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RESEARCH

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Strengthening plant health systems in South Sudan: addressing challenges and enhancing system efficiency and sustainability

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Abstract

Climate change-induced invasive pests remain a major bottleneck to agricultural productivity and food security in South Sudan. Strengthening the plant health system has the potential to contribute to reducing crop losses caused by pests. A situational analysis was conducted to assess the current state and effectiveness of plant health functions in three counties in South Sudan. Descriptive findings of data collected from 960 farmers in Juba, Yambio, and Yei indicated low access to plant health services, including advisory and extension, training, and information. There was a high dependence on NGOs and UN agencies to provide plant health services, indicating a gap in government-led initiatives. The findings demonstrate a complex relationship between plant health services and on-farm practices and regional variations in access to plant health services and resources. The findings have crucial implications for the plant health system in South Sudan, requiring the need for service accessibility, government involvement in plant health systems, strengthening of the policy and regulatory frameworks, and inclusivity in service provision.

Keywords Plant health system, Crop pests, Pesticides, Crop management practices, Advisory services, Agricultural training

Introduction

Changes in weather conditions can cause biological changes in pests and impact plant physiology, increasing plants' vulnerability to pests (FAO 2021). Climate change also increases the frequency of outbreaks of both invasive and native pests (FAO 2022; Finch et al. 2021). Like in other natural agroecosystems, climate change negatively affects plant health, food availability, and rural livelihoods in Africa (Graziosi et al. 2020). South Sudan is among the world's climate change hotspots, with increasing frequency of extreme climatic events that impact plant health. A significant concern is the increasing emergence and incidence of crop pests that threaten the plant health and livelihoods of approximately 86% of rural households in South Sudan, which depend on agriculture (UN Environmental Programme [UNEP] 2023). Common pests include elegant grasshoppers (*Zonocerus* sp.), bollworms, cassava whiteflies, cutworms, African armyworms, stalk borers, and aphids (World Bank 2021).

The fall armyworm (FAW), a relatively new pest in South Sudan and Africa (FAO 2017), is one of the invasive pests in South Sudan associated with climate change. Besides affecting maize, a predominant staple food

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crop in South Sudan, FAW also damages sorghum, millet, vegetables, and other crops (FAO 2017). The FAW is reported in various regions of South Sudan, including Equatoria, Northern Bahr el Gazal, and parts of Jonglei. Important plant diseases are cassava mosaic virus, pearl millet downy, Mildew rust that attacks maize and sorghum, and the late blight that affects tomatoes (World Bank 2021).

While data on yield losses from adverse effects of climate change in South Sudan are scarce, 87% of the total population in the country suffers from moderate to severe food insecurity (FAO et al. 2023) mainly caused by the overlapping effects of climate-induced shocks (e.g., insect pests, diseases, floods, and drought) and political and social conflicts (FAO & Tufts University 2019). For example, the papaya mealybug, a new crop pest in South Sudan, causes up to 91% yield losses of papaya, severely affecting the livelihoods of smallholder farmers in the country (CABI 2021). The spread of cassava brown streak disease (CBSD) (Alicai et al. 2016) and the increasing prevalence of cassava mosaic disease (CMD) in South Sudan (Chikoti and Tembo 2022) could be having a sizeable economic impact. Available data from East and Central Africa that encompasses South Sudan indicate that CBSD and CMD cause up to 70% and between 77 and 97% yield losses estimated at US$100 million and US$1.9–2.7 billion dollars per year (Chikoti and Tembo 2022), respectively. These example data point to the devasting effects of pests on crop production in South Sudan, which largely remain uncounted.

The plant health in South Sudan is further complicated by the limited availability of quality and clean planting materials. For instance, CBSD, which was initially prevalent in coastal East Africa and the shores of Lake Malawi, has spread across borders, with outbreaks reported in South Sudan, a country that was previously disease-free (Alicia et al. 2016; Chikoti and Tembo 2022). The spread of CBSD into the country is likely attributed to both use of contaminated planting materials and movement of insect vectors. These factors that could be associated with the a weak plant health institutional and regulatory capacity, South Sudan high dependency on imported seed, seed production challenges, and climate change (UNEP 2018; Access to Seeds Foundation 2019).

Plant health system (PHS) has evolved from the early traditional knowledge and chemical based plant health management practices in the twentieth century, to plant clinics and expansion of extension services that provide information on implementation of best practices in plant health management in the late twentieth century, and integrated pest management, diagnostic tools and information technology in twenty-first century (Danielsen & Matsiko 2016). It has also evolved to encompass a holistic and systemic collaboration across multiple disciplines, the role of policy and regulatory frameworks, and sustainability and climate change. Thus, Plantwise defines PHS as a combination of extension, research, input suppliers, regulation, and institutions that focuses on managing and preventing plant pests and diseases. The approach of plant health systems thus provides a system thinking to plant health delivery and designing strategic interventions that effectively address the inherent plant health challenges.

CABI's Plantwise program, a global plant health system initiative, partnered with several stakeholders in South Sudan to strengthen the capacity of agricultural advisory systems to address plant health challenges and enable farmers to lose less of what they grow (CABI 2023). The program aimed to prevent invasive and migratory pests through early warning, extension, and management systems (CABI 2023). As of 2020, Plantwise was evaluated to have positively impacted over 50 million smallholders, reducing crop losses from crop pests and increasing yields and income (CABI 2023). The success ushered in PlantwisePlus in 2021, focusing on low- and lower-middle-income countries.

A plant health system situational analysis was conducted in 2023 in South Sudan to (1) explore how three downstream functions of plant health systems—plant health information management, agricultural training, and farmer advisory services—influence farmers' use of crop pest management practices and technologies; (2) enable stakeholders to understand farm level status of their investments in plant health system in South Sudan; and (3) assess the strengths and weaknesses of the plant health system, identify critical areas for improvement, collaboration, learning, and adaptation. Thus, the study offers insight into the current challenges and successes of the plant health systems at the farm level and provides an indication of the effectiveness of the plant health system. The study provides a novel contribution to the growing literature on plant health systems in two ways. First, methodologically, we employ a mixed-method approach to provide deeper insights into the status of plant health in South Sudan that is policy aware, thus providing actionable interventions to improve efficiency. The mixed methods employed provided a framework for triangulation of the findings from literature and fieldwork, which enhanced the degree of dependability of the findings. Secondly, the study is conducted in a post-conflict and fragile country, where the plant health system is at the infancy stage, and there exists a paucity of literature in this space for more targeted interventions.

Methods

Study area

This study is part of a large situational analysis study conducted in South Sudan in January and February 2023. The analysis focused on the national PHS, and given the complexity, it was structured in three stages: a desk review of the state of the plant health system in the country, a survey, and stakeholder workshops. Desk review of the state of the plant health system and stakeholder workshop were nationally targeted, while the survey focused on Yei, Yambio, and Juba counties. The three counties are located in the Equatoria region that is generally considered a food basket in South Sudan. Yambio in Western Equatoria State and Juba and Yei in Central Equatoria State. The geographical locations of these counties are shown in Fig. 1. Agricultural production in Equatoria states is relatively stable compared to other regions because of favourable climatic conditions and fertile soils. Important staple food crops grown in the three states are maize, sorghum, rice, and cassava (Ministry of Agriculture and Food Security [MAFS] 2022). Of the three counties, Yei and Yambo are considered the major food baskets.

The selection of Juba, Yei, and Yambio counties for the survey was based on several factors, including geographical representation, agricultural significance, presence of critical crops and pests, accessibility and security, and representation of challenges in the PHS. In terms of geographical representation, Juba, Yei, and Yambio counties were selected because of their distinct agricultural conditions, plant health challenges (e.g., a high prevalence of insect pests and diseases, droughts, floods, and other climate-related issues that impact food production.), socioeconomic significance, and challenges (e.g., food insecurity, disrupted distribution systems, and crop production) that exemplify those faced in South Sudan, and their proximity to borders with neighbouring countries (FAO 2017; World Bank 2021). The three counties' diverse cropping systems also informed selection. Therefore, the selection of the three counties also reflects the plant health challenges facing the agricultural sector in South Sudan. Additionally, the three counties were selected because they are relatively accessible and secure compared to other counties in Equatoria regions that are marred by conflicts. Yei, Yambio, and Juba also have

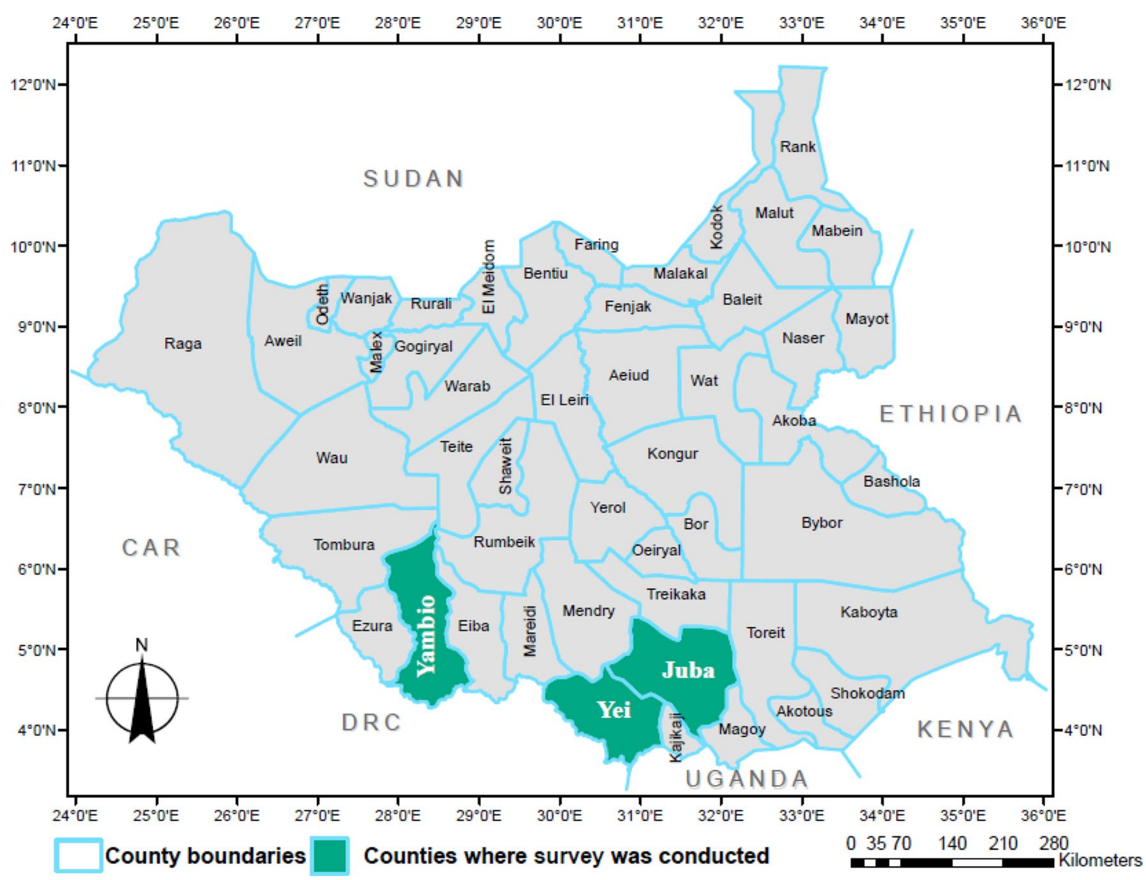

Fig. 1 Map of the study area

a high presence of key stakeholders (local and international) involved in plant health systems.

Document review

Document review allows access to historical data and understanding of the evolution of the plant health system, enabling assessment of status and identification of changes over time. In the context of this study, a desk review established the status of the plant health system after implementing the Plantwise program. The review of the grey literature, including government reports, policy papers, and legislative texts, provided insights into policy and regulatory frameworks. This contributed to understanding the regulatory and policy frameworks governing the plant health system in the country. Documents from organizations WFP, FAO, Famine Early Warning Systems Network (FEWS NET), and the local Integrated Food Security Phase Classification (IPC) were reviewed to provide a contextual understanding of food security status, climate and environment factors, humanitarian and economic impacts of insect pests and diseases on agriculture, establishment of existing early warning and monitoring systems, and stakeholder and community perspectives on plant health issues. Scientific literature, research studies, and technical reports were reviewed to gain scientific and technical information concerning insect pest and disease management efforts. Finally, the literature review provided context and foundation for the data collection and sampling design.

Data collection

Data collection was conducted to gather data from farmers and stakeholders involved in the plant health system. A mixed methods research design involving quantitative data collection of farm-level data on plant health and qualitative data collection from key informant interviews (KII) with representatives of stakeholders of plant health systems and community Focus Group Discussions (FGDs) was used. Mixed methods allowed a comprehensive understanding of the plant health systems in the study area by capturing and corroborating diverse perspectives from various stakeholders (Guest 2013). Tools used to collect quantitative and qualitative data were developed based on information gathered from desk reviews and inputs from project teams.

Quantitative data collection

Quantitative data collection involved a household survey of farmers in Juba, Yei, and Yambio. The survey explored the downstream functions of the plant health system. It was designed to assess the effectiveness of information dissemination, accessibility to farmer advisory services, effectiveness of information dissemination, and adoption of best practices and innovations in plant health. Additionally, household surveys collected data on crop losses, challenges and barriers in plant health management, and regional variations in the effectiveness and needs of plant health systems. This information was collected using a pre-tested and validated semi-structured survey questionnaire.

Multi-stage cluster sampling with a probability proportional to size sampling approach was used to select farmers who participated in the household survey. Bomas, administrative units within the three counties, were selected in the first stage because of the large, dispersed population of farmers. The bomas served as the primary sampling units, forming the clusters from which farmers were selected. Cluster sampling ensured a practical and cost-effective approach to selecting farmers from the large population in the three counties. The third stage involved using the probability proportional to size (PPS) method to obtain samples from each boma, depending on its population size. This ensured that farmers from larger populations of bomas were more likely to be included in the sample. The last step involved sampling with replacement to maintain a sample close to being as precise self-weighting as possible. Although sophisticated, this approach allowed for an efficient and diverse representation of farmers from the primary sampling units.

Applying Kothari's (2004) sampling formula for the unknown population, a sample of 384 farmers was targeted in each county. However, due to practical, logistical, resource, and security challenges, 1146 out of 1152 were surveyed across the three counties. Table 1 presents the sample size of farmers who participated in household surveys disaggregated by county. 960 of the 1146 sampled farmers participated in crop production in the most recent season targeted by the study, providing valid cases for analysis.

Qualitative data collection

Key informant interviews and FGDs were used to collect qualitative data to provide rich, contextualized, and nuanced insights into plant health systems in South Sudan. Data collected through these methods

Table 1 Sample size of farmers surveyed by county

County	Proposed sample size	Actual sample size	Confidence level (%)	Margin of error (%)
Juba	384	388	95	5
Yei	384	379	95	5
Yambio	384	389	95	5
Total	1152	1146		

were specifically utilized to uncover the practical challenges and barriers faced in implementing plant health information systems, agricultural training, and advisory services. Additionally, qualitative data collection was used to capture local knowledge and practices concerning plant health systems and agriculture and stakeholders' feedback on challenges and barriers in implementation and opportunities and suggestions for better plant health systems outcomes.

Key informant interviews involved diverse stakeholders in the agricultural sector in South Sudan. The interviewees were drawn from the Ministry of Agriculture and Food Security in Juba (Department of Plant Protection), the State Ministry of Agriculture (Department of Research), the State/County Department of Agriculture, community leaders (traditional, youth, and women), international NGO staff, academia, agro-input dealers, agricultural vocational training centre, and UN agencies (WFP or FAO) staff. A total of 20 KII were interviewed through face-to-face and Zoom platform. FGDs involved farmers drawn from communities in the study sites. The FGDs comprised men and women farmers. A total of nine (9) FGDs were conducted, with about 10–12 men and women farmers participating in each discussion. Interview and FGDs checklists validated by the in PlantwisePlus project team were used to collect qualitative data.

Stakeholder workshop

A plant health stakeholders' workshop was convened in June 2023 to validate the eight (8) functions of the plant health system in South Sudan and to collect additional data and comments. The workshop was critical in collecting diverse perspectives from farmers, agricultural experts, policymakers, NGO representatives, research organizations and regulatory agencies, and others whose input is valuable for the multifaceted aspects of plant health systems. The stakeholders discussed strengths and weaknesses, brainstormed weaknesses, and solutions, and developed consensus on the best approaches to managing plant health issues. Furthermore, the workshop provided a platform for sharing information, experiences, and knowledge in plant health systems and contributed to identifying needs and priorities for the industry. Besides serving as points for disseminating the situational analysis results, the workshops were also venues for awareness creation and capacity building in plant health, as well as identification of potential areas of stakeholder collaborations for further strengthening the plant health system in South Sudan.

Data analysis

Quantitative data were cleaned and analysed using statistical tools. Means, frequencies, and percentages were used to describe the data, which provided an overview of the data distribution for easier comprehension and communication of critical findings. Data distribution across counties was tested for any systematic differences using analysis of variance (ANOVA) for continuous variables, Pearson's chi-square test for independence, and Fisher's exact test for categorical variables. The quantitative data were analysed using Stata version 18.

The qualitative data collected from key informants and FGDs were used to triangulate the quantitative findings. The written notes during KII and FGDs were typed and analysed using content analysis. Rapporteur reports provided additional data from stakeholder workshops that were also analysed for further insights.

Results and discussion

Demographic characteristics

A summary of the characteristics of farmers who participated in the household survey is presented in Table 2. Most respondents were female, married, and living in predominantly male-headed households. Most farmers were primarily in the productive age range of 18–55 years. A considerable proportion of them had no formal education and attained some or completed primary education. Crop farming was the dominant source of income, indicating a high reliance on agriculture. The average household size was eight (8) members, with few households being victims of conflicts in South Sudan. Comparison of farmers' characteristics by county revealed significant differences for all variables, suggesting possible influence of sociodemographic on farm level implementation of plant health practices.

Households in the three counties can be categorized as poor as shown in Fig. 2. Approximately 84% of farmers in Yei, 58% in Yambio, and 29% in Juba had annual incomes below 20,000 South Sudanese pounds (SSP) ($33). 24% of farmers in Juba, 7% in Yambio, and 2% in Yei were in the higher income category of over 40,000 SSP (over $66.22). The high poverty has potential implications for plant health program adaptation to different economic realities.

Farm characteristics

The participation rate in crop production across the counties was 84% (Table 3). Participation was highest in Juba (92%) and the least in Yambio (74%). The geographical differences in participation rates in crop production could be attributed to stable living conditions in Juba or differences in the scale of disruptions in land access and

Table 2 Summary of sociodemographic characteristics of farmers by county

Variable	Response	Pooled	Juba	Yambio	Yei	P value
Gender of respondent	Female	56.81	52.12	56.73	61.44	0.033
	Male	43.19	47.88	43.27	38.56	
Gender of HH head	Female	35.69	28.57	31.13	47.04	0.000
	Male	64.31	71.43	68.87	52.96	
Age of respondent	18—35	41.54	46.3	35.09	43.19	0.000
	36—55	43.72	46.03	44.33	40.87	
	56—64	9.16	6.08	13.19	8.23	
	65 & above	3.32	1.59	2.64	5.66	
	< 18 years	2.27	0	4.75	2.06	
Marital status or respondent	Married	63.09	67.46	51.98	69.67	0.000
	Single	15.1	14.02	25.07	6.43	
	Widowed	12.48	14.29	10.55	12.6	
	Separated	5.93	3.44	5.8	8.48	
	Divorced	3.4	0.79	6.6	2.83	
Education level of respondent	No schooling	27.66	32.54	27.97	22.62	0.000
	Primary	40.84	40.74	32.72	48.85	
	Secondary	24.09	20.37	27.71	24.16	
	Vocational	3.75	2.38	6.86	2.06	
	College/university	3.66	3.97	4.75	2.31	
Household size		8.28	5.56	9.03	10.19	0.000
Residency status of HH	IDP	22.77	29.63	10.82	27.76	0.000
	Residents/host	70.42	66.93	87.34	57.33	
	Returning Refugees	6.81	3.44	1.85	14.91	
Income source	Farming (crops)	76.18	98.94	56.99	72.75	0.000
	Farming (livestock)	19.28	13.49	25.59	18.77	
	Wage/salary	12.57	12.43	12.66	12.60	

tenure associated with residency status as affirmed by the largest percentage of farmers (78%) in Yei who operated 1 to less than 2 feddan of land compared to 37% and 31% of farmers in Yambio and Juba, respectively. While 42% and 37% of farmers in Juba and Yambio operated 2 to less than 4 feddans of land, respectively, 20% of their counterparts in Yei operated similar land sizes indicating that most farmers are smallholders with limited access to resources and services critical for plant health. Maize was the most grown field crop across all counties, followed by groundnuts, cassava, sorghum, and sesame. This confirms the document review results identifying the same crops (MAFS 2022).

Status of plant health system

Farmer-centred plant health system functions

Table 4 presents data on farmers' access to various plant health system services in South Sudan, focusing on downstream functions of farmer advisory services, plant health information, and agricultural training. There was low access to advisory services, with 11% of the respondents indicating they had contact with extension officers. Yei has the highest access rate to extension and advisory services (28%), while Juba has the lowest (1%). Forty-seven percent of farmers who accessed advisory services had personal contact with extension agents, especially in Yei (52%). Other advisory services delivery methods were site-specific; delivery during the training sessions was common in Yambio—82%. The frequency of contacts was twice annually, with the lowest number of contacts reported by farmers in Juba. NGO/UN organizations such as FAO and WFP (37%), lead farmers (23%), and farmer training centres (18%) were the most reported sources of extension services. A notable gap in government provision of advisory services was noted, with state/county extension providers being less frequently mentioned by farmers.

Assessment of the plant health information function at the farm level reveals low access (22%) to information on emerging crop pests (Table 4). Access to plant health information was highest in Yei, with 42% of farmers reporting having accessed information on emerging crop pests and lowest in Yambio (9%). Farmers with access to information reported NGOs as a significant source

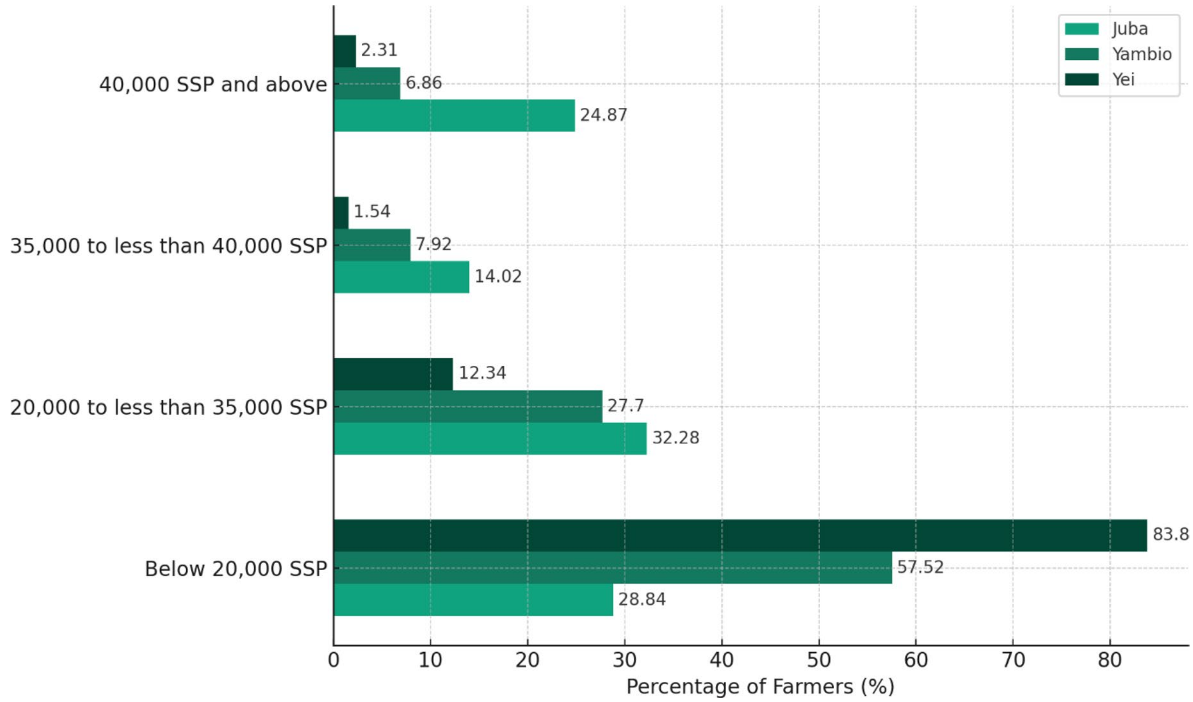

Fig. 2 Income categories of farming households by county

Table 3 Farm characteristics by country

Variable	Pooled	Juba	Yambio	Yei	P value
Crop production in recent season (%)	83.77	92.33	73.61	85.35	0.000
Land area (%)					
1 to Less than 2 feddan	42.59	31.03	37.50	77.95	0.000
2 to Less than 4 feddan	35.88	42.07	37.05	19.69	
4 to Less than 6 feddan	14.66	19.66	15.18	2.36	
6 to Less than 8 feddan	4.84	5.17	7.14	0.00	
8 to Less than 10 feddan	1.87	2.07	2.68	0.00	
Above 10 feddan	0.16	0.00	0.45	0.00	
Crop planted (%)					0.000
Maize	79.58	68.77	79.93	90.66	0.000
Groundnuts	55.00	31.52	95.70	45.48	0.000
Cassava	44.06	18.91	75.99	43.67	0.000
Sorghum	20.94	11.75	22.94	28.92	0.000
Sesame	16.56	1.72	33.33	18.07	0.000
Pigeon pea	11.04	1.43	15.77	17.17	0.000
Tomato	15.31	24.93	10.75	9.04	0.000
Eggplant	13.23	23.50	13.62	2.11	0.000
Cabbage	4.38	4.30	8.24	1.20	0.000

Mean (Area planted—in Feddan) 1 Feddan = 4200 Square meters = 0.42 HA)

of information on emerging crop pests (61%), underlining the dependency on both international and grassroots NGOs in disseminating plant health and education information. Radio as a source of information on emerging pests was reported by 21% of farmers.

The status of the agricultural training function was measured by asking farmers about their awareness of the

Table 4 Proportions of farmers accessing plant health system services by county

Variable	Pooled	Juba	Yambio	Yei	P value
Access to extension/advisory services	10.82	1.32	2.90	27.76	0.000
Extension delivery method					
Personal contact	46.77	0.00	9.09	52.78	
Training session	32.26	0.00	81.82	28.70	0.000
Site visits	5.65	80.00	9.09	1.85	
Mobile phone	15.32	20.00	0.00	16.67	
Frequency of extension contacts					0.000
Four times and more	6.45	0.00	18.18	5.56	
Once	13.71	80.00	9.09	11.11	
Thrice	25.81	0.00	63.64	23.15	
Twice	54.03	20.00	9.09	60.19	
Source of extension service					0.000
NGOs/UN agencies	37.10	40.00	72.73	33.33	
Lead farmers	23.39	0.00	0.00	26.85	
Farmer training centers	18.55	20.00	9.09	19.44	
Contact farmers	11.29	0.00	9.09	12.04	
State/county agriculture department	9.68	40.00	9.09	8.33	
Information on emerging pests	22.25	18.78	9.23	38.30	0.000
Source of insect pest/disease information					0.000
NGOs	60.56	22.86	36.91	41.57	
Radio	21.13	37.14	56.38	43.92	
Payam extension staff	9.86	14.29	3.36	6.67	
County extension staff	2.82	5.71	0.00	1.57	
Fellow farmers	4.23	8.57	0.67	2.75	
Relatives/neighbours	1.41	11.43	2.68	3.53	
Awareness of training in pest management	23.21	21.96	10.03	37.28	0.000
Attended training on pest management	17.19	14.55	5.28	31.36	0.000

availability of training in crop pest management in their localities and whether they attended the training. There was a low level of farmers' awareness (23%) of the availability of agricultural training in crop pest management in their localities. A comparison of awareness levels showed significant differences across counties—the highest was in Yei (37%) and the lowest was in Yambio (10%). The low and varying awareness levels of awareness translated into low attendance of training in crop pest management; only 17% of the farmers who were aware of the crop pest management training attended training, with the highest participation reported in Yei (31%) compared to 15% in Juba and 5% in Yambio.

Plant health challenges

Table 5 presents challenges and solutions to plant health problems. About 77% of farmers who participated in crop production experienced crop losses in the immediate season, with the highest incidences occurring in Yei (95%) and the lowest in Yambio (58%). Crop pests were the significant causes of crop losses, especially in Yambio (82%). Livestock and crop diseases were the second and third most critical causes of crop losses. 28% of the farmers used chemical pesticides to control pests, with the highest usage reported in Juba (55%), while 37% did not control the pests—57% in Yambio, 37% in Yei, and 34% in Juba. About 52% and 41% of farmers who controlled the pest in Yei and Yambio used cultural methods (e.g., application of ash and neem and manual removal of infested plants), respectively, as traditional practices to manage pests. Farmers considered the effectiveness (37%) and cost (24%) of pesticides when selecting pesticides. About 44% of farmers who used pesticides against the pests reported experiencing difficulties in accessing the chemicals, with this challenge being more prevalent in Yei (69%) compared to Juba (44%) and Yambio (16%).

The problems experienced by farmers in the use of pesticides are presented in Table 6. High cost, liquidity constraints, and lack of knowledge and skill protective equipment were the top four most reported problems experienced by farmers in using pesticides. Availability and accessibility challenges were also reported. However,

Table 5 Plant health challenges and solutions by county

Variable	Juba	Yambio	Yei	Total	P value
Experienced crop losses in the field (%)	73.64	57.71	95.48	76.56	0.000
Causes of crop losses in the field (%)					
Crop insect pests	70.04	81.99	77.6	75.92	0.014
Livestock	49.81	11.8	26.18	31.29	0.000
Crop diseases	43.58	70.19	31.23	44.08	0.000
Flooding	29.96	0	12.62	15.92	0.000
Theft	24.12	31.06	19.56	23.67	0.020
Weeds	11.67	14.91	4.42	9.25	0.000
Wildlife	9.34	77.02	17.98	27.89	0.000
Too much rainfall	5.06	3.11	62.78	29.52	0.000
Lack of rains/drought	3.89	28.57	21.77	17.01	0.000
Wildfire	0.39	10.56	0	2.45	0.000
Pest control method (%)					0.000
None	34.96	56.99	21.08	36.56	
Use of chemical substance	54.73	0.36	21.99	27.6	
Use of cultural methods	10.32	41.22	52.41	33.85	
Use of organic substance	0.00	1.43	4.52	1.98	
Criteria for pesticide selection (%)					0.000
Confidence in effectiveness	57.88	17.2	32.83	37.40	
Price	11.75	26.52	33.43	23.54	
Health safety	18.05	26.88	31.93	25.42	
Convenience/availability	12.32	29.39	1.81	13.65	
Problem accessing the pesticides	43.55	16.49	69.28	44.58	0.000

Table 6 Proportions of farmers' responses to challenges related to the use of pesticides

Challenge	Juba	Yambio	Yei	Total	p-value
High cost of pesticides	92.11	45.65	88.7	85.28	0.000
Cash shortages	64.47	69.57	23.04	42.76	0.000
Lack of knowledge and skills in their use	7.89	73.91	50.00	37.62	0.000
No protective clothing and equipment	23.68	21.74	39.57	32.01	0.001
Distances to sources of supply	3.95	34.78	7.83	9.35	0.000
Limited quantities of pesticides available locally	10.53	28.26	3.04	8.41	0.000
Pesticides not available on time	9.21	39.13	1.30	8.18	0.000
Poor quality/not effective	7.89	4.35	0.00	3.27	0.000
I am not sure of the benefits	1.97	6.52	0.43	1.64	0.011
Health/safety concerns	3.29	15.22	0.00	2.80	0.000

experiences of these challenges significantly varied across counties.

Farmers implement several practices and technologies for crop production. The results in Table 7 reveal crop rotation as the most applied crop management practice, followed by row/line planting, early planting, and crop diversification. Certified seed and chemical pesticides were the least used technologies in crop production. These technologies and practices significantly differed across counties, with crop rotation implemented by 85% of farmers in Yei and Juba compared to 23% in Yambio. Row or line planting was more commonly practiced in Yei (72%) than in Juba (36%) and Yambio (43%). A significantly higher proportion (62%) of farmers in Yambio practiced early planting compared to 36% in Juba and 38% in Yei. Crop diversification (42%) and the use of chemical pesticides (18%) were highest in Juba, while the use of certified seed was higher in Yambio (24%).

Table 7 Improved management practices or technologies implemented in crop production

Practice/technologies	Juba	Yambio	Yei	Total	p-value
Crop rotation	85.10	22.58	84.64	66.77	0.000
Row planting	36.10	43.37	71.99	50.62	0.000
Early planting	36.39	61.65	19.58	37.92	0.000
Crop diversification	41.55	25.09	34.34	34.27	0.000
Use of certified seeds	10.89	24.37	3.61	12.29	0.000
Chemical pesticides	18.34	2.51	5.12	9.17	0.000

Insights for plant health system functions

At the country level, PHS focuses on strengthening national plant protection systems, pest risk analysis, diagnostics and surveillance, contingency planning, and access to information. Based on the previous work (Williams et al. 2015), six functions of PHS were identified, including diagnostic services, information management, input supply, advisory services, policy and regulation, and research and technology development. Building from the subsequent work (Ochilo et al. 2022) and the qualitative discussion with stakeholders in South Sudan during the study, this was extended by bringing on board two extra functions: agricultural training and crop production (Table 8). During the validation workshop in June 2023, the stakeholders affirmed that the eight functions provided a systems approach to the functions evident in the country.

Crop losses due to pests, such as insects, pathogens, nematodes, and weeds, threaten food security in Africa. Sustainable strategies and investments are required to address the pest menace. Investment in research and development that generates knowledge and technology products (e.g., improved seed and pesticides) for pest control and plant health and promoting sustainable integrated pest management practices and early warning systems are necessary (IITA 2023). In addition to improved seed and pesticides, crop rotation (Zohry & Ouda 2018), crop diversification (Guinet et al. 2023; Jaworski et al. 2023), row planting (Zaefarian & Rezvani 2016), and early planting (Haldhar et al. 2017) can prevent the spread of insect pests, weeds, and diseases and reduce reliance on chemical control methods and associated effects. The farmer advisory and extension services, information, and agricultural training functions of the plant health system should promote these practices for effective plant health management.

Situational analysis results in the previous section reveal low access to services provided by farmer advisory services, plant health information, and agricultural training. These functions heavily depend on NGOs/UN agencies and personal contact methods. At the same time, farmers use state/county agricultural departments less frequently, pointing to a gap in government service provision. These results contradict desk review findings that identified the Ministry of Agriculture as the primary driver of extension/advisory services in South Sudan. Qualitative interviews revealed that farmers' training through farmer field schools and lead farmers' approach models of training in the training centres played a central role in conducting plant health research and disseminating new technologies about plant health. Survey results on plant health information dissemination, mainly by NGOs, also support desk review finding that limited access to public extension services systems is a significant

Table 8 Functions of PHS in South Sudan

Function	Detailed description of the functions
Crop production	The crop production systems' characteristics, including farmer profiling, scale, practices, and challenges
Agricultural input supply	The systems and distribution network in place to support access to inputs, including crop seeds, fertilizers, agrochemicals, and farm implements
Farmer advisory services	These include an inventory of institutions and models that provide technical assistance to farmers in crop production through capacity-building initiatives. These initiatives aim to develop farmers' skills and knowledge and provide access to technologies and innovations that improve crop performance
Research and technology development	The framework and systems of science, knowledge generation, and innovations (fashioned as technologies or practices), including their implication in crop production systems. This includes the capacity of relevant institutions to generate innovations and knowledge to support plant health
Diagnostic services	The infrastructural facilities/equipment and expertise for characterizing plant health issues, including soil health, nutrient deficiencies, insect pests, diseases, and weed challenges in crop production systems
Policy, regulation, and control	The institutional framework by government and other stakeholders to govern the PHS. This includes laws and regulations set in the country and region and internationally accepted laws and regulations
Plant health information management	The structures and platforms provide information to the diverse actors on the plant health value chain for more informed decision-making on plant health
Agricultural training	The establishments (including their infrastructural/expertise capacity) train stakeholders in the plant health value chain and provide outreach services

barrier to access to information, including plant health-related information (Eliste et al. 2022). Survey results also established a low access to agricultural training, with a low proportion of farmers aware of the availability of training services in their localities. This could be attributed to a low number of agricultural training centres in the country—only six agricultural training centres in South Sudan, as revealed by data collected from key informants.

The limitations in the three functions are reflected in challenges and constraints to the crop production function of the plant health system. Three-quarters of farmers who participated in crop production reported experiencing crop losses largely attributed to crop insect pests and disease, affecting maize, groundnuts, cassava, sorghum, and vegetable production. These are the critical crops reported in the literature (Mohamed 2013; MAFS 2022). Furthermore, survey results affirmed findings document review that isolated FAW, African armyworm, tree locusts, desert locusts, and quelea birds as the main pests affecting field crops, and cassava disease rot as constraints to crop production. Despite the devastation caused by insect pests and diseases, a low proportion of farmers applied pest management practices. Those who used pest management practices were constrained by high cost, cultural methods, lack of knowledge and skills using the chemicals, effectiveness concerns, unavailability, and accessibility challenges. KII further confirmed these quantitative results with a community leader in Yei who stated that:

> *Our sorghum farmers suffer crop losses due to infestations from fall armyworms, birds, etc., in the absence of modern insect pest and disease control methods, and this reliance on a mixture of neem leaves, pepper, and ashes for spraying crops is a myth, just because these are bitter and hot or acidic do not mean that it will kill pest and diseases, we need better sustainable solutions.*

The use of certified seeds, which are drought tolerant and resistant to insect pests and diseases, as well as the use of chemical pesticides, were low. Additionally, about 45% of farmers that applied chemical pesticides reported experiencing problems accessing the inputs. These demonstrate challenges beyond farmer advisory and extension services, plant health information, and agricultural training and castigate the agricultural input supply function. This has resulted in the persistent use of local, borrowed, or saved seeds with questionable quality in terms of being disease-free or resistant to insect pests and disease (FAO/WFP & CFSAM 2021). During FGD with female youth in Yambio, the high use of local seeds was attributed to inadequate funds and high prices that limited their ability to afford them, which is affirmed by the survey data.

Similar findings on problems encountered when using chemical pesticides, as reported in survey results, were also affirmed by qualitative findings. Female youth discussions in Yambio revealed that young farmers did not use chemical pesticides because "*pesticides are costly for us to buy. These pesticides are available in agro-dealer shops but are prohibitively expensive, and we do not receive assistance from agricultural departments or their partners*".

Other challenges in using chemical pesticides to control pests were poor quality, low effectiveness, and health and safety concerns. These problems directly relate to the status of policy, regulation, control, and diagnostic services functions of the plant health system in South Sudan. KII data support this observation. Data collected from agro-dealer informants revealed possible laxity in policy, regulation, control, and diagnostic services functions. Citing limited awareness of any public regulatory body for pesticides in their location for pest control products, an agro-dealer informant in Yambio noted that: "Since *I started my business of importing agrochemicals, I have not heard of any regulatory body in charge of pest control products in Yambio County*." This statement was affirmed by the agro-input dealer in Juba, who observed that agro-dealers in Juba had the freedom to import and sell agrochemicals without any regulatory restrictions or laws regulating their agrochemical businesses.

Furthermore, an agro-dealer informant in Juba mentioned that "importing and selling chemicals that are allowed globally is the only measure we use to ensure we import the right chemicals in the absence of national regulatory policies." This reveals a significant gap in the diagnostic and regulatory functions, including weak national regulatory policies, reliance on regional and global standards (East African Community, 2022a; b), and potential risks from chemicals not suited to the local context or banned elsewhere. Thus, there is a need for quality assurance mechanisms to ensure that all imported agricultural chemicals are safe, effective, and appropriate for their intended use. It also reveals South Sudan's importance in developing and implementing national regulatory policies and frameworks. Furthermore, this calls for strengthening the research and technology development function of the South Sudanese plant health system to conduct plant health research and disseminate new technologies on plant health suited to local contexts. This will address the challenge of inadequate attention to participatory adaptive research on farms identified by the key informant.

Table 9 Strengths and weaknesses of plant health system function of South Sudan

Strengths	Weaknesses
Crop production	
Availability of land for crop production expansion Some farmers are involved in irrigated production	Low input, e.g., fertilizer, agrochemicals, and improved seeds and low output subsistence systems of production Low uptake of conservation practices The smallholder production system has a low commercial orientation High prevalence of insect pests, diseases, and weeds accompanied by low management strategies implemented by farmers
Agricultural input supply	
The existence of seed testing labs for quality assurance The presence of plant breeders in the country involved in research on seed The presence of agro-input dealers for providing seeds, fertilizer, and pest control products The heavy presence of NGOs and the international community that supports the provision, distribution, and training on the use of inputs	There is a limited capacity of critical actors involved in input supply in the country, including breeders, to provide bespoke solutions related to plant health appropriate for different regions Limited public awareness and sensitization regarding approved inputs and existing regulations Poor infrastructure, including poor roads, fewer numbers, and equipped testing labs Lack or limited enforcement of input-specific laws/policies An inefficient input distribution network leading to high costs and unavailability of crucial plant health inputs Heavy reliance on external inputs limits self-sufficiency and context-specific solutions The low purchasing power of inputs by smallholder farmers
Farmer advisory services	
The existence of the Plant Protection Directorate (PPD) that oversees the extension system in the country Existence of agricultural training and vocational institutes (TVETs) Availability of ICTs, including. Social media and radio/TV are used to disseminate agricultural information High coverage of mobile phone services Significant involvement by NGOs providing agricultural advisory services	Limited numbers of agricultural extension service providers limiting advisory services to farmers Limited number of extension training centres in the country Limited funding for the provision of public advisory services
Research and technology development	
Established a directorate of research in the MAFS Draft policy on plant health research in the pipeline	Inadequate funding to operate research effectively Limited research institutions and researchers Limited research laboratories and equipment in the country
Diagnostic services	
A draft plant protection policy covering diagnosis and diagnostic services exists Existence of a research and plant protection directorate that oversees diagnosis, among other functions The country has a large pool of graduates in agriculture and diagnostic disciplines Basic efforts to enhance diagnostic services, e.g., through the Emergency Locust Response Project, exist	Limited diagnosticians and diagnostics labs at both national and state levels Inadequate research in plant health matters from research and academia limiting diagnosis Inadequate extension service providers for on-field diagnosis and advice to farmers Available policies are still at the draft stage, limiting implementation or enforcement
Policy, Regulation and Control	
PHS draft policies- seed, pesticides, and fertilizer- at different stages of development, which will be critical in guiding specific plant health issues, e.g., farmer advisory, subsidies, market price, and quality of inputs	Draft policies are still not implemented, providing loopholes along the PHS, including limiting enforcement Lack of established regulatory frameworks, e.g., harmonized standards, input distribution, etc
Plant health information management	
Plant protection and extension service providers are available at national and state/county levels Availability of mobile phones and other ICTs for the collection and dissemination of agricultural information	Lack of policy framework for PHIM in the country Limited infrastructure/system/database for data storage and management Limited transport infrastructure for extension service to collect and disseminate information for surveillance and early warning Insecurity in South Sudan limiting real-time surveillance
Agricultural training	
There are agricultural training facilities, both private and public Previous development partners' support efforts have enhanced their capacity to undertake training	Limited funding by the government It has limited human resource capacity that has hindered its operations, including disseminating knowledge

Strength and weaknesses

Analysis of data from the situational analysis and additional comments and data from stakeholder workshops reveal strengths and weaknesses of the plant health system in South Sudan. Cross-cutting strengths include the potential to strengthen farmer advisory and extension services to play the monitoring and surveillance role. Other strengths are emergency preparedness and response through early planting, education and public awareness using farmer field schools and training centres, and trade and certification by ensuring the quality and health of the agricultural products. Another strength is high mobile usage by farmers, a fertile group for strengthening plant health information and advisory and extension services.

Weaknesses revolve around gaps in government service provision, low access to extension services, limited agricultural training centres and low access to advisory services, limited attention to participatory adaptive research, and heavy dependence on NGOs/UN agencies for extension services. Lack of robust public extension services may affect the system's emergency preparedness and responses, low access to agricultural training and information dissemination, dependence on external agencies, and limited government involvement for trade and certification are other weaknesses. Table 9 provides function-specific strengths and weaknesses of the plant health system in South Sudan as identified by document review, stakeholder workshops, and survey results.

Conclusions

The situational analysis of the plant health system in South Sudan provides a foundational platform for targeted interventions that target to coordinate and strengthen systems for pest risk detection, response, and reduction. The assessment also contributes to enhancing the efficacy and reach of the plant health system in South Sudan, focusing on increasing awareness of, access to and use of affordable, sustainable pest management practices and technology that would relieve heavy reliance on donor or external support. Additionally, the analysis highlights opportunities in the farmer advisory, plant health information, and agricultural training in enhancing farmers' knowledge and uptake of integrated pest management practices, as well as surveillance and monitoring plant health issues, ultimately contributing to the overall improvement of agricultural productivity and sustainability in South Sudan.

The analysis reveals a lack of access to essential services, including farmer advisory, information, and training, high dependency on NGOs and UN agencies to provide plant health services, and the influence of socioeconomic and spatial factors on the adoption of plant health practices. These findings highlight weaknesses in farmer advisory services, plant health information, and agricultural training functions, a void in government-led initiatives and support for the plant health sector, sustainability and resilience issues for the plant health system and inequitable access to plant health services and resources. These gaps potentially undermine the overall effectiveness of plant health management across different farmer communities, as revealed by the low use of chemical pesticides and certified seed, as well as constraints experienced by farmers in crop production.

The findings have implications for service accessibility, government involvement in plant health systems, and inclusivity in service provision. Considering these implications, the study recommends strengthening public extension services to reduce reliance on external agencies and ensure more equitable and widespread access to plant health information and support services. The study notes that draft policies and action plans exist for the plant health systems in the country and recommends their effective implementation and enforcement. The regulatory framework should be strengthened to ensure effective management and control of plant health issues. Lastly, inclusivity in the provision of plant health services can be achieved by considering the varying socio-economic contexts during the design of plant health interventions and stakeholder engagement and collaborations to ensure that all farmers across counties have access to vital plant health services.

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Author contributions

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Availability of data and materials
All data generated or analysed during this study are included in this published article and its supplementary information files.

Declarations

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Not applicable.

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