LEVERAGING ARTIFICIAL INTELLIGENCE FOR SUSTAINABLE PRODUCTION AND MARKET ACCESS TO NSUKKA YELLOW PEPPER IN NIGERIA

African Technology Policy Studies Network (ATPS)
TECHNOPOLICY BRIEF NO. 86

Anyadike C
Okechukwu M
Egonu S
Ozioko R
Madukwe M
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Anyadike C[1,2]
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Madukwe M[2]
Eterigho E[2]
Ukoha-Onuha E[2,4]
Onyia A[3]
Ozor N[5]
Nwakaire J[5]
Nyambane A[5]

[1]Association of Professional Women Engineers of Nigeria
[2] University of Nigeria, Nsukka
[3] Educare Technology Company
[4]River State University of Technology
[5]African Technology Policy Studies Network (ATPS)

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Published by the African Technology Policy Studies Network (ATPS)
P. O. Box 10081, 00100− GPO,
Nairobi, Kenya

ISBN: 978−9966−124−44−9

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About the Project

Africa's rapidly growing population, projected to reach 2.6 billion by 2050, posed significant challenges for agricultural and food systems. To meet the increased demand for food, production needed to rise by up to 70%. However, resource scarcity, climate change, the impact of the COVID−19 pandemic, and socioeconomic hardships made this a daunting task. Recognizing these challenges, the initiative focused on leveraging emerging technologies, particularly artificial intelligence (AI), to transform Africa's agricultural and food systems.

The project successfully advanced the responsible development, deployment, and scaling of AI research and innovations tailored to address Africa's agricultural challenges. A key achievement of the initiative was the establishment and management of the AI for Agriculture and Food Systems (AI4AFS) research network, which comprised ten innovation research projects. These projects focused on creating and implementing homegrown AI solutions that were tested, deployed, and scaled to meet Africa's specific agricultural needs.

The initiative deepened the understanding of how AI can be responsibly developed and scaled for sustainable agriculture in Africa. By building the capacity of African researchers and innovators, the project equipped them to create and apply AI solutions that had a tangible impact on agriculture and food systems. Moreover, the project contributed to shaping both African and international AI policy and practice by sharing valuable insights gained through research and innovation.

Throughout the project, several key activities were carried out, including issuing calls for Expressions of Interest (EOI), conducting training workshops for preselected consortia, and engaging with selected grantees. The project was overseen by the Hub Management Committee (HMC), which worked closely with a Hub Advisory Team (HAT) of experts to ensure strategic guidance and support. A robust Monitoring, Evaluation, and Learning (MEL) framework was implemented to track progress and ensure that the project remained on course. The initiative also fostered networking and collaboration through platforms for knowledge exchange, with quality assurance mechanisms in place to ensure transparency and credibility at every stage.

As a result of the project, African researchers and innovators were empowered with enhanced research infrastructure and a conducive environment to lead in AI for

Agriculture and Food Systems (AI4AFS). The research network was strengthened, generating new AI research and innovations that tackled pressing agricultural challenges in Africa. Additionally, the project contributed to the development of more inclusive policies and strategies that supported transformative change in AI for agriculture and food systems, based on the needs of African societies.

This initiative was part of the larger Artificial Intelligence for Development Africa (AI4D Africa) program, which was co−funded by Canada's International Development Research Centre (IDRC) and the Swedish International Development Agency (Sida). AI4D Africa aimed to create a future where Africans across all regions use AI to lead healthier, happier, and greener lives. Through this completed project, the mission to promote responsible AI innovation, improve quality of life, and drive sustainable development in Africa was successfully realized.

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Acknowledgement

We would like to extend our deepest gratitude to all the individuals and organizations who contributed to the development of this policy brief on leveraging artificial intelligence for sustainable production and market access to Nsukka Yellow Pepper. Special thanks go to the African Technology Policy Studies Network (ATPS) for their unwavering support and guidance throughout the research process. We also acknowledge the generous funding support from the International Development Research Center (IDRC) of Canada under the AI4D Initiative. Our appreciation extends to the Association of Professional Women Engineers of Nigeria (APWEN), the University of Nigeria Nsukka, and the local farmers and stakeholders in the Nsukka Agricultural Zone for their invaluable insights and participation in the fieldwork.

Figure 1 Engr Prof. Chinenye Anyadike teaches women on the use of an AI disease detection tool

Key Messages:

- Artificial Intelligence technologies significantly enhance pest detection, soil monitoring, irrigation efficiency, market access, and empower rural women in Nsukka Yellow Pepper (NYP) farming. AI-driven pest detection and soil monitoring tools enable early identification of pests and nutrient loss, ensuring higher yields and better quality NYP. Smart irrigation systems optimize water usage, crucial for addressing high water demand from climate change. AI tools provide real-time market information, reducing reliance on exploitative middlemen and improving market access. Additionally, these AI interventions empower rural women farmers by boosting their productivity and market engagement.

- Addressing gender-specific challenges and infrastructure gaps is essential for successful AI adoption in NYP farming. Women in NYP farming face obstacles in land ownership, access to resources, and decision-making, hindering their productivity and economic participation. The lack of reliable internet and electricity in rural areas limits the effectiveness of AI tools and technologies. These issues prevent women farmers from fully benefiting from AI interventions and restrict overall productivity improvements.

- Strategic investment, training, infrastructure, and partnerships are crucial for AI adoption in NYP farming. Invest in AI research tailored to NYP farming to enhance productivity and sustainability. Implement gender-sensitive training programs to equip farmers with AI skills, ensuring women farmers receive targeted support. Improve rural infrastructure, providing reliable internet and electricity to facilitate AI deployment. Encourage public-private partnerships to develop and scale AI technologies, making them accessible and affordable for smallholder farmers. These steps will collectively enhance productivity, sustainability, and market access in NYP farming.

1. Introduction

Nsukka Yellow Pepper (NYP) is a unique variety of pepper grown predominantly in the Nsukka Agricultural Zone of Enugu State, Nigeria. Renowned for its distinctive aroma, vibrant yellow colour, and high capsaicin content, NYP has a significant market demand both locally and internationally. The economic importance of NYP cannot be overstated, as it forms a critical part of the livelihood for many rural farmers in the region, particularly women, who constitute a significant portion of the workforce in NYP farming. Despite its economic potential, NYP production faces numerous challenges that hinder its productivity and profitability. These challenges include pest and disease infestations, depleted soil nutrients, high water demand due to climate change, and inadequate support from extension services. Furthermore, the marketing of NYP is plagued by the exploitation of middlemen, which leads to low-profit margins for farmers and limited market access.

The adoption of artificial intelligence (AI) in agriculture presents a transformative opportunity to address these challenges and enhance the productivity, sustainability, and economic viability of NYP farming. AI tools can provide innovative solutions for early pest and disease detection, efficient soil nutrient monitoring, optimized water usage through smart irrigation systems, and improved market access through real-time market information.

The purpose of this policy brief is to highlight the challenges, opportunities, and recommendations for enhancing stakeholder engagement in the development, deployment, and use of AI tools in the agriculture and food systems (AFS) of Nigeria, with a particular focus on NYP. The brief aims to provide policymakers, stakeholders, and development partners with insights into the benefits of AI adoption in NYP farming and the necessary steps to support its implementation. Through an enhanced collaboration among stakeholders in leveraging AI technologies, rural farmers, especially women can be empowered to overcome production and market challenges, thereby improving their livelihoods and contributing to the sustainable development of the agricultural sector. This policy brief underscores the importance of inclusive AI adoption, stakeholder participation, and supportive policies in achieving the goals of enhanced productivity, sustainability, and economic growth in the NYP sector.

2. Rationale for the development and adoption of IoT and AI enabled mini weather stations

Nigeria faces critical challenges caused by climate change which include increase pest and disease infestation of agricultural plants. Couple with the issues of climate change, the increased demand for water use in farming cause economic losses to the farmers especially women and marginalized communities. The issue of market access due to bad rural roads frustrates farmers cause the middlemen to have undue advantage over the gains made by farmers. AI technologies can transform NYP farming by addressing critical challenges such as pest management, soil nutrient depletion, water scarcity, and market access (Adepoju et al., 2022). AI-driven pest detection allows for early identification and targeted interventions, reducing crop losses and chemical use. AI-driven solutions can provide precise recommendations for soil fertility management and pest control, reducing crop losses and improving farm profitability (Oyetunde-Usman et al., 2020). Additionally, AI can assist in overcoming barriers such as limited access to extension services and training, ensuring farmers are well-equipped to adopt sustainable practices (Olatade et al., 2016). The adoption of AI create unique needs which include; investment in digital infrastructure, training programs for farmers to improve digital literacy, and policies supporting AI integration in agriculture. Stakeholders must collaborate to address these challenges and harness AI's potential to transform Nigeria's AFS, thereby enhancing food security and economic growth.

3. Methodology

The research employed a participatory action approach to ensure inclusivity and relevance, engaging stakeholders, particularly farmers, in the development process of AI tools to address their specific needs. The process began with a comprehensive desk review of existing literature on NYP production, identifying knowledge gaps in pest and disease management, soil nutrient levels, irrigation practices, and market dynamics. This was followed by a field survey in the Eziani community, Nsukka Agricultural Zone, involving 243 respondents through semi-structured interviews, aiming to understand current farming practices, challenges, and perceptions of AI technology. Additionally, qualitative data were gathered through focus group discussions, key informant interviews, and in-depth interviews to gain insights into socio-cultural dynamics, gender roles, and specific challenges faced by different groups in NYP farming.

The project team engaged community members, including local leaders, women's groups, youth groups, and persons with disabilities (PWDs), through community entry meetings to introduce the project, discuss objectives, and gather consent. Active participation of farmers in co-developing AI tools for pest detection, soil nutrient monitoring, smart irrigation, and e-extension services ensured iterative testing and refinement based on their feedback. Capacity-building sessions were conducted to train farmers on using AI technologies. Quantitative data were analyzed statistically to identify key trends, while qualitative data were analyzed thematically to extract socio-cultural insights. The findings from both analyses informed the development and deployment of AI tools, providing insights into policy issues discussed during a policy dialogue.

4. Major Findings

The project yielded several significant findings that underscore the potential benefits and challenges of adopting AI in NYP farming and the need for collaboration among stakeholder. These findings are categorized into key areas such as pest and disease management, soil and water management, market challenges, gender dynamics, technology acceptance, and institutional support gaps.

4.1 Early pest detection, soil nutrient and water management, and market access

The study highlighted key challenges in pest and disease management, soil and water management, and market access for NYP farms. Traditional pest control methods were ineffective, while AI-driven detection systems improved early identification and reduced pesticide use. Soil nutrient depletion and high water demand due to climate change were mitigated by AI tools for precise fertilizer application and smart irrigation. Market challenges, including exploitation by middlemen and fluctuating prices, were addressed through AI platforms offering real-time market information and direct farmer-to-buyer connections, enhancing profitability and market access.

4.2 Women are pivotal in NYP farming but face significant challenges

Women constitute a significant portion of the workforce in NYP farming, yet they encounter obstacles in land ownership, access to resources, and decision-making. Due to socio-cultural norms, 85% of women interviewed showed that they faced obstacles in acquiring land as it is frowned at by the communities, hence they must access land through their husbands or transferred ownership by inheritance from parents, which is a rare scenario. This situation affects their productivity and economic participation. The lack of reliable internet and electricity in rural areas limits the effectiveness of AI tools and technologies affecting the women's interest in the use of technology. Also, most of the women interviewed showed that they are not organized in cooperative groups or societies that is key to accessing funds from government in order to support access to implements and tools such as AI in agricultural operation. The project intervention assisted the women to create a cooperative society, improved their skill in using AI tools through targeted training in software installation and water conservation. This increase the ability to increase the number of hectares of farm production from 1 to 4 hectare during the project duration. There were able to identify early

disease attacks and through the support of the extension agents, were able to choose the right treatment for their plants. They also expanded the crop varieties because they have built the capacity to manage more crops. The study emphasized the need for gender-sensitive approaches in AI adoption to empower women and enhance their productivity and economic participation. AI interventions that reduce labour burdens, improve access to market information, and provide targeted training can significantly benefit women farmers.

4.3 Stakeholder collaboration and engagement in AI technology adoption

AI technology acceptance is improved when there is a collaborative engagement among stakeholders. Due to the engagement of farmers from the start of AI tools development, they showed a positive attitude towards adopting new technologies, recognizing the potential benefits for productivity and market access. Both men and women agreed that AI could enhance NYP production, reduce labour burdens, and increase incomes. However, concerns about the cost of technology, potential job losses, and ease of use for persons with disabilities were noted. The study underscored the importance of addressing these concerns through affordable and user-friendly AI solutions, along with comprehensive training and support for farmers.

4.4 Gaps in institutional support for Nsukka Yellow Pepper Farmers

The study identified a lack of training, extension services, and support from government and development agencies. This gap has hindered the adoption of advanced technologies and the implementation of best practices in NYP farming. The findings highlight the need for strengthened institutional support, including training programs, extension services, and partnerships with development agencies, to facilitate the adoption of AI technologies and improve NYP farming practices.

5. Conclusion and Implications

The study revealed that AI technologies have the potential to address critical challenges in NYP farming, such as pest and disease management, soil nutrient depletion, water scarcity, and market access. AI-driven pest detection, soil nutrient monitoring, smart irrigation systems, and real-time market information can enhance productivity, sustainability, and economic viability. Policymakers and stakeholders need to invest in AI research and development, provide comprehensive training for farmers, and improve rural infrastructure to support AI adoption. Partnerships between government, private sector, and academia are essential for scaling AI technologies and ensuring their affordability and accessibility. The adoption of AI in NYP farming can significantly improve agricultural productivity and sustainability, contributing to economic growth and food security. It also promotes gender equality by empowering women farmers. Strengthened institutional support is crucial for realizing these benefits and achieving sustainable development in Nigeria's agricultural sector.

6. Policy Recommendations

Recommendation 1: Increase Investment in AI research and development to support inclusive technology development and deployment while engaging end-users mainly the women farmers: The Government should allocate resources for the development and implementation of AI tools tailored to the specific needs of NYP farming. This includes funding for research, pilot projects, and the development of AI-driven solutions for pest detection, soil nutrient monitoring, smart irrigation, and market access. Investing in AI research and development ensures that the tools and technologies developed are specific to the unique challenges faced by NYP farmers. Tailored AI solutions can significantly enhance productivity, sustainability, and economic viability in NYP farming. The project on "using AI to enhance the production, management, and marketing of Nsukka Yellow Pepper has shown that AI-driven pest detection systems can reduce crop losses and minimize the use of chemical pesticides, enabling precise fertilizer application and improving soil health, and optimizing water usage, enhancing crop resilience to climate variability.

Recommendation 2: Provide comprehensive capacity enhancement to farmers to enable them to efficiently use of the AI tools and technologies: The Government through the Ministry of Agriculture, Research and Extension Units in public and private institutions should implement training programs that equip farmers with

the knowledge and skills to effectively use AI tools and technologies. They should use gender-sensitive approaches to ensure that women farmers, who make up a significant portion of the NYP farming workforce, receive targeted support and training. Training should cover the operation of AI tools, data interpretation, and best practices for AI-driven farming. Effective training ensures that farmers can fully utilize AI technologies to enhance their productivity and economic participation. Gender-sensitive approaches ensure that women farmers receive the necessary support to overcome barriers and benefit equally from technological advancements. Research indicates that targeted training programs improve the adoption and effective use of AI tools among farmers, leading to increased productivity and reduced labour burdens.

Recommendation 3: Government and private organization should improve rural infrastructure that support strong internet and communication signals: Enhance rural infrastructure to support the deployment of AI systems. This includes ensuring reliable internet and electricity access in farming communities, as these are essential for the operation of AI tools. Improving rural infrastructure is crucial for the effective deployment and use of AI technologies in agriculture. Reliable internet and electricity access enable farmers to utilize AI tools continuously and efficiently. Evidence from the project implemented show that access to reliable internet and electricity is a significant enabler for the adoption of AI technologies in rural areas as this was a barrier to installation and real-time monitoring of the farms.

Recommendation 4: There should be an enhanced public-private partnership to ensure collaborative development and deployment of responsible AI tools and technologies*:* Encourage collaboration between government, private sector, and academia to support AI-driven agricultural innovations. Public-private partnerships can facilitate the development, deployment, and scaling of AI technologies, ensuring that they are accessible and affordable for smallholder farmers. Public-private partnerships utilize the strengths of various stakeholders, including financial resources, technical expertise, and innovative capabilities, to drive the development and adoption of AI technologies in agriculture. Successful public-private partnerships have been shown to enhance knowledge exchange, capacity building, and resource mobilization, leading to the development of accessible and affordable AI solutions for smallholder farmers.

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African Technology Policy Studies Network (ATPS)
Contact Executive Director:
executivedirector@atpsnet.org
8th Floor Chancery Building, Valley Road
P.O. Box 10081-00100 Nairobi
Tel: +254 (020) 2714092
www.atpsnet.org

Science, Technology and Innovation for African Development

ISBN: 978-9966-124-44-9