One hundred priority questions for the development of sustainable food systems in sub-Saharan Africa

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Article

One Hundred Priority Questions for the Development of Sustainable Food Systems in Sub-Saharan Africa

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Abstract: Sub-Saharan Africa is facing an expected doubling of human population and tripling of food demand over the next quarter century, posing a range of severe environmental, political, and socio-economic challenges. In some cases, key Sustainable Development Goals (SDGs) are in direct conflict, raising difficult policy and funding decisions, particularly in relation to trade-offs between food production, social inequality, and ecosystem health. In this study, we used a horizon-scanning approach to identify 100 practical or research-focused questions that, if answered, would have the greatest positive impact on addressing these trade-offs and ensuring future productivity and resilience of food-production systems across sub-Saharan Africa. Through direct canvassing of opinions, we obtained 1339 questions from 331 experts based in 55 countries. We then used online voting and participatory workshops to produce a final list of 100 questions divided into 12 thematic sections spanning topics from gender inequality to technological adoption and climate change. Using data on the background of respondents, we show that perspectives and priorities can vary, but they are largely consistent across different professional and geographical contexts. We hope these questions provide a template for establishing new research directions and prioritising funding decisions in sub-Saharan Africa.

Keywords: agricultural development; agroecosystems; environmental impacts; horizon scan; food security; food systems; social inclusion; Sustainable Development Goals; trade-offs

1. Introduction

Global agriculture faces the critical challenge of producing an ever-increasing amount of food while also maintaining the sustainability, equitability, and resilience of food systems. This challenge is perhaps greatest in sub-Saharan Africa, where the human population is projected to double over the next quarter century [1,2], potentially leading to a near-tripling of food demand in the region from 2010 to 2050 [3,4]. Meeting this demand poses a wide array of environmental, political, and socio-economic difficulties, not least in balancing the trade-offs between competing agendas and policy targets.

The imperative of increased agricultural production in sub-Saharan Africa can be viewed in the context of clear trade-offs between the United Nation's Sustainable Development Goals (SDGs). Widely reported trade-offs between food production (SDG 2 'Zero Hunger'), inequality (SDG 10 'Reduced inequalities'), and ecosystem health (SDG 15 'Life on Land') [5–8] seem unavoidable, given that the current agricultural development strategies are often in direct conflict with environmental conservation and restoration policies [9,10], with negative effects on marginalised communities dependent on wildlands for their livelihoods [11,12]. In addition, policies may favour industrial or foreign agricultural business interests over small holders, further accentuating economic inequalities [13,14]. To navigate such challenges, decision makers require access to current research exploring the nature of these trade-offs and the most appropriate solutions [15]. The first step to achieving this is by identifying the most critical questions, which, if answered, would provide the necessary information to address fundamental trade-offs.

Despite the urgent need for evidence-based policy and management, knowledge exchange between researchers and decision makers is often limited. In the context of agricultural development in sub-Saharan Africa, reduced or ineffective knowledge transfer may reflect a mismatch between the priorities and needs of research producers (e.g., academic researchers) and end-users (e.g., policy makers and local practitioners) [16]. For example, curiosity-driven research may focus on topics with little relevance to real-life problems, while research explicitly targeting these problems may be presented in ways that seem obscure or impenetrable to those most in need of the information. Perhaps unsurprisingly, therefore, many agricultural or land-use policies are developed and implemented based on little evidence. The wide gulf between research and practice in this sector can only be bridged with an interdisciplinary and inclusive approach that involves and engages representatives from a range of backgrounds and disciplines, drawing expertise and opinions from research producers and end-users alike.

In this study, we use a well-established horizon-scanning approach [17–20] to establish a realistic and inclusive roadmap for research. Because views on research priorities and opportunities may be strongly contingent on local context, we invited suggestions from people operating in a range of sectors across sub-Saharan Africa and beyond. We then used a series of transparent and iterative stages to process their responses into a prioritised list of 100 critical research questions. By adapting our methods to the context of sub-Saharan Africa, we aimed to identify high-priority questions that will guide the development of a research agenda explicitly designed to promote more sustainable approaches to regional agricultural development and land-use management.

A key challenge for our methods is that identifying experts based on research networks or published literature is certain to introduce strong biases, over-representing professional academics, and under-representing researchers from sub-Saharan Africa, where authorship of publications is much reduced for a range of structural and economic reasons [21,22], including so-called ‘helicopter science’ [23,24]. In addition, standard horizon-scanning methods can tend to overlook the views of people working in governmental and commercial sectors or representing small-holder farmers. We attempted to minimize biases so that all relevant voices are considered, particularly those of under-represented groups living in sub-Saharan Africa. To examine the effects of including a wider diversity of views than most previous horizon scans, we collected basic information about each participant and assessed how their perspectives and priorities were shaped by their geographical location and professional context.

2. Materials and Methods

2.1. Diversifying and Quantifying Participation

We used a variety of approaches to ensure that a diverse sample of participants contributed to the horizon-scan. As a first step, we identified individuals with expertise in agricultural research, SDG trade-offs, and the science-policy interface in sub-Saharan Africa using a combination of literature searches, professional mailing lists, and in-person meetings. For literature searches, we used Google Scholar and Web of Knowledge to search for research publications containing the following terms: [sub-Saharan Africa* OR Ghana* OR Zambia* OR Ethiopia* OR South Africa* OR Nigeria* OR Kenya* OR Uganda* AND sustainable develop* OR agricultural develop* OR trade-off*]. We confined our search to literature published after the launch of the SDGs in 2015.

To maximize the participation of researchers based in sub-Saharan Africa, particularly those working in non-academic and commercial sectors, we conducted a series of workshops and presentations. These were designed not only to share knowledge but also to specifically attract informed and motivated participants from diverse sectors. These events took place in Ghana, Zambia, and Ethiopia in July 2018. Additionally, we engaged with participants at the Independent Science and Partnership Council (ISPC) Science Forum meeting in Stellenbosch, and the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) Biennial Conference in Nairobi, both in October 2018. The ISPC is an independent advisory body of the Consultative Group on International Agricultural Research (CGIAR). The ISPC Science Forum and the RUFORUM Biennial Conference were chosen as they attract a diverse audience, including academics and policymakers working in the sub-Saharan African agricultural sector.

Despite our best efforts, these meetings were attended by very few participants from the business sector, including landowners and agribusinesses. This may be due to various factors, such as travel or time constraints, perceived irrelevance of the research, or communication challenges regarding the importance and potential impact of participation. In view of these obstacles, we took a targeted approach to encourage engagement from a wider sample of perspectives. We directly contacted individuals, asking them to submit questions and share the activity within their respective businesses, organisations, and networks. This approach aimed to elicit more diverse responses by engaging stakeholders not reached or motivated by the traditional format of workshops and conferences.

To broaden our participant base further and to minimise potential biases associated with using a limited set of contact methods, we disseminated invitations globally through social media and various professional networks, including the International Water Management Institute (IWMI) and the Platform for African–European Partnership in Agricultural Research for Development (PAEPARD) mailing lists. Moreover, to address the low response rates from African participants, we specifically invited a larger number (ratio 2:1) of individuals in sub-Saharan Africa, including non-academic positions in institutes, organisations, and businesses. This involved directly approaching policymakers, land-use managers, farmers, cooperatives, landowners, and agriculturalists in the business sector during earlier mentioned meetings and events. However, engaging specific stakeholders remained challenging, and many invitations to participate were rejected or ignored.

All potential participants identified through literature searches, meetings, and broader outreach efforts were contacted directly via email or, when possible, in person. In total, we received 318 responses, either directly from meetings, events, and emails, or indirectly through dedicated webpages on our project website (see Supplementary Materials Figure S1).

Every participant was invited to submit an unlimited number of research questions, regardless of how they were contacted. Additionally, participants were asked to provide their self-identified country of residence, the sub-Saharan African countries they worked in, and their professional backgrounds. Based on this information, participants were categorised according to geographical and professional background. First, we classified respondents according to whether they were based inside or outside sub-Saharan Africa, and whether they worked in an academic or non-academic setting. For participants working in a professional capacity both inside and outside sub-Saharan Africa, we used their country of residence to determine their location. Similarly, for individuals who worked in both academic and non-academic settings, we categorised them based on their primary position.

2.2. Identifying and Prioritising Questions

In line with other horizon-scanning methods in the conservation and environmental science sector [18–20,25], we used a modified form of the Delphi technique, on the grounds that it is highly structured, inclusive, and designed to reduce the potential influence of social pressure and bias among respondents [26]. Applying this technique involved a three-stage approach to identify 100 high-priority research questions (Figure 1).

Figure 1. Flowchart of the horizon-scanning process. Schematic representation of the three-stage process used in this study to identify and evaluate key research questions. This approach follows methods commonly applied in horizon-scanning procedures in conservation science and related fields.

In Stage 1, we used a relatively unstructured approach to maximize the breadth of contributions. Each participant was asked to put forward research questions—in either English or French—related to topics of food and nutrition security, reducing inequality, and ecosystem health in sub-Saharan Africa. Participants were informed that there were no restrictions on the type or number of questions that could be submitted, provided they met the following criteria: (1) not answerable with a simple 'yes' or 'no' response; (2) not dependent on the outcome of another question; (3) address a knowledge gap(s) that can be filled within a reasonable time frame (e.g., <10 years) using a realistic research design; and, where possible, (4) specify a subject and an intervention, including a measurable outcome if it relates to an impact and intervention.

We analysed the corpus of research questions using a Structural Topic Models (STM) machine learning approach in the STM package (version 1.3.6) [27]. This topic modelling method is specifically designed for social science research, allowing each question to be associated with important covariates (e.g., participant demographic information), thus helping the interpretation of the factors affecting the topic prevalence and content [28,29].

Using the STM approach, we identified 12 broad topic clusters from the entire pool of questions. We first screened the individual randomised questions against the Stage 1 criteria and then assigned them to one of these 12 topic clusters. Out of the 1339 questions, 1092 (82%) were allocated to a specific topic cluster and considered for short-listing. Since the questions were not evenly distributed across the topic clusters, we further consolidated them into four key research themes: (1) Food and Nutrition/Agricultural sector; (2) Environment/Climate; (3) Policy/Development/Technology; (4) Inequality/Productivity/Sustainability. We then evenly distributed the questions across these themes, resulting in 273 questions per theme.

In Stage 2, the questions and research themes refined from Stage 1 were used as the foundational elements of an online survey using the SurveyMonkey platform. All respondents from Stage 1 were invited by email to assist in the short-listing and scoring of questions. To prevent voter fatigue, we asked each participant to score a subset of seven questions selected randomly using a blockchain method from each of the four key research areas. This approach ensured each question was reviewed equally by participants. In total, each participant scored 28 questions (four sets of seven questions) on a scale of 1 ('topic is not important because already well understood or will not have a critical impact') to 1000 ('topic is highly important because poorly known and likely to have critical impact'). This high-resolution rating scale was chosen as it helps to minimise score overlaps, improves analysis precision, and enables more effective identification of differences in participant viewpoints [30,31]. The median score for each research question was used to rank them in order of priority within each of the four research themes. In total, 250 participants completed the survey, and the top 546 (50%) questions were put forward to stage 3. This approach ensured that the most critical and impactful questions identified in Stage 1 were carried forward and prioritised, helping to shape the direction of Stage 3.

In Stage 3, a two-day virtual workshop was held in September 2021, facilitated by four individuals with experience running horizon-scanning workshops or similar style activities. A total of 73 participants from Stage 1 were invited, of which 48 attended both days. Selection was based on several criteria to ensure diverse representation: self-identified country of residence, area of expertise, career stage, and demographics (age and gender). We aimed to include at least one participant from each country represented in Stage 1, a range of expertise from the three priority SDG areas, and a balance between genders as well as between early and late-career professionals, aiming for a 50:50 split where possible. A stipend was provided to all participants to cover costs associated with attending the event and to ensure good internet access.

Before the workshop, all participants received the 546 retained questions, subdivided among the four key research themes identified in Stage 2. Participants were asked to read the questions and identify at least 25 questions they thought were the most important and potentially impactful from the theme they felt most knowledgeable and informed about.

During the workshop, questions were reviewed and discussed collectively and in four parallel sub-groups, each supported by one facilitator. Questions were arranged based on pre-workshop participant assessments. Participants were initially assigned to one sub-group but could move between groups to encourage greater discussion and cross-pollination of ideas. After the first day, participants were asked to, collectively in their groups, put forward at least 50 questions from each of the four research themes. These were then individually scored using a five-point Likert scale from (1) 'not very important or novel' to (5) 'very important and novel'. The top 30 questions from each research cluster were put forward for further consideration.

On the second day, consensus on the most important questions was reached through a group activity using a shared interactive Miro board (https://miro.com/; accessed on 2 September 2021). Participants, both individually and in sub-groups, were instructed to organise questions within an interactive Venn diagram designed to highlight intersections among the three key SDG areas: food and nutrition security, inequality, and ecosystem health. Participants were encouraged to consider trade-offs and synergies between questions associated with these themes. Perceived connections were annotated directly on the diagram for clear visualisation. This process allowed participants to arrange questions under subheadings, and to merge or split questions as required. A total of 118 questions were arranged on the Venn diagram. Post-workshop, these questions were collated and shared among all participants for merging and editing. The final list of 100 questions was then circulated for wider consensus and review.

2.3. Evaluating Research and Development Priorities

Allocating research funding and attention often involves making critical decisions about where to channel resources and which topics to prioritise. Various biases can influence these choices [32], often contributing to a disconnect between researchers and policymakers [33,34]. To investigate the priorities of our participants and their potential influence on research question formulation, we used two different approaches.

Initially, we focused on the three key SDGs: food and nutrition security, reducing inequality, and ecosystem health. During Stage 1, participants were either asked to score (using a Likert scale of 1–10) or rank a series of six questions related to these three SDGs (see Table S1 for the questionnaire), based on their importance in terms of influencing the agricultural development decision-making or funding allocation process. We then used a non-parametric Wilcoxon signed rank test to assess the effect of background (either academic or non-academic) and geographic location (either within or outside sub-Saharan Africa) on the participants' perceived priorities. The outcomes of this analysis were then juxtaposed and compared against the overall rankings of the participants.

Alternatively, instead of asking participants to explicitly state their priorities, we examined the raw questions submitted by the participants in Stage 1 to determine if the questions they asked reflected their primary concerns. We were particularly interested in identifying any noticeable variations in the selected research themes or topics, which could provide insights into their priorities. This analysis was conducted in two different ways.

Firstly, we performed a keyword search within these categorised questions, based on a predetermined set of 10 keywords per SDG.

- Food security concerns: crop; drought; food prices; food security; hunger; livestock; malnutrition; market; production; yield.
- Social concerns: terms access; education; gender; inequality; infrastructure; land ownership; opportunity; poverty; unemployment; wage.
- Environmental concerns: biodiversity; carbon; conservation; deforestation; degradation; environment; nature; pollution; sustainability; wildlife.

The total count of these identified keywords was then divided by the total count of questions within each category, resulting in a proportional score for each set of SDG keywords. These scores were then compared against participants' backgrounds and geographic locations using a parametric *t*-test.

As an alternative to the keyword approach, we applied STMs (as described above) to analyse the corpus of questions submitted in Stage 1. To simplify the procedure, we reduced the number of research topics from an initial twelve to eight. This allowed the formulation of broader, more encompassing topics that captured the underlying themes of the submitted questions without sacrificing significant detail or granularity. The model was set up to run for a maximum of 75 iterations using the 'Spectral initialization' method to ensure stable and reliable topic assignments.

To examine the contextual factors shaping perspectives and priorities, each question was assigned binary covariate information based on each participant's background and geographical location. This allowed us to use the prevalence of these eight topic clusters to represent the priorities of the different participant groups. Although qualitative, this method has been successful in previous studies in identifying factors influencing topic prevalence and content [28,29].

3. Results

In Stage 1, a total of 1339 scientific questions were gathered from a diverse sample of 331 stakeholders, spanning 55 countries and a wide range of backgrounds and expertise (Figure 2). Notably, our respondents were predominantly from the Global South, with 75% (248 individuals) based in sub-Saharan Africa. Academics constituted the largest group of contributors, accounting for 49% (161 individuals) of our participants, and of these, 36% (119 individuals) were based in sub-Saharan Africa, contributing 35% (464 questions) of the total questions gathered (Figure 2).

3.1. Research and Development Priorities

The analysis of the Likert scores revealed only minor differences in perceived priorities among participants, irrespective of whether they worked within or outside sub-Saharan Africa or were affiliated with academic institutions (Figure S1). The main exception was that participants based in sub-Saharan Africa and working in academia assigned significantly higher scores to environmental preservation compared to their counterparts outside sub-Saharan Africa ($U = 8790$, $p < 0.005$; Figure S1A) and non-academics ($U = 9812$, $p < 0.05$; Figure S1B). Interestingly, when asked to rank priorities for agricultural development, most participants opted for 'reducing inequality' as the lowest priority (Figure S2A), with 'food security' as the most important priority (Figure S2B). Moreover, 57–61% of participants (164–168 individuals) considered 'food security' to be the highest priority in terms of funding allocation. These were consistent patterns irrespective of geographical location or professional background (Figures S2 and S3).

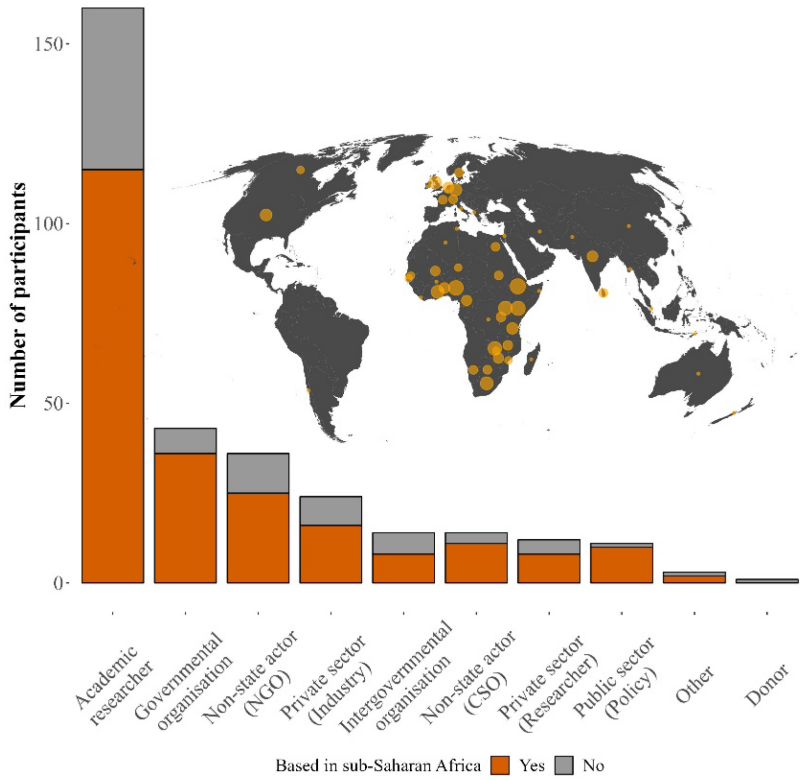

Figure 2. Geographical distribution and occupational background of participants. The inset map shows the geographical location of 331 participants who submitted questions during Stage 1 of the horizon scanning procedure (see Materials and Methods). Each dot represents a country, and the size of each circle corresponds to the number of participants from that country, log-transformed and incremented by 1 for clarity. The histogram shows how the participants were partitioned across 10 occupational contexts. Assignments to these categories were conducted by the participants, who were asked to identify the area that best represents their work from the list of 10 categories. Most participants were agricultural or environmental experts working in academia and based at public or private universities. Response rates from private sector contacts were low; those working in industry were largely from the agricultural sector, including agribusinesses, commercial enterprises, and agro-chemical manufacturers. NGO = non-governmental organizations; CSO = civil society organizations.

Applying an alternative keyword-based approach to discern participants' priorities, we identified variations in their perspectives based on geographical location (Figure 3). Notably, whether they were based inside or outside sub-Saharan Africa, participants shared similar concerns for food security ($t = 0.624$, $p = 0.533$; Figure 3A). However, we found significant differences in their views on social ($t = 3.263$, $p < 0.001$; Figure 3C) and environmental ($t = 2.016$, $p < 0.05$; Figure 3E) concerns. Specifically, individuals based outside sub-Saharan Africa showed a stronger inclination towards environmental matters, while those within sub-Saharan Africa tended to emphasise social concerns. Despite these differences, participants' viewpoints remained consistent regardless of their occupational setting, be it academic or non-academic (Figure 3).

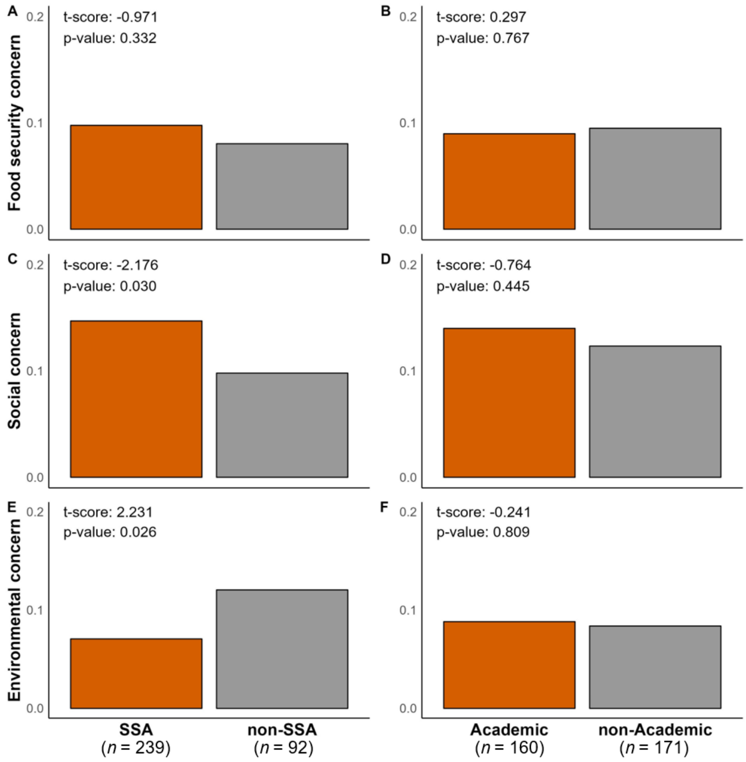

Figure 3. Key concerns of participants in relation to their geographical distribution and occupational background. Emphasis on major topics was determined by searching for sets of indicative keywords in all questions (n = 1339) submitted for consideration in Stage 1 of the horizon scanning procedure. Prevalence of three key concerns was quantified using a set of ten keywords: (**A**,**B**) food security (identified by the terms crop, drought, food prices, food security, hunger, livestock, malnutrition, market, production, and yield); (**C**,**D**) social concerns (identified by the terms access, education, gender, inequality, infrastructure, land ownership, opportunity, poverty, un-employment, and wage); and (**E**,**F**) environmental concerns (identified by the terms biodiversity, carbon, conservation, deforestation, degradation, environment, nature, pollution, sustainability, and wildlife). Y axes are the proportions of the total number of questions contributed by each participant group.

Further analysis of participants' questions revealed variations in their research priorities based on phrasing and word choices. Using an STM machine learning approach to reduce subjectivity, we found evidence of geographical biases. For example, participants from sub-Saharan Africa predominantly favoured questions focusing on 'food and nutrition security' or 'resource management'. In contrast, those based outside the region placed greater emphasis on questions related to 'biodiversity conservation' and 'technology adoption'. Interestingly, this topic clustering approach revealed no biases or clear differences in research priorities between academics and non-academics when controlling for their geographic locations (Figure 4B).

3.2. Final List of Questions

Overall, participants showed a preference for cross-cutting questions, such as those addressing trade-offs between food production and the environment, rather than questions focusing solely on food systems. To provide a more easily navigable structure for end-users, the final list of 100 questions was organised into 12 thematic sections. Unlike the STM approach, which aimed to uncover latent topic patterns, the grouping into thematic sections was determined based on the thematic areas outlined during the Stage 3 workshop, which aligned more closely with the needs of intended users. Each thematic section was accompanied by a concise introductory paragraph, serving to contextualize the questions and establish connections to existing research.

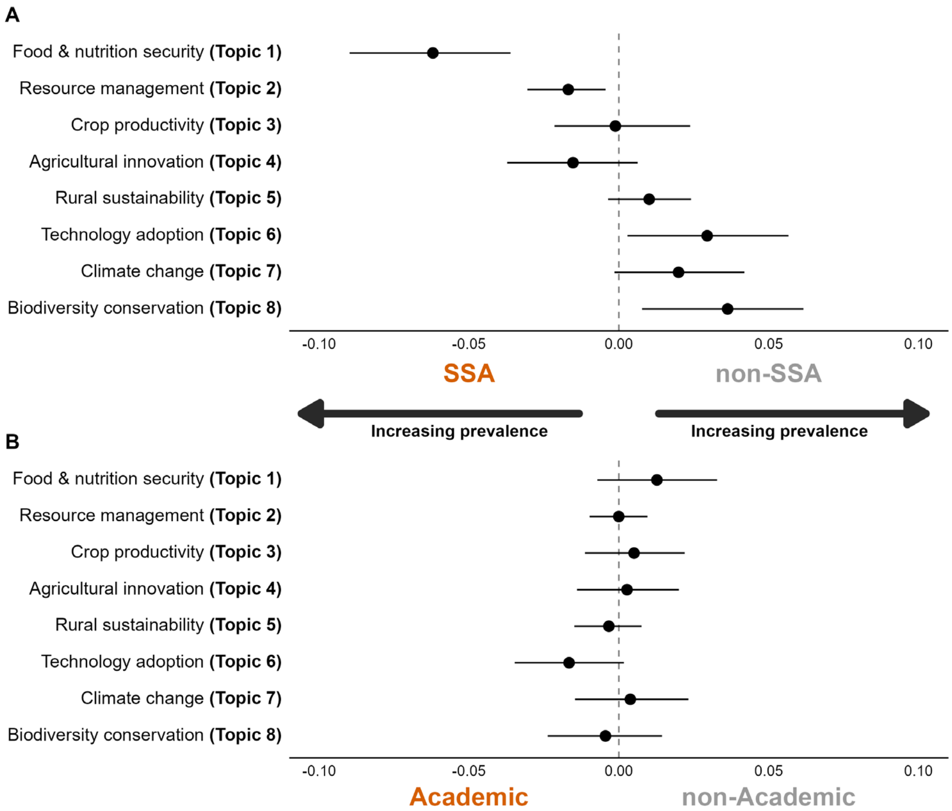

Figure 4. Comparing research priorities for participants in different geographical and occupational settings. Panels show the association of eight key topics determined by a Structural Topic Model (STM) based on 1295 initial questions submitted by 331 participants during Stage 1 of the horizon-scanning process. Results are derived from differences in topic prevalence in (**A**) participants based in sub-Saharan Africa compared with those based outside the region, and in (**B**) participants based in academia (that is, working in the university and higher education sectors) compared with non-academics. The data points show estimated mean divergence in topic prevalence between different categories of participants, the farther these values are from the center line without intersecting it, the more significant and prevalent the discrepancies in the topic are amongst the participant groups. Error bars show ±95% confidence intervals.

Gender inequality

Women comprised nearly 50 percent of the employed workforce in agriculture in low-income countries, yet have reduced access to income, resources, and opportunities in comparison with men [35,36]. To develop more sustainable, diverse, and resilient agricultural systems, we need to promote gender equality through appropriate policy and practice [37,38].

1. What knowledge gaps and barriers hinder progress in female economic empowerment and the achievement of gender equality in the context of sustainable food systems, rural livelihoods, and climate change?
2. How can agricultural development research meaningfully integrate gender-equality issues into both policy and practice relating to food and nutrition security?
3. How can gender equality and female empowerment in agriculture support locally led climate change adaptation?
4. How do we enhance the education and leadership potential of girls and young women in sectors such as agriculture to accelerate the development of sustainable food systems?
5. What impact does female empowerment in agriculture have on dietary diversity in sub-Saharan Africa?

Sustainable and inclusive food systems

In comparison to other regions, agricultural productivity has increased far more slowly in sub-Saharan Africa, where most of the food is produced on small farms [39]. Much debate exists around the urgent need to transform the sub-Saharan African food system to improve both local and national food and income security, as well as international demand [40,41]. While reforming sub-Saharan Africa's food system is important, it is critical that such transformation does not come at the expense of the rural poor and/or the environment [42]. This will require greater integration and alignment between recommendations for food and land use practices, together with an understanding of the political economy context and identification of entry points for change [43].

6. What are the key drivers for achieving inclusive sustainable food and nutrition security in sub-Saharan Africa?
7. How can we build sustainable and resilient local food systems to tackle hunger, poverty, and malnutrition?
8. What are the most efficient ways of achieving broad-based growth and food security in sub-Saharan Africa, including pathways to opening new trading opportunities and self-reliance in food production?
9. What impacts do a growing population and demographic changes in sub-Saharan Africa have on achieving food security for all?
10. How will improvements in education in sub-Saharan Africa affect income, population growth rates, and projected food demand?
11. What are the impacts of large-scale commercialized agriculture on equality and social inclusion, female empowerment, changing land access, and land concentration/ownership in rural areas?
12. What are the benefits of more intensive agriculture compared to subsistence agriculture and how can we reduce inequalities between large-scale farmers and smallholders?
13. How can we maximize the number of smallholders that benefit from (or not be disadvantaged by) the inevitable increase of small farm commercialisation across sub-Saharan Africa?
14. How does access to land (including security of land tenure) impact gender equity and agricultural production?
15. How can we improve livelihoods and access to land for landless youth in developing countries without destroying the environment?
16. What are the trade-offs between the economic contributions of large-scale agricultural investment and its impacts on biodiversity and food and nutrition security?
17. What impacts are increases in agricultural productivity having on socio-cultural dynamics in sub-Saharan Africa?
18. How should agricultural sciences be redesigned in and for sub-Saharan African universities to address both current and future challenges?
19. What is the role of the informal sector, consisting of unregulated activities and workers, in supporting food and nutrition security, and how can it be better recognized in policy debates?
20. How can we build the skills, knowledge, and capacity of rural communities for modernizing agriculture systems?

Climate change

Climatic changes are leading to warmer temperatures and altered rainfall patterns, increasing the occurrence of adverse events, such as extreme heat, droughts, and flooding. Such events have the potential to decrease the productivity and nutrient content of Afrotropical crops, affecting food security, nutrition, and health [44,45]. For these reasons, climate change is a major threat to sustainable growth and development in sub-Saharan Africa [46], with potentially catastrophic impacts, particularly for the poorest and most vulnerable people. In addition, climate change will inevitably alter the trade-offs between agricultural development and the effective management of environmental resources and biodiversity. Consequently, managing, understanding, and mitigating these impacts is a key priority for international and national decision makers and practitioners alike [47].

21. What are the impacts of climate change on agricultural production and expansion in sub-Saharan Africa?
22. How can food and nutrition security be maintained in sub-Saharan Africa given the twin challenges of human population growth and climate change?
23. How will the spread of animal and plant pests and diseases be impacted by climate change in sub-Saharan Africa, and which regions and farming systems are expected to be the most vulnerable?
24. Will currently available climate-resilient crop and seed varieties be enough to maintain or enhance agricultural productivity under climate change, and in what cases will more resilient varieties need to be developed?
25. How can we maintain water supplies in rain-fed agricultural systems in the face of ongoing climate variability?
26. How will climate change affect the ongoing challenge of closing gaps between real yields and potential yields (so-called 'crop yield gaps') across the wide variety of environmental contexts in sub-Saharan Africa?
27. Given that harmful food production methods can exacerbate the impacts of climate change, which in turn may pose a risk to future food production and livelihoods, how can we strike a balance between efficient food production methods and minimizing socioeconomic or environmental damage?
28. How can the capacity of farmers in sub-Saharan Africa to respond adaptively to climate change be improved by initiatives, such as government policies, educational outreach activities (including extension services), agricultural development research, or development agency programs?
29. What strategies can be developed and implemented in collaboration with subsistence farmers to enhance climate resilience in agriculture, and how can training and capacity building be optimised in this process?
30. How can we manage increasing conflicts over natural resources caused by climate-related scarcity (such as in the Sahel) to minimize negative effects on local communities, especially vulnerable groups like ethnic minorities, women, and youth?
31. What technological innovations, such as irrigation techniques, renewable energy, and climate-smart agricultural practices, can help us to meet the challenge of food production over the coming decades in sub-Saharan Africa?
32. How do we harness the power of new and innovative Internet of Things (IoT) technologies and cloud-based platforms to improve the livelihoods of communities vulnerable to climate-related disasters?
33. In the context of climate change adaptation and mitigation, how can we achieve food and nutrition security in arid and semi-arid areas while avoiding environmental degradation and biodiversity loss?

Technology access, adoption, and use

The question of sub-Saharan Africa's readiness for high technology adoption in agriculture has been the focus of ongoing debate [48,49]. While the region has seen rapid uptake in the Information and Communication Technology (ICT) sector, the adoption of farm management technologies that exist to improve yields has been slow [50,51]. There are many potential applications of emerging technologies, such as data sharing, data trust, and decentralised learning, all of which could play a role in facilitating more efficient data exchange and fostering collaboration in the region [52,53]. However, it is crucial that any technological intervention developed to improve agricultural development in sub-Saharan Africa must also include ways to overcome constraints on access, adoption, and use.

34. What factors influence farmers' willingness or resistance to adopting new and improved agricultural technologies, and how do these factors vary across different contexts in sub-Saharan Africa?
35. What methods are most accurate and cost-effective for monitoring, mapping, and forecasting the spread of agricultural pests and diseases in sub-Saharan African smallholder farming systems?
36. What are the key challenges and opportunities in consolidating educational outreach resources into a single, easily accessible, and interpretable database for both farmers and intermediaries in sub-Saharan Africa?
37. What are the potential impacts of mobile technology on food and nutrition security and inequality in underserved areas of sub-Saharan Africa?
38. What is the potential of ICTs and data analytics to improve food and nutrition security and environmental sustainability in sub-Saharan Africa, and what are the key barriers to their adoption and utilization?
39. How does the lack of open-access datasets, digital storage, and platforms affect the dissemination and impact of research findings in sub-Saharan Africa?
40. What are the key barriers that prevent end users (farmers) from accessing and utilizing agricultural research findings in sub-Saharan Africa, and how can these barriers be overcome?

Economic transformation and investment flows

Many countries in sub-Saharan Africa have seen consistent economic growth, largely generated by industries that extract natural resources [54]. To keep growing sustainably, investments are required in new business opportunities, along with improvements in land-tenure systems that bring legal clarity, efficiency, and flexibility to the purchasing and selling of land [55]. Removing trade frictions, such as poor access to markets, remains an important goal for many sub-Saharan African economies, which are currently hampered by inefficiencies in the "value chain", particularly the steps a product goes through from creation to sale. In terms of making these improvements sustainable, the main goal for the agricultural industry and food production systems in sub-Saharan Africa is to streamline the local economy and integrate with the global economy in ways that benefit everyone, specifically poorer communities, without destroying the environment [56].

41. What interventions and innovations work best to promote value addition in the agriculture industry in sub-Saharan Africa?
42. What effect will globalization and the removal of trade barriers have on food and nutrition security in sub-Saharan Africa?
43. How does farming that requires significant financial investment impact livelihood transformation and diversification, urbanization, rural services, and the growth of smaller market towns?
44. How do farmer organizations (such as producer groups or farmer federations) promote more business-oriented farming and improve access to input and output markets?
45. Under what conditions (such as public policies, socio-technical regimes, and payments for environmental services) can sub-Saharan Africa improve the contribution of smallholder intensive agriculture to GDP so that it can compete with large-scale commercialized agriculture?
46. What advantages do remittances—money or other resources—sent by the African diaspora bring to their families and friends in sub-Saharan Africa, and what measures can be implemented to magnify these benefits?
47. How can agricultural investments be utilized to increase the profitability of family farming, enhance food production, and productivity, and ultimately improve household food security?

48. What are partnership models and incentive structures that can foster the development and implementation of highly attractive business cases with the private sector, supported by national and international climate finance?

Land-use planning and policy

Land use is a key policy area that can further economic, environmental, and social goals. Therefore, harmonising the various land uses—whether for agriculture, conservation, development, and/or recreation—requires a more inclusive and participatory 'bottom-up' land-use planning approach with consistent cross-sectoral and governmental support [57].

49. To what extent is land-use planning contributing to managing trade-offs between food production and deforestation?
50. To what extent is land-tenure security contributing to managing land-use trade-offs?
51. What successful sustainable initiatives exist at the local level, and how can we identify and promote them to a wider audience, including researchers and decision makers, to ensure that these success stories inform policy?
52. How do we influence policy at different scales (national/regional/global) to integrate more farmer-led and/or agroecological approaches into agricultural research development?
53. How can the collective capacity of multi-stakeholder groups be improved to facilitate information sharing with decision makers (e.g., policy implementers) and how will this impact food security in sub-Saharan Africa?
54. What are the political economy barriers to developing synergised policy and planning in relation to food and nutrition security?

Urbanisation

Africa is projected to have the fastest urban growth rate in the world [58]. This urbanisation is projected to have profound impacts on sub-Saharan Africa's workforce, whose agricultural productivity is higher in the rural sector. To what extent this rural-to-urban migration changes pressures on the environment remains unclear, as local demand may be overtaken by increased demand for food and other natural resources from rapidly growing African cities [59].

55. How will persistent droughts, flooding, and shifts in climate and weather patterns influence the movement of people from rural to urban areas, and what impact will this have on urban stress?
56. What is the impact of urbanisation, population growth, and competing urban and rural demands on water resources (such as irrigation, hydropower, industrial and household demands)?
57. What impacts do rapid urban development and climate change have on high-quality farmland on the urban periphery?
58. What are the implications of rapid urbanisation on food security?
59. How do the current methods of food production and environmental preservation align with emerging challenges such as climate change, population growth, and urbanization?

Natural resource management

Many sub-Saharan African countries are endowed with abundant natural resources; however, relatively few have managed to effectively use these resources to build resilient, diversified, and competitive economies [60]. With cropland in sub-Saharan Africa predicted to expand by more than 10 percent by 2025 [61], it is critical that improvements be made to the management of resources (including water) if countries hope to achieve more sustainable economic development.

60. How does the expansion of built infrastructure and monocultures in sub-Saharan Africa impact climate, sustainable natural resource management, ecosystem conserva-

tion, livelihoods, and human wellbeing, and how do these effects vary across different future governance and climate change scenarios?
61. How is agricultural expansion (to meet food and energy demands) in sub-Saharan Africa impacted by spatial inequalities?
62. What has been learnt from previous areas of agricultural expansion and how can this be used to protect areas at greatest risk from future agricultural expansion (i.e., biodiversity hotspots, migration corridors, etc.)?
63. What can be done to improve water management in agricultural systems in sub-Saharan Africa?
64. What is necessary for sub-Saharan Africa to become self-sufficient and self-reliant on its own resources to improve water and food security at different scales?
65. What are innovative and practical ways smallholder farmers can enhance water security in arid and semi-arid areas?
66. Is irrigation development in sub-Saharan Africa threatening water resources (surface or underground) and can it be designed to be more environmentally sustainable?
67. To what extent will increases in agricultural crop productivity in sub-Saharan Africa lead to land degradation and/or loss of soil fertility?

Post-harvest management

A major source of food production losses occurs post-harvest during harvesting, handling, transportation, storage, processing, packaging, and distribution. It is estimated that anywhere between 8 and 17.2% of food is lost post-harvest in sub-Saharan Africa [62,63]. Post-harvest losses can result not only in a reduction in food quantities, higher prices, and lower incomes (for farmers, processors, etc.), but also in more environmental impacts (due to coping strategies through agricultural expansion, harmful input use, etc.) [64].

68. How do post-harvest losses affect food and nutrition security in sub-Saharan Africa in terms of food costs and availability, and what measures can be taken to reduce these losses?
69. How do post-harvest losses affect incomes and livelihoods along agricultural value chains in sub-Saharan Africa, and what measures can be taken to mitigate these losses?
70. What are the benefits of post-harvest loss management (for example, increasing farm productivity, using fewer harmful inputs, and reduced expansion into fragile ecosystems)?

Indigenous peoples and knowledge systems

The use of plants has changed dramatically over the last 500 years [65], driven by the predominantly Western view of the need to maximise yields and profit. Often these improvements have come at the expense of indigenous peoples and smallholder producers [66]. Increasingly, however, there is growing global recognition of the importance and value of Indigenous Knowledge Systems as a key resource that could contribute to the improved efficiency, effectiveness, and sustainability of the agricultural development processes, both globally and in sub-Saharan Africa [67–69].

71. What challenges affect the adoption of Indigenous knowledge for natural resource management and related policies?
72. How can we encourage our communities to consume more local and traditional foods?
73. Compared to top-down and more technological solutions, how well do traditional plant-breeding systems perform in developing climate-resilient and locally adapted varieties?
74. Can neglected native edible plant species help to tackle malnutrition in children and mothers in cash crop-dominated areas of sub-Saharan Africa?
75. How can semi-domesticated and wild food species enhance food and nutrition security for smallholder farmers (including pastoralists and agropastoralists) during the dry season in arid and semi-arid parts of sub-Saharan Africa?

76. Should sub-Saharan African countries be encouraged to diversify their crop production to include more nutritious food sources, or should they specialize in producing a few main crops and purchase the remaining from international markets?
77. What can we learn from traditional food systems and biocultural heritage (the knowledge and practices of Indigenous people and their biological resources) to enhance ecosystem preservation and inform future policy?

Ecosystem preservation and restoration

Desertification, land degradation, and drought affect sub-Saharan Africa more than any other region on earth [70]. Under the African Forest Landscape Restoration Initiative (AFR100), 33 sub-Saharan African governments along with numerous technical and financial partners have committed to restore 100 million hectares of land by 2030 [71]. The goal of this initiative is to restore the land to a more natural state, which includes re-establishing native vegetation and improving soil health, to enhance its resilience to climate change, support biodiversity, and improve livelihoods for local communities. Achieving this objective while simultaneously avoiding further environmental degradation will require increased knowledge about the sensitivity and resilience of these ecosystems to resource extraction, agricultural expansion, and climate change.

78. How do we reconcile agricultural development in sub-Saharan agriculture with biodiversity conservation and the maintenance of ecosystem services across a range of landscapes from arid semi-deserts and savannahs to rainforests?
79. How resilient are sub-Saharan terrestrial and aquatic ecosystems to rapid transformation by land-use change and what impact do these changes have on ecosystem service provision?
80. How does fragmentation of natural vegetation impact ecosystems and ecosystem service provision, including nature's contributions to agriculture (including water management, pollination, and pest control)?
81. What impact will ongoing agricultural intensification in sub-Saharan Africa have on ecosystem function and stability?
82. How does the reliance on rain-fed agriculture methods in sub-Saharan Africa impact ecosystem preservation and restoration, and what challenges are faced in adopting more sustainable irrigation technologies?
83. What are the consequences—both short-term and long-term—of protected area management on food security and inequality?
84. How can safeguarding biodiversity at local or regional scales contribute to agricultural productivity and household food security, for instance, by improving water supply and boosting natural pest control; and how can this knowledge be used to improve current and future management of agricultural landscapes?
85. How can biodiversity and ecosystems within and outside protected area networks be made more resilient to changes in land use and climate without compromising community development goals (such as food and nutrition security)?
86. What proportion of forest degradation in sub-Saharan Africa is caused by large-scale producers compared to small-scale farming, and what are the best ways of mitigating this degradation?
87. Can we devise biodiversity or functional metrics to identify, evaluate, and monitor progress towards climate-smart, wildlife-friendly, and resilient agricultural production systems?

Food production and consumption

Agriculture forms the backbone of many economies throughout sub-Saharan Africa. However, despite consistent growth in food crop and livestock production since the 1960s, the region still lags behind other parts of the world [72,73]. Much of the growth so far has been driven by the expansion of farmland into previously intact areas [74,75]. With an estimated 275–350 million people facing food shortages in the region [76], African nations are urgently seeking innovative solutions to ensure food and nutrition security for the coming decades. This has led to calls for a shift away from industrial farming towards more agroecological food systems (e.g., intercropping, agroforestry, mixed crop-livestock systems, etc.), a transformation that could improve the prospects for a more environmentally sustainable and socially equitable agricultural landscape in sub-Saharan Africa [77]. However, many questions remain about the capacity of these more traditional systems to produce food at a sufficient scale given projected future demand [3,4].

88. What are the environmental, social, and health costs of different agricultural production systems in the context of sub-Saharan Africa?
89. What are the opportunities to drive synergistic or parallel advances in food security and nutrition, equality, and ecosystem conservation?
90. What can be done to design/promote tools and predictive models that estimate the benefits of sustainable agriculture and agroecosystems?
91. How can resilience to shocks, change, and disruption be enhanced for food production systems?
92. How can we identify and develop agroecology approaches which incorporate nature-based solutions to optimize and increase food production, while minimizing environmental impacts?
93. What is the scope for using agrobiodiversity to increase food production in sub-Saharan Africa in the context of climate change adaptation and mitigation?
94. What is the potential impact of organic, agroecological, and/or regenerative agriculture on food and nutrition security and the sustainability of ecosystems?
95. Will solving food security issues in one area have negative effects on food security and ecosystem health in other regions, and how might these spillover effects be managed and mitigated?
96. How significantly do forest resources impact food, nutrition, and livelihood security in sub-Saharan Africa, and what are the key factors influencing this contribution?
97. How can synergies and trade-offs between food production and ecosystem conservation help alleviate poverty, improve nutrition, and enhance food security without compromising existing ecosystems; and what policies are needed to enact these changes?
98. How do we develop a sub-Saharan African approach to achieving food and nutrition security; and what are the advantages of a regional approach compared with adopting Western/Chinese methods and policies?
99. How does the One Health framework (which recognizes the interconnectedness of human, animal, and environmental health, and the importance of the health and well-being of animals) contribute to the consumption of safer animal-based food sources?
100. How can we diversify and develop healthy agroecosystems that promote nutrition-rich diets in sub-Saharan Africa and make them a viable alternative to cassava- and maize-based staple diets?

4. Discussion

Agricultural development is an urgent priority in sub-Saharan Africa to boost food production and economic growth, but these imperatives often directly conflict with environmental goals and can exacerbate social inequality [41,42,78,79]. Addressing these different targets is a major challenge, not least because we still lack the basic knowledge required to understand and manage trade-offs among different agendas. Using a targeted horizon-scanning exercise, we identified 100 practical or research-focused questions that, if addressed, will help to deliver the information most urgently needed by end-users, including agricultural communities, commercial enterprises, and policy makers.

4.1. Assessing Variation in Priorities

In the context of agricultural development, the perspectives and priorities of different stakeholder groups are often divergent, complicating the formulation of strategies or policies to promote sustainability [80,81]. Our analyses provide a preliminary assessment of this issue, revealing notable contrasts in priorities between participants according to their geographical location and professional background. For example, while food and nutrition security emerged as a universal concern, participants based within sub-Saharan Africa tended to focus more on social issues, such as inequality, whereas those from outside the region placed greater emphasis on environmental considerations, including ecosystem management and biodiversity conservation. The disparity among viewpoints and priorities may reflect differences in expertise, as well as the unique needs and priorities of specific stakeholder groups. Such differences are integral to the sustainable development agenda and need to be borne in mind when designing research projects and implementing policies, to ensure they are effective and relevant to local contexts [23].

Nonetheless, the gulf between local and international viewpoints is relatively narrow, suggesting that efforts to improve awareness and encourage compromise could potentially bridge this gap. Even more encouragingly, we found a broad overlap in the views and thematic priorities of respondents working within and outside academia, challenging the assumption that differences exist between academic and non-academic perspectives [80,81], at least in the field of agricultural development. Our finding is that goals are closely shared across very different professional settings, offering hope for cooperation and productive dialogue between academia and industry in developing effective research programmes and policy interventions.

4.2. Limitations and Caveats

All horizon-scan exercises face the challenge of minimising bias in the range of viewpoints sampled. By inviting responses from a broad array of participants with a wide range of backgrounds, we hoped to reduce biases and broaden the knowledge base feeding into our questions. However, further complications and biases are introduced due to the inclusion of many respondents with local expertise and little familiarity with recent research. Many contributors commented that they felt secure in their particular area of competence and geographical focus, but less comfortable judging whether their suggestions were relevant at a regional scale. Thus, our final list of 100 questions unavoidably reflects some subjectivity, both in terms of the preliminary pool of questions and the participants engaged in the selection procedure. For example, the number and precision of questions relating to environmental concerns are inevitably much reduced because most of our participants work in fields related to agriculture and development.

We selected final questions based on their relevance to cross-cutting research themes at the intersection of food security, social inequality, and environmental challenges. One obstacle in formulating a research agenda targeted at sub-Saharan Africa is the tendency for research output and funding decisions to be made by individuals based in the Global North, often without adequate consideration of the knowledge and needs of those in the Global South [21–23,82]. Moreover, the communication gap between academia and other sectors, such as corporations, government agencies, and non-governmental organisations, is a significant barrier to aligning research with societal needs and translating findings into real-world applications [16,83]. We took steps towards bridging this gap with a more inclusive and collaborative approach, emphasising contributions from colleagues in the Global South. By engaging a diverse array of stakeholders in the identification of key research questions, we hope to inspire further dialogue between different regions and sectors, promoting collaboration through a shared understanding of priorities.

While the broad spectrum of participants with local rather than regional knowledge allows us to scan a wider and more inclusive horizon of potential research targets, it shapes the style and content of questions in other ways. The topics that gained traction with the largest number of participants were—unavoidably—those applicable to a broader geographical area or touching on multiple subjects of interest. The selection procedure favours highly non-specific and interdisciplinary topics. Although many of the questions in the final selection may appear overly generic, they are deliberately phrased to encompass a range of specific contexts. They should be viewed as catalysts for investigations that will require further refinement during project design and development phases, with specific details tailored to local conditions.

4.3. Conclusions

The future of agriculture in sub-Saharan Africa hangs in the balance. Choosing the best and most sustainable pathways for agricultural development in the region will require careful management of synergies and trade-offs between food security, social equality, and environmental agendas. To further our collective understanding of how these areas overlap via complex inter-dependencies, we conducted one of the most extensive horizon-scanning processes yet attempted. The responses highlight differences in perspective depending on the geographical and professional backgrounds of respondents, yet overall, one of our most striking findings is that people working in different sectors and based in different parts of the world share similar goals. By summarising these goals into 100 questions, we provide a clear roadmap for researchers and decision makers. We hope that these questions promote a deeper understanding of current challenges and improve the prospects for long-term sustainability in African agriculture.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land12101879/s1, Figure S1. Variation in perceived research priorities according to geographical and professional context. Panels show boxplots comparing Likert scores (on a scale of 0–10) provided by participants asked to score the importance of three Sustainable Development Goal (SDG) areas; black diamond shows the mean; centre line shows the median; box shows the inter-quartile range; whiskers show 1 standard error. Panel (A) compares scores for participants based inside (n = 232) and outside (n = 87) sub-Saharan Africa. Participants outside sub-Saharan Africa were mainly based in the Global North. Panel (B) compares scores for participants that self-identify as an academic (n = 161) and non-academic (n = 163). Statistics and p-values are from paired Wilcoxon signed-rank tests; Figure S2. Influence of geographical location on perceived research and funding priorities for agricultural development. Panels show barplots comparing how three agricultural development priorities–food security, reducing inequality, and preserving the environment–were prioritised by participants based inside (n = 175) and outside (n = 75) sub-Saharan Africa. Participants outside sub-Saharan Africa were mainly based in the Global North. Data show variation in the choices made by participants when asked to select (A) the least important and (B) the most important goals for agricultural development, as well as the area they would rank as the highest priority for funding allocation (C); Figure S3. Influence of professional context on perceived research and funding priorities for agricultural development. Panels show barplots comparing how three agricultural development priorities–food security, reducing inequality, and preserving the environment–were prioritised by participants based in (n = 152) and outside (n = 126) academia. Data show variation in the choices made by participants when asked to select (A) the least important and (B) the most important goals for agricultural development, as well as the area they would rank as the highest priority for funding allocation (C); Table S1. Questions posed to participants during Stage 1 of the horizon-scanning procedure. For multiple choice questions, participants were given three options for Question 4 and 5 [Preserving terrestrial environments; Food and Nutrition Security; Reducing Inequality] and Question 6 [Environmental research; Food self-sufficiency research; Social equality research].

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Data Availability Statement: The anonymised dataset used in this study is available upon request from the corresponding author. For further analysis and replication of the study findings, the R codes utilised in the analyses and the creation of figures can be accessed via the following repository: https://github.com/adevenis/horizon_scanning.git, accessed on 29 May 2023.

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