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Enhancing Food Security in Nigeria Using Climate –Smart, Green Chemistry Technology for Stabilization of Niger Delta Coastal Soils: Bayelsa Experience

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ABSTRACT

The Nigerian oil reserve is largely found in the Niger Delta Region, (NDR) where most of the oil bearing communities are found along the coastal line. Majority of the land areas in these coastal communities are characterised by very poor soil chemistry. Bayelsa State, being at the center of coastal lines, is denoted as swampy area with soils characterised as strongly acidic and strongly clayey in most places. Being swampy, sand-filling is a common trend. It is, therefore, not a profitable venture to grow economically viable agricultural raw materials that could promote food security. Consequently, most of the economically viable raw products are imported into Bayelsa from other regions, resulting in high cost of living, hunger and poverty. The NDR is reputed for petroleum – based economy and this in turn is pivotal to national economy. This study explored the option of transforming these unsuitable land areas into arable land by modifying soil chemistry via an innovative in-country climate – smart, green chemistry technology. Results from pilot study showed that the applied technology positively modified soil chemistry and enabled the production of economically viable agricultural raw products with potential for transformation to value-added products. Study is a contribution to using chemistry as a tool to enhancing food security creating potential platform for national economic diversification, capable of job creation, reduction of hunger and poverty, in line with sustainable development goals.

KEYWORDS: Green chemistry, food security, soil stabilization, Climate-smart.

1. INTRODUCTION

Nigeria is presently facing food security crisis, attributed to insurgencies, conflicts and insecurity that have disrupted food production value chain resulting in food shortages. Aside these disruptions, there are other factors such as poor infrastructure. economic challenges, poor agricultural practices, climate change and poor soil chemistry with the coastal communities more affected. The Niger Delta region of Nigeria, including Bayelsa State, is characterised by a complex network of rivers, mangroves, swamps, coastal areas, soil degradation, erosion, flooding, and impact of oil spills that have significantly reduced the quality of arable land in the area, limiting the region's food production potential via agricultural productivity and threatening food security[1,2].

Green chemistry offers a promising approach for addressing these challenges through the development and application of environmentally friendly technologies that reduce or eliminate the use and generation of hazardous substances[3]. Climate-smart, green chemistry technology aims to stabilise and remediate coastal soils by enhancing soil structure and chemistry, achieved through sustainable soil regeneration and management practices including the use of climate – smart commodities, which can enhance soil carbon sequestration and improve the resilience of the soils, enhancing food security, contributing to sustainable development goals by promoting environmentally responsible crop production practices and mitigating the effects of climate change[4,5,6,7]. Addressing soil chemistry issues is very critical to proffering solution for improved crop production and food security in Bayelsa coastal communities and similar coasts in Nigeria, in general.

The objective of this study was, therefore, to explore the option of transforming these unsuitable land areas into arable land by modifying soil chemistry via an innovative climate-smart, in-country green chemistry technology. In this study, various food crops served as bio - indicators to assess the potency of the innovative technology in soil regeneration. However, this paper will focus only on one crop - Scotch Bonnet peppers (*Capsicum Chinense*).

2. MATERIALS AND METHODS

2.1. Soil Stabilization Procedure

This pilot study was conducted in Federal University Otuoke, Bayelsa, Nigeria using twelve plots of virgin mangrove swampy land area allocated to the research group (AgriChemTech) by the University Management in 2021. The area was cleared and delineated into different plots of dimension 30 m by 12 m each. Each plot was divided into two columns with each column further sub-divided into 12 to 13 units. Each unit was referred to as a windrow and was regenerated using customised, climate-smart commodities [plant-based polymers (EcoGrow and EcoFix)], with the basic feedstock preparation reported in[8] but modified by the use of biopolymers produced from invasive plant species found in the marine waters of Otuoke. Regenerated and stabilized windrows were then allowed to equilibrate for one week before use. Soil samples were collected before and seven days after stabilization procedure and analysed for relevant properties following the method of [9] but only pH and electrical conductivity (EC) are reported in this paper. Crop growth dynamics were then monitored with time.

2.2. Extraction of Humic and Fulvic Acids from EcoGrow and EcoFix with Subsequent Chemical Characterizations

Extraction of humic acid (HA) and fulvic acid (FA) and subsequent chemical characterisations were carried out, adopting procedures reported in [10]. The extracted and purified HA and FA were subjected to spectroscopic analysis using an FTIR spectrophotometer at the Multidisciplinary Central Research Laboratory (MCRL). University of Ibadan. Optical density (E_4/E_6 ratio) was evaluated using UV-Visible spectrophotometer (HACH DR390 Model) with absorbance values taken at 465 nm and 665 nm for E_4 and E_6 values respectively.

2.3. Assessing the Potency of the Regenerated Soil for Crop Growth Enhancement

Bio-indicator crops including but not limited to plum and cherry tomatoes, bell peppers (yellow and red variants), scotch bonnet peppers (yellow, orange and red variants), water leaf, New Zealand spinach, fluted pumpkin, exotic grape vines (green, red and purple variants), okro, water melon, eggplant (green and white variants), broccoli, cucumber, plantain, carrot, cassava and cabbage. Soil nutrient management and crop protection were achieved by the application of a tailored plant-based biopesticide (EcoShield). All the three products (EcoGrow, EcoFix and EcoShield) were prepared by our multidisciplinary research group (AgriChemTech, Federal University Otuoke). The humic fractions (Humic acid and Fulvic acid) of EcoGrow and EcoFix were characterised via infrared spectroscopic, volumetric and UV-visible spectrophotometric analyses for functional group evaluations following the procedures of [8]. Watering of indicator crops was carried out three times a week using irrigation system designed by the research group. Irrigation water was treated using methods described in [11]. It is good to emphasize that this study neither involved genetic modification, use of chemical fertilizer nor chemical pesticide but involved 100% green crop production and pest management. Screen house was erected over each plot to provide a controlled environment only. Similar crops grown without the application of the technology under investigation served as controls.

3. RESULTS AND DISCUSSION

3.1. Information from Acidity Group Contents, Infrared and UV-Visible Absorptions of Extracted Humic and Fulvic Acids

(a) Infrared absorptions: Information from infrared absorption characteristics (Table 1) showed that the molecular fragment of the humic acid (HA) and Fulvic acid (FA) were enriched with chemical bonds such as O-H, indicating hydroxyl groups for aliphatic hydroxyl (ROH) and phenyl hydroxyl (PhOH) found in carboxylic acids (CO_2H), alcohols and or phenols. N-H bond indicated the presence of nitrogenous compounds such as amine (NH_2) and amides. The C=O bond could be attributed to the presence of carboxylic acid, aldehyde (RCHO), ketone (RCOR') and amide (RCONR'). Data also suggested the presence of unsaturated hydrocarbons (alkene and aromatics) and substituted hydrocarbons, which could be cyclic/acyclic.

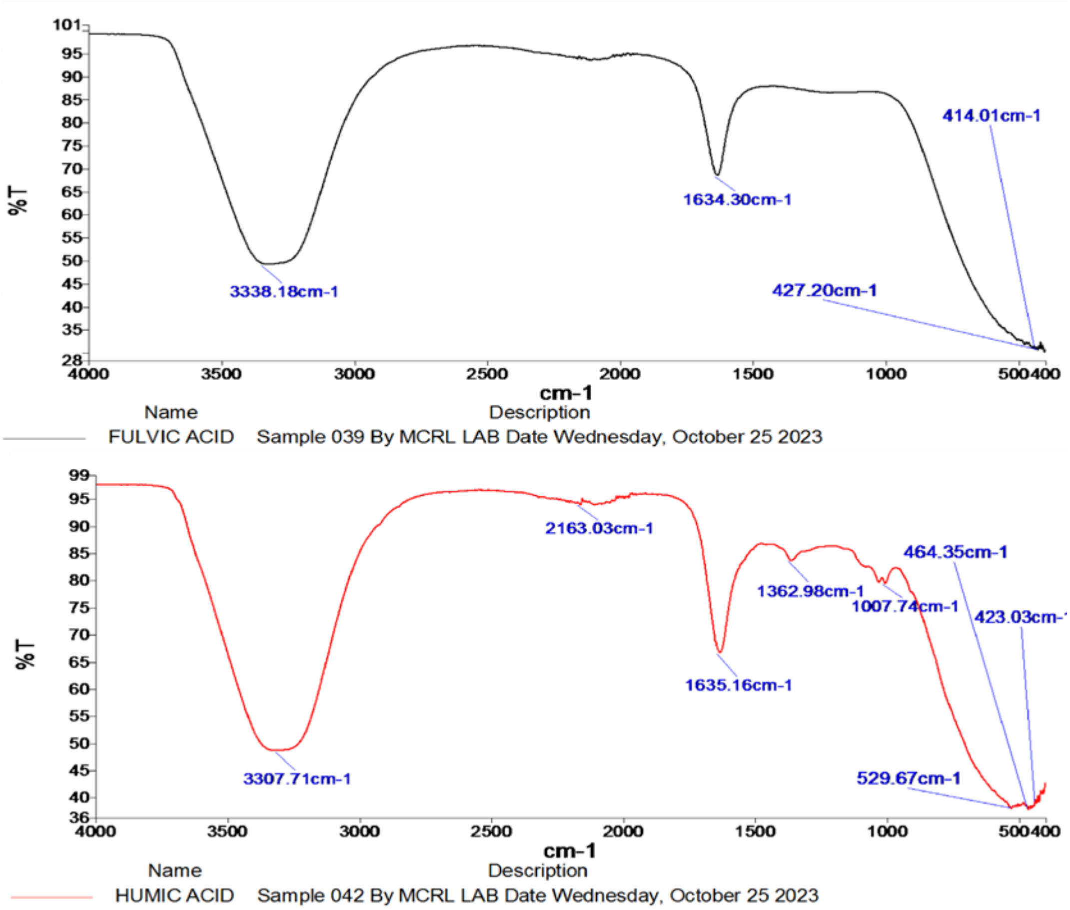

Fig.1: Infrared absorption spectra for humic acid and fulvic acid extracted from soil health enhancing biopolymer used in this study

(b) Acidity Group Content: Carboxylic acidity measures the concentration of carboxyl groups (-COOH), phenolic acidity measures the concentration of phenolic hydroxyl groups (-OH) and total acidity measures the total concentration of both, expressed in units of meq/g.

Table 1: Infra-red Absorption Characteristics of Humic and Fulvic Acids Extracted from EcoGrow and EcoFix

S/N	Absorption Band (cm^{-1})	Absorption Band Characteristics	Suspected Bond/Functional group	Inference
Humic Acid				
1	3307.71	Very strong and strongly broad	O-H (s) N-H (s)	Hydroxyl and amine groups
2	1635.16	Strong, moderately broad	C= C (s) C=O (s) N-H (b)	Hydrocarbon (alkene and aromatics), amide and carbonyl groups
3	1362.98	Very weak	C-H (b) C-N (s) N-O (s)	Substituted hydrocarbon and amine
4	529.67	Very strong and strongly broad	C-C (b) C-O (b)	Cyclic/acyclic compounds

5	1007.74	Very weak	C- O (s) C - C (s)	Alcohols, carboxylic acids. Unsaturated hydrocarbons and aromatics
Fulvic Acid				
1	3338.18	Very strong and strongly broad	O-H (s) N-H (s)	Alcohols, hydroxyl, phenols, amines
2	1634.30	Strong, moderately broad	C = C (s) C = O (s)	Alkenes, aromatics, amides, carbonyls
3	427.20	Very strong and strongly broad	C-C (b) C-O (b)	Cyclic/acyclic compounds

They are essential parameters for characterising HA and FA, influencing their properties and applications. Results are in line with key properties of HA. Total acidity influences reactivity with metals, minerals, and organic compounds. Carboxylic and phenolic groups form complexes with plant nutrient elements, enhancing bioavailability [12].

(b) Optical Characteristics: The E_4/E_6 ratio (optical characteristics) obtained for HA ranged from 4.0 to 4.3 with a mean of 4.2 ± 0.1 for HA and 5.3 to 5.9 with a mean of 5.6 ± 0.2 for FA. The E_4/E_6 ratio is a significant parameter in characterising HA and FA, which are key components of humic substances. The significance lies in the fact that it serves as (i) humification index, indicating the degree of humification, with lower values suggesting more advanced humification, a pointer to increased degree of condensation or unsaturation in the molecular fragment, (ii) molecular weight: E_4/E_6 ratio is inversely related to molecular weight; lower values indicate higher molecular weight and (iii) aromaticity: E_4/E_6 ratio reflects the aromaticity of HA and FA; lower values suggest higher aromaticity. Regarding HA, E_4/E_6 ratio between 3 and 5 indicates more humification, higher molecular weight and increased aromatic characteristics. E_4/E_6 ratio greater than 5.0, which is characteristic of FA indicates less humification, lower molecular weight and less aromatic

Table 2: Acidity groups and optical characteristics of HA and FA extracted from the EcoGrow and EcoFix

S/N	Variable	Range	*Mean	**CV (%)
Humic Acid				
1	Carboxyl acidity (meq/g)	5.3 to 6.7	6.6 ±0.9	13.6
2	Phenolic acidity (meq/g)	6.5 to 10.6	8.0 ± 1.8	22.5
3	Total acidity (meq/g)	12.2 to 18.5	14.6 ± 2.7	18.5
4	E_4/E_6 ratio	4.0 to 4.3	4.2 ± 0.1	2.4
Fulvic Acid				
1	Carboxyl acidity (meq/g)	4.7 to 5.4	4.6 ± 0.8	17.4
2	Phenolic acidity (meq/g)	6.3 to 8.2	7.4 ± 0.9	12.2
3	Total acidity (meq/g)	9.8 to 13.7	12.0 ± 2	16.7
4	E_4/E_6 ratio	5.3 to 5.9	5.6 ± 0.3	5.4

*Mean was obtained from four replicates, ** CV = Coefficient of variation,

molecular fragment. E_4/E_6 ratio influences nutrient availability and soil fertility, mobility and reactivity of HA and FA [12,13]. All these impact nutrient availability, microbial activity, and plant growth, explaining the great impact of the products in enhancing crop growth and productivity.

3.2. Effect of Applied Climate - Smart, Green Chemistry Technology on Selected Soil Properties and Growth of Scotch Bonnet Pepper (*Capsicum chinense*)

Digital capture (Fig.2) revealed typical soil characteristics in the study area: strongly clayey outlook in the dry season (a) with potential to be moulded into a brick (b), characterised with high water table characteristics in the wet season (c) and the outlook of a typical regenerated and stabilised soil via the application of the innovative in-country green chemistry technology (d). The pH value for unregenerated soil ranged from 3.8 to 4.0 with a mean of 3.9 ± 0.1. Soil regeneration technology applied in this study raised the pH from 3.9 ± 0.1 to 5.9 ± 0.2 (range: 5.6 to 6.2). Based on the mean values, there was a 20-fold reduction in soil acidity by the applied green chemistry technology.

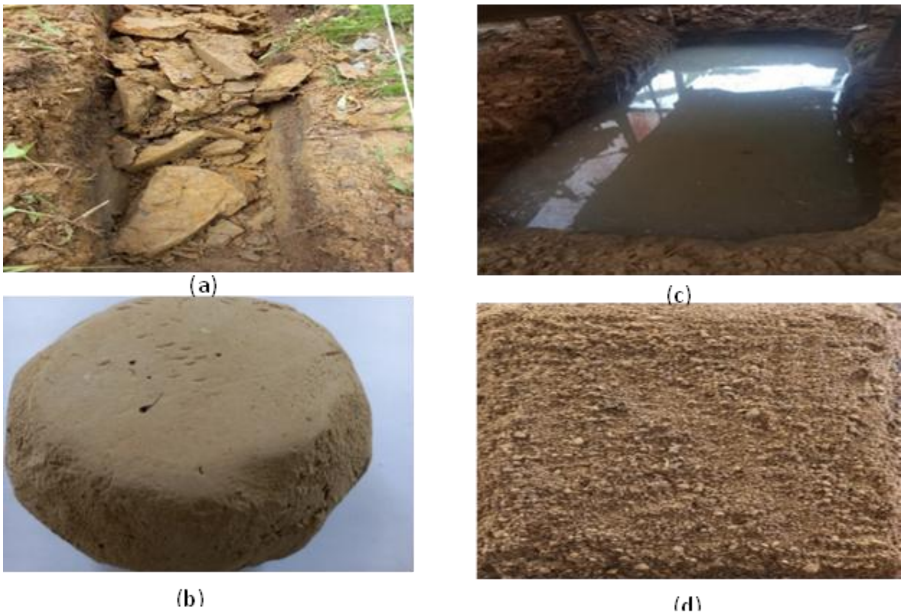

Fig.2: Typical outlooks of soil in the study are in dry (a, b) and wet season (c) versus soil regenerated by applied green chemistry technology (d)

Soil pH impacts the solubility and availability of essential plant nutrients. Maintaining pH between 6.0 and 7.0 for most crops is essential for maximizing nutrient bioavailability, fostering healthy microbial population and promoting robust plant growth. It is good to note that different crops have soil pH preferences [12]. Similarly, soil electrical conductivity (EC) ranged from 41 to 52 with a mean of 47 ± 6 for the unregenerate and 371 to 489 with a mean of 420 ± 52 for the regenerated soil, unit in μScm^{-1}, corresponding to 8.9 – fold increase based on the mean values. Soil electrical conductivity (EC) is a measure of the soils ability to conduct electrical current, which primarily depends on the concentration of soluble salts. It provides insight to soil salinity, nutrient availability and overall soil fertility. Optimal EC ranges from 200 to 1200 μScm^{-1}, ideal for most crops, promoting plant growth. Above 1200 μScm^{-1}, indicates excessive salts that can harm sensitive plants. Below 200 μScm^{-1} indicates nutrient deficiencies, a pointer to low soil fertility [7,9,2]. By implication, the soil under study was infertile (EC: 47 μScm^{-1}) but green chemistry technology applied to the soil in this study modified the EC to fall within the optimal range and restored soil fertility, thereby, promoting crop growth. Applications have been made over two years without the tendency of raising the EC above 1200 μScm^{-1} countering concerns of cumulative effect.

The trend in crop growth indices (plant height, stem girth, leaf number and canopy spread) showed vibrant and steady increase with time as presented in Fig.3. Pearson correlations between these indices and period of growth gave positive, strong and significant ($p < 0.05$) correlation coefficients, obtained as +0.990 for plant height, + 0.977 for stem girth, + 0.973 for leaf number and + 0.997 for canopy spread.

Growth rates were obtained as 1.5 cm per day for plant height, 0.04 cm per day for stem girth, 3 per day for leaf number and 0.08 cm for canopy spread.

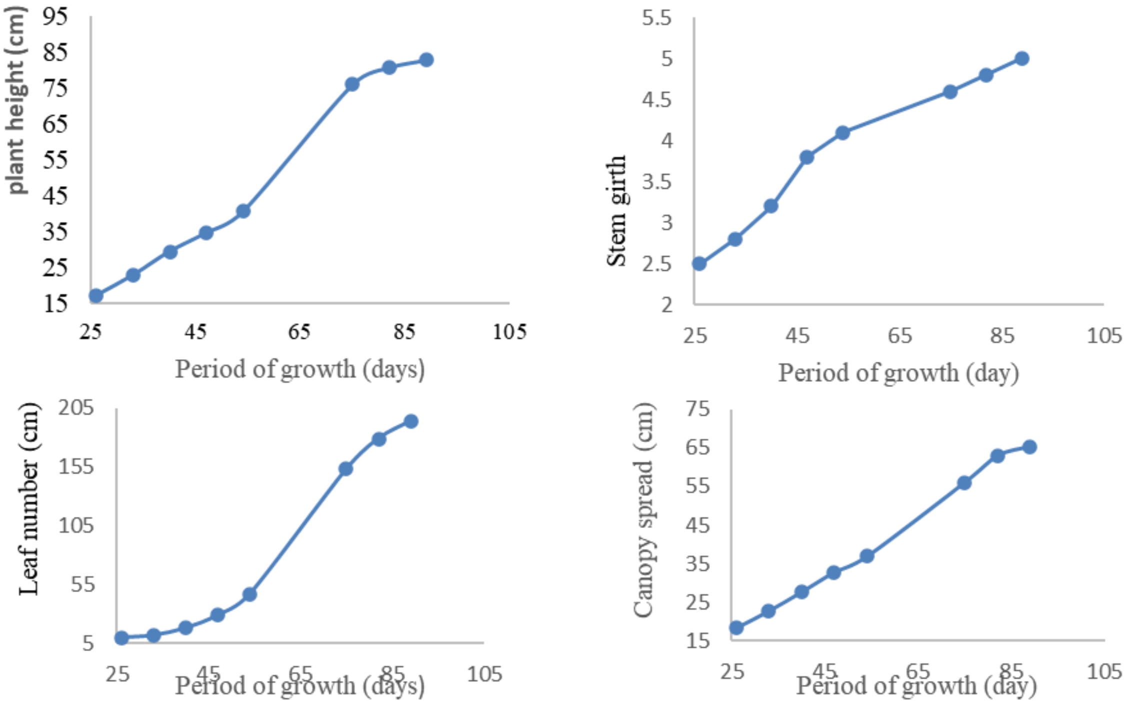

Fig.3: Growth dynamics of crops grown in green chemistry regenerated soil

A comparative evaluation between performance of Scotch Bonnet pepper grown in control (unregenerated soil) in the same project site and the crop grown in the regenerated soil (Fig.4) showed an excellent performance of the regenerated soil over the unregenerated control. Results also showed that the unripe pepper is a better source of immune boosting nutrients such as zinc (Zn): 0.58 ± 0.01 for the unripe fruit and 0.33 ± 0.01 for the ripe; Copper (Cu): 0.23 ± 0.01 for the unripe and 0.21± 0.01 for the ripe. Both elements were within acceptable limits of 0.6 for Zn and 10 for Cu (FAO,2013) with unit in mg/kg. Zinc (Zn) and copper (Cu) are essential trace minerals with key roles in the human body: zinc supports immune function, aiding in the defense against infections, is essential for wound healing and skin health, plays a role in DNA synthesis, cell division, and protein synthesis. It is important for proper growth and development, especially in children, and contributes to taste and smell. Copper is involved in energy production through the enzyme cytochrome c oxidase., supports the formation of red blood cells and maintains healthy nerves and blood vessels, contributes to iron absorption, helping prevent anemia, acts as an antioxidant, protecting cells from damage and helps in collagen production for skin, bones, and connective tissue. Crop protection management was in line with best practices [14].

Crop growth in unregenerated soil

Crop growth in green chemistry regenerated

Fig.4a: Crop growth enhancement by green chemistry versus traditional method

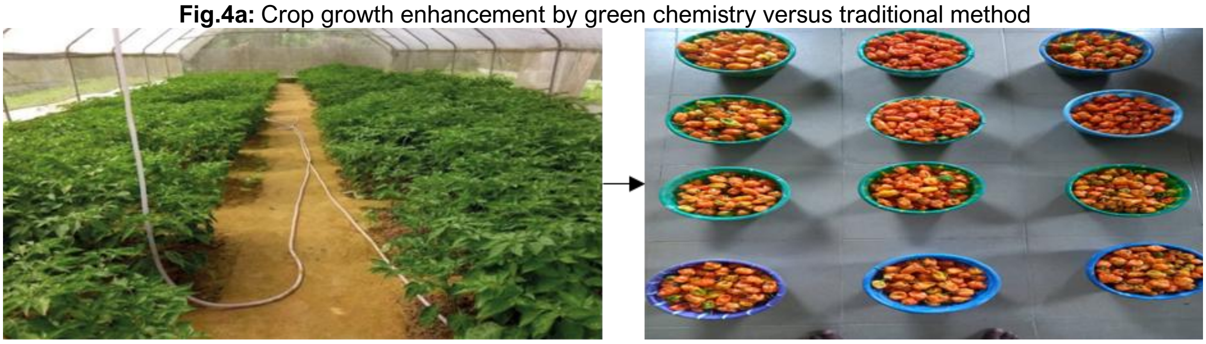

Fig.4b: Average daily harvest from crop grown in soil regenerated t by green chemistry

Fig.4c: Digital capture of scotch bonnet pepper, harvested from crops grown in soil regenerated by green chemistry technology

4. CONCLUSION AND RECOMMENDATIONS

The innovative climate smart, green chemistry-based soil regeneration technology investigated in this study offers a sustainable solution to Nigeria's food security challenges by improving soil health and fertility. By promoting resilient crop production approach, it addresses the impact of climate change and boosts crop productivity. Regeneration of coastal soil of Bayelsa by green chemistry improved soil health by positive modification of soil chemistry and improvement of soil fertility and promotion of plant growth, especially Scotch Bonnet (*Capsicum chinense*). This climate-smart technology has scalability potential and is recommended for adoption in the country to ameliorate the prevailing food security crisis. Capacity building through training of youths and small holder farmers is recommended as a drive to provide alternative economic diversification platform in Nigeria.

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