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Research Article

Climate-Smart Agriculture, Insect Farming and Integrated Waste Management for Livelihood Improvement and Urban Greening in Kaduna Metropolis, Nigeria

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ABSTRACT

Climate change, environmental degradation, and poor organic waste management pose significant challenges to sustainable agriculture and urban livelihoods in Kaduna Metropolis. This study assessed the potential of Climate-Smart Agriculture (CSA), insect farming, and integrated waste management to improve household livelihoods and promote urban greening. A mixed-methods, cross-sectional design combined a structured survey of 400 randomly selected farming households (from a target population of 39,082), 20 key informant interviews, focus group discussions, and six-month pilot demonstrations across eight neighbourhoods of Kaduna Metropolis. Quantitative data were analysed using descriptive statistics and cross-tabulations; qualitative data were analysed thematically. Adoption of drought-tolerant (80%) and pest-resistant (75%) crop varieties was relatively high, while adoption of rainwater harvesting (35%) and crop rotation (30%) remained low. Awareness of CSA was 35.0% and of insect farming 24.0%, varying by education, age, and gender. During the pilot, 2,450 kg of organic waste was converted into 462 kg of black soldier fly larvae and 1,180 kg of compost; 74.2% of households adopted at least one promoted technology, and 59.2% sustained use through six months of monitoring. Key barriers to sustained adoption were inadequate finance, limited technical support, land constraints, and weak market linkages. Insect farming, composting, and selected CSA practices are feasible at pilot scale and can diversify household livelihoods and improve waste management when supported by extension services, finance, and market development. As these findings derive from a six-month pilot in selected communities, they should be treated as preliminary; longer-term studies with larger populations are needed to assess sustainability, economic viability, and environmental impact before broader implementation.

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1 Introduction

According to the National Bureau of Statistics (2020), one of the supports for Nigeria's economy is Agriculture, which employs over 60 percent of the population and contributes approximately 24 percent to Gross Domestic Product. In Kaduna State, smallholder farmers dominate the landscape, engaging predominantly in subsistence and small-scale commercial farming, particularly within Kaduna Metropolis (Onwunali et al., 2025). These farmers, operating mainly in peri-urban and urban settings, face mounting challenges, including environmental degradation, notably climate variability and socio-economic constraints (Abdulkadir, 2024).

Climate change worsens these challenges through unpredictable rainfall patterns, rising temperatures, increased pest and disease outbreaks, and land degradation (Edewor & Ogbe, 2026). Such impacts threaten the sustainability and productivity of farming systems, especially among smallholder farmers with limited access to modern technologies, information, and financial resources (FAO, 2014). Addressing these issues necessitates integrated, pragmatic solutions that enhance resilience, improve productivity, and promote environmental health.

Climate-Smart Agriculture (CSA) offers a comprehensive framework for tackling these challenges, advocating sustainable practices that increase productivity, bolster resilience to climate shocks, and reduce greenhouse gas emissions (FAO, 2013). Innovative approaches such as insect farming for sustainable protein and agricultural waste management can complement traditional farming, diversify income streams, and mitigate environmental impacts, aligning with circular economy principles (Dogo et al., 2024). This study, situated within Kaduna Metropolis, establishes a detailed baseline of current agricultural practices, perceptions of climate change, and waste management strategies, and evaluates the potential for tailored CSA interventions to foster sustainable development, improved livelihoods, and urban greening.

Despite Nigeria's agricultural significance, farmers within Kaduna Metropolis confront formidable challenges aggravated by climate change. Declining yields, water shortages, and escalating pest incidences threaten food security and livelihoods (FAO, 2018), while widespread limited awareness and inadequate access to resilient farming practices hinder adaptation efforts and are projected to compound future crop losses if adaptive

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capacity is not strengthened (Ojo et al., 2020). Simultaneously, waste management remains a critical concern: open dumping, incineration, and unregulated disposal of organic waste led to environmental pollution, health hazards, and greenhouse gas emissions. The absence of sustainable waste-recycling systems and alternative protein sources constrains farmers' capacity to diversify income and adopt environmentally friendly practices (FAO, 2021). Without context-specific, scalable interventions, improved water management, waste recycling, and innovative protein sources, communities risk persistent food insecurity, environmental degradation, and socio-economic instability (Lipper et al., 2014).

The aim of the study is therefore to establish a comprehensive baseline of agricultural practices, perceptions, and needs within Kaduna Metropolis, and to pilot tailored CSA strategies, including insect farming and waste management, to promote sustainable livelihoods and urban greening. Specifically, the study sets out to document existing agricultural and waste-management practices and farmers' knowledge, perceptions, and attitudes toward climate change; identify the socio-economic, infrastructural, and environmental challenges farmers face; introduce and evaluate pilot CSA practices, such as insect farming and organic-waste composting, adapted to urban and peri-urban contexts; assess community awareness, acceptance, and potential for scaling these practices; and develop actionable recommendations for policy, capacity building, and the expansion of successful interventions.

The study is significant on several fronts. For farmers, it enhances awareness, capacity and access to climate-resilient practices, including insect farming and waste recycling, with the potential to improve livelihoods; for policymakers, it provides evidence-based insights to inform policies promoting CSA practices, waste management and urban greening; for development organisations, it demonstrates scalable, community-based models for climate adaptation; for environmental sustainability, it points to pathways for reducing greenhouse gases via composting and alternative protein sources; for academia, it contributes to the limited body of knowledge on urban CSA implementation within Kaduna State and entire Nigeria; and for the wider community, it supports resilience, food security, environmental health and urban greening.

1.1 Literature Review

Nigeria is among the most vulnerable African countries to climate change impacts, which threaten agricultural sustainability (Omokaro, 2024). Rising temperatures, irregular rainfall, droughts, floods, and land degradation are especially severe in semi-arid and coastal regions, affecting crop yields, water availability, and land productivity (FAO, 2014). Smallholder farmers, who form the backbone of Nigeria's agriculture, are especially vulnerable owing to limited adaptive capacity, and national studies have documented declining yields and rural livelihoods under climate stress (Akpenpuun & Busari, 2013; Adewuyi & Anuoluwapo, 2018). Global and national responses increasingly emphasise resilient, climate-smart agricultural systems (FAO, 2013).

CSA rests on three pillars: increasing productivity and incomes through improved varieties and efficient resource use; building resilience through diversification, agroforestry and water harvesting; and reducing emissions through conservation tillage and organic farming (FAO, 2013; Lipper et al., 2014). Despite the benefits of CSA, global adoption remains limited at roughly 20% (FAO, 2010), constrained by low awareness, inadequate input access and policy gaps; within Nigeria, adaptation studies similarly report uneven uptake of resilient practices among smallholder farmers, with adoption skewed toward low-cost, immediately beneficial measures over those requiring sustained investment (Ojo et al., 2020).

It's against this backdrop that insect farming is emerging as an environmentally sustainable alternative to conventional livestock for addressing global protein deficits. Edible insects such as crickets, mealworms, grasshoppers and black soldier fly larvae (BSFL) are rich in high-quality protein, fats, vitamins and minerals (van Huis et al., 2013). Crickets, for instance, require only about 1.7 kg of feed per kilogram of body-weight gain compared with roughly 8 kg for cattle, and insects generally produce fewer greenhouse gases while requiring less land and water. Because insects can be farmed on organic waste, according to Bosch et al. (2021), they turn waste into high-value protein while supporting circular-economy objectives, with applications spanning human food, animal feed, and biodiesel production.

This waste-to-protein pathway is particularly relevant given that unmanaged organic waste decomposes anaerobically, emitting methane and polluting groundwater (Diener et al., 2009; Kumar et al., 2025). Black soldier fly larvae and housefly maggots can convert such waste into protein- and lipid-rich biomass, yielding substantial reductions in methane emissions, nutrient recycling, organic-fertiliser (frass) production, and reduced waste volume (Bosch et al., 2021), as summarised in the bioconversion pathway in Figure 1. The resulting insect meal also has recognised value further up the value chain: rising global seafood demand necessitates sustainable feed alternatives to fishmeal, and studies indicate that insect meals, particularly from BSFL, can replace fishmeal at varying levels without compromising growth or health across multiple fish species, for example, up to 50% replacement in rainbow trout diets showed no adverse effects (Renna et al., 2020), while complete replacement may alter fatty-acid profiles yet maintain acceptable growth (Kroeckel et al., 2012). Insect meals also contain bioactive compounds such as chitin and carotenoids that can enhance immune response (Kim et al., 2016; López et al., 2018).

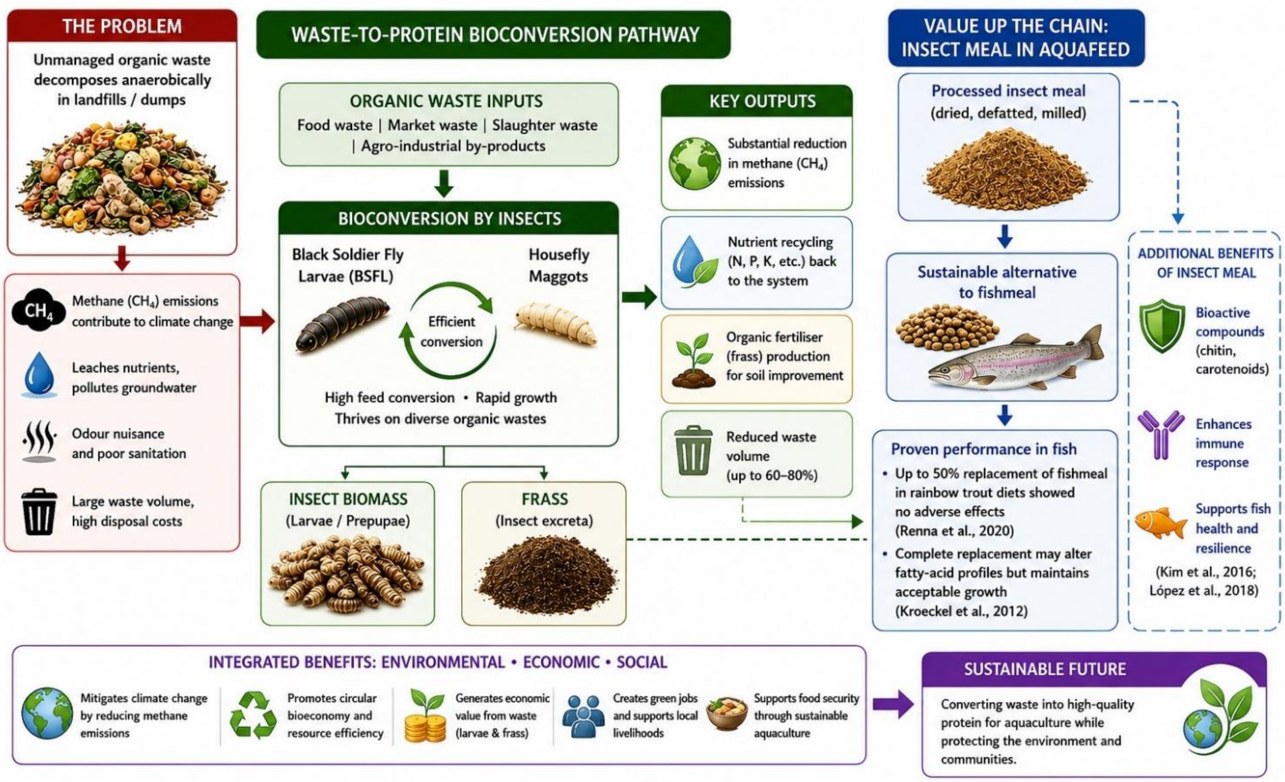

Figure 1: Waste-to-protein bioconversion pathway using BSFL and housefly maggots

Notwithstanding this potential, challenges to scaling insect-based systems include variability in nutrient content, cultural perceptions and acceptance issues, regulatory hurdles, production costs, and potential allergenicity (Kumar & Singh, 2021). Opportunities include a sustainable and cost-effective protein source, waste valorisation, enhanced food security, reduced environmental footprints, and the development of new markets. Complementary waste-management strategies include composting, the biological decomposition of organic waste into biofertiliser that improves soil fertility and water retention (Gajalakshmi & Abbasi, 2008), and anaerobic digestion, the microbial breakdown of waste to produce biogas and digestate fertiliser while reducing methane emissions (Amrul et al., 2022). Together with insect farming on waste streams, these approaches reduce waste volume, convert waste into value, and promote a circular economy, yielding lower greenhouse-gas emissions, pollution mitigation, income diversification, and organic-fertiliser or biofuel production.

This study establishes both the vulnerability of Nigerian smallholder agriculture to climate stress and the technical promise of insect farming and organic-waste valorisation as complementary responses. However, the literature reviewed here is weighted heavily toward global technical and international-agency sources (FAO) and toward biological or engineering studies of insect bioconversion, with comparatively little Nigerian, and almost no Kaduna-specific, evidence on how urban and peri-urban households actually perceive, adopt, or sustain these practices. This gap, between demonstrated technical feasibility and locally grounded evidence on uptake, motivates the baseline and pilot approach adopted in this study.

2 Materials and Methods

2.1 Study Area

Kaduna Metropolis is situated in northern Nigeria between latitudes 10°23′00″ and 10°39′00″ N and longitudes 7°20′16″ and 7°35′00″ E, with an estimated area of 3,156 km² (Abubakar et al., 2025). It is one of the key urban and commercial hubs with a vibrant mix of markets, educational institutions, and open spaces suitable for urban agriculture. The population is ethnically diverse, comprising principally Hausa, Fulani, and Gbagyi groups; the community is youthful, with over 50% of residents under 30 years old, and an average household size of roughly five to seven members (Umar et al., 2025). Most households engage in smallholder farming, cultivating maize, millet, sorghum, cowpeas, groundnuts, and vegetables, predominantly by traditional methods with gradual adoption of improved seeds, fertilisers, and agroforestry (FAO, 2014). The climate is tropical savanna, with a rainy season from April to October averaging 900–1,200 mm of annual rainfall (Ahmad et al., 2025). High temperatures in dry months cause water stress and soil erosion, and climate variability, together with deforestation, threaten land productivity.

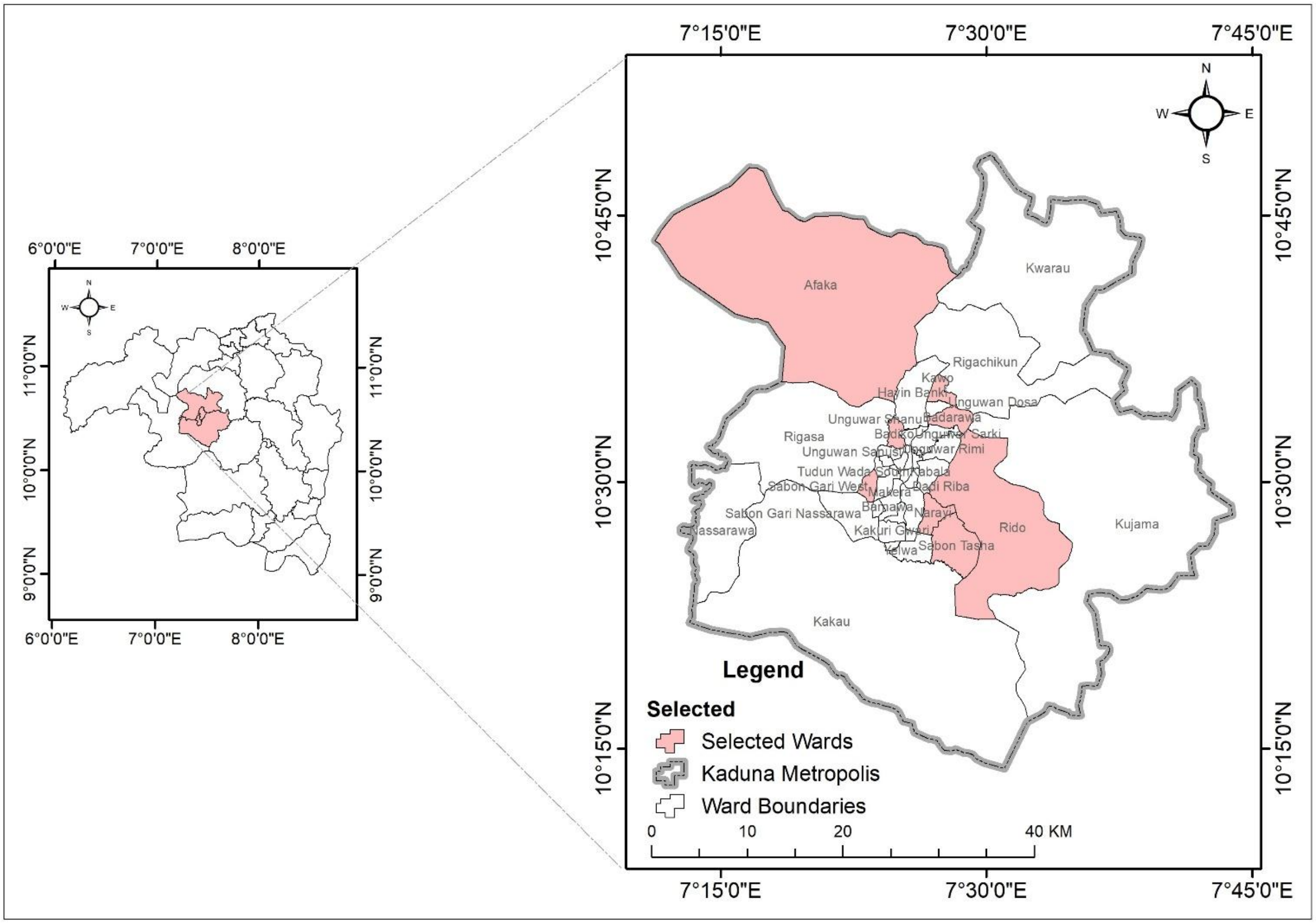

Figure 2: Kaduna Metropolis showing the study neighbourhoods (Sabon Tasha, Kabala West, Mando, Kawo, Malali, Kurmin Mashi, Narayi, New Millennium City)
Source: Adapted from GRID3 – Nigeria, 2024

2.2 Research Design

This study adopted a mixed-methods, cross-sectional research design involving a household survey, key informant interviews, focus group discussions, and participatory pilot demonstrations in selected neighbourhoods of Kaduna Metropolis, namely Sabon Tasha, Kabala West, Mando, Kawo, Malali, Kurmin Mashi, Narayi, and New Millennium City. The target population comprised 39,082 farming households across Chikun, Kaduna North, Kaduna South, and Igabi Local Government Areas, based on records from the Kaduna State Ministry of Agriculture (2026).

2.3 Sample Size

The sample size was determined using the Yamane (1967) formula, which yielded a minimum of 396 households. This was increased to 400 households to improve representativeness and account for possible non-response. A stratified random sampling technique was used, with the four Local Government Areas serving as strata, while households within the selected neighbourhoods were selected through simple random sampling. For the qualitative component, 20 key informants were purposively selected based on their expertise in agriculture, waste management, and community development. A total of 430 questionnaires were distributed, of which 400 were completed and returned, resulting in a 93.0% response rate.

2.4 Data Collection and Analysis

Data were collected using structured questionnaires, key informant interviews, and focus group discussions. Quantitative data were analysed using SPSS Version 27 with descriptive statistics and cross-tabulations, while qualitative data were analysed using thematic analysis. Ethical approval and informed consent were obtained before data collection, and participants' confidentiality was maintained throughout the study.

3 Results

Pilot interventions were conducted over the period of 6 months, through 8 demonstration plots, one in each selected case study within Kaduna Metropolis. Each demonstration plot measured approximately 20 m × 20 m (400 m^2) and demonstrated drought-tolerant crop production, black soldier fly (*Hermetia illucens*) larvae production, cricket farming, composting, rainwater harvesting, and organic waste recycling.

Black soldier fly larvae were reared using household organic waste, including fruit and vegetable residues, food waste, and poultry manure. Compost was prepared from crop residues, household organic waste, and poultry manure using standard composting methods. Farmers received practical training on waste segregation, insect farming, compost production, water conservation, and climate-smart agricultural practices.

The demonstration plots were monitored monthly throughout the six months. Monitoring focused on insect survival, compost quality, crop performance, farmer participation, training attendance, and the continued use of the promoted technologies. Early adoption was measured by the continued use of at least one promoted technology during the monitoring period, while uptake referred to the number of trained households that independently adopted insect farming, composting, rainwater harvesting, or other climate-smart agricultural practices after the training.

Qualitative feedback from farmers and stakeholders was collected through key informant interviews, focus group discussions, and field observations. The responses were analysed using thematic analysis, and the findings were integrated with the quantitative survey results to assess the effectiveness, acceptance, and scalability of the pilot interventions.

Table 1. Socio-Economic Characteristics of Surveyed Households

Variable	Category	Frequency (n)	Percentage (%)
Mean age of respondents	–	45 years	–
Gender	Male	340	85.0
	Female	60	15.0
Education	Islamic or Primary Education (majority)	–	–
Mean farm size	–	1.6 ha	–
Land ownership	Inherited	256	64.0
	Purchased	92	22.9
	Other tenure arrangements	52	13.1

Table 1 presents the socio-economic characteristics of the 400 surveyed households in Kaduna Metropolis. The results indicate that the mean age of respondents was 45 years, suggesting that most household heads were within the economically active age group. This implies that the respondents possess sufficient farming experience and are still capable of adopting and implementing improved agricultural technologies, including climate-smart agriculture (CSA), insect farming, and integrated waste management practices.

The gender distribution shows that 340 respondents (85.0%) were male, while 60 respondents (15.0%) were female. This indicates that farming activities within the study area are predominantly male-dominated, reflecting the traditional pattern of land ownership and agricultural decision-making in northern Nigeria. However, the relatively low participation of women suggests the need for more gender-inclusive agricultural extension programmes to enhance women's involvement in climate-smart agricultural interventions.

Regarding educational attainment, the majority of respondents had Islamic or primary education. This finding suggests that although basic literacy exists among most farmers, relatively few possess advanced formal education. Consequently, agricultural extension messages and training programmes should employ simple, practical, and demonstration-based approaches to facilitate understanding and encourage the adoption of improved farming technologies.

The results further show that the mean farm size was 1.6 hectares, indicating that the respondents were predominantly smallholder farmers. This finding is consistent with the structure of Nigerian agriculture, where small-scale farming constitutes the dominant production system. The relatively small farm sizes underscore the importance of promoting affordable and resource-efficient technologies, such as climate-smart agriculture, insect farming, and composting, which can improve productivity without requiring extensive land resources.

With respect to land ownership, 256 respondents (64.0%) inherited their farmland, 92 respondents (22.9%) acquired land through purchase, while 52 respondents (13.1%) accessed land through other tenure arrangements, including leasing and communal ownership. The predominance of inherited land ownership suggests relatively secure land tenure for many respondents, which may encourage investment in long-term agricultural practices such as agroforestry, compost application, and soil conservation. Nevertheless, households operating under temporary or informal land tenure arrangements may be less willing to invest in sustainable land management practices because of uncertainty regarding future access to land.

3.1 Adoption of Climate-Smart Agricultural Practices

Adoption of CSA practices varied markedly by practice type (Figure 3). Uptake was highest for drought-tolerant crop varieties (80%) and pest/disease-resistant varieties (75%), reflecting farmers' immediate concern with yield stability under variable rainfall. Conversion of flood-prone areas to alternative use was reported by 67% of households. By contrast, water-conserving and soil-management practices lagged considerably: only 35% of households practised rainwater harvesting and just 30% practised crop rotation. This pattern suggests that farmers preferentially adopt practices with visible, short-term productivity benefits (improved varieties) over practices requiring sustained investment in infrastructure or changes to established cropping calendars (water harvesting, rotation).

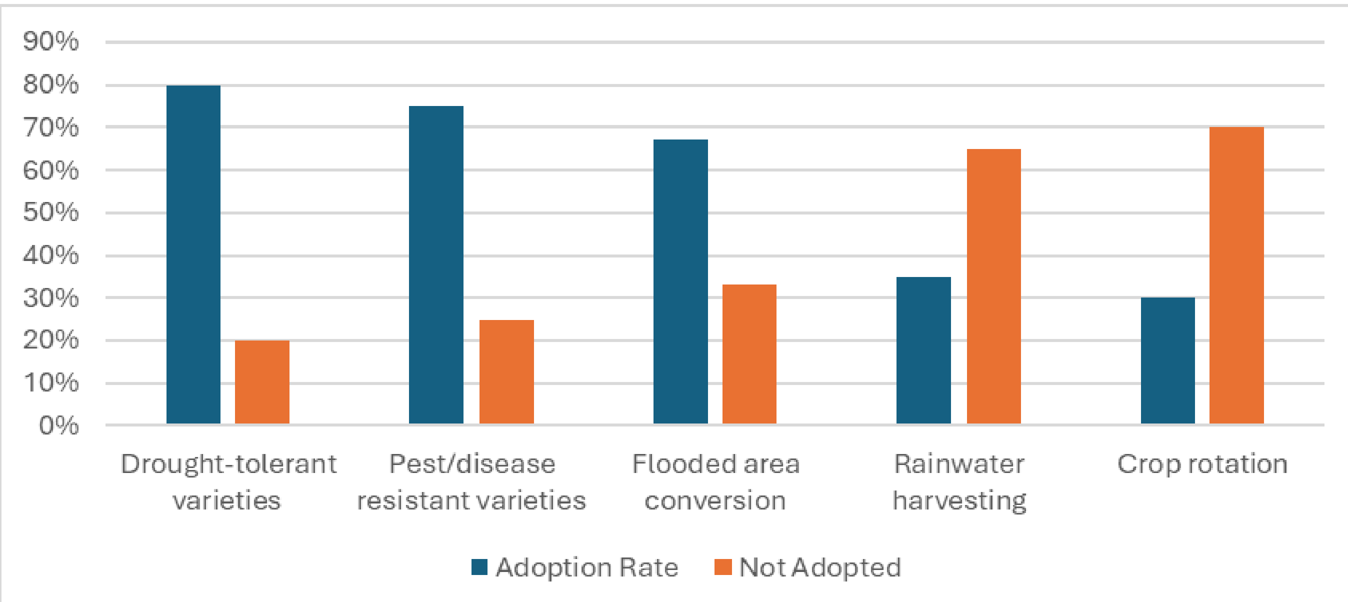

Figure 3: Adoption of climate-smart agricultural practices among surveyed households in Kaduna Metropolis.

Fig. 3 presents the adoption of selected climate-smart agricultural (CSA) practices among the 400 surveyed households in Kaduna Metropolis. The findings show that 320 respondents (80.0%) had adopted drought-tolerant crop varieties, while 80 respondents (20.0%) had not. This indicates that improved crop varieties are widely accepted because they help farmers cope with irregular rainfall and prolonged dry periods, thereby improving crop productivity.

Similarly, 300 respondents (75.0%) reported adopting pest- and disease-resistant crop varieties, whereas 100 respondents (25.0%) had not adopted this practice. The high adoption rate suggests that farmers recognise the importance of resistant crop varieties in reducing crop losses and improving farm yields.

The results further reveal that 268 respondents (67.0%) had adopted flood-prone area conversion, while 132 respondents (33.0%) had not. This suggests that a considerable proportion of farmers have modified their farming practices to minimise the adverse effects of flooding and soil degradation.

In contrast, only 140 respondents (35.0%) practised rainwater harvesting, while 260 respondents (65.0%) did not. The relatively low adoption may be attributed to inadequate infrastructure, limited financial resources, and insufficient technical knowledge required for establishing rainwater harvesting systems.

Crop rotation recorded the lowest adoption level, with only 120 respondents (30.0%) practising crop rotation, compared with 280 respondents (70.0%) who did not. This finding suggests that many farmers continue to cultivate the same crops on the same land, which may reduce soil fertility and increase susceptibility to pests and diseases over time.

Thus, the results indicate that respondents were more likely to adopt CSA practices that provide immediate and visible economic benefits, such as improved crop varieties, than management practices requiring additional investment, planning, or technical support. The findings underscore the need for strengthened agricultural extension services, practical farmer training, and financial support to improve the adoption of water conservation and sustainable soil management practices in Kaduna Metropolis.

3.2 Waste Management and Urban Greening

Waste disposal among surveyed households was found to be largely informal, dominated by open burning or uncontrolled dumping. Awareness of composting and recycling was low, and correspondingly minimal in practice. Urban green spaces were found to be underutilised, constrained by infrastructural deficits and limited community engagement in tree-planting and greening initiatives (Ogunleye et al., 2018).

3.3 Perception and Awareness of CSA and Insect Farming

Table 2 presents residents' perception and awareness of Climate-Smart Agriculture (CSA) in Kaduna Metropolis.

Table 2: Awareness of Climate-Smart Agriculture (CSA) and Insect Farming by Socio-Demographic Characteristics

Variable	Category	Aware of CSA n (%)	Aware of Insect Farming n (%)
Gender	Male (n = 220)	90 (40.9)	62 (28.2)
	Female (n = 180)	50 (27.8)	34 (18.9)
Age (Years)	18–35 (n = 130)	60 (46.2)	42 (32.3)
	36–45 (n = 110)	42 (38.2)	28 (25.5)
	Above 45 (n = 160)	38 (23.8)	26 (16.3)
Educational Level	Primary or Below (n = 120)	24 (20.0)	15 (12.5)
	Secondary (n = 130)	42 (32.3)	28 (21.5)
	Tertiary (n = 150)	74 (49.3)	53 (35.3)
Overall	N = 400	140 (35.0)	96 (24.0)

Table 2 shows that 140 out of the 400 respondents (35.0%) were aware of Climate-Smart Agriculture (CSA), while only 96 respondents (24.0%) were aware of insect farming, indicating that awareness of insect farming remains relatively low within the study area. This suggests that although CSA has gained some recognition through agricultural programmes and extension services, insect farming is still an emerging innovation with limited public awareness.

The results further indicate differences in awareness across socio-demographic groups. By gender, 40.9% of male respondents were aware of CSA compared with 27.8% of female respondents. Similarly, awareness of insect farming was higher among males (28.2%) than females (18.9%). This difference may reflect greater participation of men in agricultural training programmes, extension activities, and farm decision-making within the study area.

With respect to age, younger respondents aged 18–35 years recorded the highest awareness of both CSA (46.2%) and insect farming (32.3%), followed by respondents aged 36–45 years. Respondents above 45 years exhibited the lowest awareness levels. This finding suggests that younger farmers are generally more receptive to agricultural innovations and are more likely to access information through extension services, digital media, and educational programmes. The results are similar to the findings of Mustapha et al. (2026), which found that Kaduna Metropolis has a large population of young people.

The analysis by educational level reveals that awareness increased with educational attainment. Respondents with tertiary education recorded the highest awareness of CSA (49.3%) and insect farming (35.3%), while those with primary education or below had the lowest awareness (20.0% and 12.5%, respectively). This indicates that education plays an important role in improving access to agricultural information, understanding of climate-related challenges, and acceptance of innovative farming technologies.

Therefore, the findings demonstrate that education, age, and gender significantly influence respondents' awareness and perceptions of CSA and insect farming. The relatively low overall awareness, particularly of insect farming, highlights the need for targeted awareness campaigns, farmer education programmes and strengthened agricultural extension services, especially among women, older farmers, and respondents with lower educational attainment, to enhance the adoption of climate-smart agricultural technologies.

3.4 Pilot Intervention Outcomes

Table 3 indicates that the pilot interventions generated measurable improvements in sustainable agricultural practices and waste management among participating households. A total of 120 households participated in the demonstrations, with an attendance rate of 95.8%, indicating strong community participation throughout the training period. During the six months, approximately 2,450 kg of household organic waste was converted into 462 kg of black soldier fly larvae and 1,180 kg of compost, demonstrating the technical feasibility of integrating insect farming with organic waste recycling.

Table 3: Summary of Pilot Intervention Outcomes (N = 120 Participating Households)

Indicator	Result
Demonstration plots established	8
Participating households	120
Farmers trained	120
Training attendance rate	95.8%
Organic waste processed	2,450 kg
Black soldier fly larvae produced	462 kg
Compost produced	1,180 kg
Households practising composting after training	82 (68.3%)
Households practising BSF farming after training	56 (46.7%)
Households adopting at least one CSA technology	89 (74.2%)
Households continuing the technologies after six months	71 (59.2%)
Average reduction in household organic waste	41.5%
Farmers reporting improved soil condition after compost application	64 (53.3%)
Farmers reporting additional income from compost or larvae sales	38 (31.7%)

Following the training, 68.3% of participating households adopted composting, while 46.7% established small-scale black soldier fly production units. Thus, 74.2% of the households adopted at least one climate-smart agricultural practice introduced during the pilot, and 59.2% continued using the technologies throughout the monitoring period, suggesting moderate retention and continued application beyond the initial training.

The interventions also generated environmental and livelihood benefits. Participating households reported an average 41.5% reduction in organic waste disposal, while 53.3% observed improvements in soil quality after applying compost to their farms. In addition, 31.7% of participants reported earning supplementary income through the sale of compost or black soldier fly larvae, indicating the potential of the technologies to diversify household livelihoods.

Despite these positive outcomes, several constraints limited wider adoption. Farmers identified inadequate access to land, limited start-up capital, insufficient technical knowledge, and weak market linkages for insect-based products as the principal barriers to scaling the interventions. These findings suggest that while the pilot successfully demonstrated the technical and economic potential of climate-smart agriculture, insect farming, and integrated waste management, sustained adoption will depend on continued extension support, access to finance, stronger value chains, and supportive government policies.

4 Discussion

The findings indicate that smallholder farmers in Kaduna Metropolis have begun adopting selected climate-smart agricultural (CSA) practices, particularly drought-tolerant (80%) and pest-resistant (75%) crop varieties. However, the adoption of water conservation (35%) and crop rotation (30%) practices remains relatively low. This pattern is consistent with findings from Nigeria by Ojo et al. (2020), who reported that farmers are more likely to adopt technologies with immediate economic benefits than practices requiring greater investment, technical knowledge, or behavioural change. Similarly, Adeagbo et al. (2018) observed that inadequate extension services, limited access to finance, and poor awareness remain major constraints to the adoption of climate-smart agriculture among Nigerian smallholder farmers. The findings therefore suggest that increasing awareness alone may not substantially improve adoption unless accompanied by improved access to financial support, extension services, and agricultural inputs.

The study also found that awareness of Climate-Smart Agriculture was relatively moderate (35%), whereas awareness of insect farming was considerably lower (24%). Awareness was higher among younger, male, and better-educated respondents, indicating that socio-economic characteristics influence the diffusion of agricultural innovations. This finding agrees with studies conducted in Nigeria, which have shown that education and access to agricultural extension services significantly influence farmers' willingness to adopt improved agricultural technologies (Ojo et al., 2020; Akpenpuun & Busari, 2013). The relatively low awareness of insect farming therefore reflects the limited promotion of insect-based technologies within Nigeria's agricultural extension system rather than a lack of technical feasibility.

The pilot interventions demonstrated that integrating climate-smart agriculture with insect farming and organic waste management can provide measurable environmental and livelihood benefits. During the six-month demonstration period, 2,450 kg of organic waste was converted into 462 kg of black soldier fly larvae and 1,180 kg of compost, while 74.2% of participating households adopted at least one promoted technology and 59.2% continued using the technologies after the training period. These findings support previous Nigerian and African studies showing that organic waste recycling and composting can improve soil fertility, reduce waste disposal problems, and create additional livelihood opportunities for farming households. However, because the intervention covered only 120 participating households over six months, the results should be interpreted as evidence of short-term feasibility rather than proof of long-term sustainability.

Although the pilot produced encouraging outcomes, several limitations suggest caution when considering large-scale implementation. The continuation rate of 59.2% indicates that a substantial proportion of trained households discontinued the technologies during the monitoring period. Discussions with participants revealed that limited access to start-up capital, inadequate technical support, uncertain markets for insect products, and land constraints remained significant barriers. These findings are consistent with Nigerian studies that identify financial constraints, weak extension systems, and poor market development as persistent obstacles to the adoption of agricultural innovations (Ojo et al., 2020). Consequently, scaling up insect farming and integrated waste management cannot rely solely on demonstration activities but requires institutional support, access to credit, reliable input supply, and market development.

Meanwhile, the study demonstrates that climate-smart agriculture, insect farming, and integrated waste management have considerable potential to improve livelihoods and environmental sustainability in Kaduna Metropolis. Nevertheless, the evidence from this study is based on a relatively small-scale pilot and a short monitoring period. Further longitudinal studies involving larger populations, multiple production seasons, and detailed economic and environmental assessments are required to establish the long-term impacts, cost-effectiveness, and scalability of these interventions within Nigeria. This more cautious interpretation provides a stronger evidence base than broad advocacy and aligns the findings with existing Nigerian literature on climate-smart agriculture and sustainable agricultural development.

5 Conclusion

This study examined the current status of climate-smart agriculture (CSA), insect farming, and integrated waste management among smallholder farming households in Kaduna Metropolis. The findings indicate that while the adoption of drought-tolerant and pest-resistant crop varieties was relatively high, the uptake of water conservation, composting, and insect farming remained limited. Awareness of CSA was moderate, whereas awareness of insect farming was comparatively low, particularly among older and less-educated respondents.

The pilot interventions showed that insect farming, composting, and other climate-smart agricultural practices are feasible at the demonstration level and were accepted by a proportion of participating households. The recorded improvements in organic waste utilisation, compost production, and continued adoption by some households suggest that these practices have potential to contribute to improved waste management and livelihood diversification. However, the findings also revealed important constraints, including limited access to finance, inadequate technical support, land limitations, and weak market linkages, which may affect wider adoption.

Given that the pilot interventions were implemented over a relatively short period and involved a limited number of participating households, the findings should be interpreted as preliminary evidence rather than confirmation of long-term impacts. Further longitudinal studies involving larger populations and extended monitoring are required to assess the sustainability, economic viability and environmental impacts of these interventions under different farming conditions.

Therefore, the study provides baseline information on farmers' awareness, adoption and perceptions of climate-smart agriculture, insect farming and integrated waste management in Kaduna Metropolis. The findings can inform future research, extension programmes and policy discussions aimed at promoting sustainable agricultural practices and improving urban environmental management within the study area.

5.1 Policy Recommendations

The findings of this study indicate that awareness of Climate-Smart Agriculture (CSA) and insect farming remains relatively low, with only 35.0% of respondents aware of CSA and 24.0% aware of insect farming. Awareness was particularly lower among older respondents and those with lower educational attainment. Consequently, agricultural extension services should be strengthened through regular community-based training, demonstration farms, and awareness campaigns that specifically target these groups. Expanding extension activities would improve farmers' knowledge and increase the adoption of sustainable agricultural practices.

The study also revealed that although farmers readily adopted drought-tolerant (80%) and pest-resistant (75%) crop varieties, the adoption of rainwater harvesting (35%) and crop rotation (30%) remained low. This suggests that farmers are more likely to adopt technologies that provide immediate production benefits than those requiring additional investment or technical skills. Government agencies and development partners should therefore provide technical assistance, training, and financial support for water conservation and soil management technologies to encourage their wider adoption.

The pilot intervention demonstrated that black soldier fly farming and composting can effectively convert household organic waste into valuable agricultural products. During the six-month pilot, 2,450 kg of organic waste was converted into 462 kg of black soldier fly larvae and 1,180 kg of compost, while 68.3% of participating households adopted composting after the training. These findings suggest that insect farming and composting have practical potential for improving waste management and supporting sustainable agriculture. However, wider adoption will require continued technical support, access to starter materials, and practical training for farmers.

Although 74.2% of participating households adopted at least one of the promoted technologies during the pilot, only 59.2% continued using the technologies throughout the monitoring period. Discussions with participants identified inadequate finance, limited technical support, and lack of market opportunities as the major constraints to sustained adoption. There is therefore a need for government and financial institutions to improve access to microcredit, agricultural grants, and affordable inputs while strengthening extension services to provide continuous technical guidance.

The study further found that uncertainty regarding markets for insect products and organic fertilisers discouraged some participants from continuing the technologies after the pilot. To improve sustainability, efforts should focus on developing reliable value chains through farmer cooperatives, quality standards, product certification, and stronger linkages with livestock, poultry, and aquaculture industries that can utilise black soldier fly larvae as an alternative feed ingredient.

Finally, because the pilot interventions were monitored for only six months, the study provides preliminary evidence of the feasibility of integrating climate-smart agriculture, insect farming, and waste management rather than evidence of long-term impacts. Future research should therefore undertake longitudinal evaluations over multiple farming seasons to assess the sustainability of technology adoption, changes in household income, improvements in soil quality, and the long-term environmental benefits of these interventions. Such studies would provide stronger empirical evidence to guide policy formulation and large-scale implementation in Kaduna Metropolis and other urban centres in Nigeria

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