RESEARCH ARTICLE

What shapes water use and variety decisions? Evidence from Tomato Farmers in Kaduna and Oyo States Nigeria

[version 1]

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Abstract

Understanding the factors that influence farmers' water use practices and varietal choices is essential for improving productivity and climate resilience in vegetable production. This study examines the determinants of water source and tomato variety decisions among smallholder farmers in Kaduna and Oyo States, Nigeria. Primary data were collected from tomato producers through a structured household survey. A multinomial logit model was employed to analyze how socio-economic, institutional, and farm-level factors shape farmers' choices of water sources and tomato varieties (local, improved, and hybrid). The results show that access to credit, cooperative membership, extension services, and farm size significantly influence the likelihood of adopting improved and hybrid tomato varieties. Gender and location effects were also significant, with male farmers and those in Kaduna State more likely to adopt improved varieties, while hybrid adoption was associated with higher resource availability and institutional support. Water use decisions were strongly influenced by access to irrigation infrastructure, farm characteristics, and farmers' financial capacity. The findings highlight the importance of strengthening rural credit systems, farmer organizations, and extension services to enhance the adoption of improved technologies and efficient water use practices. These results provide policy insights for promoting sustainable tomato production and improving smallholder resilience to climate variability in Nigeria.

Keywords
Water-use, Rain, Pump/well, Dam, Improved varieties, Hybrid varieties, Local varieties

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1. Introduction

Horticultural value chains have expanded rapidly across many African countries in response to changing consumption patterns driven by urbanization and rising incomes. As household incomes increase, a larger share of the food budget is typically allocated to fruits and vegetables. For instance, the value share of fruits and vegetables in national consumption in sub-Saharan Africa has risen to 10–15% (Theriault *et al.*, 2021). In Nigeria, nearly all households consume some vegetables, with an average of 6.7% of total food expenditure allocated to vegetables. Leafy greens and tomatoes are consumed by 48% and 88% of households, respectively (Parkhi *et al.,* 2023). Given Nigeria's favorable agro-ecological conditions and the growing domestic demand, tomato is widely cultivated across the country.

Smallholder farmers cultivating approximately 0.5 to 5 hectares continue to dominate Nigeria's tomato sector, accounting for nearly 90% of national production, while commercial farms account for the remainder (Norbert *et al.*, 2023; Osunmuyiwa *et al.,* 2021). Nigeria remains one of Africa's major tomato producers, with an estimated 702,000 hectares harvested in 2022, placing the country among the top global producers (FAOSTAT, 2022; Helgi Library, 2025). Despite this extensively cultivated area, productivity remains low.

Although national output ranges between 3.7 and 4.1 million tons annually, average yields are approximately 5.2 t/ha, substantially below those of Egypt (30–50 t/ha), Kenya (18-25 t/ha) and South Africa (70-90 t/ha) according to FAOSTAT (2024), as well as global benchmarks (IndexBox, 2025). The persistent yield gap is attributed to constraints such as suboptimal agronomic practices, limited access to improved varieties, pest and disease pressures, and post-harvest inefficiencies across the value chain (Osunmuyiwa *et al.,* 2021).

In addition to low tomato yields, tomatoes are highly sensitive to climatic variability, particularly irregular water availability during rainfed or supplemental irrigation. Water stress at any stage of growth can adversely affect plant development, flowering, pollination, fruit set, and ultimately yield (Afroza *et al.,* 2010). Despite increasing evidence on climate change impacts on agricultural production, there is limited evidence on horticulture production relative to other crops particularly cereals (such as maize and rice) and starchy staples such as cassava (Lobell *et al*., 2024). In addition, the limited literature on climate change impact on horticulture has focused primarily on agronomic trials with limited empirical documentation on how smallholder farmers are adapting to climate change in terms of water use and varietal adoption.

To address this knowledge gap, this study examines the nature and drivers of tomato farmers' adoption of improved tomato varieties (resilient to climate-related fluctuations) and water use practices. We analyze these adaptation strategies among tomato farmers in Nigeria, the most populous African nation and the continent's second largest tomato producer. Our study differentiates adaptation strategies across two distinct agro-ecological and economic zones, providing insights into how context shapes farmer decisions.

Increasing smallholder adoption of irrigation in Nigeria requires a comprehensive understanding of the constraints farmers face in using private irrigation systems. While most irrigation systems in Nigeria are gravity-fed, diverse agro-ecological and socio-economic conditions and farmers' heterogeneous capacity to overcome such constraints suggest that the demand for irrigation technologies varies widely. This diversity underscores the need for irrigation policies tailored to the specific needs and conditions of different farmer groups. In this paper we distinguish between different sources and methods of water supplementation, using wetlands, pumping groundwater from wells, or diverting water from dams or streams. This is important because each approach reflects different investment requirements and environmental consequences, and long-term sustainability implications. Wetland-based irrigation often depends on naturally occurring moisture or seasonal flooding, making it highly vulnerable to climate variability and potentially risky for ecosystem health if overused. In contrast, well-based irrigation requires substantial upfront investment in pumps and boreholes, depends on groundwater availability, and raises concerns about aquifer depletion and energy costs. Diversion channels or pump-fed surface water systems rely on hydrological conditions in rivers or dams, involve communal infrastructure, and can create downstream externalities or allocation conflicts. Treating all these systems as the same obscures the different constraints farmers face, the varying levels of capital and maintenance required, and the distinct environmental trade-offs associated with each, ultimately limiting the ability to design targeted, effective irrigation policies and interventions. Table 1 presents a description of the irrigation methods currently employed by farmers in the study areas.

We also distinguish between improved and hybrid tomato varieties. This distinction is critical because these technologies represent different adaptation pathways. Improved varieties (see table 2 for details) offer relatively low-cost, lower-risk productivity gains suitable for resource-constrained farmers (and amenable to climate variability), while hybrid varieties (see table 2 for details) provide higher yield potential but require greater financial investment and management capacity.

Table 1. Irrigation systems and level of adoption by smallholder farmers.

Water sources and application methods	Description
Rainwater	Rainwater refers to precipitation collected directly from rainfall or stored through runoff harvesting systems such as farm ponds, tanks, or bunds. It is widely used in rain-fed and supplemental irrigation systems, particularly in Sub-Saharan Africa where rainfall variability constrains production.
Water from a well using pumps	Well water refers to groundwater extracted from shallow or deep wells using pumps. It provides a relatively reliable and year-round source of irrigation water, especially in areas with seasonal rainfall. Groundwater irrigation is important for stabilizing crop yields, enabling dry-season farming, and supporting smallholder intensification, though over-abstraction may pose sustainability risks in some regions.
Water from a dam or stream	Water from dams, rivers, or streams represents surface water used for irrigation largely through gravity flow, pumps, or diversion channels. In our sample, majority of the access is via diversion channels. Small reservoirs and dams store runoff and river flow for later use, improving water availability during dry periods and supporting expanded cultivated areas and crop diversification. Surface water irrigation is a dominant source in many developing regions and is crucial for farmer-led irrigation systems.
Wetland	Wetlands (fadama/valley bottoms/floodplains) provide naturally water-saturated soils that retain moisture for extended periods, allowing crop cultivation with minimal irrigation. Farmers often rely on shallow groundwater, seasonal flooding, or residual soil moisture in wetlands for dry-season production. These areas are particularly important for small-holder irrigation and vegetable farming because they provide relatively reliable water access and fertile soils.

Source: IFPRI 2010

Table 2. Tomato varieties and their description.

Tomato varieties	Description
Local varieties	Traditional open-pollinated cultivars maintained by farmers and adapted to local environments. They are genetically diverse and resilient but usually produce lower and less uniform yields. Seeds are saved and reused, making them accessible to smallholders. (Ogundeji & Ogunwande, 2024). Examples are farmer-saved types, including Hausa local tomato and Yoruba local tomato.
Hybrid varieties	First-generation crosses designed to exploit hybrid vigor, resulting in higher yield, uniform fruits, earlier maturity, and stronger resistance. Seeds must be purchased each season because saved seed does not retain desired traits (Nawaz *et al*., 2023). Examples include Platinum F1, Cobra F1, Padma F1, Anna F1, Shanty F1.
Improved varieties (OPV/breeder lines)	Developed through formal breeding programs to improve yield, fruit quality, and resistance to diseases. They outperform local varieties and may allow limited seed recycling depending on type. This makes the adoption of improved varieties easier than hybrid varieties that must be purchased each season. Improved seed adoption is associated with higher productivity and income gains (Ogundeji & Ogunwande, 2024). Examples include Roma VF, UC82B, Tropimech, NGB

Consequently, varietal choice reflects not only productivity considerations but also farmers' risk tolerance, access to credit, and adaptive capacity under increasing climate variability.

2. Methodology

2.1 Study area

This paper leverages on data from tomato farmers in two Nigerian states, Kaduna and Oyo. These states were purposively selected for two main reasons. First, because of their prominent roles in Nigeria's tomato production (NAERLS, 2022). Kaduna State, located in the northwestern region, is a major supplier of tomatoes to markets nationwide, while Oyo State is a leader in regional production (for the southwest) and primarily serves local and neighboring markets. Kaduna and Oyo also represent contrasting agroecological and market environments. Kaduna lies in the Guinea–Sudan savanna, which is well suited for vegetable cultivation, while Oyo's rainforest and derived savanna zones are less so but have seen rapid growth in tomato production (Adelodun & Choi, 2018; NAERLS, 2022). Kaduna is a net supplier of tomatoes, with long supply chains reaching southern markets over 600 km away (Liverpool-Tasie *et al.,* 2025). Oyo, by contrast, is a net consumer, serving shorter regional markets and relying partly on northern supplies. Selecting two states (one in the north and one in the south) is important because the two regions differ in socioeconomic and cultural characteristics. The north has lower education levels, population density, and higher poverty (around 75%) compared to about 45% in the south (Otekunrin *et al*., 2019; Cableindex, 2025).

In each state, the top two Local Government Areas (LGAs) for tomato production (in terms of volume produced) were identified with the assistance of a national research institute called the National Agricultural Extension and Research Liaison Services (NAERLS) and local extension agents, verified by field teams from the Federal Universities in each state. Next, the top two wards (in terms of volume of production) were identified within each LGA, and then the top two communities within each ward. All households and farms in these communities were listed. Using a finite population correction for simple random sampling (Lohr, 2010; Cochran, 1977), we calculated a minimum sample size of 384, assuming a 95% confidence level, 5% margin of error, and maximum variability (p = 0.5). To allow for robust comparisons, we targeted 400 tomato farmers per state. From a listing of 2,026 tomato-farming households, all female-managed and households with jointly-managed plots were included. The remaining sample was randomly selected. Sample weights were applied to reflect household representation.

Ethical approval and consent statement

This study (MSU Study ID: STUDY00007403) received ethical approval from the Institutional Review Board of Michigan State University, and all interviews were conducted in accordance with the local legislation and institutional requirements.

Informed consent was obtained verbally from all participants after explaining and prior to survey administration. Verbal consent was chosen because many farmers had limited literacy and time constraints within the environment, making written consent impractical; however, participation was entirely voluntary.

2.2 Data analysis

Multiple non-linear response models were used to analyze different measures of the main study outcomes related to water and tomato seed variety use. In this study, varietal adoption was measured using three binary variables: (1) *Improved seed* coded 1 if a farmer used an improved seed during the last production season and 0 otherwise, and (2) *Hybrid seed*, coded 1 if a farmer used a hybrid tomato variety and 0 otherwise (3) Local seed coded as 1 if a farmer used a local seed during the last production season and 0 otherwise. Because these three outcomes are binary and mutually exclusive (a) farmer may adopt only one of the three options, a multinomial logit model was employed based on McFadden (1986). The framework for the multinomial logit model used in the study context has each farmer facing three possible varietal options for their tomato production: (1) Local/traditional seeds (2) improved seeds, and (3) Hybrid seeds. Farmer's representative utility is derived from his experience with each variety j, j = 1, 2, 3, as follows:

$$V_{ij} = X_i\beta_j + \varepsilon_{ij} \tag{1}$$

where X_i is a vector of all farm, farmer and market factors that affect this utility. These include their age, level of education, years of experience in tomato farming, their scale of operation (land under tomato cultivation), and their household size. Vector X_i also includes geographical factors such as the distance of their farm to the market, whether the farmer is based in the north (Kaduna) or south (Oyo) of Nigeria. We also account for farmers' membership in local rotating savings and credits association (ROSCA) and their market channels (who they typically sell to) as this might be an important source of resources for investment in their tomato farming and inputs and could also incentivize their adoption of particular technologies. The vector βj represents the coefficients for the vector of explanatory variables, and ε_{ij} refers to the random errors that are assumed to be independent and identically distributed across the *j* alternatives.

The choice probability associated with each alternative (local, hybrid and improved varieties) can be expressed by the following multinomial logit framework:

$$p_{ij} = \Pr\begin{cases} \Pr(y_i = 1|X_i) = \dfrac{1}{1+\sum_{k=2}^{j}\exp(X_i\beta_k)} & for\ \ j=1 \\ \Pr(y_i = J|X_i) = \dfrac{\exp\left(X_i'\beta_j\right)}{1+\sum_{k=2}^{j}\exp(X_i\beta_k)} & \text{For}\ \ \text{j} > 1 \end{cases} \tag{2}$$

Which is the probability of farmer *i* choosing alternative *j.* where y_i is the varietal option *i* faces. We normalize the equation by establishing the base outcome to receive local/traditional seeds and imposing the usual identifying restriction that $\beta_1 = 0$.

The associated log likelihood is thus:

$$\prod_{i}^{n}\prod_{j}^{J} 1(y_i = j)\ln\Pr(y_i = j|X_i)$$

where $1(y_i = j)$ is the indicator of the farmers varietal choice outcome (equal to 1 if they selected a particular variety and 0 otherwise). To maximize this log-likelihood function, we adopt the Newton-Raphson approximation method.

3. Results and discussions

Table 3 describes the study sample of tomato producers in Kaduna and Oyo States, with notable demographic and farm-level differences across the two states. Plot managers in both states are typically male (though with slightly higher female managed plots in Oyo (at 15%). However, the average age of plot managers was almost 10 years younger in Kaduna (at ~40 years) compared to 48 years in Oyo. Household size also differed substantially, with an average of 7 household members in Kaduna compared with 5 members in Oyo.

We find that tomato farmers in Kaduna reported an average of 10 years of farming experience, while those in Oyo averaged 13 years. While the average number of production cycles per season was 1 in both states, mean farmland size varied across the two locations, with households in Kaduna cultivating an average of 1.14 hectares and those in Oyo cultivating 1.92 hectares. Market access differs slightly across the two study states with the average distance from farm to market at 11 km in Kaduna and 14 km in Oyo. Together, these descriptive statistics highlight the importance of distinguishing between tomato producers in the north vs. south of Nigeria when trying to understand their decision around the adoption of important productivity and profit maximizing technologies.

Table **4** presents the distribution of respondents' adoption of various water use practices across the study sample. The results indicate that rainfall was the predominant source of water, accounting for 92% in Oyo State and 69% in Kaduna State. This difference reflects the variation in rainfall distribution between the two ecological zones. The use of pumps or wells was reported by 23% of respondents in Kaduna State and only 3% in Oyo State. The use of dams or streams was the least common, with 4% in Kaduna State and 0.5% in Oyo State. Wetland use was low but at 4% in both states.

The observed variations in water use practices between Kaduna and Oyo States reflect the influence of ecological, climatic, and infrastructural factors on agricultural production systems. The high dependence on rainfall as the primary water source generally, but particularly in Oyo State suggests that tomato production in both areas is predominantly rain-fed. This reliance exposes farmers to significant risks associated with rainfall variability and changing climate patterns, which can affect both yield and production stability. The relatively higher use of pumps and wells in Kaduna State indicates a growing adaptation toward groundwater-based irrigation systems, likely driven by the need to supplement limited and erratic rainfall patterns. This finding aligns with studies such as Adeoye *et al.* (2020) and Nnaji *et al.* (2019), which reported increasing adoption of small-scale irrigation technologies in northern Nigeria to mitigate climate-induced production risks.

The minimal use of dams and streams across both states further highlights the limited availability or accessibility of surface water resources and irrigation infrastructure, which may restrict dry-season tomato cultivation. Strengthening institutional support and promoting farmer awareness on water conservation could enhance the resilience of tomato production to climatic and environmental challenges in both Kaduna and Oyo States.

This finding aligns with studies such as Ahmed and Gomina (2019) who reported increasing adoption of small-scale irrigation technologies in northern Nigeria to mitigate climate-induced production risks. Onwuegbunam *et al.* (2021) demonstrated how deficit irrigation strategies in Kaduna improved water productivity in tomato farming. Further, Bello *et al.* (2021) found that uptake of small-scale irrigation technologies remains low in many vegetable-producing zones, indicating a gap in infrastructure. Additionally, Ahmed *et al.* (2020) reported on inefficiencies in irrigation practice among tomato farmers in Kaduna State, underscoring the need for targeted training and improved resource access.

Table 5 presents the distribution of tomato producers' choice of tomato varieties in the study sample. We highlight four key findings. First, improved varieties were adopted far more widely in Kaduna State (62%) than in Oyo State (13%). Second, hybrid varieties also showed higher uptake in Kaduna (10%) compared to Oyo (2%). Third, local varieties were predominantly used in Oyo State (85%) compared with Kaduna (28%). These figures show a clear contrast in varietal choice across states, with Kaduna farmers more likely to use improved and hybrid types while Oyo farmers rely largely on

Table 3. The main descriptive statistics on explanatory variables.

Variables	Kaduna		Oyo		Pooled	
	Mean	SD	Mean	SD	Mean	SD
Gender of plot manager (prop. Male only)	0.98	0.14	0.71	0.45	0.85	0.36
Plot manager’s age (in years)	39	11.9	48	13.99	44	13.64
Plot manager’s education (prop. no formal education)	0.08	0.27	0.15	0.36	0.12	0.32
Plot manager’s education (prop. primary education)	0.49	0.5	0.3	0.46	0.4	0.49
Plot manager’s education (prop. secondary education)	0.34	0.47	0.47	0.5	0.4	0.49
Plot manager’s education (prop. above secondary)	0.09	0.29	0.08	0.27	0.09	0.28
Household size (mean numbers)	7	3.82	5	2.32	6	3.46
Plot size (hectares)	1.14	1.52	1.92	2.65	1.53	2.19
Farming experience (in years)	10	8.06	13	9.54	12	8.91
Used improved variety	0.69	0.46	0.13	0.34	0.41	0.49
Used hybrid variety	0.13	0.34	0.02	0.15	0.08	0.27
Used local variety	0.18	0.39	0.85	0.36	0.52	0.5
Distance to market (in km)	11	72.66	14	54.63	12	64.26
Farm only in dry season	0.54	0.5	0.02	0.15	0.28	0.45
Farm only in wet season	0.34	0.47	0.81	0.39	0.58	0.5
Farm in wet and dry season	0.46	0.5	0.98	0.15	0.72	0.45
Plot manager is a ROSCA member	0.16	0.37	0.58	0.49	0.37	0.48
Farmer sell to rural aggregator (prop.)	0.53	0.5	0.35	0.48	0.44	0.5
Farmer sell to wholesaler (prop.)	0.52	0.5	0.65	0.48	0.59	0.49
Farmer sell to retailer (prop.)	0.11	0.32	0.05	0.21	0.08	0.27
Farmer sell to other market channels (prop.)	0.07	0.25	0.13	0.34	0.1	0.3
Number of production cycles (mean)	1.04	0.23	1.46	0.73	1.25	0.58
Plot manager earned credit from bank (prop.)	0.05	0.22	0.04	0.19	0.05	0.21
Plot manager earned non-farm income (prop.)	0.58	0.5	0.34	0.48	0.46	0.5
Number of observations	400		400		800	

Source: Author calculations from field data. From 800 tomato samples, 13 households are managed by both male and female plot managers and hence are categorized under female plot managers because females are taking part in some form of decision-making.

Table 4. Farmer adoption of different water use practices (%).

Primary sources of water	Kaduna	Oyo	Pooled.
Rain	69	92	81
Pump well	23	3	13
Dam or stream	4	1	2
Wetland	4	4	4
Total	100	100	100

Source: Author calculations from field data

local varieties. Fourth, we find that the adoption of improved varieties is much higher than the adoption of hybrid varieties in both states.

Table 6 presents the results from the multinomial logit estimations on factors associated with farmer water use. It presents the coefficients associated with the key study explanatory variables expected to influence the sources of water used by

Table 5. Farmer adoption of main crop varieties.

Main variety cultivated	Kaduna	Oyo	Pooled.
Improved Variety	62	13	37
Hybrid Variety	10	2	6
Local Variety	28	85	57
Total	100	100	100

Source: Author calculations from field data

tomato farmers. We highlight five key findings. First, wet-season farming is associated with less reliance on water from wells, dams/streams or wetlands and greater reliance on rain as the primary water source. Reduced rainfall drives farmers toward alternative water sources such as wells and irrigation systems (Onwuegbunam *et al.,* 2021; Ahmed *et al.,* 2020). Second, we find that education is positively associated with the adoption of irrigation systems that draw water from dams and streams, but less so for systems using water from wells. Farmers with at least primary or secondary education (compared to no formal education) have a significantly higher probability of using water from a dam or stream rather than relying on rainfall. Similarly, post-secondary education is associated with a higher probability of using dam/stream water as well as wetlands. These patterns suggest that farmers with formal education are more likely to access surface water resources and irrigation infrastructure than those without formal schooling. Overall, our findings align with literature showing that higher educational attainment enhances farmers' ability to evaluate water availability, reliability, and management options, thereby influencing their water-use decisions (Abdulai and Huffman, 2014; Asfaw and Admassie, 2004).

Third, we find that gender matters. Tomato farmers that are men are more likely than women to use a dam/stream, possibly due to cultural norms or greater access to land and production resources (Yahaya *et al.,* 2022; Adeoye *et al.,* 2020). Fourth, we find a positive correlation between the use of modern seed varieties and the adoption of supplemental water practices. More specifically, the use of both improved and hybrid varieties is significantly and positively associated with sourcing water from dams and streams. This finding is consistent with the complementarity of the two technologies in agriculture. Improved seeds yield their full potential only when water stress is minimized, increasing the incentive for using supplemental water sources Interestingly, we find that farmers are less likely to use hybrid tomato seeds on wetlands. This might be because wetlands already provide naturally high soil moisture, reducing the yield advantage that hybrids typically offer under controlled water conditions. In addition, since hybrid seeds require higher management precision and greater upfront cost, farmers may prefer to reserve them for better-drained, more controllable environments where their higher yield potential can be reliably realized.

Fifth, we find that supplemental water from dam/streams is more common on larger plots consistent with scale justifying the investments in large irrigation equipment. We also find that farmers whose primary market outlet is a wholesaler are less likely to rely on wetlands than those selling mainly to rural aggregators, all else equal. This pattern may reflect differences in land-use strategies if for example, smaller farmers supplying rural aggregators often cultivate more diversified plots, including wetlands, whereas farmers targeting larger wholesalers tend to operate on better-drained upland soils that support higher volumes and more consistent production. Somewhat unexpectedly, farmers who accessed bank credit are less likely to invest in supplemental water sources such as dams or streams. This may reflect the fact that credit-constrained farmers who secure formal loans often must prioritize expenditures with more immediate return or requirements such as inputs, labor, or debt servicing, leaving less resources available for longer-term irrigation investments. Overall, these results highlight the dynamic interplay between demographic, institutional, market and environmental factors influencing water source selection among tomato farmers in the study sample.

Table 7 presents the results of the multinomial regression analysis, which identifies the key explanatory variables influencing the choice of tomato varieties. Five main findings emerge. First, being a male farmer is associated with a higher probability of adopting hybrid tomato varieties compared to being a female farmer. This result reveals the need for attention to gendered access to technologies and is consistent with findings from Yahaya *et al.* (2022) and Adeoye *et al.* (2020), which showed that male farmers often have greater access to land, inputs, and extension services.

Second, similar to the findings related to water use, where statistically significant, farmers with formal education above secondary are more likely to use hybrid varieties, suggesting that higher educational attainment contributes to greater adoption of modern seed technologies. This aligns with studies emphasizing that farmer education positively influences technology uptake and productivity (Adeniyi and Akinbile, 2019).

Table 6. Drivers of adoption of different water use practices.

	Wetland	Pump/well	Dam/stream
Variables	**[Base outcome - Rainfall]**		
Gender of plot manager (Male = 1)	−0.707	1.166	13.952***
	−0.546	−0.865	−0.64
Household size (Number)	−0.139	0.022	−0.127
	−0.096	−0.042	−0.087
Plot manager's age (Number)	0.002	−0.007	0.034
	−0.02	−0.012	−0.024
Plot manager is primary education (base no formal education)	0.288	0.458	14.905***
	−0.612	−0.507	−0.598
Plot manager is secondary education (base no formal educ.)	0.247	0.331	15.500***
	−0.585	−0.531	−0.668
Plot manager is above secondary (base no formal education)	1.671**	0.746	14.439***
	−0.735	−0.632	−1.055
Plot manager has non-farm income (base no income)	−0.14	−0.044	0.942
	−0.404	−0.259	−0.61
Experience (years of farming)	−0.008	0.002	0.032
	−0.024	−0.019	−0.023
Area of Plot (in hectares)	0.002	−0.096	0.129*
	−0.088	−0.078	−0.071
Distance from farm to market (km)	0.001	0.001	0
	−0.002	−0.001	−0.001
Main market channel is wholesalers (base rural aggregator)	−1.252**	−0.212	−0.915
	−0.494	−0.261	−0.593
Main market channel is retailers and others (base rural aggregator)	−0.432	0.21	0.052
	−0.594	−0.343	−0.827
Plot manager received credit from bank	0.207	−0.57	−14.750***
	−1.037	−0.828	−0.84
Plot manager is a member of a ROSCA	0.498	−0.022	0.354
	−0.468	−0.313	−0.693
Wet season farming (base dry season only)	−2.733***	−2.326***	−2.325***
	−0.509	−0.33	−0.565
Kaduna (base Oyo State)	−0.932	0.668	0.634
	−0.613	−0.471	−1.079
Improved variety (base local variety)	0.163	−0.387	0.656*
	−0.409	−0.341	−0.378
Hybrid variety (base local variety)	−14.676***	0.505	1.435**
	−0.438	−0.472	−0.671
Constant	0.62	−1.991*	−33.593***
	−1.463	−1.103	−1.878

Table 6. *Continued*

	Wetland	Pump/well	Dam/stream
Variables	**[Base outcome - Rainfall]**		
Observations	800		
LR ^2	−284.9		
Prob < ^2	0		
Pseudo R-squared	0.235		

Source: Author calculations. Robust standard errors in parentheses,
***p < 0.01,
**p < 0.05,
*p < 0.1

Third, being a member of a ROSCA is positively associated with the adoption of hybrid varieties while receipt of formal credit is negatively associated with the adoption of both improved and hybrid varieties. This might reflect the substitutive role of social network effects in ROSCA's on farmers' awareness of information and support for adoption of modern technologies (such as collective input purchasing and knowledge sharing) compared to formal credit sources that might be used for other household activities or debt servicing that households turn to in distress. Together, these factors lower financial and informational barriers, making the adoption of modern tomato varieties more feasible and attractive (Martey *et al*., 2020).

Fourth, we find that market access matters for the adoption of improved varieties. Surprisingly, farmers' distance to the nearest market was positive and significantly associated with the adoption of both improved and hybrid varieties, likely reflecting that farmers adopting these modern varieties might be located in more remote locations.

Fifth and consistent with our descriptive results, we find that farmers in Kaduna State are much more likely to adopt both improved varieties and hybrid varieties compared to their counterparts in Oyo State. This demonstrates that farmers in Kaduna are more likely to adopt innovations associated with tomato. This likely reflects Kaduna's prominence in Nigeria's tomato production and dependence on the crop. Kaduna is among the top northern states that supply majority of tomato markets nationwide (NAERLS, 2022) and is thus more vulnerable to the consequences of exposure to drought and heat. Farmers in Kaduna are more likely to adopt these non-traditional varieties that are stress-tolerant, and can be transported over long distances without compromising quality (Onwuegbunam *et al.,* 2021; Ahmed *et al.,* 2020). Together, these results confirm the importance of farmer and local context conditions in explaining farmers' decisions about which varieties of tomatoes to use.

Conclusion and policy implications

This study reveals marked regional variation in water-use practices and varietal choices among tomato farmers in two major producing states in Nigeria, shaped by differing ecological conditions and production systems. While rainfall remains the primary water source in both regions, Kaduna farmers exhibit greater reliance on supplementary sources, particularly pumping water from wells compared with farmers in Oyo, where rain-fed production dominates. Similarly, varietal adoption patterns differ significantly across states with improved and hybrid tomato varieties much more common in Kaduna, whereas local varieties are overwhelmingly used in Oyo. We also find that the adoption of improved varieties is much higher than the adoption of hybrid varieties in both states, largely due to a combination of accessibility, cost, and risk. Improved varieties (often open-pollinated or breeder-stabilized lines) are widely available through local seed systems and research–extension channels, making them more affordable and easier for smallholders to access. Because these varieties can be recycled, they also reduce recurring input costs and financial risk.

In contrast, hybrids are more expensive, require annual purchase of F1 seed, and often demand higher levels of input management (fertilizer, irrigation, pest control) to achieve their yield potential. These requirements may exceed the resources of smallholder farmers, particularly in Kaduna. Farmers may also view hybrids as riskier, since mismanagement or environmental stress can lead to sharper yield losses and seeds cannot be reused. These are important considerations when promoting these modern technologies.

A multivariate regression analysis further highlights the demographic, educational, financial, and market-related factors driving these decisions. Water-use choices are strongly influenced by production season, education level, credit access, location, use of non-local seed varieties and gender. Varietal adoption is shaped by gender, educational attainment, membership in informal financial groups, access to formal credit, and geographic location. Across both technologies, Kaduna farmers consistently demonstrate greater adoption of alternative water-use strategies and modern seed types than their counterparts in Oyo. However, the regression findings indicate that once plot manager, and market, and agronomic

Table 7. Drivers of adoption of improved and hybrid tomato varieties (marginal effects).

	Improved variety	Hybrid variety
Variables	**[Base outcome – Local variety]**	
Gender of plot manager (Male = 1)	0.344	13.990***
	−0.344	−0.339
Household size (Number)	0.034	0.075
	−0.033	−0.052
Plot manager's age (Number)	−0.004	−0.029
	−0.008	−0.021
Plot manager is primary education (base no formal education)	0.660**	0.154
	−0.337	−0.743
Plot manager is secondary education (base no formal educ.)	0.483	0.423
	−0.35	−0.753
Plot manager is above secondary (base no formal education)	0.766	1.734**
	−0.49	−0.821
Plot manager has non-farm income (base no income)	0.154	−0.305
	−0.199	−0.355
Experience (years of farming)	0.007	0.003
	−0.011	−0.027
Area of Plot (in hectares)	0.009	0.057
	−0.046	−0.045
No of production cycles	0.15	−0.041
	−0.159	−0.372
Distance from farm to market (km)	0.002*	0.004***
	−0.001	−0.001
Main market channel is wholesalers (base rural aggregator)	0.09	0.582
	−0.196	−0.355
Main market channel is retailers and others (base rural aggregator)	−0.284	−0.004
	−0.243	−0.473
Plot manager received credit from bank	−1.183**	−2.267**
	−0.478	−1.048
Plot manager is a member of a ROSCA	−0.245	0.752**
	−0.23	−0.37
Wet season farming (base dry season only)	−0.213	0.373
	−0.234	−0.41
Kaduna	2.365***	2.880***
	−0.31	−0.56
Constant	−2.684***	−18.249***
	−0.685	−1.517
Observations	800	
LR ^2	4094	
Prob < ^{2}	0	
Pseudo R-squared	0.242	

Source; Author calculations. Robust standard errors in parentheses,
***p < 0.01,
**p < 0.05,
*p < 0.1

factors are taken into consideration, state does not matter for water use practices. However, for varietal decisions state location matters and being in Kaduna is positive and statistically significantly correlated with using both hybrid and improved varieties (at 1%), and the effect is large in magnitude, all else equal. Together, these findings reveal a tomato production landscape characterized by substantial heterogeneity, shaped by farmers' characteristics, resource access, and market engagements, as well as regional ecological pressures.

The study's findings underscore the importance of addressing gender, education, market access, and geographic disparities in promoting the adoption of improved tomato varieties and irrigation technologies. Male farmers' greater use of improved and hybrid varieties, alongside their higher likelihood of adopting dam and stream water, highlights persistent gender gaps in access to agricultural technologies. Expanding women farmers' access to improved seed varieties, irrigation equipment, and tailored extension services is therefore essential to ensure equitable participation in high-value horticultural production. The strong positive influence of higher education on the uptake of improved varieties further emphasizes the need for investments in farmer education and adult-learning programs that enhance the capacity to access, interpret, and apply agronomic and climate-related information. The significant difference in the rates of adoption of improved and hybrid varieties across Kaduna and Oyo indicates that a one-size-fits-all approach to promoting varietal improvement is unlikely to be effective. Policies aimed at increasing the uptake of improved varieties should therefore be tailored to the specific constraints and incentives faced by different farmer groups. Further research is needed to understand the reasons for low varietal adoption in Oyo, including the extent to which ecological conditions, local market dynamics, and state-level institutional environments shape farmers' choices.

Heterogeneous water-use patterns across states also point to the need for state-specific but coordinated irrigation policies and programs. In Kaduna, where irrigation reliance is already more prevalent due to widespread dry-season tomato cultivation, policy actions should prioritize expanding the use of these services while simultaneously promoting efficient irrigation technologies. Groundwater monitoring, and training on irrigation scheduling to prevent over-extraction and water loss as well as extension programs promoting drip irrigation, mulching, and other water-saving practices can support improved water-use efficiency under growing climate variability. In Oyo, where production is primarily rain-fed with limited supplemental irrigation, efforts should focus on rainwater harvesting, soil moisture conservation, and drainage improvements to buffer farmers against rainfall variability. Additional research on the reason for the low adoption of modern irrigation practices is also necessary. Across both states, harmonized policies that expand access to affordable small-scale irrigation equipment, improved climate information services, and tomato varieties with higher water-use efficiency will help enhance productivity while protecting scarce water resources.

Taken together, these policy directions underscore the need for integrated strategies that combine gender inclusion, human capital development, and stronger input and output market integration. Equally important are efforts to improve varietal availability and affordability alongside targeted irrigation investments, essential for building a more productive and resilient tomato production system in Nigeria.

Ethical consideration

This study (MSU Study ID: STUDY00007403) received ethical approval from the Institutional Review Board of Michigan State University, and all interviews were conducted in accordance with the local legislation and institutional requirements.

Informed consent was obtained verbally from all participants after explaining and prior to survey administration. Verbal consent was chosen because many farmers had limited literacy and time constraints within the environment, making written consent impractical; however, participation was entirely voluntary.

Disclosure

The authors have used AI software from Grammarly and Co-pilot for assistance with grammar and applied to the authors' original writing.

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