabled the capture of longer-term experiences relevant to farmer decision-making and adaptation. In addition, the study did not incorporate remote sensing, land-use analysis, or formal climate trend modelling. Despite these limitations, the study provides empirical evidence on the prevalence of farmer-reported hazards and their impacts on banana production in Kyabugimbi subcounty, Bushenyi district, southwestern Uganda, thereby offering a useful basis for informing localized adaptation planning and guiding future studies that incorporate experimental, longitudinal, or modeling approaches. Regarding limitations/delimitations of the study.

Author contributions

Dickson Muruhara conceived and designed the study, coordinated field data collection, conducted the primary data analysis, and led manuscript writing. Grace Rugunda Kagoro contributed to study design, supervised data collection, and reviewed and edited the manuscript. Ronald Byaruhanga supported data analysis and interpretation and contributed to writing and structuring the results. Robert Bitariho provided methodological guidance, advised on analytical framing, and critically revised the manuscript for intellectual content. John Bosco Nkurunungi contributed to conceptual development, supervising overall research implementation. All authors read and approved the final version of the manuscript.

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Data availability

The data cannot be shared due to the confidentiality of the participants but can be made available upon reasonable and justifiable request.

Declarations

Ethics approval and consent to participate

Ethical approval for this study was obtained from the Mbarara University of Science and Technology Research Ethics Committee, and the study was registered with the Uganda National Council for Science and Technology (UNCST).
In addition, the study adhered to strict ethical guidelines to protect participants' rights and confidentiality. Informed consent was obtained at various stages prior to, during, and following the interviews and all identifiable information was anonymized, particularly when sensitive statements were involved. Ethical considerations also encompassed careful data management and precautions to prevent any potential harm to participants or their organizations. Participation in the study was voluntary, and informed consent was obtained from all participants prior to data collection. Participants were informed about the purpose of the study, procedures involved, and their right to decline participation or withdraw at any stage without consequence.

Consent for publication

All the authors have given their full consent for this article to be published.

Competing interests

The authors declare no competing interests.

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