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Absence of climatic factors influence on the prevalence of COVID-19 in Benin: A spatiotemporal analysis

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ABSTRACT

Epidemiological surveillance of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) infection remains crucial at the waning stage of the pandemic. It helps monitor the persistence of infection within the community and strengthens preparedness for future health crises. The aim of this study was to track the evolution of SARS-CoV-2 infection in southern Benin in 2022, while assessing the impact of climatic factors on disease transmission and severity. SARS-CoV-2 screening was performed using RT-qPCR on nasopharyngeal swabs collected from patients presenting at health centers in Cotonou, Sakété, and Cômè between January and December 2022. Samples that tested positive were sequenced using nanopore sequencing technology. The prevalence of SARS-CoV-2 infection was 8.01% among 4,382 participants. Three distinct variants were identified: Alpha (1%), Eta (8%), and Omicron (53%), along with unclassified variants (38%). No statistically significant association was found between infection status and demographic variables such as age or sex. Furthermore, infection dynamics showed no marked seasonality, suggesting transmission independent of climatic variations. This study highlights the complexity of viral spread in this region and underscores the importance of sustained epidemiological vigilance and preventive measures. These efforts remain essential to control viral transmission, particularly in the presence of circulating variants such as Omicron.

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INTRODUCTION

Respiratory infections are ubiquitous and affect all age groups (Van Doorn and Yu, 2020). They originate from various causes and, in most cases, continue to persist once they appear. Such is the case of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), first reported by the World Health Organization (WHO) in December 2019 following a case of viral pneumonia in Wuhan, Hubei Province (Zhou *et al.*, 2020). This virus belongs to the same category as other influenza-like coronaviruses such as SARS-CoV and Middle East Respiratory Syndrome Coronavirus (MERS-CoV) (Islam *et al.*, 2021). It is transmitted by both asymptomatic and symptomatic infected individuals, primarily via respiratory droplets, and through direct human-to-human contact or contact with contaminated surfaces (Bashir *et al.*, 2020; Elengoe, 2020).

Within a few weeks, the virus had spread worldwide, causing high mortality rates. On March 11, 2020, the WHO officially declared COVID-19 a pandemic and emphasized the urgent need for every country to adopt appropriate measures to control its spread. As of November 2, 2023, more than 700 million cases and 6 million deaths had been reported globally WHO (2023). In Benin, the first case was recorded on March 16, 2020, and the first death occurred on April 6, 2020. By March 9, 2023, national statistics reported 27,999 cases and 163 deaths (World Health Organization, 2023).

Like other RNA viruses, which have higher mutation rates than DNA viruses due to the lower replication fidelity of viral RNA polymerases compared to DNA polymerases, SARS-CoV-2 has undergone mutations and recombinations within its genome. These events led to the emergence of mutant viral populations commonly known as variants. Mutations occurred primarily in the spike glycoprotein, which is critical for viral entry, resulting in increased infectivity, increased transmissibility, and immune escape, sometimes contributing to greater disease severity (Hirabara *et al.*, 2022 ; Rouzioux, 2022).

Although Tahira and colleagues (Tahira *et al.*, 2021) reported no link between pandemic spread and climatic factors, several studies have shown that SARS-CoV-2 transmission is influenced by various abiotic factors, such as climate, temperature, humidity, wind speed, air and water quality, solid interfaces, and frozen food products. Biotic factors, including age, sex, blood group, population density, and behavioral characteristics, also play a significant role (Dalziel *et al.*, 2018; Bashir *et al.*, 2020; Conti and Younes, 2020; Hardy and Flori, 2021).

While many studies worldwide, including in some African countries, have examined factors influencing viral transmission, few have specifically investigated the impact of seasonal variations on the resurgence of infections. To our knowledge, no study in Benin has yet analyzed the influence of seasonal variation on viral spread. However, given the widespread damage to health systems both nationally and internationally, and particularly the increase in respiratory infections, it is crucial to clarify the factors contributing to viral transmission. The present study focuses on the dynamics of SARS-CoV-2 infection in southern Benin and evaluates the impact of climatic factors on disease transmission and severity. This investigation is expected to provide valuable data for the development of improved strategies for infection control and prevention.

MATERIALS AND METHODS

Study design

This was a cross-sectional study conducted from January to December 2022. The sample consisted of 4,382 nasopharyngeal swabs collected from individuals suspected of having COVID-19 or presenting for voluntary screening at health centers in Sakété, Comé, Mènontin, Suru-léré, and other facilities in Cotonou involved in SARS-CoV-2 surveillance during this period. Samples were obtained by inserting a swab through the nostrils into the nasopharynx and collecting cells by rotating the swab against the mucosal surface. The study participants were men, women, and children who presented at the designated collection centers in the selected cities for COVID-19 testing during 2022. No exclusion criteria were applied.

Study procedures

Detection of SARS-CoV-2 in samples

SARS-CoV-2 inactivation and RNA extraction were performed using the QIAGEN kit. The extracted RNA was incorporated into a pre-prepared reaction mixture based on the Daan Gene kit. For each sample, the reaction mixture was subjected to amplification in CFX96 thermocyclers, following the manufacturer's protocol. Fluorescence curves generated after amplification were analyzed to identify positive samples. The latter were preserved at −80°C for genetic material sequencing.

Viral RNA sequencing

RNA from the PCR-positive samples with a cycle threshold (Ct) ≤ 30 was subjected to sequencing. In total, 273 RNA samples were analyzed using Oxford Nanopore sequencing technology. Libraries were prepared with the barcoding kit and Midnight extension, ensuring full genome coverage and accurate variant identification. Sequencing data, generated in FASTQ format, were imported into (https://edge-covid19.edgebioinformatics.org/). This platform, designed for SARS-CoV-2 genomic data analysis, enabled in-depth evaluation and accurate interpretation of genetic variations, thereby facilitating the monitoring and understanding of viral mutations.

Meteorological data

Meteorological data were obtained from three synoptic stations (Cotonou, Sakété, and Comé) through the National Meteorology Bureau of Benin. Two key parameters were considered: temperature and relative humidity, including their minimum, mean, and maximum values.

Data analysis

Data were entered and graphs generated using Microsoft Excel (version 2021). Descriptive statistics were applied, with results expressed as percentages for qualitative variables and as mean ± standard deviation for quantitative variables.

RESULTS

Socio-demographic characteristics of patients in the study

Before SARS-CoV-2 screening, the 4,382 samples were categorized by sex, age, and participants' recruitment site (Table 1). Most individuals were recruited from health centers in Sakété (41%), with majority being women (61%). The mean age of participants was 35 ± 5 years (range: 1–89 years), with the 20–30-year age group being the most represented (29%) and the 80–90-year group the least represented (1%).

Table 1. Sociodemographic profile of study participants

Socio-demographic characteristics		Count	Percentage (%)
Gender	Male	1709	39
	Female	2673	61
Age groups (year)	]0 ; 10]	131	03
	]10 ; 20]	570	13
	]20 ; 30]	1271	29
	]30 ; 40]	701	16
	]40 ; 50]	482	11
	]50 ; 60]	657	15
	]60 ; 70]	351	08
	]70 ; 80]	175	04
	]80 ; 90]	44	01
Sites	Cotonou	920	21
	Sakété	1797	41
	Suru-Léré	745	17
	Comé	88	02
	Ménontin	833	19
Total		4382	100

Prevalence of SARS-CoV-2 infection

The prevalence of infection in the study population was 8.01%, corresponding to 351 positive cases among the 4,382 participants (Fig. 1).

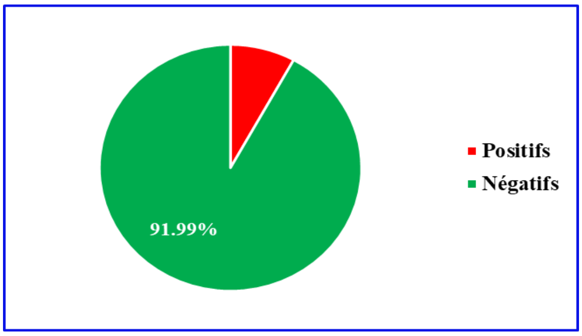

Fig. 1. SARS-CoV-2 infection rate in the study sample

Sociodemographic characteristics of subjects infected with SARS-CoV-2

Most positive cases occurred among women (65%), with the largest proportion recruited from Sakété health centers (51%). The age of infected individuals ranged from 2 to 82 years, with a mean of 33.25 ± 7.85 years (Table 2).

Table 2. Sociodemographic profile of participants infected with SARS-CoV-2

Socio-demographic data of PCR-positive participants		Count	Percentage
Gender	Male	123	35
	Female	228	65
Age groups	]0 ; 10]	42	12
	]10 ; 20]	56	16
	]20 ; 30]	60	17
	]30 ; 40]	72	20.5
	]40 ; 50]	35	10
	]50 ; 60]	49	14
	]60 ; 70]	18	5
	]70 ; 80]	14	4
	]80 ; 90]	5	1.5
Sites	Cotonou	53	15
	Sakété	179	51
	Suru-Léré	49	14
	Comé	11	3
	Ménontin	60	17
Total		351	100%

Distribution of SARS-CoV-2 infection throughout 2022

Monthly infection rates (Fig. 2) varied between 0% and 20%, with an average of 29 positive cases per month. The highest positivity rates and case counts were recorded in February and between August and November 2022.

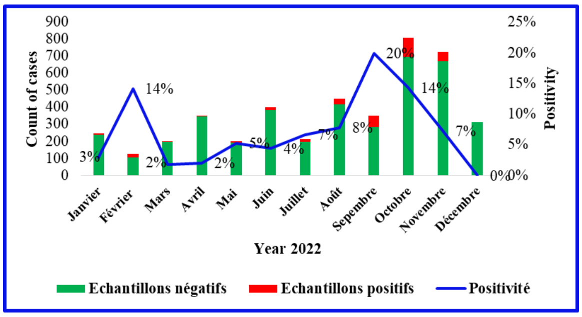

Fig. 2. Monthly evolution of the SARS-CoV-2 infection rate in 2022

Distribution of infection cases according to the variants involved

A total of 173 samples met the quality criteria for bioinformatics analysis, enabling the identification of four variant groups according to the World Health Organization (WHO) classification. These included Alpha, Eta, Omicron, and one unclassified group, accounting for 1%, 8%, 53%, and 38% of samples, respectively (Fig. 3).

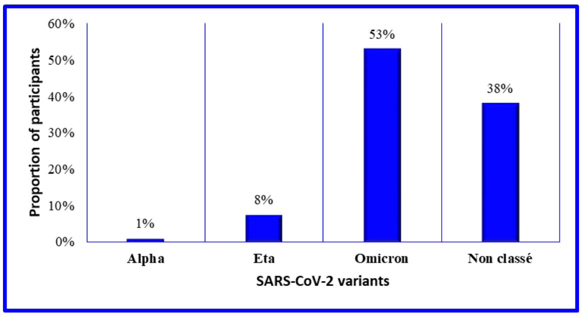

Fig. 3. Distribution of infection cases according to the variants involved

Sociodemographic characteristics of participants in whom variants were identified

Except for participants infected with the Eta variant, most individuals carrying other variant groups were women. The majority of variants were detected in individuals aged 20–30 years (27%) and were primarily associated with samples from Sakété health centers (43%), followed by Mènontin (29%), with proportions ranging from 73% to 83%. The remaining participants with identified variants were travelers preparing to leave the country (Table 3).

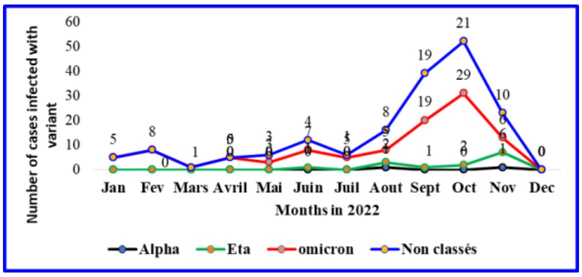

Fig. 4. Infection dynamic around 2022

Seasonal distribution of SARS-CoV-2 variants during the sampling period

In 2022, both Omicron and unclassified variant infections were recorded every month. Cases associated with the Alpha variant were detected from June to November, while Eta variant infections were observed between August and November. These findings illustrate the evolving dynamics of circulating variants throughout the year (Fig. 4).

Table 3. Sociodemographic profile of participants in whom variants were identified

Socio-demographic data		Variants				Total
		Alpha	Eta	Omicron	Non-identified	Percentage (Count)
Gender	Male	0	54%	36%	35%	37% (64)
	Female	100%	46%	64%	65%	63% (109)
Age groups	]0 ; 10]	0%	8%	13%	5%	9% (16)
	]10 ; 20]	0%	15%	15%	6%	12% (20)
	]20 ; 30]	50%	23%	25%	29%	27% (46)
	]30 ; 40]	0%	23%	19%	18%	18% (32)
	]40 ; 50]	0%	8%	12%	17%	13% (23)
	]50 ; 60]	0%	15%	8%	20%	13% (23)
	]60 ; 70]	50%	0%	3%	3%	3% (6)
	]70 ; 80]	0%	8%	3%	2%	3% (5)
	]80 ; 90]	0%	0%	1%	2%	1% (2)
Sites	Cotonou	0%	0%	26%	0%	14% (24)
	Ménontin	0%	31%	14%	52%	29% (51)
	Suru-Léré	100%	69%	0%	17%	13% (22)
	Sakété	0%	0%	59%	32%	43% (75)
	Comé	0%	0%	1%	0%	1% (1)
Total		1% (02)	8% (13)	53% (92)	38% (66)	100% (173)

DISCUSSION

This study aimed to characterize SARS-CoV-2 infection in selected departments of southern Benin during 2022. To this end, a large-scale screening for SARS-CoV-2 was conducted among patients admitted to public health centers in Cotonou, Sakété, and Comé. These sites were selected for their proximity to major points of entry into the country: Cotonou, which is home to the international airport, and Sakété, located near the Nigerian border, a country that alone accounted for more than 61% of SARS-CoV-2 cases reported among Benin's neighboring countries in 2022 (Okoroiwu *et al.*, 2021).

Among the 4,382 participants included in this study, the prevalence of infection was 8.01%. Out of infected individuals, 65% were women reflecting the female overrepresentation in the sample. This female predominance contrasts with findings from other studies in which men were more frequently represented among infected cases (Plaçais and Richier, 2020), but is consistent with the study of Raiah and colleagues (Raiah *et al.*, 2022). We hypothesize that this distribution may reflect factors specific to the local context. For instance, in Benin, women are often more present in healthcare facilities, not only for prenatal visits, but also as caregivers for their children. On the contrary, men may be less likely to promptly seek care due to social norms that discourage health-seeking behaviors, which could explain the overrepresentation of women in our study paticipants.

Our results showed peaks in infection rates in February and September, with relatively high levels maintained between August and November. According to climatic data from the municipalities of origin of the participants, the months of September, October, and November were characterized by average temperatures ranging from 26°C to 28°C, while the mean temperature observed in February was 30°C. Differences across localities generally did not exceed ±1°C. A high prevalence of infections was recorded between September and November, which corresponds to relatively cooler months. February, a warmer month, also showed an elevated positivity rate. In contrast, March and April, with mean temperatures of 28°C to 29°C, recorded very low infection rates.

These findings contradict previous reports suggesting that higher temperatures limit the spread of SARS-CoV-2. According to those studies, viral transmission requires the virus to remain suspended in respiratory droplets in the air for a sufficient duration. At elevated temperatures, droplets become heavier, settle more rapidly onto surfaces or the ground, and therefore travel shorter distances through the air (Jayaweera *et al.*, 2020; McClymont and Hu, 2021). Conversely, small droplets (<100 µm) evaporate quickly in the air before reaching the ground, producing bioaerosol residues that remain suspended for longer periods and can transmit infection if infectious (Jayaweera *et al.*, 2020).

The present results are consistent with studies conducted in China and across 144 regions of Canada, which found no correlation between temperature and viral spread (Jamil *et al.*, 2020; To *et al.*, 2021). Similar findings were also reported in a study conducted in Nigeria between January and April 2020 (Taiwo and Fashola, 2020). We therefore consider that, although temperature may not be a primary determinant, it could nonetheless influence disease transmission. For example, during cooler periods, an increase in sneezing is often observed, which may contribute to enhanced viral spread, particularly when barrier measures are not strictly observed.

Studies suggest that high humidity levels, like temperature, may help reduce the airborne viral load. Boukhari and colleagues observed that countries with the highest numbers of COVID-19 cases were generally those characterized by relatively low humidity levels (Hardy and Flori, 2021). In our study, relative humidity levels ranged between 78% and 88%. The months of February (81%) and September (87%) showed higher infection prevalence, whereas June, with a humidity of 89%, was associated with markedly lower positivity rates.

These findings appear to contradict earlier reports suggesting that high humidity reduces viral load. Instead, they align with the conclusions of 14 out of 37 studies reviewed by Zheng and collaborators, which indicated that the impact of climatic factors on COVID-19 transmission is not uniform and may vary according to contextual factors (Zheng *et al.*, 2021).

Genomic sequencing of viral RNA in our sample revealed the presence of Alpha, Eta, and Omicron variants in Benin during the study period, with Omicron showing particularly high prevalence. Omicron has been found to carry at least 50 mutations compared with the wild-type strain, around 30 of which are located in the spike protein. These mutations significantly increase Omicron's affinity for ACE2 receptors, thereby contributing to its enhanced transmissibility (Sah *et al.*, 2023). Omicron was detected throughout the year and remains, to date, the main circulating variant of concern because of its high transmission potential. In contrast, Alpha and Eta variants were reported between June–November and August–November, respectively. These findings indicate that seasonality does not influence the circulation or predominance of specific variants under given climatic conditions. Moreover, Omicron infection may boost immune responses against other variants, but not against Omicron itself (Sah *et al.*, 2023).

According to our results, with the exception of participants infected with the Eta variant, most individuals carrying the other variants were women. Currently, there is no conclusive evidence to suggest a sex-specific affinity for particular variants. Most research on variants has instead focused on their effects on transmissibility and disease severity.

CONCLUSION

Viral infections generally persist within populations for several years, often becoming endemic at relatively stable levels. However, viral mutations may lead to renewed outbreaks, resulting in additional socio-health challenges. Continuous surveillance aimed at improving the understanding of SARS-CoV-2, and thereby informing the implementation of appropriate measures, is therefore essential for more effective control should a new wave emerge.

The findings from this study indicate that climatic factors have no significant impact on viral transmission and, thus, should not be regarded as critical determinants in controlling its circulation. Strict adherence to barrier measures remains the most reliable and effective strategy to limit the spread of infection.

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