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SARS-CoV-2 seroprevalence and COVID-19 vaccination coverage in two states of Nigeria from a population based household survey

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SARS-CoV-2 population-based seroprevalence surveys are useful for estimating the extent of SARS-CoV-2 infections, which may be underestimated by COVID-19 case counts. Surveys conducted in October 2020 in four Nigerian states showed that SARS-CoV-2 seroprevalence ranged from 9.3% in Gombe (northeast) to 25.2% in Enugu (southeast) after the first COVID-19 wave, more than 100 and 700 times higher than the official number of COVID-19 cases in these two states, respectively. We conducted a serosurvey after the second COVID-19 wave to evaluate the extent of SARS-CoV-2 infections, attitudes to COVID-19 vaccines, and COVID-19 vaccination coverage in two regions of Nigeria. Using the World Health Organization (WHO) Unity protocol, 34 enumeration areas (EAs) each in the Federal Capital Territory (FCT) (Northcentral Zone) and Kano State (Northwest Zone) were sampled in June 2021, using probability proportional to estimated size; 20 households in one EA were randomly selected. All consenting and assenting members of a household were asked about risk behaviors; adults who were 18 years and above (the eligible population for COVID-19 vaccination in Nigeria) responded to questions on COVID-19 vaccine attitudes and receipt. Blood and nasal/oropharyngeal samples were taken from all consenting and assenting household members. Blood samples collected were tested with the Luminex xMAP® SARS-CoV-2 Multi-Antigen IgG Assay and swabs by reverse-transcriptase-PCR (RT-PCR). Overall response rates were 76.8% in the FCT (n = 1,505 blood draws) and 80.4% in Kano State (n = 2,178 blood draws). Following the second COVID-19 wave in Nigeria, more than 40% of residents in the FCT (40.3%, 95% CI: 34.7–45.9) and Kano State (42.6%, 95% CI: 39.4–45.8) had evidence of prior SARS-CoV-2 infection. There were no active SARS-CoV-2 infections detected by RT-PCR in either the FCT or Kano State. In the FCT and Kano State, 3.4% and 1.6% of people surveyed reported receipt of any COVID-19 vaccine, three months after vaccines were available in country. In the FCT, 77.5% of adults were aware of COVID-19 vaccines, of whom 46.9% reported willingness to receive them. In Kano State, 48.7% of adults were aware of COVID-19 vaccines, of whom 61.1% were willing to receive them. In both regions, about 84% of those reporting unwillingness to accept COVID-19 vaccines cited concerns over vaccine safety. "Serosurvey findings revealed that SARS-CoV-2 infection was far more widespread in both the Federal Capital Territory and Kano State than indicated by reported case numbers. Despite high awareness, COVID-19 vaccine uptake remained low, primarily due to concerns about vaccine safety. These results highlight the urgent need for targeted risk communication to address vaccine hesitancy and improve coverage. Serosurveys provide valuable insights that can guide public health interventions and future pandemic preparedness in Nigeria."

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On March 11, 2020, the World Health Organization (WHO) declared the novel coronavirus (COVID-19) outbreak a global pandemic[1,2]. Nigeria announced the first COVID-19 case on the 27th February 2020[3]. Like most other countries early in the pandemic, reports of confirmed cases in Nigeria focused on individuals with clinical features of SARS-CoV-2 infection and index contact tracing using polymerase chain reaction–(PCR-) based testing[4]. This strategy likely missed individuals who had asymptomatic or mildly symptomatic infection, and individuals with symptoms who had not been tested due to the limited availability of tests[4]. Details of the initial Nigeria COVID-19 response have been described elsewhere[5,6]. Nigeria adopted the strategy of conducting SARS-CoV-2 population-based seroprevalence surveys for estimating the extent of SARS-CoV-2 infections, which can be underestimated by COVID-19 case counts. Sero-epidemiology reports are critical to track the spread of infection, identify disproportionately affected groups, supplement case-based surveillance, accurately inform public health intervention and response, particularly vaccination strategies, inform population levels of infection and immunity, containment measures, and facilitate the evaluation of experimental therapeutics and vaccines[7–9].

Although the COVID-19 pandemic created a global human, economic, and social crisis, there exist relatively sparse published data on population-level SARS-CoV-2 serosurveys in Nigeria and the rest of Africa, compared to other parts of the world[10–12]. As of February 2022, about 1,923 SARS-CoV-2 serological surveys had been published in peer-reviewed journals globally, but serological data from sub-Saharan Africa remain few and, in most cases, restricted to subgroups such as healthcare workers that might not represent the overall population. Furthermore, the existing published peer-reviewed SARS-CoV-2 seroprevalence studies in sub-Saharan Africa were based on data from early waves of the pandemic[13]. A SARS-CoV-2 seroprevalence meta-analysis in Africa in 2021 showed a pooled seroprevalence of 22%. Seroprevalence was highest in studies conducted in Central Africa compared to Southern Africa, West Africa, North Africa, and East Africa[12].

In Nigeria, the first SARS-CoV-2 seroprevalence surveys in four states conducted in October 2020 showed that SARS-CoV-2 seroprevalence was lowest in Gombe (Northeast Zone) with 9.3% and highest in Enugu (Southeast Zone) with 25.2% after the first wave of COVID-19 pandemic; more than 100 and 700 times the official COVID-19 case counts in these two states, respectively[14]. Interestingly, seroprevalence among residents of Lagos State (23.3%), considered to be the epicenter of the COVID-19 pandemic in Nigeria with much higher official case counts per population than other states, was comparable to that in Enugu[14]. In a different survey conducted in June 2020 in Niger State, a seroprevalence of 25.4% was reported[15]. Similarly, surveys conducted in 2021 in Anambra State using the WHO-recommended health facility-based cross-sectional approach and Kaduna State with the WHO Solidarity Protocol among hospital outpatients, found mean seroprevalences of 48.0% and 17.6%, respectively[13,16]. During the early phase of vaccine rollout in Nigeria, study by Kolawole, Tomori, Agbonlahor in a 12-state study in Nigeria, a high SARS-CoV-2 seroprevalence rate of about 78.9% was obtained among the study population during the low level of vaccination at the time of the survey[17–21].

As COVID-19 vaccine rollouts were initiated, global, multifactorial, and complex disparities in both vaccine access and uptake were raised[22]. These disparities may interact to affect both population-level immunity and the burden of COVID-19 in different communities[23,24]. COVID-19 vaccination began in Nigeria on 5 March 2021. As of 10 July 2022, about 36,313,593 people, or 17.6% of the eligible population, had received at least the first dose of the COVID-19 vaccine, and 24,281,618 people, or 11.8% of the eligible population, had received their second dose[25,26]. COVID-19 vaccination introduction in Nigeria was not without its challenges. Some people refused to accept the vaccine because of conspiracy theories, disbelief, concerns of vaccine safety, vaccine side effects, and the fear of the unknown[27].

Serosurveys, assess the proportion of individuals in a population who have developed antibodies against specific pathogen and are essential tools in public health. They provide good insights into the spread of SARS-CoV-2. Beyond the traditional surveillance system, that counts cases but underreport cases that are asymptomatic or undiagnosed. Serosurveys uncover the actual extent of disease spread by detecting antibodies indicative of past infections, give overview into the level of immunity within a community, whether from natural infection, vaccination, or both, identify populations or regions at high-risk with low immunity levels, guiding targeted and effectiveness public health interventions. They inform strategies for disease control, eradication and support in health evaluation of the vaccine effectiveness in the population.

However, many studies have documented persistent regional and demographic inequalities in vaccination coverage, with the northern regions and children of young mothers particularly under-immunized. Recent reviews have mapped barriers and facilitators to immunization uptake, highlighting the influence of maternal education, health literacy, and local context. It should be noted that, there is limited integration of how these factors interact at sub-national levels and how they have evolved with recent policy changes[28]. While post-campaign surveys have assessed immediate coverage rates after mass immunization campaigns, there is a paucity of longitudinal data evaluating the sustainability of these gains and the factors influencing drop-off in coverage over time. Although seroprevalence studies have estimated population-level immunity, few have

directly linked serological findings with individual vaccination histories and sociodemographic determinants in a representative, multi-regional sample[29].

This study addresses these lacunae by- Providing a comprehensive, multi-state analysis that integrates recent seroprevalence data with detailed vaccination histories and sociodemographic information, allowing for a nuanced understanding of immunity gaps and their drivers. Examining the sustainability of campaign-driven coverage improvements by following up with cohorts beyond the immediate post-campaign period. Employing advanced statistical modeling to disentangle the effects of policy interventions, health system factors, and community-level determinants on both seroprevalence and vaccination uptake. Offering actionable recommendations tailored to the most affected subpopulations and regions, thereby supporting targeted strategies for closing the remaining immunization gaps.

The second serosurvey in Nigeria for the FCT and Kano was conducted after the second COVID-19 wave (25 October 2020 to 3 April 20,210)[30]. The objective of the study was to estimate the seroprevalence of SARS-CoV-2, COVID-19 vaccination coverage and acceptability in the Federal Capital Territory (FCT) and Kano State in Nigeria., and to assess malaria prevalence and its overlap with SARS-CoV-2 infection."

Methods

Study area

The COVID-19 household seroprevalence survey (CHSS) was completed in the FCT and Kano State (both in the northern region of Nigeria) in June 2021. In 2018, the FCT was characterized as 75% urban with a projected population of 1,406,239, Kano State as 43% urban and a projected population of 9,401,288[31]. The two northern states were chosen for their similarities to Lagos State in the south in terms of the population dynamics and availability of both national and international gateways that favoured high transmission of COVID-19.

Study design and study population

CHSS was a cross-sectional, population-based household survey under an adapted version of the WHO Unity Protocol[32]. Methods have been described in Audu et al. [14,33] Additional survey questions included COVID-19 vaccine receipt and attitudes. The sampling frame consisted of 40,001 enumeration areas (EAs) and 10,807,527 individuals, based on the projections extrapolated from the 2006 National Census for 2018 for these two regions.

Study population

Sample size determination

Assumptions include: 34 enumeration areas (EAs) sampled per state, 20 households sampled per EA, 68% response rate, Intra-cluster correlation (ICC) of 0.05–0.10 Relative standard error (RSE) ideally < 0.30Standard error of survey divided by point estimate, using Adequate precision could be obtained if seroprevalence is 1.5% (or greater).

Table of sample size calculation

ICC	Seroprevalence	RSE	95% CI lower limit	95% CI upper limit
0.05	1%	0.43	0.1%	1.9%
0.05	1.5%	0.35	0.4%	2.6%
0.05	2%	0.30	0.8%	3.2%
0.05	5%	0.19	3.1%	6.9%
0.10	1%	0.57	−0.2%	2.2%
0.10	1.5%	0.47	0.1%	2.9%
0.10	2%	0.40	0.3%	3.7%
0.10	5%	0.25	2.5%	7.5%

Sampling techniques

The survey employed a stratified, two-stage cluster-sample survey approach.

Stage 1: selection of Enumeration areas.

Enumeration areas (EAs) were obtained from the National Population Commission (NPopC) from the FCT and Kano state.

Stage 2: selection of households: Survey teams map EA and enumerate households, Simple random sampling used to select households in the EA, Enumeration areas were categorized into urban and rural by (NPopC), Targeting 5 individuals in 20 households in each enumeration area.

Laboratory methods

Sample collection and processing

Nasopharyngeal and oropharyngeal (NP/OP) swabs and blood samples collected from the field were processed at the states' satellite laboratories and transported at 2–8°C to the National Reference Laboratory (NRL) Gaduwa in Abuja, Nigeria under temperature monitoring devices to track temperature excursions throughout sample transport. Plasma specimens were stored at the biorepository of the NRL at −80°c until testing[14]. During the household survey, a malaria rapid diagnostic test (RDT) (SD Bioline Malaria Antigen Pf (HRP2)) was administered using collected blood; survey participants who tested positive for malaria were treated with antimalarial treatment according to the National Malaria Elimination Programme guidelines.

Sample testing

The qualitative detection of nucleic acids from SARS-CoV-2 in NP/OP swabs was performed using a real-time polymerase chain reaction (RT-PCR) test with fully automated sample preparation (nucleic acid extraction and purification) capacity, PCR amplification, and detection capability[14].

For the serological analyses, the Luminex xMAP® SARS-CoV-2 Multi-Antigen IgG Assay (multiplexed microsphere-based assay), which targets the nucleocapsid protein, spike protein, and the receptor-binding domain of SARS-CoV-2, was used. The kit was validated at the NRL. All tests were performed according to the manufacturer's guidelines[34,35].

The positive and negative results were determined using the xMAP Multi IgG CoV-2 Multi-Antigen IgG assay software. The software used an algorithm based on the microsphere counts and median fluorescence intensity (MFI) of controls checked against pre-defined threshold values. A specimen was called SARS-CoV-2 IgG positive if the NCP target antigen control was above the set threshold and at least one of the spike protein target antigen controls (S1 or RBD) was above the threshold.

In summary, a sample was deemed SARS-CoV-2 IgG positive if the median fluorescence intensity (MFI) value of the nucleocapsid target antigen control exceeded the established threshold, and at least one of the MFI values for the other target antigen control, either the spike (S1) subunit or the receptor binding domain of the spike protein, was also above the threshold.

RT-PCR results were sent to the State Surveillance team through the State Epidemiologists to communicate to the survey participants. All positive results were reported in the COVID-19 surveillance platform to the Surveillance Outbreak Response Management and Analysis System (**SORMAS**) platform of the Nigeria Centre for Disease Control and Prevention (NCDC). Details of laboratory procedure, sample collection, processing and testing have been previously reported[14].

Statistical analysis

All data were captured on tablets using the Census and Survey Processing System application in both FCT and Kano State. Encrypted household, individual, and specimen data were uploaded to a central server daily.

We calculated household response rates using the American Association for Public Health Opinion Research rate method[36]. Vacant and destroyed households, and household units with no eligible respondents (e.g., adult, or emancipated minor), were considered ineligible and excluded from the calculation. Individual response rates were calculated as the number of individuals interviewed divided by the number of individuals eligible to participate. Blood draw and swab response rates were calculated as the number of individuals providing a specimen divided by the number of individuals interviewed. A combined wealth score for the two states was created using principal component analysis and divided into quintiles[37,38].

Descriptive analyses (e.g., proportions) and prevalence ratios from Poisson regression were calculated accounting for the complex survey design and analysis weights. Analyses were conducted using SAS 9.4 (Carey, NC) and Stata 16 (College Station, TX).

Results

Sixty-eight EAs (34 FCT and 34 Kano State), 1,119 households (the FCT 560, Kano State 559) and 3,820 individuals (the FCT 1,535; Kano State 2,285) participated in the survey, yielding response rates of 100%, 87%, and 97% respectively. Individuals living in the rural areas had higher overall response rates than their urban counterparts and the age – sex distribution of the household population by state see Fig. 1.

[α]All percentages are weighted.

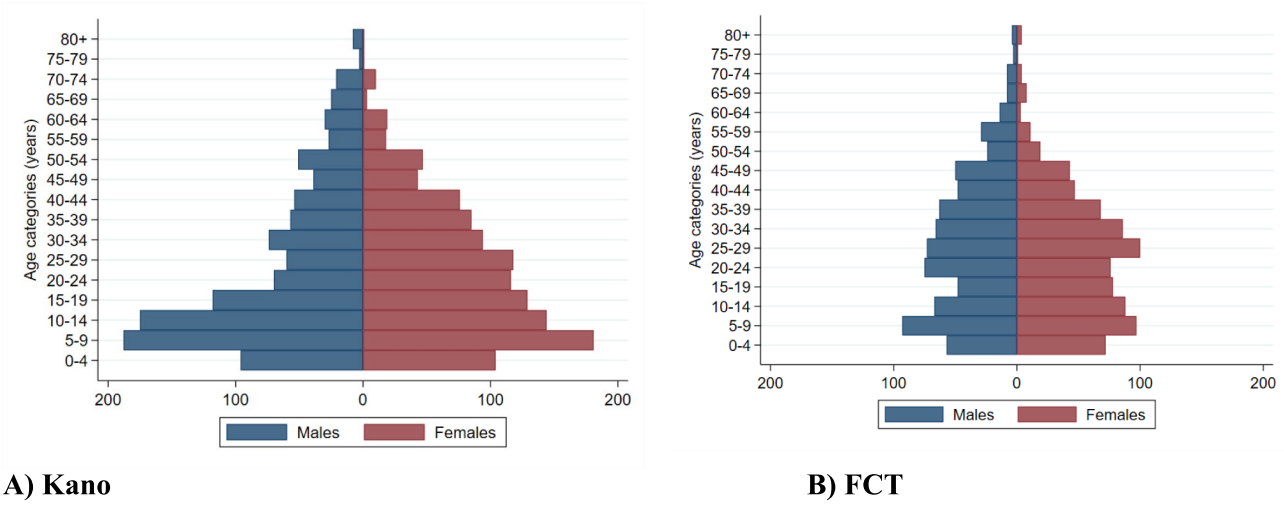

Fig. 1. Age – sex distribution of household population by state in the FCT and Kano Nigeria June 2021. FCT= Federal Capital Territory.

Approximately half of survey respondents in both states (52% in Kano State and 51% in the FCT) were women. Participants in the FCT had more urban dwellers (60.7%); and participants in Kano State had more rural dwellers (74.3%). Sixty-four percent of participants in the FCT were in the highest wealth quintile compared to 12.7% in Kano State (Table 1).

SARS-CoV-2 active infection and seroprevalence

Among the 1,119 households with 3,820 individual respondents, no individual tested positive for SARS-CoV-2 by real-time PCR. The overall seroprevalence of SARS-CoV-2 was 41.5% [the FCT 40.0% (95% CI 34.7–45.9) and Kano State 42.6% (95% CI 39.4–45.8)]. In the FCT, 37.0% (95% CI 31.7–42.7) and 43.1% (95% CI 36.6–49.7) of men and women, respectively, were seropositive. In Kano State, 45% (95% CI 40.9–49.0) and 40.4% (95% CI 36.6–44.2) of men and women, respectively, were seropositive (Table 2). Seropositivity differed by age for the FCT and Kano State. In Kano State, participants 10 years and above had considerably higher seropositivity compared to those less than 10 years, but this difference was not seen in FCT (Fig. 2).

Across the FCT and Kano State, 22.6% (95% CI 13.8–31.5) of seropositive participants reported at least one symptom consistent with SARS-CoV-2 since November 2020 (Table 3), and this proportion did not differ meaningfully by sex or by age (data not shown).

Characteristic	Total (N = 3,820)			
	FCT (n = 1,535)		Kano State (n = 2,285)	
	n	%[α]	n	%[α]
Sex				
Men	730	47.9	1,096	48.9
Women	805	52.1	1,189	51.1
Residence				
Urban	876	60.7	804	25.7
Rural	659	39.3	1,481	74.3
Marital status[1]				
Married or living together	587	56.7	932	78.8
Divorced or separated	27	2.2	21	1.5
Widowed	36	3.8	64	4.9
Never married	354	37.3	230	14.8
Education[2]				
No education	77	6.7	667	50.0
Some Primary	138	9.6	342	17.7
Primary completed	160	11.5	195	8.6
Some Secondary	322	22.6	285	13.2
Completed Secondary or higher	519	49.7	227	10.5
Occupation[1]				
Farmer	187	16.4	294	30.2
Daily labourer	19	1.6	115	9.9
Merchant/shop owner	118	11.8	72	7.3
Health worker	5	0.4	7	0.4
Government employee/civil servant	99	12.0	38	2.1
Private sector	181	18.1	40	2.0
Hawker/marker seller	81	6.8	171	11.9
Student	103	10.5	87	4.9
Unemployed	151	12.1	417	31.0
Other	61	10.3	9	0.4
Wealth quintile				
Lowest	12	0.8	489	30.4
Second	34	2.1	485	19.4
Middle	154	9.0	456	20.7
Fourth	416	24.4	436	16.8
Highest	919	63.7	419	12.7

Table 1. Demographic characteristics of the participating population by state, Nigeria, June 2021. FCT – Federal Capital Territory. [1]Includes only participants 18 years old and above (n = 2,143). [2]Includes only participants 10 years old and above (n = 2,820). [α]All included percentages were weighted and may sum up to more than 100 due to rounding.

Characteristics	SARS-CoV-2 seropositivity Total (N=3,683)							
	FCT (n=1,505)				Kano State (n=2,178)			
	n	%	95% CI		n	%[a]	95% CI	
Sex								
Men	258	37.2	31.6	42.7	468	45.0	40.9	49.0
Women	322	43.1	36.6	49.7	447	40.4	36.6	44.2
Residence								
Rural	241	36.5	30.9	42.1	580	41.9	37.8	46.0
Urban	339	42.9	35.4	50.5	335	44.0	38.8	49.2
Age (years)								
Less than 2	8	30.9	14.3	47.6	8	18.6	4.5	32.7
2–9	93	33.6	27.0	40.1	133	26.8	23.8	29.8
10–17	81	36.9	28.2	45.6	215	49.0	43.6	54.5
18–64	385	43.1	36.1	50.1	522	46.8	43.7	49.9
65 and older	13	31.9	18.8	45.0	37	54.5	41.0	68.0
Total	580	40.3	34.7	45.9	915	42.6	39.4	45.8

Table 2. SARS-CoV-2 seroprevalence among survey participants by state and selected demographic variables, Nigeria, June 2021. FCT – Federal Capital Territory. [a]All percentages are weighted.

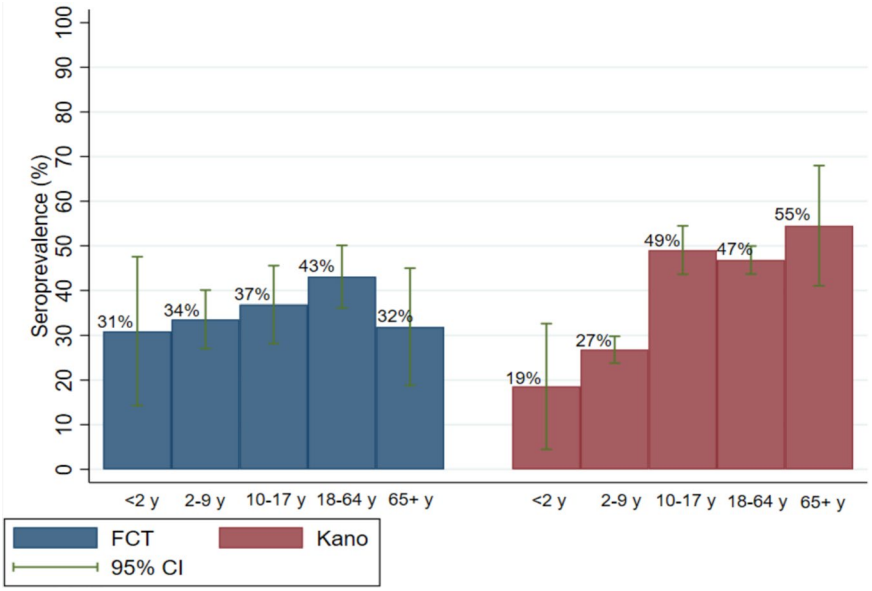

Fig. 2. SARS-CoV-2 Seroprevalence among survey participants by age and state, Nigeria, June 2021. FCT – Federal Capital Territory.

Major comorbidities identified among seropositive symptomatic and asymptomatic respondents were diabetes hypertension, and asthma. About 5% of asymptomatic and 15% of symptomatic women presented with at least one comorbidity (Table 4).

Malaria co-infection

All consenting participants in the survey had blood samples tested for malaria using a malaria rapid diagnostic test (RDT) kit.

Of the 1,504 participants in the FCT, 131 (8.7%) tested positive to P. falciparum only, while 72 (4.7%) were coinfected with SARS-CoV-2. Similarly, in Kano state, of the 2,174 participants, 218 (10.0%) tested positive to P. falciparum only, while 151 (6.9%) were coinfected with SARS-CoV-2. See table S1.

COVID-19 vaccination coverage

In the FCT, 3.4% (95 CI 1.3–5.4) of vaccine-eligible participants reported receiving a COVID-19 vaccine, including 5.0% of men and 1.7% of women. In Kano State, 1.6% (95% CI 0.7–2.4) of vaccine-eligible participants reported receiving a COVID-19 vaccine, 2.0% of men and 0.2% of women. In the FCT, among those who reported receiving a COVID-19 vaccine, 89.9% had received one dose. In Kano State, among those who reported

	Antibody positive (N = 1,495)				Antibody Negative (N = 2,188)			
	Men (n = 726)		Women (n = 769)		Men (n = 1,037)		Women (n = 1,151)	
Symptoms since November 2020	n	%[a]	n	%[a]	n	%[a]	n	%[a]
Fever	64	6.4	72	8.2	83	7.3	123	8.3
Rash	7	1.0	6	0.4	12	1.2	17	1.3
Chills	19	2.2	16	1.2	23	1.2	30	1.6
Diarrhea	18	2.4	10	1.3	32	3.9	37	3.7
Cough	36	4.1	38	5.4	59	4.9	64	5.1
Vomiting	12	1.8	15	2.4	15	0.8	27	2.3
Sore throat	10	1.6	7	1.1	12	0.9	21	1.4
Loss of appetite	0	0.0	14	1.2	9	0.8	18	1.4
Shortness of breath	5	0.5	2	0.2	2	0.2	6	0.7
Muscle aches	7	1.0	8	0.5	7	0.5	12	0.9
Fatigue	11	1.5	15	2.0	17	1.2	14	1.1
Conjunctivitis/pink eye	2	0.3	2	0.4	4	0.3	3	0.3
Runny nose	47	7.0	40	5.7	63	5.6	59	5.1
Joint aches	12	1.8	18	2.1	27	1.9	25	2.0
Headache	76	9.8	103	12.1	106	7.2	131	9.5
Loss of smell (anosmia)	0	0.0	5	0.6	1	0.2	3	0.3
Nosebleed	2	0.0	1	0.2	2	0.2	3	0.4
Loss of taste (ageusia)	0	0.0	3	0.2	2	0.2	2	0.4
Seizures	2	0.4	0	0.0	1	0.1	0	0.0
Altered consciousness	1	0.0	1	0.0	3	0.2	3	0.3
Other symptoms	1	0.2	2	0.2	3	0.1	1	0.0
Symptomatic *	187	22.9	192	22.4	263	20.6	310	22.3
Asymptomatic*	539	77.1	577	77.6	774	79.4	841	77.7

Table 3. SARS-CoV-2 Seroprevalence among survey participants by sex and reported symptoms, Nigeria, June 2021. FCT – Federal Capital Territory. *Symptomatic individuals are defined as those reporting any symptom from March 2020. Asymptomatic individuals are defined as those reporting no symptoms from November 2020. [a]All percentages are weighted.

receiving a COVID-19 vaccine, 67.4% had received only one dose. All participants reported receiving the Astra Zeneca vaccine, except 1 participant in Kano who did not know the type.

Awareness of COVID-19 vaccines was higher in the FCT at 77.5% (95% CI 69.8–85.3) compared to Kano State's 48.7% (95% CI 37.8–59.6). By sex, for participants aged 18 years and older, in the FCT, 81.9% of men and 73.4% of women were aware of the vaccine, while in Kano State, 49.9% of men and 37.6% of women were aware (Table S2). Of those aware of the vaccine, 46.9% in the FCT reported being willing to be vaccinated compared to 61.1% in Kano State. Across both the FCT and Kano State, over 95% of participants who reported being willing to be vaccinated reported protecting themselves as a reason. Approximately 84% of participants who reported not being willing to be vaccinated reported concerns over vaccine safety as a reason.

Discussion

In June 2021, SARS-CoV-2 seroprevalence was over 40% in the FCT and Kano State after the second COVID-19 wave. COVID-19 vaccination coverage was below 5% among vaccine-eligible participants approximately three months after vaccine introduction in Nigeria. Despite high awareness of the vaccine, a large proportion of the population did not intend to get vaccinated, with safety concerns being the most frequent reason. About 35% of those who intended to get vaccinated reported the protection for themselves as the most frequent reason.

The COVID-19 seroprevalence study in the FCT and Kano State in Nigeria was conducted between the second and third waves of the COVID-19 pandemic. This period of the pandemic was characterized by relaxation of public policies and infection prevention measures. At the time Nigeria started the COVID-19 vaccination programme, it was likely that few people were wearing masks, and more people were gathering indoors to eat, drink, celebrate and socialize without physical distancing, leaving many people vulnerable to infection. It was also the beginning of the spread of the Delta variant, considered, at the time, to be the most contagious variant of the SARS-CoV-2 virus[39].

The seropositivity in the FCT (40.3%) and Kano State (42.6%) in June 2021, was almost twice as high as the seropositivity in Lagos State, which is considered to be the epicenter of COVID-19 in Nigeria, with 23.3% from October 2020[14,40,41]. However, the time difference between the two surveys, with the waves of virus spreading, likely contributed to observed difference found in the results of the survey. In another study in Lagos, the seropositivity was considerably high when compared with seropositivity in the first study Antibody

	Asymptomatic (N = 1,116)				Symptomatic (N = 379)			
	Men (n = 539)		Women (n = 577)		Men (n = 187)		Women (n = 192)	
Co-morbidities	**n**	**%[α]**	**n**	**%[α]**	**n**	**%[α]**	**n**	**%[α]**
Currently pregnant*	0	0.0	12	3.4	0	0.0	4	2.6
Diabetes	5	0.7	2	0.3	2	0.7	2	0.2
Hypertension	5	0.3	19	2.9	11	5.4	15	9.0
Heart disease	0	0.0	0	0.0	2	0.8	1	0.8
Asthma	2	0.3	2	0.4	1	0.8	1	0.9
Tuberculosis	0	0.0	0	0.0	1	0.8	0	0.0
Chronic kidney disease	0	0.0	1	0.0	0	0.0	5	1.2
Emphysema/Chronic bronchitis/COPD	0	0.0	0	0.0	1	0.2	2	1.5
HIV**	0	0.0	2	0.0	0	0.0	0	0.0
Sickle cell disease	1	0.0	0	0.0	1	0.1	1	0.9
Cancer	1	0.0	1	0.2	0	0.0	0	0.0
Other co-morbidity	0	0.0	0	0.0	0	0.0	0	0.0
No reported co-morbidity	526	98.7	540	94.2	171	92.1	162	84.8
1 co-morbidity	12	1.2	35	5.5	14	7.2	29	14.4
2 or more co-morbidities	1	0.0	2	0.3	2	0.7	1	0.8

Table 4. Prevalence of co-morbidities among SARS-CoV-2-positive individuals, by sex and symptomatology Nigeria, June 2021. FCT – Federal Capital Territory. *This question was limited to women aged 15–49 years old. Eligible participants could also refuse to answer this question, which could impact the denominator. **Participants could refuse to answer these questions, which could impact these denominators. [α]All percentages are weighted.

data demonstrated high SARS-CoV-2 seroprevalence of 72·4% (97/134) in HCWs and 60·3% (70/116) in the general population was observed. This high SARS-CoV-2 with low mortality rate in Africa and supports the need to better understand the implications of SARS-CoV-2 cellular immunity and, coverage of other parts of the geopolitical zones in the country[18]. A range of surveys during the beginning of the pandemic found ranges from 10.6% in Zambia, 32% in Cameroon, 9.1% in Kenya, 7.6% in Addis Ababa, Ethiopia, and varied seroprevalence from 30.6%–46.2% in subdistricts Cape Town, South Africa[7,42–45].

Similar to the study in Cape Town, seroprevalence rates in a community survey in Zimbabwe conducted in 2020 and again in 2021, before and after second wave, were 2.47 times higher after the second wave[46]. Ndongo, et. al, reported findings from Yaounde, Cameroon, where the overall age-standardized SARS-CoV-2 IgG seroprevalence increased from 18.6% in the first survey conducted during the first quarter of 2021 to 51.3% in the second survey conducted in second quarter of 2021[47]. These studies showed that COVID-19 seropositivity increased with sustained transmission and number of waves. However, temporality, variant of concern, and variant of interest could influence the interpretation of these results. Follow up seroprevalence studies are recommended to detect trend in seropositivity for sustained SARS-CoV-2 transmission.

The seropositivity in both regions was similar in men and women. Seropositivity was also similar in urban and rural areas in FCT and Kano. In the FCT, higher seropositivity was found in adults 18–64 years old and was lower in both extremes of life (younger and older) when compared with Kano State where seropositivity increased with age. This contrast could be ascribed to household representation in each region, with more urban households in FCT and more rural ones in Kano State. The similarity in age and SARS-CoV-2 infection varied across different study environments, however, other researchers found low seroprevalence in the younger children[14]. A systematic review and meta-analysis of standardized seroprevalence studies by Lewis, et. al., on African studies concluded that seroprevalence was highly heterogeneous; lower seroprevalence for rural than urban geographic areas with children aged 0–9 years having the lowest seroprevalence[48].

In this study, in both the FCT and Kano State, only 22.6% of seropositive individuals in the survey showed no less than one symptom compatible with SARS-CoV-2 in the last six months (since November 2020). While more than 4 in 10 people had evidence of prior infection (seropositivity of 40.3% in the FCT and 42.6% in Kano), no single SARS-CoV-2 PCR-positive individual was detected among survey participants in either the FCT or Kano State. Fryatt, et. al., in Zimbabwe observed that almost half of all participants who were seropositive, reported no symptoms in the preceding six months[49]. In Mexico, 67.3% had been asymptomatic in a nationally representative SARS-CoV-2 antibody prevalence estimate after the first epidemic wave[50].

This emphasized the importance of carrying out valid seroprevalence studies during active outbreaks of microorganisms with predominantly asymptomatic phenotypes.

to provide evidence-based data in understanding the burden of the disease and mobilizing resources for effective control. The observed similarity in symptom reporting by seroprevalence status was consistent across the two states and in the first round of surveys in four states[14].

Only a small percentage of the population (14.4% of symptomatic seropositive women and 7.2% of symptomatic seropositive men) had at least one co-morbidity. Data show that patients with COVID-19 disease,

who have comorbidities, are more likely to develop more severe disease. Similarly, infected older patients, (65 years and above) with comorbidities, have an increased admission rate with poor prognosis. Intensified public health measures aimed at protecting this category of patients from contracting COVID-19 can reduce the disease burden in the population[51,52].

Understanding the burden of SARS-CoV-2 and its associated risk factors is fundamental to identifying key risk mitigation strategies. Comparing the findings of the surveys of the first four (Enugu, Gombe, Lagos and Nasarawa) states and this present survey in the FCT and Kano State, the first four states found higher seroprevalence among the older age group and identified frequent visits to the market and reported contact with someone with COVID-19 symptoms suggestive of COVID-19 as factors associated with seropositivity[14]. According to Oyetunde, Alao, Akinsola et al., observed no significant associations were found between seropositivity and familiar demographic factors like age, gender, or occupation indicating global transmission across all groups. However, they observed elevated seroprevalence among married individuals, self-employed workers, suggesting higher exposure in household and occupational settings, opined the need to tailor public health strategies with local data[53].

In the present study, the survey participants who were 10 years and above in Kano State had higher seropositivity in comparison with those less than 10 years of age; however, this observation of differences in SARS-CoV-2 seropositivity and age in FCT were not observed.

This findings from COVID-19 seroprevalence studies in Kano and the FCT has provided information on area with high risk and need to consider vaccinating high-risk groups such as the elderly, healthcare workers, areas with low immunity and individuals with comorbidities in the distribution of vaccine across the country, The integration of the COVID-19 with other routine immunization will help in the vaccines uptake.

These two settings are malaria endemic as other parts of Nigeria, current/recent infection with malaria or of malaria with previous infection of SARS-CoV-2 was higher among rural dwellers, adolescents and young adults, and those in poorer wealth quintiles, compared to urban dwellers, adults and senior adults, and those in the highest wealth quintile in both states, largely reflecting background patterns of malaria infection risk in Nigeria[49]. Vaccines, including those for COVID-19, have been proven to be effective interventions that can reduce the high burden of diseases globally[51]. Globally, the COVID-19 pandemic was associated with high mortality rate[54] spurring a large investment in rapid vaccine development. With the development and supply of the vaccines, it is essential that a critical mass of the population gets vaccinated. This underscores the need for the government to prioritise vaccine manufacturing to provide enough vaccines are available for those that need it across the region. In Central Africa, Manirakiza, Malaka, Mossoro-Kpinde et al. noted sharp increase in the seroprevalence among health worker (HCWs) after pre and post vaccination serosurveys and attributed the increase to be primarily due to the synergistic effect of the infection and the implementation of vaccines against COVID-19[55].

Misconception, misinformation, and other conspiracy theories affected both COVID-19 virus transmission and vaccination, as observed in Nigeria[25]. COVID-19 vaccine hesitancy and the initial lack of availability of the vaccines affected public uptake of the COVID-19 vaccine in different ways[25]. It is paramount for the policies makers to map out risk communication strategies to engage the gate keepers and religious leader to providing transparent information about vaccine safety and efficacy, and countering misinformation and vaccine hesitancy that might be created during the vaccine rollout[56].

In this study, there was higher awareness of the COVID-19 vaccine in FCT (78%) compared to Kano (49%), although the desire to take it among those aware was higher in Kano (61%) compared to FCT (47%). Hesitancy around COVID-19 vaccines has been seen in other settings globally. In Jordan, the public acceptability of COVID-19 vaccines was low (37.4%)[57]. In western Ethiopia, healthcare professionals in the study area had negative attitude towards the COVID-19 vaccine[58]. Knowledge about the COVID-19 vaccine, age of healthcare workers, and place of work are factors which affect attitudes towards COVID-19 vaccine. Vaccination coverage was low in both states (2.7%). Major reasons reported for low uptake of the COVID-19 vaccine in Nigeria included quality, efficacy/ability of the vaccine to protect, initial unavailability of the vaccine, distrust of the government, non-acceptance of COVID-19, conspiracy theories, disbelief, vaccine safety and side effects, and the fear of the unknown[25]. "This is a very significant occasion—the arrival of the COVID-19 vaccines into Nigeria is critical in curbing the pandemic. The only way out of this crisis is to ensure that vaccinations are available to all." The initial vaccine supply to Nigeria was targeted towards the vaccination of Nigerians in priority groups, starting with frontline healthcare workers. Accessing the COVID-19 vaccine by the general public at this initial stage of the vaccine rollout was difficult[59]. Public awareness campaigns centered on reviving trust in national health authorities that offer transparent, accurate, and consistent information about the safety and efficacy of the vaccines, as well as the technology used to produce them would be beneficial**.** Adapting a guiding policy as above to gate keepers and religious leaders to counter misconception and vaccine hesitancy is apt in Nigeria and other African countries.

Limitations to the study

A higher refusal rate was observed in this survey than in the previous serosurveys, which may lead to biased results if those missed were not represented by those surveyed. Survey teams encountered hesitation among residents to participate in the survey due to a lack of trust in the government and other misconceptions associated with COVID-19. The self-reported rates of various symptoms were generally lower than expected, raising the possibility of recall bias for the symptom questions. Finally, the survey was conducted only three months after the commencement of COVID-19 vaccination in Nigeria. At this point, COVID-19 vaccine access and uptake could be still low, affecting the vaccination coverage among respondents in both the FCT and Kano State. With the recommended 8 to 12 weeks between dose 1 and dose 2 of the Astra Zeneca vaccine, most respondents were likely not yet eligible for their second dose.

Conclusion

This population-based serosurvey conducted in the Federal Capital Territory and Kano State after Nigeria's second COVID-19 wave reveals that a substantial proportion of the population—over 40% in both regions—had evidence of prior SARS-CoV-2 infection, far exceeding the number of reported cases and highlighting the extent of under-detection through routine surveillance. Despite high levels of seroprevalence and significant awareness of COVID-19 vaccines, actual vaccination coverage remained low, with only 3.4% of respondents in the FCT and 1.6% in Kano reporting receipt of any COVID-19 vaccine three months after vaccine introduction. Notably, concerns about vaccine safety were the predominant barrier to vaccine acceptance, cited by approximately 84% of those unwilling to be vaccinated.

These findings underscore the critical need for targeted risk communication and community engagement strategies to address vaccine safety concerns and misinformation. Enhancing public trust in vaccines is essential to improving uptake and achieving broader population immunity. Furthermore, the high seroprevalence observed supports the value of serosurveys as a complement to case-based surveillance, offering a more accurate picture of infection spread and informing public health interventions. Continued investment in surveillance, vaccination campaigns, and community education will be pivotal in mitigating the impact of COVID-19 and strengthening preparedness for future public health threat, integration COVID-19 vaccination into the national routine immunization programmes to improve vaccine uptakes in Nigeria. "Invest in local pharmaceutical production and supply and vaccine production capabilities to ensure readiness and self-sufficiency in times of need and to improve vaccine uptake in the communities.

Data availability

The data from this survey are owned by the Nigeria Centre for Disease Control and Prevention. Deidentified survey data and qualitative laboratory results are available upon request from the NCDC after approval of a proposal with a signed data access agreement. The data for this study is available and can be made available on request to the Research Governance Unit of the NCDC through the Corresponding Author.

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Author contributions
Writing – original draft: NWE. BSI, CDN, KAS, NB, LS, IEI, MA. Writing – review & editing: All authors. Funding acquisition: EI, KAS, LS, SMG, ID, CI. Supervision: NWE. BSI, KAS, SA, LS, NCI, EI, IEI, FM, AM, EUI, CLO, SMG, ZI, RAA, ID, OI, NM, CI, IA, GSA Methodology: NWE. KAS, LS, MA. NA, JA Laboratory Testing Investigation: NCI, NM, CO, AM, OO, OB, IB, SO, CEI, AA, CO. Data curation: KAS, LS, NB, AM, McPO, CO. Formal analysis: NB, AM, KAS, LS, NCI Project administration: SA, IEI, KAS, LS, ID, NWE. EI Resources: EI, LS, IEI, KAS, LS, ID, CI Validation: KAS, LS.

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Declaration

Competing interests
The authors declare no competing interests.

Ethics approval
The study was approved by the Nigeria Health Research Ethics Committee, Number NHREC Approval Number NHREC/01/01/2007–01/09/2020B the University of Maryland, Baltimore Institutional Review Board, and the United States Centers for Disease Control and Prevention. Approval to carry out the survey was given by the FCT and Kano states governments. In addition to this, all methods were performed in accordance with the relevant guidelines, standard operating procedures (SOPs) and regulations.

Consent for publication
All the participants are informed about the study, and they have all signed the informed consent form.

Additional information
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