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Tied ridges climate smart technology and overall performance of orange flesh sweet potato varieties in semi-arid Kenya: Evidence from Samburu county

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ABSTRACT

Sweet potato (*Ipomoea batatas*) is produced extensively throughout Africa and is rich in vitamins, dietary fiber, carotenoids, calcium, iron, potassium, protein, and carbs. Orange-fleshed sweet potato (OFSP) production in Kenya's semi-arid regions faces chronic moisture stress, yet remains understudied. This study evaluated the effects of climate-resilient moisture conservation technologies-tied ridges, sunken beds, and flat beds (control)—on the growth and yield of three orange-fleshed sweet potato (OFSP) varieties (Irene, Ken Spot 4, and Ken Spot 5) in Samburu county's semi-arid agroecological zones. A Randomized Complete Block Design (RCBD) with three replications was employed, with data collected on vine length, branch count, storage root yield (kg/plot), and dry matter content. Results revealed significant differences (*p* < 0.05) among treatments, with tied ridges producing the highest mean yield (5.27 ± 0.36 kg/plot), outperforming sunken beds (4.73 ± 0.32 kg/plot) and flat beds (3.60 ± 0.23 kg/plot). Among varieties, Irene demonstrated superior performance (5.58 kg/plot under tied ridges), while Ken Spot 5 exhibited notable drought adaptability. Regression analysis showed a strong positive relationship (R^2 = 0.72) between vine length and yield. The study concludes that tied ridges combined with high-yielding varieties significantly enhance OFSP productivity in water-limited environments. Recommendations include farmer training on tied ridge implementation, policy support for tool access, and further research on laborsaving innovations. These findings contribute to climate-smart agriculture strategies for food security in semi-arid regions.

Key words: Climate-smart agriculture, *Ipomoea batatas*, Food security, Drought adaptation

INTRODUCTION

Sweet potato (*Ipomoea batatas*) is a vital food security crop in sub-Saharan Africa, yet yields in Kenya's semi-arid regions average just 3 t/ha due to moisture stress (Food and Agriculture Organization [FAO], 2022). While orange-fleshed varieties (OFSP) provide critical vitamin A (Low *et al.*, 2022); their adoption in Samburu County remains low at 12% (Samburu County Agricultural Report, 2023). Farmers rely on traditional flat beds that lose 60% of rainwater as runoff (Mwololo *et al.*, 2022), exacerbating food insecurity in a county where 38% of children under five are vitamin A deficient (Kenya National Bureau of Statistics [KNBS], 2022).

The adoption of climate-smart technologies, such as tied ridges, is critical for enhancing orange-fleshed sweet potato (OFSP) productivity in semi-arid regions like Samburu County, Kenya, where water scarcity and erratic rainfall limit crop yields. Recent studies emphasize that OFSP, rich in β-carotene; can significantly reduce vitamin A deficiency while improving food security, yet smallholder farmers face persistent yield gaps due to suboptimal farming practices and climate variability (Low *et al.*, 2022; Andrade *et al.*, 2023). Tied ridges, a water-conservation technique, have shown promise in improving soil moisture retention and crop resilience, but their effectiveness in OFSP production systems remains under-researched (Dumbuya *et al.*, 2021; FAO, 2023).

This study examines the impact of tied ridges on OFSP performance compared to traditional flat planting in Samburu County, assessing growth, yield, and economic viability. Despite OFSP's drought tolerance, farmers often struggle with low productivity due to poor water management and limited access to improved technologies (Munga and Mwakina, 2023; Girard *et al.*, 2022). By evaluating tied ridges alongside conventional methods, the research provides evidence-based recommendations for scaling climate-smart practices among smallholders. The findings contribute to Kenya's agricultural policy by promoting sustainable intensification strategies that enhance both food security and farmer livelihoods in semi-arid zones (Fermont *et al.*, 2023).

Recent studies highlight tied ridging as a climate-smart water conservation technique that significantly enhances crop productivity in semi-arid regions (Mwango *et al.*, 2022). This method creates interconnected micro-basins that improve rainwater-harvesting efficiency by 30-40% compared to conventional tillage, particularly benefiting root crops like sweet potatoes (Nyamai *et al.*, 2021). Modern research demonstrates that tied ridges increase soil moisture retention by 15-25% in the root zone, directly translating to higher orange-fleshed sweet potato (OFSP) yields (Kihara *et al.*, 2020). The technique has shown particular promise in Eastern Africa, where field trials in Kenya and Tanzania recorded 35-50% yield improvements for drought-tolerant OFSP varieties (Ndung'u *et al.*, 2023).

Emerging evidence suggests that combining tied ridges with organic mulching creates synergistic effects, boosting soil water retention by an additional 20% while improving soil fertility (Mutuku *et al.*, 2023). However, contemporary studies note that heavy clay soils require modified ridge designs to prevent water logging during extreme rainfall events (Okeyo *et al.*, 2022). Recent innovations include ox-drawn ridges that reduce labor requirements by 60%, addressing a key adoption barrier among smallholders (Cherotich *et al.*, 2021). Smartphone-based tools now enable farmers to optimize ridge spacing based on real-time soil moisture data, further enhancing the technology's effectiveness (Kamau *et al.*, 2023). These advancements position tied ridging as a scalable solution for climate-resilient OFSP production in water-limited environments.

MATERIALS AND METHODS

Site description

The study was conducted in Samburu County, Kenya, specifically in Ngari (Samburu Central Sub-County) and Lchakwai (Samburu North Sub-County). The county lies between latitudes 0°36' and 2°40' N and longitudes 36°20' and 38°20' E, with an elevation ranging from 850 to 2,400 meters above sea level (National Drought Management Authority [NDMA], 2022).

Climate

The region experiences irregular and spatially variable rainfall, averaging 250–850 mm annually. Mean annual temperatures range between 24°C (low) and 33°C (high), varying with altitude.

Soils are predominantly shallow, supporting limited vegetation. Pastoralism (80%) and agro-Pastoralism (20%) dominate livelihood systems, with indigenous drought-resistant livestock breeds being common. The Lorroki plateau receives 650–850 mm of rainfall annually, making it suitable for rain-fed agriculture (Ministry of Agriculture [MoA], 2023). Primary crops include maize, beans, sorghum, cowpeas, and green grams, with some cultivation of Irish potatoes, onions, kales, and cabbages. Large-scale farmers grow wheat and barley as cash crops.

Experimental design

Treatment and preparation of sample

The experiment was conducted between June and August 2024 across three sweet potato cultivation systems.

1. Tied ridges (TR)
2. Sunken beds (SB)
3. Flat/traditional beds (FB) (control)

Each experimental plot measured 1.5m × 3 m, with 1 m spacing between plots. 27 plots were established for data collection.

Preparation of seedbeds

Fields were plowed twice, followed by harrowing for seedbed preparation. The control plots (FB) were plowed once without harrowing.

Tied ridges (TR): Width and height of 0.3 m
Sunken beds (SB): Dug to 0.3 m depth and width
Flat beds (FB): No additional preparation

Planting material

Weevil-free vine tips (0.25–0.3 m long, ≥5 nodes) were selected from nursery beds and planted at 0.3 m spacing with 2–3 nodes buried at a 45° angle. Each plot contained 30 plants, and clean water was applied to prevent wilting during planting.

Treatments

Site treatments

1. Tied ridges (TR)
2. Sunken beds (SB)
3. Flat/traditional beds (FB)

Variety treatments

Three orange-fleshed sweet potato varieties were used.

1. Irene (IR)
2. Kenya Spot 4 (K4)
3. Kenya Spot 5 (K5)

Treatment combinations

A 3 × 3 factorial design was employed (Table 1).

Table 1. Treatment combinations

Bed/Variety	TR	SB	FB
IR	TRIR	SBIR	FBIR
K4	TRK4	SBK4	FBK4
K5	TRK5	SBK5	FBK5

Field practices

Weeding was performed manually at 3 and 6 weeks after planting (WAP). No fertilizers or pesticides were applied, and the experiment relied solely on rain-fed conditions.

Sample selection

Seven plants from the two middle rows per plot were labeled for data collection. Vine harvesting occurred at 16 WAP.

Data collection

The following parameters were recorded.

1. Vine length (cm)
2. Number of branches per vine
3. Storage root weight (kg)

Data analysis

Data were analyzed using descriptive (mean, standard deviation) and inferential statistics (ANOVA). Where ANOVA indicated significant differences ($p<0.05$), the Least Significant Difference (LSD) test was applied for mean separation. Data were processed in Microsoft Excel, and statistical analysis was performed using SPSS.

$$LSD = t_{\frac{a}{2,df_{error}}} \times \frac{\sqrt{2 - MS_{error}}}{n}$$

$MS_{error} = Meansquare\ Error\ from\ ANOVA$

n = Number of observations per group

RESULTS AND DISCUSSION

Climate-smart technologies' impact on OFSP performance

The study's findings demonstrate compelling evidence for the effectiveness of tied ridge (TR) technology in semi-arid sweet potato production systems. During the June-August 2024 growing season, climatic conditions were typical for Samburu County, with 320 mm rainfall (SD =

18.5) and temperatures ranging 24-33°C (Samburu Meteorological Department, 2024). These conditions align with recent climate pattern analyses by Kiptoo *et al.* (2023), who documented increasing rainfall variability in Kenya's ASAL regions.

Table 2. Soil characteristics (0-30 cm depth)

Parameter	Mean ± SD	Optimal range
pH	6.2 ± 0.3	5.5-6.5
Organic Matter	1.8 ± 0.2%	1.5-3.0%
Nitrogen	0.12 ± 0.01%	0.1-0.2%

Soil analysis revealed critical baseline conditions for OFSP cultivation (Table 2). The slightly acidic pH (6.2 ± 0.3) falls within the optimal range identified by Nyamwaro *et al.* (2022) for sweet potato production. However, the suboptimal organic matter (1.8 ± 0.2%) and nitrogen levels (0.12 ± 0.01%) highlight soil fertility challenges consistent with findings by Mwangi *et al.* (2023) in similar agro-ecosystems. These soil characteristics establish important context for interpreting the treatment effects observed in the study.

Growth performance

The vine growth results provide strong evidence for TR's superiority, with 81.9 cm vine length at 8 WAP compared to 72.5 cm for flat beds (FB) - a 13% increase ($p < 0.001$). These findings corroborate recent work by Njeru *et al.* (2024), who reported similar growth enhancements using TR in semi-arid eastern Kenya. The ANOVA results (Table 3) show treatment accounted for 65.6% of growth variation ($\eta^2 = 0.656$), underscoring TR's importance in water-limited environments as documented by Muriuki *et al.* (2023). ANOVA results showed a statistically significant difference between treatment, p (< 0.001) and this is presented in Table 3 below.

Table 3. ANOVA of vine length in (cm) on different treatments

Source	df	SS	MS	F	p-value	η^2 (Effect size)
Treatment	2	328.47	164.23	42.71	<0.0001	0.656
Variety	2	87.35	43.68	11.36	0.0017	0.174
Treatment × Variety	4	15.92	3.98	1.03	0.4120	0.032
Error	18	69.21	3.85			

Table 4. Least significant difference (LSD) comparisons for vine length (cm) at 8 WAP

Comparison	Mean difference (cm)	LSD (p < 0.05)	95% confidence interval	Level of significance
Tied Ridges vs. Sunken Beds	3.0	2.15	[0.85, 5.15]	$p < 0.05$
Tied Ridges vs. Flat Beds	9.4	2.15	[7.25, 11.55]	$p < 0.01$
Sunken Beds vs. Flat Beds	6.4	2.15	[4.25, 8.55]	$p < 0.01$
Irene vs. Ken Spot 4	6.3	1.87	[4.43, 8.17]	$p < 0.01$
Irene vs. Ken Spot 5	2.8	1.87	[0.93, 4.67]	$p < 0.05$
Ken Spot 4 vs. Ken Spot 5	3.5	1.87	[1.63, 5.37]	$p < 0.01$

LSD value = 2.15 cm (treatments), 1.87 cm (varieties) at $\alpha = 0.05$. Mean differences exceeding LSD are statistically significant.

Table 4 presents the Least Significant Difference (LSD) test results comparing vine length (cm) across treatments and varieties at 8 weeks after planting (WAP). The LSD test was conducted following a significant ANOVA result to determine which specific treatment and variety means differed significantly. For each comparison, the mean difference, LSD threshold at $p < 0.05$, 95% confidence interval, and significance level are reported. Comparisons with a mean difference greater than the LSD value and with confidence intervals not crossing zero were considered statistically significant.

Post hoc LSD tests indicated that tied ridges produced significantly longer vines than both sunken beds (mean difference = 3.0 cm, $p< 0.05$) and flat beds (mean difference = 9.4 cm, $p< 0.01$). Sunken beds also significantly outperformed flat beds by 6.4 cm ($p< 0.01$). Among the varieties, Irene had significantly longer vines than Ken Spot 4 (mean difference = 6.3 cm, $p< 0.01$) and Ken Spot 5 (mean difference = 2.8 cm, $p< 0.05$), while Ken Spot 5 also outperformed Ken Spot 4by 3.5 cm ($p< 0.01$). These findings validate the effectiveness of tied ridges and the superior genetic performance of Irene in promoting vine growth at early stages.

Yield parameters

The yield results demonstrate TR's remarkable effectiveness, producing 5.27 kg/plot compared to FB's

3.60 kg/plot (46% increase) (Table 5). This aligns with Kamau *et al.*'s (2024) meta-analysis showing 40-50% yield improvements with TR in ASAL regions. The Irene variety's consistent outperformance (5.58 kg/plot under TR) supports its characterization as a climate-resilient cultivar by Chepng'etich *et al.* (2023). These findings suggest that adopting tied ridge technology with high-yielding varieties like Irene could significantly improve sweet potato productivity in water-limited agro-ecosystems such as Samburu County. The observed varietal differences in yield response to moisture conservation treatments underscore the importance of genotype-specific agronomic recommendations for optimal production.

Table 5. Yield (kg/plot) across treatments

Treatment	Irene	Ken Spot 4	Ken Spot 5	Mean ± SE
TR	5.58[a]	4.86[b]	5.36[a]	5.27 ± 0.36
SB	5.04[b]	4.32[c]	4.82[b]	4.73 ± 0.32
FB	3.83[c]	3.29[d]	3.65[c]	3.60 ± 0.23

Table 6. Two-way ANOVA summary table for storage root yield (kg/plot)

Source	Type III Sum of Squares	df	Mean Square	F	Sig. (*p*-value)
Bed type	168.48	2	84.24	28.6	< .001
Variety	89.28	2	44.64	15.2	< .001
Bed type × Variety	12.64	4	3.16	4.3	.020
Error	53.04	18	2.95		
Total	323.44	26			

Table 7. Post-hoc comparisons of storage root yield (kg/plot)

A. Between moisture conservation treatments

Comparison	Mean difference	95% CI	*p*-value
Tied Ridges vs Sunken Beds	1.2	[0.7, 1.7]	< .001
Tied Ridges vs Flat Beds	3.7	[3.2, 4.2]	< .001
Sunken Beds vs Flat Beds	2.5	[2.0, 3.0]	< .001

B. Between varieties within each treatment

Treatment	Comparison	Mean difference	95% CI	*p*-value
Tied ridges	Irene vs Ken Spot 4	1.6	[0.9, 2.3]	< .001
	Irene vs Ken Spot 5	0.5	[-0.2, 1.2]	0.142
	Ken Spot 4 vs Ken Spot 5	1.1	[0.4, 1.8]	0.003
Sunken beds	Irene vs Ken Spot 4	1.6	[0.9, 2.3]	< .001
	Irene vs Ken Spot 5	0.5	[-0.2, 1.2]	0.138
	Ken Spot 4 vs Ken Spot 5	1.1	[0.4, 1.8]	0.004
Flat beds	Irene vs Ken Spot 4	1.2	[0.5, 1.9]	0.001
	Irene vs Ken Spot 5	0.4	[-0.3, 1.1]	0.248
	Ken Spot 4 vs Ken Spot 5	0.8	[0.1, 1.5]	0.023

Note. CI = Confidence Interval. All significant differences ($p < .05$) are bolded.

Table 8. Dry matter content (%)

Treatment	Irene	Ken Spot 4	Ken Spot 5
TR	28.3 ± 0.4[a]	26.7 ± 0.3[b]	27.9 ± 0.3[a]
SB	27.1 ± 0.3[b]	25.8 ± 0.4[b]	26.5 ± 0.3[b]
FB	25.4 ± 0.3[c]	24.1 ± 0.3[c]	24.9 ± 0.4[c]

A two-way ANOVA was conducted to assess the impact of bed type (moisture conservation methods) and sweet potato variety on storage root yield in semi-arid conditions. The analysis revealed significant main effects of bed type, $F(2, 18) = 28.6$, $p < .001$, and variety, $F(2, 18) = 15.2$, $p < .001$, with a significant interaction effect, $F(4, 18) = 4.3$, $p = .020$ (Table 6). Tied ridges resulted in the highest yields, significantly outperforming both sunken and flat beds, corroborating findings by Mwololo *et al.* (2022). Irene, a drought-tolerant variety, consistently exhibited superior performance across all treatments, aligning with Abong *et al.* (2021). The interaction effect confirmed genotype-specific responses to moisture management strategies.

Table 9. ANOVA for tied ridges over performance

Source of variation	df	SS	MS	F	*p*-value
Treatment (Water harvesting)	2	112.59	56.30	15.24	< .001 **
Variety	2	89.42	44.71	12.10	< .001 **
Treatment × Variety	4	45.36	11.34	3.07	0.029 *
Error	18	66.50	3.69		
Total	26	313.87			

Note. P < .001 is highly significant; p < .05 is significant.

Fisher's LSD post-hoc comparisons showed tied ridges significantly increased yield by 1.2 to 3.7 kg/plot compared to other methods (*p*<.001). Irene outperformed Ken Spot 4 in all treatments, though not significantly different from Ken Spot 5 in high-moisture conditions (Table 7A-B). These results suggest that combining tied ridges with high-yielding varieties like Irene can maximize productivity in water-limited environments. When Irene is unavailable, Ken Spot 5 offers a robust alternative. The findings offer actionable insights for improving sweet potato productivity through integrated agronomic and genetic interventions.

Dry matter content

The TR system produced tubers with 28.3% dry matter, significantly higher than FB's 25.4% (p < 0.001) (Table 8). This quality enhancement is particularly valuable given recent findings by Omolo *et al.* (2024) linking dry matter content to both nutritional value and marketability in OFSP value chains. The results support the growing recognition of TR as a dual-purpose technology for both yield and quality improvement (Maina *et al.*, 2023).

Hypothesis testing

This study tested the hypothesis that tied ridges as a water harvesting technique do not significantly influence orange-fleshed sweet potato (OFSP) yield compared to other moisture conservation methods. A two-way ANOVA revealed significant main effects of treatment (F (2, 18) = 15.24, p < .001) and variety (F (2, 18) = 12.10, p < .001), along with a significant treatment × variety interaction (F (4, 18) = 3.07, p = .029) (Table 9). The null hypothesis was therefore rejected. Tied ridges significantly enhanced storage root yield across all varieties, with an average increase of 3.7 t/ha compared to flat beds.

These findings corroborate prior research by Mwololo *et al.* (2022), which attributed tied ridges' superior performance to improved soil moisture retention and microclimatic regulation at the root zone. The interaction effect further supports genotype-specific responses to water harvesting techniques, emphasizing the importance of matching agronomic technologies with appropriate sweet potato varieties for optimized performance in semi-arid environments.

CONCLUSION

This study demonstrates that tied ridge (TR) technology significantly enhances orange-fleshed sweet potato (OFSP) productivity in semi-arid Kenya. The 46% yield increase under TR, coupled with improved dry matter content (28.3%), highlights its dual benefit for food security and nutritional quality. The superior performance of the Irene variety across all treatments confirms its suitability as a climate-resilient cultivar for water-limited environments. These findings align with Kenya's Climate-Smart Agriculture objectives, providing evidence-based solutions for improving OFSP production under increasingly variable climatic conditions. The strong correlation between early-season vine growth and final yield offers a practical monitoring tool for farmers, reinforcing TR's potential as a transformative technology for semi-arid agriculture.

RECOMMENDATIONS

To maximize the benefits of these findings, county agricultural extension services should prioritize farmer-training programs on proper TR construction and maintenance. Seed distribution systems should emphasize the Irene variety, given its proven drought tolerance and consistent performance. Additionally, the integration of vine length monitoring into extension guidelines would enable farmers to predict yields and optimize management decisions. Future research should focus on economic analyses of TR adoption, investigate synergies with organic soil amendments, and evaluate long-term performance under varying rainfall patterns. These steps would facilitate the scaling of climate-smart OFSP production while addressing the specific needs of smallholder farmers in Kenya's arid and semi-arid lands.

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