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Integrating Agrinutrition Models in Dryland Farming and Livelihood Systems: Enhancing Pastoralists' Households' Food, Income, and Nutritional Security in Turkana, Kenya

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Abstract: Food insecurity and malnutrition in dryland areas are health threats to people of all ages. Scarcity of food is predisposing individuals, households, and communities to many dangers, and the coping mechanisms employed, such as skipping meals and same diets, exacerbate starvation, malnutrition, and stunting that are already affecting human wellbeing. Integrating agrinutrition models to production and livelihood systems is a paradigm shift for building consciousness that considers the importance of understanding dietary needs, home economics, and healthy living for the populations affected. The study objectives were (i) assess the agriculture, food security and nutrition context of Turkana; (ii) identify opportunities for improving Turkana County's agri-food system; (iii) investigate agri-nutrition gaps and integration challenges to local production systems; and (iv) define pathways from agriculture to agri-nutrition in dryland areas. The study areas selected were (a) Lokichoggio for rainfed crop production and cross-border trade with South Sudan; (b) Kakuma for refugee food security and agricultural nutrition interventions; (c) Lodwar for the county government headquarters food security and nutrition focal points; (d) Turkana South for food production in potential irrigation schemes; and (e) Turkana East for the role of livestock in food security and nutrition. A total of 148 participants were involved in this study, i.e., 80% at the primary (farm) level, 15% at the secondary (county and policy) level, and 5% at the tertiary (scholars and experts) level. Both quantitative and qualitative data were analysed, triangulated and subsequently validated by stakeholders through a series of consultative meetings. The study results show that the food and nutrition security challenges in Turkana arise from structural inefficiencies rather than low productivity. These inefficiencies impact food availability, pricing, and safety for low-income households. Solutions require market-driven changes focusing on aggregation systems, maintaining first-mile value, and aligning production with market demands. To enhance climate resilience, investments in infrastructure and diverse systems are crucial, and reforming the food system can boost production and income while ensuring equitable value distribution. A coordinated investment strategy addressing malnutrition and integrating agriculture with nutrition and public health is essential, with nutrition education and entrepreneurial training improving home nutrition and food safety. A shift from fragmented initiatives to cohesive, market-orientated strategies is needed to realise the agricultural potential and improve food and nutrition security within dryland farming and livelihood systems.

Keywords: *Food security, Agri-food system, Nutritional security, Agriculture policy, Health standards, and Market access, and Turkana County.*

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INTRODUCTION

Multiple sources, including the Food and Agriculture Organization (FAO), characterise Nutrition-Sensitive Agriculture (NSA) as a food-centric strategy for agricultural development that prioritises nutritionally dense foods, dietary diversity, and food fortification to combat malnutrition and micronutrient deficiencies. This approach emphasises the numerous advantages of consuming a diverse array of foods, acknowledging the nutritional importance of food for optimal health, and the social relevance of the food and agriculture sector in sustaining rural lives. The primary aim of nutrition-sensitive agriculture is to enhance the global food system's capacity to yield favourable nutritional results.

The Sustainable Development Goal (SDG 2) Zero Hunger aims to eliminate stunting and wasting in children under five years of age, address the nutritional requirements of adolescent girls, pregnant and lactating mothers, and older individuals, and eradicate all kinds of malnutrition. The initiative sought to double agricultural productivity and the incomes of small-scale food producers, particularly women, indigenous peoples, family farmers, pastoralists, and fishers, ensuring secure and equitable access to land, productive resources, inputs, knowledge, financial services, markets, and opportunities for value addition and non-farm employment. SDG 2 also aims to ensure sustainable food

production systems and implement resilient agricultural practices by 2030, which enhance production and productivity, preserve ecosystems, bolster adaptation capacity to climate change, extreme weather, drought, flooding, and other disasters, and progressively enhance land and soil quality.

The worldwide frameworks targeting hunger and poverty include Sustainable Development Goals 1 and 2, which seek to eradicate poverty and hunger while promoting sustainable agriculture by 2030, and the African Union Agenda 2063, which focuses on modernising agriculture to improve productivity and assure food security. The principal national frameworks comprise Kenya's Constitution of 2010, which ensures the right to sufficient food, and Vision 2030, which aims to establish a modern agricultural sector for food security. The National Food and Nutrition Security Policy 2012 emphasises the rights-based aspects of food security, the Agricultural Sector Transformation and Growth Strategy (ASTGS) 2019 aims to improve food resilience in at-risk communities, particularly among smallholder farmers, and the Kenya Nutrition Action Plan (KNAP) 2018 highlights the significance of nutrition within the food system. The Agri-Nutrition Implementation Strategy (ANIS) 2020-2025 aimed to address malnutrition through coordinated efforts; however, agricultural and nutritional components are largely absent from the County Integrated Development Plans (CIDP) of a good number counties in Kenya, highlighting the need for integrated agriculture to enhance food security. The East African Community (EAC) protocol facilitates cross-border trade and the pooling of natural resources and incentives to enhance food security and income levels.

Pastoralist regions in Kenya encounter significant challenges due to recurrent droughts and famine, resulting in elevated levels of hunger and malnutrition. Climate change impacts agricultural output, while inadequate infrastructure and insecurity from cattle rustling intensify the challenges to food security and livelihoods. Notwithstanding initiatives to address hunger, local food production continues to be inadequate, leading to increasing rates of stunting and underweight among children and women of reproductive age. Combating hunger necessitates a comprehensive strategy, encompassing agricultural investments that empower women and youth and enhance food systems.

Literature Review

Agriculture, food security, and nutrition

The study conducted by Anno (2025) on strategic outcomes to food security challenges in the drylands, with a focus on the transformation of agriculture from a subsistence economy to market-oriented systems, identifies the primary factors that impede the transition of dryland agriculture. The study concludes that inadequate research, a lack of centralised meteorological systems, inefficient market development, and weak supply-demand relationships are the primary obstacles. These results are consistent with those of van Dorp, Oenema, and Verdonk (2011), who identified food and nutrition security strategies for food-insecure areas to include educating local farmers on the limitations of subsistence farming, promoting research frameworks, and enhancing stakeholder engagement with early warning systems (EWS), as well as improving agroecologies through innovative practices and strengthening market access.

Kadiyala et al. (2014) conducted a study on agriculture and nutrition in India with the objective of mapping evidence for pathways. The study revealed that progress against undernutrition has been sluggish, despite the agriculture sector's critical role in enhancing diets, care practices, and maternal health. The research indicates that agriculture can have a substantial impact on nutrition by concentrating on the nutritional effects of agricultural production, incomes, and food prices. Nevertheless, the persistent nature of food insecurity and undernutrition may be exacerbated by the deficits in knowledge, particularly in the context of agriculture-gender relationships. The results of this study are consistent with those of Kerr, Berti, and Shumba (2011), who reported that the effects of a participatory agriculture and nutrition education project on child growth in northern Malawi were significantly influenced by long-term efforts to enhance child nutrition through participatory agricultural interventions. This result is the outcome of strategies that have been implemented to enhance household food production, as well as the efficient preparation of food recipes that are most suitable for children and the management of foodstuffs.

Strategies for the development of markets and food security efforts

The study conducted by Hoddinott (2012) on agriculture, health, nutrition, and linkages demonstrates that human societies have historically experienced fluctuations in food availability and nutrition of food is influenced by factors such as temperature, moisture, and soil fertility. Traditional storage techniques, such as dehydrating and salting, necessitate minimal energy input, while contemporary methods, such as refrigeration and canning, necessitate more energy. This is also acknowledged by van Dorp, Oenema, and Verdonk (2011). The global system that distributes fresh and preserved foods has been facilitated by the advancement of food transportation, which has alleviated concerns regarding food productivity. Nevertheless, the sustenance of an expanding urban population in the face of diminishing fossil fuel resources presents substantial challenges due to the reliance on energy-intensive technologies.

Anno (2025) conducted an additional study on strategic approaches to food security and market development in arid and semi-arid lands (ASALs). This study emphasised the systemic barriers to food security and market growth in arid regions, identifying challenges such as inadequate research, pest issues, poor seed technology, and limited dietary diversity as hindrances to food security efforts. The study underscored the necessity of conducting research on drought-resistant crops and efficient farming techniques, in addition to implementing educational initiatives for farmers on market orientation. The study also suggests that the enhancement of agro-processing and transportation, the promotion of the digitisation of practices, the leveraging of agricultural coaches, and the improvement of extension services can increase agricultural operational efficiency in food-secure areas, resulting in agribusiness and the affordability and diversity of food commodities in local food markets (Anno, 2025). These findings are similar to those provided in Kerr, Berti, and Shumba (2011).

The influence of food security on the outcomes of birth and nutrition

Abu-Saad and Fraser (2010) conducted a study on the relationship between maternal nutrition and birth outcomes. The report concluded that maternal nutrition is a modifiable risk factor of public health importance that can be integrated into initiatives to prevent adverse birth outcomes, particularly among economically

developing/low-income populations. This assertion is also consistent with the results of Branca and Ferrari (2002), who conducted a study on the impact of micronutrient deficiencies on human growth. Their findings indicate that stunting has an impact on child development from conception to approximately age four, and is influenced by factors such as maternal and child nutrition, micronutrient deficiency, challenging environments, and inadequate care.

Food insecurity and malnutrition results in growth retardation and complex syndromes, including developmental delays and metabolic disturbances. The prevention strategies, which entail promoting exclusive breastfeeding for the first six months and ensuring adequate micronutrient intake through complementary and family foods, are consistent across both studies. Nevertheless, additional research is required to fully understand the potential hazards of accelerated growth velocity. The Department of Economics (2025) Annual Meeting Report 2024-2025 emphasises the necessity of establishing systems that can sustain the economic stability of states and regions by enhancing infrastructure developments that can develop food security capacities. This is particularly important in areas that have been severely affected by the climate change phenomenon, as it aims to reduce human suffering.

de Pee et al. (2015) conducted a study on the prevention of acute malnutrition through the distribution of special nutritious foods and cash, and addressing underlying causes. The study demonstrates that the ability of individuals to produce their own food, preserve, and utilise it effectively is a sustainable mechanism for food security and nutrition, rather than relying on emergency food supplies. This method exacerbates the nutritional status of populations, particularly those in food-insecure regions. These findings are also consistent with those in Mukhebi, Mbogoh, and Matungulu (2011), that provide an overview of the food security situation in eastern Africa. The study suggests that food policies have not been successful in addressing food availability and accessibility in many parts of the world.

To improve the effectiveness and efficacy of policies, the Mukhebi, Mbogoh, and Matungulu (2011) study recommends that the reorientation and improvement of the implementation process be contingent upon the availability of resources, ensuring affordability and sustainability. In order to empower the agricultural and business communities, food security and nutrition policies should be implemented through an integrated approach that capitalises on the will and commitment of all stakeholders. In their study on malaria and anaemia among expectant women, Ouma et al. (2007) also mention that food and nutrition are essential for the prevention of preventable diseases and for the maintenance of good health. Access to nutrient-dense and high-quality food commodities is a health solution.

Food distributions to households

Gamboa (2014)'s research on household food distribution patterns and their impact on nutritional status suggests that disparities in food distribution among family members have a significant impact on nutrition outcomes, with infants, mothers, the elderly and the people living with disabilities and chronic illnesses being the most affected. The study also emphasises the significance of nutritional education at the domestic level in order to raise awareness of healthy living and nutrition. Wibowo et al. (2015) also advocate for household education and training on season-long food and nutrition security, which is consistent with these findings. According to Makokha et al. (2002), traditional foods are organically produced and contain a variety of nutrients. However, traditional households are restricted in their ability to create effective recipes using these foods, as they lose a significant amount of nutrients due to improper food management and preparation.

Basic nutrition principles, detailed food functions, nutritional requirements, consequences of deficiencies, and food suggestions for families are prioritised in the study conducted by FAO (2015) in Zimbabwe, which focuses on the promotion of a healthy harvest through community worker training in food production, preparation, and processing. It also encourages the establishment of nutrition gardens and the selection and cultivation of crops for productivity with minimal inputs. Anno (2025) also concurs with these findings, which underscore the necessity for cost-effective and expeditious meal preparation, as well as the implementation of optimal food harvesting, storage, preservation, and processing methods to ensure year-round nutrition. The necessity of effective food storage for the preservation of its viability is also underscored in the study conducted by Prentice and McLachlin (2010). In contrast, Hammond et al. (2015) present traditional storage methods such as dehydrating, salting, and smoking, which consume minimal energy, while modern techniques like canning and refrigeration are energy-intensive. However, the fundamental principle remains that the preservation of food is a critical component of nutrition and food security.

Enhancing agri-nutrition policies

Specifically, van Dorp, Oenema, and Verdonk (2011) emphasise the importance of the integration of nutritional factors into agricultural policies and programmes, as well as the reinforcement of value chain development and food security, as strategies to support the increasing international emphasis on the connection between agriculture and nutrition. They explicitly investigate how agricultural interventions can improve nutritional outcomes and the conditions required for linkages. The findings of the Wrottesley, Lamper, and Pisa (2016) study are further substantiated by the study's endorsement of pathways for enhancing the well-being of individuals of varying ages through the use of food security, nutrition, and livelihoods.

The CHS (2013) community nutrition guidelines prioritise community health education for health promoters as a method of facilitating the expansion of community members' knowledge through health promotion education, screening, referrals, and self-care advice for improved living. The contents of this resource material are consistent with the food-based dietary guidelines developed in South Africa by the Department of Health and Social Development (DHSA) in 2013. These guidelines offer evidence-based recommendations for healthy diets that are customised to the cultural contexts, food accessibility, and public health requirements of each country. These recommendations provide guidance on the dietary patterns and food groups that are essential for the prevention of chronic diseases and the maintenance of optimal health.

Methodology

The research procedure integrated desk reviews and field visits to the designated food production sites in Turkana County. Strategic papers, including scientific articles and policy and project documents on agriculture and agri-nutrition, particularly in dryland regions, were reviewed, and the findings were correlated with the

food security and nutrition context and programming in Turkana County. This study purposively sampled five areas within the county: (a) Lokichoggio for rainfed crop production and cross-border trade with South Sudan; (b) Kakuma for refugee food security and agricultural nutrition interventions; (c) Lodwar for the county government headquarters food security and nutrition focal points; (d) Turkana South for food production in potential irrigation schemes; and (e) Turkana East for the role of livestock in food security and nutrition. A total of 148 participants were involved in this study, i.e., 80% are at primary (farm) level, 15% secondary (county and policy) level, and 5% tertiary (scholars and experts) level. Both quantitative and qualitative data were analysed, triangulated and subsequently validated by stakeholders through a series of consultative meetings.

Results and Discussion

Food and nutrition security in Turkana livelihood zones

Turkana County, located in north-western Kenya, borders Samburu, Marsabit, and West Pokot Counties of Kenya, as well as Uganda, Ethiopia, and South Sudan. It spans approximately 77,000 km² with a projected population of 1,022,773 (505,390 males, 517,384 females). The county is administratively divided into eleven sub-counties, with seven operational. Its four main livelihood zones are Pastoral (60% of the population), Agro-pastoral (20%), Fishing (12%), and Formal Employment (8%). In the Pastoral zone, livestock production dominates cash income at 91%, while in the Agro-pastoral zone, food crop production contributes 40%. Fishing accounts for 54% of cash income in the Fishing zone. The county faces significant poverty challenges, with an overall incidence of 77.7%, including 45.7% hard core poverty and 63.4% food poverty (KNBS, 2021).

The impact of the showers in Turkana's livelihood zones remains inconsistent, with some regions experiencing normal to above-average precipitation and others experiencing below-average precipitation. The consequence of crop production is also mixed, as the majority of rainfed farms fail to reach maturity and the yield is consistently lower than anticipated. Especially in pastoral regions with high disease prevalence and low fertility rates, livestock conditions have remained progressively poor. In general, Turkana County has been classified to be in a 'Crisis' state in numerous food security assessments.

State and determinants of agri-food system in Turkana

The research indicated that in Turkana County, over 63% of food consumed is acquired through purchase, while merely 7% is produced locally. Supplementary food sources comprise personal stock (13.8%) and donations (16%). Agriculture, pastoralism, and fisheries constitute 74% of the county's revenue, although the food supply is predominantly dependent on imports from counties such as Trans Nzoia, West Pokot, Uasin Gishu, and Moroto in Uganda, mainly including sorghum, maize, pulses, and assorted vegetables and fruits. The 2024 Kenya Integrated Household Survey indicates about 79.5% of Turkana's population resides below the poverty line, with 63.4% categorised as food insecure. Irrigated agriculture in Turkana centers on the Turkwel and Kerio rivers, with sorghum and maize being the principal crops.

In Turkana, sorghum production surpasses maize owing to inconsistent rainfall; nonetheless, the total cultivated area has diminished due to inactive irrigation systems, silted waterways, and restricted and costly mechanization. Challenges encompass the expansion of Prosopis juliflora, insufficient water availability due to extended drought, pests, diseases, suboptimal soil health, utilisation of unsuitable seeds, and ineffective agricultural practices. As a result, the yield of both sorghum and maize is anticipated to go below typical levels due to diminishing precipitation, decreased river capture, and Prosopis j. prolonged colonisation of fertile agricultural lands. Agricultural inputs, including enhanced seeds, fertilisers, agrochemicals and pharmaceuticals, can augment food yield and security in the county.

In Turkana County, access to high-quality seeds is restricted, and smallholder farmers frequently lack localised soil and crop information. They depend on intuition and counsel from local agro-dealers, which may cause discrepancies between applied and requisite nutrients, leading to economic losses and environmental deterioration. Agricultural extension is essential for providing on-farm technological information and improving farmers' technical and managerial competencies. It offers a return on investment ranging from 8% to 49%, markedly enhancing production and alleviating food insecurity. Turkana encounters insufficient and inefficient extension services, worsened by the exodus of numerous public extension officers, particularly due to retirement and search for better jobs. To resolve the human resource challenge, recruiting additional technical and extension personnel and equipping them with essential tools, such as knowledge, skills, and technology related to dryland farming and climate change adaptation techniques, will enhance food production, resilience, and self-sufficiency among local farmers.

Figure 1: Agrinutrition interventions for pastoralists in Lokichoggio, Turkana County

Opportunities for improving agri-food system in Turkana

The research indicates that political good is essential at the global, regional, national, and municipal government levels to address potential policy and institutional challenges that are encountered in food-insecure regions. It facilitates the ratification of policies and regulations, as well as the mobilisation and allocation of resources to support food security programmes. A market is prepared for nutritionally necessary food commodities due to the growing demand for diverse and nutritious foods for direct consumption and processing. A niche is emerging for farmers and agriculture enterprises in Kenya's high-production regions to supply fresh produce to markets in high-food deficit areas, as a result of the increasing human population, shifts to health eating, and preference for food commodities produced responsibly. The quality of agricultural products is being reinforced by the use of climate-smart and adaptive farming practices, as well as the development of farmers' skills and knowledge, and the implementation of dryland farming technologies with focus on value addition.

There are approximately 31 operational irrigation schemes in Turkana County; however, none are capable of producing sufficient quantities of food to support the local populace. The agri-food system in Turkana is still heavily reliant on external production, supply systems, and entrepreneurs, despite enormous resources deployed to these irrigation schemes. The management of these challenges can be achieved by addressing the diverse systemic constraints of irrigation schemes, including land infertility, salinity, water scarcity and poor water supply systems, limited access to quality agricultural inputs, weak extension systems, high prevalence of pests and diseases, lack of affordable credit for farmers and agriprenuers, and low utilisation of ICT. The expansion of ICT and technological innovations in production, marketing, and processing in Kenya is creating new opportunities, as the availability of arable land for agricultural production increases productivity when fully utilised. The research also demonstrated that the increased yield per unit area is a result of youth involvement in agricultural activities, the accessibility of ICT and other innovations, and the presence of multiple development partners who are willing to support the production and share information, mobilise resources, and partner in the implementation of agri-food system interventions.

Roadmap for food and nutrition security in Turkana

For Turkana to have a sustainable food and nutrition security roadmap, the study established that evidence-based data that is anchored on food security and socioeconomic policies of the state and county government which is used to create collaborations and partnerships among development partners in programming will enhance strategic approaches to developing a robust and sustainable agri-food system. This strategic outcome is realized further through resource planning, capacity investment, financing, and creation of a conducive environment for programmes implementation. These efforts will at higher level promote production towards diversification of foodstuffs, improve food availability, access and consumption, enhance value addition through storage, processing and marketing, and create competitiveness of local producers and entrepreneurs in their local markets. The diagram below depicts this result chain:

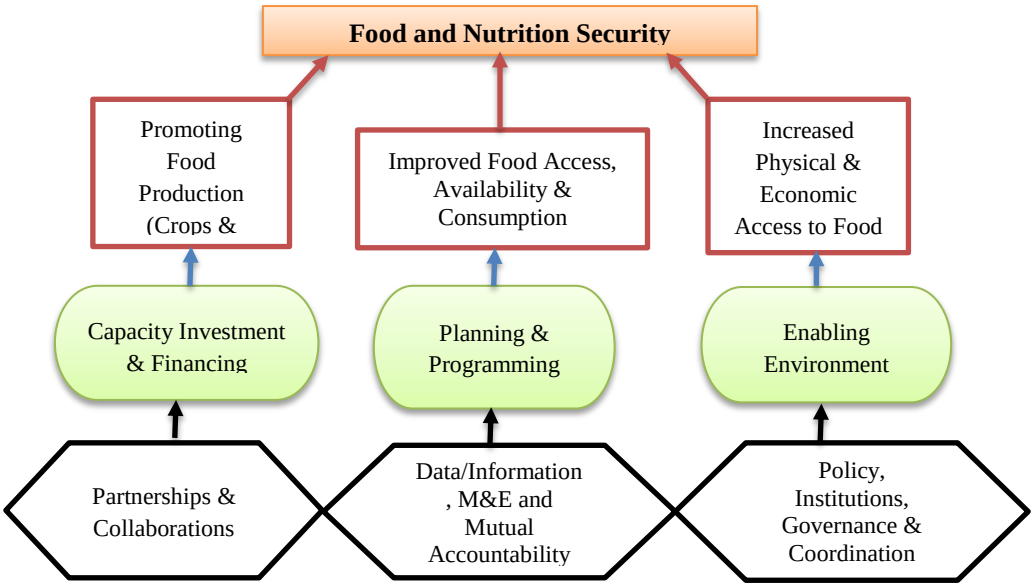

Figure 2: Agrinutrition result chain proposed for Turkana food security ecosystem

The study also found that in Turkana County, there is a significant lack of human resource capacity to implement nutrition-sensitive programmes. This challenge can be addressed through periodic training of extension officers and market systems strengthened to enhance sustainable access to nutritious foods. The food supply value chain is significantly improved by the involvement of private sector and non-state actors and leveraging resources and increasing investment in nutrition-sensitive agriculture (NSA) initiatives necessitates the establishment of public-private partnerships. Communities are essential for food production; however, they frequently lack the capacity to produce and consume nutrient-dense foods.

Empowerment initiatives encompass the establishment of forums for NSA interventions, the development of community capacity, and the promotion of innovative financial services. A policy and institutional framework that is supportive is essential for the implementation of NSA programming. The primary objectives are to enhance governance and coordination by conducting policy evaluations and advocating for the integration of the NSA into food security and resource economics planning. It is essential to establish a systematic approach to data administration in order to monitor and evaluate NSA programmes. In order to guarantee stakeholder engagement and effective decision-making, the integration of NSA data with local and international information systems is critical.

Agri-nutrition gaps and integration challenges in Turkana

Dietary diversity and agrinutrition hazards

The most significant agrinutrition gap in Turkana is the insufficient production of crop varieties by producers. This is further exacerbated by the inadequate selection of food categories in the market by local consumers. The insufficient understanding of the nutritional requirements of the region and the production of the corresponding food commodities is the likely cause of these issues. It has also been determined that destitution is the most significant impediment to dietary diversification, as the majority of consumers are unaware of their nutritional needs. Certain households, including those that are capable of consuming alcohol, tend to allocate household funds and dietary resources to beverages that are not consumed by children.

It is also discovered that the most significant obstacles to food production and nutrition management in Turkana are pre- and post-harvest management, which are caused by the limited knowledge of farmers to manage crops in the field and after harvest. This challenge is further exacerbated by the county's inadequate storage and agricultural processing facilities. The risk of aflatoxin contamination remains apparent as a result of the absence of food preservation and packaging materials. For an extended period, the county has been deprived of a strategic framework for food and agrinutrition security due to the absence of a comprehensive, robust, and widely applied agrinutrition strategy. The quantity and quality of farm produce are decimated by an increase in the build-up of farm and storage pests, resulting in food loss, reduced value and quality.

Figure 3: Refugee household in Kalobeyei preserving surplus vegetable harvest

Agribusiness and Livelihoods

The study emphasises the importance of the Turkana poor cash economy, which is reducing the purchasing power of households, farmers, and agriprenuers for agricultural supplies and services. Additionally, the low degree of exploitation of income-generating activities diminishes the amount of cash at the individual, household, and business levels. The purchasing power of a substantial number of individuals is significantly reduced as a consequence of the increase in the price of basic commodities and services. Additionally, there is a lack of knowledge expertise, particularly in the field of agribusiness research, as well as unbalanced and limited market information. This is further impeded by the insufficient dissemination of current agribusiness research, the absence of market intelligence, and the scarcity of mentors and advisers in business incubation and development programmes.

Other factors that impede Turkana's agribusiness and livelihoods include the absence of sufficient agro processing facilities and apparatus for market-demanded agricultural value chains, which is a result of subsistence agriculture, as well as low-value addition capabilities that are optimised by knowledge, skills, and costs. Agroprocessing is expensive in Turkana due to the addition of little value to grains and horticultural commodities. Further, farmers in the region lack the necessary enterprise specialisation and diversity skills to compete for market opportunities and manage change. This is the reason why external entrepreneurs dominate nearly all agricultural markets in Turkana. It is also evident that economic returns through value addition are minimal as a result of the absence of processing cottage industries, insufficient raw materials for production, and sustained agro processing. The movement of farm produce from the farm to offtake locations is weakened by the absence of effective aggregation centers and models, which increases the risk of pre- and post-harvest losses.

Private sector engagements and marketing

Due to the fact that the majority of the finished products in the market are processed and supplied from industrial cities in Kenya and through suppliers, the manufacturing economy of Turkana County is severely unbalanced. The study did, however, observe the growing number of local companies that are producing mineral water and honey products and their strategies for securing these markets. The county's agricultural and market access growth are significantly hampered by the nonmarket constraints, which are primarily regulatory. Consequently, agricultural products and other food-based commodities are in short supply, particularly in trading centers that are remote from the main roads. This is despite the efforts of local industrial actors. The production output in potential agricultural areas is significantly below capacity, particularly in irrigation schemes and open fields, where soil and water salinity significantly influence the market and consumers' flavour and preferences. Consequently, the supply and demand of these products in the market are reduced.

The county is also suffering from a lack of private sector participation, which results in insufficient assistance for producers to improve their agricultural and business endeavours. Additionally, there is a lack of sufficient extension service providers to enhance the competitiveness and awareness of local farmers and agripreneurs in their native markets and beyond. The county has a substantial limited public-private producer partnership (PPPP). This situation further diminishes the ability of local producers to produce and market their crops. This situation is further exacerbated by the low cooperative growth of producer organisations and their participation in the local economies. The underutilisation of market stalls in secondary livestock markets is apparent, as pastoralists prioritise the trading of live animals. Conversely, this is not the case in agricultural and fresh produce markets, where the demand for booths is substantial and the majority of them are occupied.

Imperfect commodity marketing systems also afflict the county. This is predicated on the continued existence of conventional marketing and trade systems, such as barter trading of commodities, which denies both sellers and consumers market-based opportunities, such as real-time pricing and the ability to compete in a market-based economy. The commodity supply capabilities of local merchants are being impeded by their

inadequate transportation capacity. While this inability may be attributed to a variety of factors, business capital continues to be a significant challenge for a variety of business proprietors, business organisations, and local businesses, as well as the unreliable and insufficient availability of the produce that is in demand in the market. Despite the county's efforts to establish a robust market economy, the provision of free production inputs, including seeds, agricultural tools, and equipment, as well as the provision of free mechanisation services, is leading to a decrease in the competitiveness and profitability of local agripreneurs.

Access to finance and market networking

The financial institutions in Turkana County are insufficient to finance agricultural ventures. Motivation to participate in market-led agricultural and agribusiness activities is impeded by their absence. The study revealed a low level of access to financial institutions for the purpose of financing agricultural enterprises. This challenge is rooted in the risks associated with agricultural production and the obstacles that limit production outputs key in loan repayment. Additionally, interest parties are unable to secure loans in the absence of collateral, which is not a defined term in the context of Turkana and the majority of pastoral areas.

The formation and development of farmer cooperatives are restricted by the low rate of success of agricultural enterprises in capturing local and external market share. The study also observes that the few businesses and farmer producer groups that have been established and are operational in Turkana are significantly lacking viable business strategies. This situation undermines the strategic intent of these community-based organisations and diminishes their credibility as viable business entities in the market. The farmer associations are hesitant to accept long-term loans due to the high rates of interest, the fear of defaulting, penalties, and legal repercussions that result from their involvement in non-viable enterprises. The overreliance on donor funding and free donations from the county government and civil society networks is another challenge that affects the significance of agriculture and the performance of businesses in Turkana.

Farmers have low literacy levels, while financial ineptitude is prevalent in business organisations. Poor management and performance of business enterprises are also influenced by insufficient business management expertise and experience. The county lacks sufficient adoption of digital agricultural technologies to enhance the agricultural economy and market performance, as well as fewer and inferior microfinance organisations, limited market networks, and lacks networking skills. It is also observed that a significant number of farmers have limited exposure to well-performing agribusiness and business enterprises, which restricts their entrepreneurial mindset and ability to alter their conduct. A centralised market data system, sustained functionality of market connections, and business-to-business networking are also absent to facilitate the administration of agricultural enterprises and trade.

Strategies to enhance integration of agrinutrition to dryland farming systems

Dietary diversity and Nutrition education

Agriculture and food security stakeholders in Turkana and comparable dryland ecosystems are collaborating to enhance the training and instructions provided to all farmers and households regarding food production and consumption. This action will motivate farmers to cultivate as many and as diverse crop varieties as their agroecologies will permit. Furthermore, the integration of agrinutrition into the way of life of the locals will be facilitated by the development of capacities for farmers to understand the technical aspects of dietary diversity and nutrition that are crucial for home economics and healthy living, as well as the support of communities' preparedness to address health and nutrition-related concerns through initiatives such as Malezi Bora and other forums for knowledge exchange and learning. To increase the availability of nutrient-dense foodstuffs at the household level and to expand the adoption and replication of dryland farming technologies to a broader geographic area, kitchen gardening should be encouraged in specific households, schools, and health centers. This will not only provide the highly necessary nutrient-dense vegetables and fruits, but also serve as a demonstration of efficient dryland technologies that are both economical and efficient in terms of production resources.

To enhance the capabilities of extension personnel in both public and private sector domains, promoters of agrinutrition must disseminate nutrition research and enable personnel to reach and empower farmers and households in their respective areas of responsibility. The translation of the current and future agrinutrition manuals and essential messages into Kiswahili and the local languages will enhance the learning and application of knowledge among the local populace. In addition to enhancing agrinutrition communication, learning, and knowledge adoption in displacement contexts, the fact that a significant portion of the human population in Turkana are refugees and have acquired Kiswahili will also contribute to this improvement. The learning materials should be structured to include the use of basic and pictorial tools that clearly demonstrate agrinutrition training in pre-, post-, and food-handling technologies.

Although the majority of food production, preservation, and utilisation are conducted using conventional methods, it is imperative to document common nutritional hazards and their repercussions, including contamination and inadequate food preparation procedures. It is also worthwhile to invest in the capacity building of farmers, extension agents, and agriprenuers in the fortification and biofortification technologies of local products. This can be achieved by utilising the cereal milling and fortification equipment that are already available in Lokori (Turkana East) and Kakuma (Turkana West), which are managed by local millers. The milling activities can be sustained by the large quantities of sorghum and maize that are produced in the county during fairly good rainy seasons, as well as the fact that supplies of maize can be sourced from Kitale.

Milling and fortification of cereal products can further be supported by the expansion of production at local irrigation schemes, which will provide local farmers with a ready market and local entrepreneurs with a greater opportunity to reduce the costs of milling and fortification. Aflatoxin and its mitigation strategies can be learned by stakeholders, including the public health department, in order to increase their awareness and capabilities to prevent food contamination. To effectively address the aflatoxin challenge over the long term, this action may necessitate a programmatic approach anchored on public health and food safety regulations.

Agribusiness, cash economy and livelihoods

To address the challenges of the cash economy, Turkana County should encourage the expansion of additional income-generating enterprises, advocate for the regulation of prices for critical food security and nutrition commodities, and enhance

microfinance initiatives among farmers with the support of private sector actors. It is recommended that private sector entities responsible for financial inclusion programmes incorporate financial literacy and utilise SACCOs to encourage saving and lending, with the potential to establish connections to the formal financial sector. The county trade and cooperatives departments should establish databases of real-time market data and promote the orientation that is essential for empowering county business entities, particularly local producer groups and small-scale enterprises.

Agribusiness forums and business connections for market participants can also be supported and enhanced by the private sector. Expanded training on market and marketing skills is provided to various categories of market stakeholders to further enhance this initiative. The county production plan, which encompasses strategies for farmer empowerment, can also be actively developed by the private sector. This is further accomplished by collaborating closely with academicians and research institutions that specialise in the development of entrepreneurship, nutrition management, and food security. The consistent transformation of local economies toward market orientation necessitates the transformation of the knowledge, skills, and mindsets of local actors to incorporate new knowledge, as agribusiness is a market-oriented system.

Agro processing and product distribution channels

The challenges associated with product value addition and distribution will be mitigated by educating farmers and local agriprenuers on the processing and development of value chains. The county's anticipated agrinutrition benefits will be further enhanced by the provision of equipment and training on its utilisation. Knowledge, in conjunction with equipment technology, will facilitate value chain specialisation and diversification, thereby expanding the potential for agribusiness and agro processing business ventures. The establishment of product aggregation centers will enhance the production and adoption of various commodities by establishing a well-designed system for aggregation and supply to the intended markets.

The county has the option to establish processing cottage industries on a small scale in order to boost the local consumption of agricultural products. These industries are more suitable for the processing of tomatoes, groundnuts, and vegetables. These enterprises are emphasised because processing was attempted at the county level, but it was unable to be sustained due to technological, financial and knowledge constraints. Turkana County has the potential to capitalise on the refining of these products through appropriate investments. To maintain and expand agro-processing, the county government of Turkana and development partners would need to increase the production of raw materials by leveraging the available irrigation schemes, factors of production, and economies of scale, which are essential for profitability due to the reduced cost of unit production. It is imperative to enhance the relationship between supply and demand forces in marketplaces by enhancing the production and delivery of high-quality commodities to the market.

Managing the consequences of non-market forces and utilising them to the benefit of agriculture can advance and promote the food, income, and nutrition security of rural and urban inhabitants. Additionally, the objectives of achieving sustainable and meaningful agroprocessing and finished product distribution to a variety of markets within and outside the county will be further bolstered by providing farmers, consumers, and entrepreneurs with education on the economics and technicalities of supply and demand forces and their influence on production and market access.

Private sector engagements and market functionality

By addressing the challenges associated with public-private partnerships, the county government of Turkana, in collaboration with a variety of development partners, can improve the quality of these forums. Financing agricultural activities with low-interest loans and business grants, where applicable, can enhance the value of private/financial institutions to producers. The competitiveness and profitability of business ventures will be enhanced by the development of local producer organisations' capacity and their conversion to cooperatives. This support should also be extended to the federation of shared interest groups, with the ultimate objective of transforming them into cooperatives, thereby transforming them into robust and competitive producer organisations. In addition to facilitating the fulfilment of business commitments and contracts by farmers, entrepreneurs, and investors, the promotion of PPPP collaborations with solid business outcomes will also foster the development of a robust market economy in the county.

The competitiveness of local economies and market activity are stimulated by the enhancement of agribusiness. This is further improved by the implementation of capital resources, partnerships and alliances, reliable transport, communication networks, ethics, and market functionality. Using well-designed and risk-free business models, local producers, entrepreneurs, and merchants can enhance their competitive and comparative advantages by enhancing the ability of local suppliers to compete in a variety of markets. Educating suppliers on the significance of possessing an adequate amount of market information can mitigate price distortions at the farm gate and in the marketplace. Inputs can be subsidised, if necessary, rather than providing them for free. The selection and planning of business ventures that are competitive, profitable, and sustainable in the long term will be achieved by supporting local farmers in their participation in regional agricultural shows, continuing price sensitivity training and gross margin analysis, expanding the entrepreneurial capabilities of agri-vendors, and creating feasible business model canvas and business appraisal toolkits, such as RuralInvest.

Pathways from agriculture to agrinutrition

To attain sustainable agriculture, food security, and nutrition in Turkana and broader dryland ecosystems, it is essential to use system-based techniques that integrate all components required for establishing an agricultural economy that delivers not just food but also income and nutrition. This is more effectively achieved by focusing production on the nutritional advantages of food commodities. It is essential to establish an agri-food system that delineates household food security assets and livelihoods vital for food production, job creation, and the involvement of women and youth in agricultural endeavours.

This result is enabled by fair access to land, water, knowledge, labour, and technology. These capacities will augment food production, generate income from agricultural and non-agricultural operations, and facilitate market access, as well as boost food availability and affordability. Access to household food, health services, and supportive caregiving behaviours will ultimately enhance human health, benefiting mothers and children. Notably, community, governmental, and private entities play a

crucial role in maintaining revolutionary frameworks for agriculture and nutrition, ensuring year-round access to food, improved nutrition, and enhanced income for all.

Conclusion

The study concludes that food and nutrition security issues in Turkana stem from structural inefficiencies rather than insufficient productivity. For individuals with low income, these inefficiencies affect food availability, pricing, and safety. Interconnected market-driven alterations to the food system are necessary to identify solutions. The adjustments should focus on aggregation systems, the maintenance of first-mile value, and the synchronisation of production with market demands. To withstand shocks, it is imperative to enhance climate resilience through the fortification of infrastructure and the implementation of diverse systems. The study's findings indicate that reforming the food system might enhance food production and increase earnings for both households and farmers while also assuring equitable value distribution.

To enhance production and adaptability in Turkana's agricultural and food sector, a meticulously coordinated investment strategy is imperative to address malnutrition. The amalgamation of agriculture, nutrition, public health, education, and policy will augment and synchronise stakeholders' efforts to connect agriculture with nutrition. Integrating nutrition education with behavioral influence will enhance home nutrition and guarantee food safety. Training in entrepreneurial skills is crucial, since it enables the management of various challenges. Moreover, innovative agriculture technology is essential for improved resource utilisation and higher revenues. Food security in Turkana encompasses access to safe and nutritious food, as well as education, hygienic conditions, clean water, healthcare facilities, and adequate care. A multitude of domestic and national concerns affects food security and infrastructural development.

The agriculture and food sector in Turkana possesses significant potential; however, to actualise this potential, it is imperative to transition from fragmented initiatives to cohesive and market-orientated strategies. Focusing on market systems that facilitate production and inclusive market development, while strengthening critical system enablers, delineates a clear trajectory for integrated agri-nutrition within dryland farming systems, aimed at enhancing productivity, promoting inclusive economic growth, and improving food and nutrition security. This goal is achieved by concentrating on market mechanisms that facilitate production and promote food preservation and judicious utilisation.

Recommendations for Application

- To increase food security and nutrition, it will be necessary to adapt national policies to local settings. This will need strategic planning and coordination of agricultural and nutritional operations, as well as the mobilisation of resources and the dissemination of information through lobbying and training.
- A regularised evidence-based monitoring of agri-nutrition indicators, the acquisition of necessary resources such as training materials, the integration of interventions into existing health programmes, and the provision of ongoing professional education and training on agri-nutrition practices will enable farm and market-based stakeholders and households to treat food security and nutrition as both a developmental and safety matter for a prosperous and healthy sociality. This will allow for the measurement of the integration of agri-nutrition into the Turkana food system.
- The government and development partners need to advance the food security agenda to enhance the connections between food security initiatives and nutrition. This is best accomplished by guidelines demonstrating the integration of programmes and the establishment of synergistic agrinutrition as a consideration in the planning and implementation of food security initiatives. All relevant stakeholders will collaborate to achieve this alteration. The communities receiving services should be receptive and rational in their behaviours, activities, and purchasing decisions to substantiate the significance of agricultural nutrition in their well-being.
- Turkana County to execute the county agrinutrition strategy formulated in partnership with the development partners active in the region. The failure to implement this framework would indicate that the county lacks a strategic plan to facilitate the integration of agrinutrition protocols into the local economy.

Areas for Future Research

This study identifies key areas for future research, specifically the knowledge of food scarcity in Turkana and its effects on population well-being. What actions can the public do to maintain health and productivity in a climate of food scarcity? This study is multidisciplinary and multisectoral, necessitating a stakeholder approach and sufficient resources.

Disclaimer

- The views stated in this article are those of the author and do not necessarily represent those of any of the entities mentioned.

Interest Conflicts

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