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Challenges of Liquid Biofuel Policies and Institutions in Eastern Africa Countries of Ethiopia, Kenya and Tanzania

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Abstract

Most African countries made deliberate decisions to invest in liquid biofuel leading to the formulation of the bioenergy strategy in 2007. The study on challenges and policies on liquid biofuels was conducted in eastern Africa countries of Ethiopia, Kenya and Tanzania to understand institutional, marketing, and policy challenges. The study was based on interviews and discussions with stakeholders related to liquid biofuels. In marketing, policies affecting business were not stable as strongly agreed by 36.4% of the respondents, and agreed by 45.5% of the respondents. The liquid biofuels especially biodiesel was relatively new in the countries, and most relevant issues were unknown. The major problems with liquid biofuels were land rights that created conflict as stated by 54.5% of the respondents, lack of updated policies and strategies focusing on .provision of incentives, institutional strengthening, l monitoring and evaluation systems. The liquid biofuel investment in eastern Africa was affected by crop and forest land because it was not based on pre-assessment of land use planning. The 2010s failure of the eastern Africa Governments ambitious plan to produce liquid biofuels was caused by institutional, market, and technical challenges which can be solved by creating smallholders awareness, and modifying policies.

Key words: institutions, investment, opportunity, policy, smallholders, and trade

Introduction

Liquid biofuels are clean renewable energy sources that have the potential to contribute to climate security enhanced energy access and improved air quality of t rural households. Globally, about 2.7 billion people will have no access to clean cooking energy by 2030 (OECD/ IEA, 2017). According to IEA (2019), 850 million people globally and over 550 million in Africa (48% of the world) have no access to electricity (OECD/IAE, 2017). Bioenergy, as one of the seven "key pillars" of decarbonisation for getting to Net Zero by 2050, is a key driver to attaining energy for all and ensuring world temperatures are "well below 2°C and limited to 1.5°C" as per the Paris Agreement (Brito Cruz *et al*., 2014; Rogelj *et al*., 2016). IEA (2021) .

The main commercialized transport liquid biofuels made from biomass materials are bioethanol and biodiesel, commonly produced from sugarcane or corn and soybean or palm oil. The global market shares of bioethanol and biodiesel in 2017 was 64% and 36% respectively (Trent, 2019). Using pure or blended bio-ethanol and bio-diesel as alternative fuel, with conventional fuel is an important option to reduce petroleum fuel consumption and holds potential to reduce GHG emissions. Biodiesel reduces emissions of carcinogenic compounds by as much as 85% compared with petro-diesel (Yage et al., 2009).

Solid biomass and fossil fuels which are sources of greenhousegases (GHGs), can be substituted by liquid biofuels. In eastern Africa, families are expected to switch to hydroelectricity as a cheaper and cleaner alternative. However, hydroelectricity production is influenced by climate change while biomass based energy sources are less influenced by climate change. Production and utilization of liquid biofuels in Africa can strengthen management and use of forest ecosystems for sustainable development, reduce dependence on solid biomass fuels, address poverty reduction and environmental protection and reduce indoor air pollution (CRGE, 2011).

Africa countries made investments in green energy including liquid biofuel since 2007, which was guided by individual countries policies and regulations. The evolving picture is one of an unclear development of the biofuel industry on the continent; therefore, it is important to understand the status of the biofuel industry and what guidance individual countries can use in developing policies and regulations to guide the industry with higher domestic energy demand, which is mostly satisfied by imports of foreign energy.

Accordingly, the present study investigated the existing and likely future opportunities or prospects, in addition to the challenges in production and use of biofuels in eastern Africa; assessing the competitiveness of African biofuels in the international market; identifying policy, regulatory and institutional frameworks and their weaknesses and strengths relevant to liquid biofuel production in the context of changing climate in order to facilitate planning the growth and development of local, national and sub-regional liquid biofuels sector.

Materials and methods of the study

Pre-tested questionnaires were used to interview respondents while Global Positioning System (GPS) were used to give coordinates of locations. The locations of the field studies are shown in Figure 1.

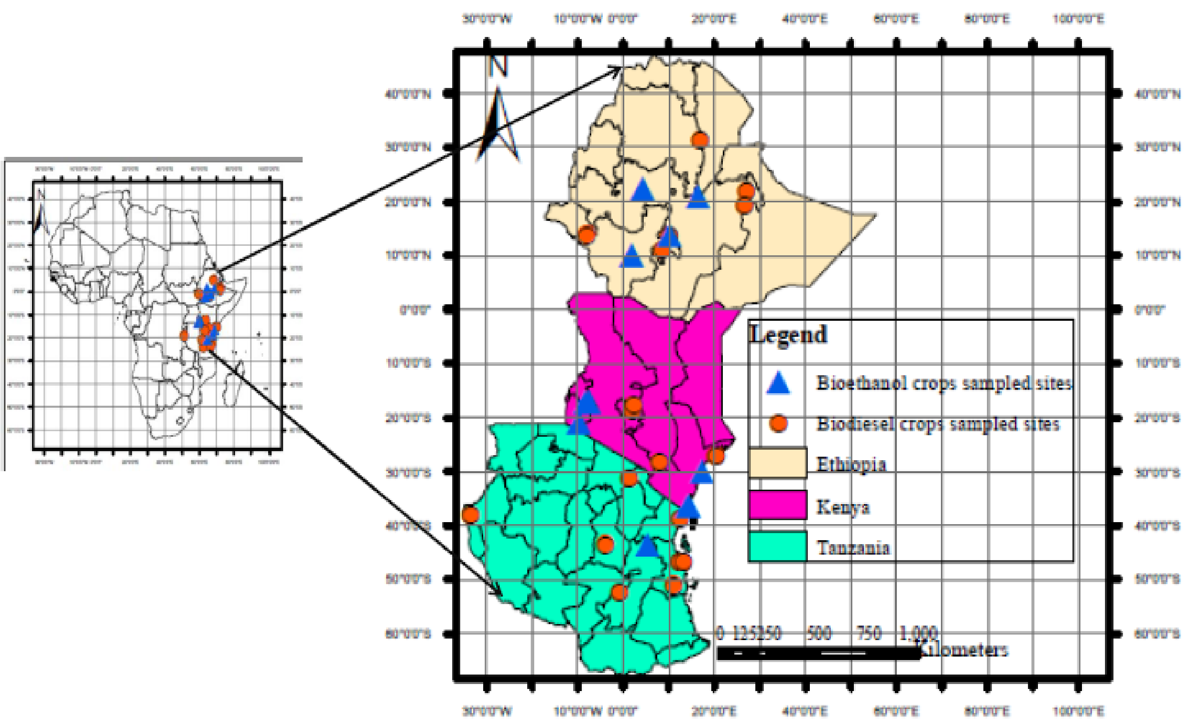

Figure 1: Location of the field study sampled areas

Study areas and data collection procedures

Different regions of Ethiopia, Kenya and Tanzania were assessed, 6 to 10 key informants and three focused groups were identified and recruited from a constellation of producers and processors of feedstock, research institutions and universities, relevant lead agencies, national and international NGOs. In the study primary and secondary data sources were assessed in February to May 2021. The primary field data was collected by purposive sampling technique and interviews on the technical and socio-economic aspects related to the production and use of liquid biofuels.

Purposive sampling technique is widely used in qualitative research for the identification and selection of information-rich cases related to the phenomenon of interest (Palinkas et al., 2015).

Key informants and focused groups were interviewed about the past activities and current status of liquid biofuels by using pretested structured and semi-structured questionnaire. The assessment of biofuel condition was carried out based on guidance of experts of energy and environment sectors.

The interview responses obtained from the smallholder farmers and their associations was triangulated with the respective district development agents and official government reports, and private sectors and GHG emissions were compared based on the availability of liquid biofuels from previous literature. Qualitative data was summarized by narration and quantitative data was analysed by descriptive statistics. Sugar factories were interviewed on types and cost of feedstock, cost of technology and financing, market mandates and targets, and customer demand. The responses were further categorized on levels of agreement as Strongly Agree; Agree; neither Agree nor Disagree; Disagree; and Strongly Disagree.

Results and discussion

Development of liquid biofuel systems creates income opportunities for farmers by diversifying crops for both food and biofuel production, creates investments infrastructure like roads construction, offers prospects of energy security, reduce pressure on forests for wood fuel, and reduce dependency on oil imports (UN, 2007). The other prospects are development of local industries, provision of alternative energy for rural mechanization, foreign exchange earnings from exports, import substitution of fossil fuels, long-term financial, social and environmental sustainability. The availability of suitable land, water, cheap labour, suitable climate for growing many of bio-energy crops in the eastern African region, in addition to global warming due to climate change that requires a shift to bioenergy are the opportunities. Existence of national and international legislations and commitments to guide production of feedstocks and use in ways that ensure safety to the environment and consumers are ways of promoting the opportunities.

Table 1 shows socio-economic challenges of production and utilization of liquid biofuels in eastern Africa. For instance, while pastoralist areas prioritized for Jatropha growing for biodiesel, facts on ground have showed that these areas are not suitable for producing Jatropha due to their aridity with limiting soil moisture of less than 200 mm annually. This is corroborated by findings by a study on, "Jatropha: Reality Check" (GTZ, 2009). . The lack of budget for processing of Jatropha seeds to oil and biodiesel resulted in dumping about 50 tons of seeds in Bati district of Ethiopia (Figure 2).

Figure **2**: Jatropha seeds in Bati, Amhara region of Ethiopia

Other challenges were lack of accurate and sufficient data on biofuel crops, general institutional, market, economic, social, technical, legal challenges; lack of incentives in biofuel development and utilization; internal company problems, and lack of monitoring and evaluation of project activities, weak policies and weak institutional capacity (Table 1).

The coping mechanisms of biofuel production and utilization challenges were found to be creating institutional reform, creating market access, providing credit access and grant, creating awareness of local people about liquid biofuel, capacity building of institutions and factories, limiting the blending levels of biofuel, providing subsidies and incentives to new biofuel sectors, improving productivity, sustainable management, modifying land tenure policy, and dissemination of research information (Table 2).

Table 1. Major socioeconomic challenges in liquid biofuel production in eastern Africa countries of Ethiopia, Kenya and Tanzania

Major challenges	Ethiopia	Kenya	Tanzania
Institutional	• Weak coordination among different agencies concerned with biofuel development. • Frequent structural changes in administration • No clarity of activities at Federal and Regional levels, lack of political support for biofuel activities • Lack of sustainable land use policy	• Lack of policy and regulatory support and no well-structured institutional arrangements • Lack of incentives and Government support	• Absence of proper policy • Absence of institutional memory that the biofuel one stop centre, Tanzania Investment centre (TIC) was not found upon visitation.
Market	• Buyers did not get sufficient amount of first generation biofuel feedstocks to process to liquid biofuel. • Sellers had no market for the small biofuel feedstock and there was no local processing.	• Lack of markets and investments in first generation biofuels • Feedstock are currently not profitable.	• Biofuels access to gas station market was hindered in Tanzania due to lack of blending ratios.
Economic	• High initial investment costs of biofuel production in marginal areas, • At the market level, the petroleum price was by far lower than liquid biofuel price,	• Limited sources of investment capital • High prices of biofuels compared to petro-based fuels	• Lack of initial price guarantee for biofuels investment (e.g. through fixed prices by the Government)
Social	• Lack of smallholders participation • Lack of local community support • Lack of feasibility study • Land use conflict	• Biodiversity loss and conflict with local people.	• Control of land and irrigation water sources by biofuel crops and fear of food security
Technical	• Lack of trained people • Lack of quality planting materials • Lack of techniques on silvicultural/ agronomic management, • Absence of quality standards • Lack of clear definition of marginal land to promote biofuel production • Old ethanol factories, poor maintenance and lack of spare part,	• Lack of quality planting material • Lack of enough trained people • Nnon-mechanized system of production, • Marginalized lands not clearly defined • Factories that used to process biofuels delapitated,	• Modern technologies were expensive to acquire and use.
Regulations and incentives	• There was limited incentive in biofuel production and blending,	• Biofuels strategy lavcking on incentivization of biofuels production	• Lack of long term, stable and clear policies, regulations and incentives.

Productivity	• Low yields of jatropha, and infestation by pest and disease • Shortage of ethanol production currently for fue,	• Poor productivity of biofuel or food crop • Occurrence of pests and diseases	• Poor productivity of degraded and marginal lands
Experience and monitoring and evaluation	• Fresh graduate who have no administrative and technical experience managed the biofuel project at higher level, • Lack of monitoring and evaluation	• No follow up to sustain the liquid biofuel sector. • Lack of implementation of research findings	• Issues around biofuel are unknown, • Lack of knowledge on land rights and biofuel production, • No follow up to sustain the sector.
Land tenure	• Land ownership remains with the state and fear of unclear future tenure change; conflict of local people on land	• Unclear land tenure system	• Unclear land tenure system
Poor research information	• Unstability of research coordination offices of bioenergy activities	• Poor research on breeding of quality planting material.	• Lack of researches to uncover areas where the production of biofuel plant species can be profitable.

Table 21. Coping mechanisms for addressing the challenges in liquid biofuel production in eastern Africa countries of Ethiopia, Kenya and Tanzania

Coping mechanisms of biofuel challenges	Ethiopia	Kenya	Tanzania
• **Institutional reform**	• Key government institutions responsible for biofuel development need to be strengthened at regional, zonal and district levels, • Policy amendments to cope up with the failure of biofuel investment.	• Formulation of regulatory support and well-structured institutional arrangements, and guarante markets,	• Formulation of framework to support biofuel development at specific ministry level or its departments
• **Market access**	• Creating local markets like sugar factories and biogas agency, • Link farm producers with small and medium enterprises (SMEs)	• Creating local markets of biofuels by the government,	• Determining biofuel blending ratios and creating local enterprises and market,
• **Credit access and grant**	• Provision of credit to the biofuel producers association at lower interest rate of banks with initial grant in interest free period and searching innovative financial mechanisms through bids	• Providing initial investment capital in the same was as Ethiopia	• Provision of initial price guarantee for biofuels (e.g. through fixed prices by the Government)
• **Awareness creation**	• Creating awareness of local community on importance of liquid biofuel, • Local determination and demarcation of land and plant species for biofuel feedstock production, • Conducting feasibility study and environmental impact assessment on the profitability of biofuel production and utilization, • Promoting smallholders and outgrowers for biofuel crop production,	• Limiting biodiversity hotspots from biofuel crop production, • Local determination and demarcation of land and plant species for biofuel • Feasibility study and environmental impact assessment of liquid biofuel,	• Determining land, plant species and irrigation water sources for surrounding farmers and for biofuel production, • Creating awareness of the local community on importance of biofuel, • The same as Kenya
• **Capacity building**	• Technically capacity building of staffs and laboratories,	• The same as Ethiopia,	• The same as Ethiopia

	• Training in growing and management of biofuel crop production, financial incentive for inputs, and long-term credit schemes etc. • Hiring trained people and allowing on job training of local people, • Solve the power shortage and poor maintenance in sugar factories.	• The same as Ethiopia, • Creating mechanized system of production	
• **Limiting the blending levels**	• Fixing the blending ratio of biodiesel and bioethanol depending on the availability of feedstock in the country,	• The same as Ethiopia	• The same as Ethiopia
• **Tax weaver, subsidy and incentives**	• Tax weaver in importing biofuels, tools and equipment required for liquid biofuel production and blending, • Financial incentives to attract private sector in blending; government subsidy such as grant, tax reduction and land allocation	• Address transport tariff of imported fossil fuel so as to increase the demand for locally produced biofuels.	• Estblishment of long term, and stable incentives.
• **Productivity improvement**	• Local breeding of quality planting material of the biofuel crop, • Improving productivity of biofuel plant species by selecting, diversifying breeding, and by enhancing soil fertility; pest and disease control; • Awareness creation on the importance of biofuels	• The same as Ethiopia	• The same as Ethiopia
• **Sustainable management**	• Developing monitoring and evaluation strategy for liquid biofuel, • Establishment of institutional clear mandate in liquid biofuel sector, • Promote the manufacture of local technologies to supply spare parts,	• The same as Ethiopia	• The same as Ethiopia
• **Land tenure policy**	• Establishing clear land tenure system and secure land ownership	• Establishing clear land tenure system	
• **Disseminate research information**	• Searching highly productive and profitable.biofuel crops, • Conducting research on breeding of quality planting material, high yield, and water use efficiency, for liquid biofuel production.	• The same as Ethiopia	• The same as Ethiopia

The sustainability of bioethanol production was generally found to be fluctuating because of biomass supply and low technical capacity of factories. In the case of biomass feedstock supply, interviewed bioethanol producing sugar factories provided different responses as summarized in Table 3. Most of the responses were agreeing on the issues, risks and barriers of liquid biofuel production. For example, about the presence of enough incentives to companies to grow feedstock for biofuel plant, 63.6% Agreed that incentives were lacking, 9.1% of the respondents Strongly Disagreed and the same percent Strongly Disagreed. In marketing, the policies affecting the business were not stable and clear, as 36.4% Strongly Agreed, 45.5% Agreed, 18.2% neither Agreed nor Disagreed and none of the respondents Agreed in their responses (Table 3).

Table 3. Perception of different stakeholders on liquid biofuel production in eastern Africa countries

Issues, Risks and Barriers	Percentage of respondents				
Feedstock:	SD (1)	D (2)	NAD (3)	A (4)	SA (5)
Companies do not get enough incentives to grow feedstock for biofuel plants.	9.1	0.0	18.2	63.6	9.1
There is not enough feedstock for advanced biofuels business expansion.	0.0	9.1	36.4	54.5	0.0
Smallholder farmers are willing to sacrifice land for biofuel feedstock production	0.0	18.2	9.1	63.6	9.1
There is inadequate regulation for biomass feedstock quality in the country/region	0.0	9.1	9.1	63.6	18.2
Competing uses for biomass feedstock (such as heat, power and bioproducts) pose a major risk for our biofuel business	0.0	18.2	18.2	54.5	9.1
Biofuel feedstock can outcompete food production and water	0.0	9.1	9.1	63.6	18.2
Biofuel feedstock caused deforestation and reduced stream water levels	0.00	7	11.2	18.2	63.6
Better mechanisms are needed to monitor biofuel feedstock prices	0.0	9.1	18.2	63.6	9.1
Biomass transport and storage logistics are not available at volumes required by full-sized biorefineries	0.0	0.0	0.0	100.0	0.0
Feedstock price uncertainty hampers our business.	0.0	0.0	18.2	63.6	18.2
Feedstock quantity and quality variations disrupt our production and low productivity	0.0	0.0	18.2	63.6	18.2
Cost of Technology and Financing:					
The eastern Africa region is not ready for second level generation biofuel due to technology constraints	0.0	9.1	9.1	63.6	18.2
eastern Africa countries can afford the technology that goes with large scale advanced biofuels deployment	0.0	9.1	18.2	54.5	18.2
Inadequate transport infrastructure will constrain the marketing of advanced biofuel products.	18.2	36.4	18.2	27.3	0.0
Eastern Africa countries will be producing second generation biofuels at significant levels in the 2040.	0.0	0.0	36.4	63.6	0.0

Lack of funding /financing is a major barrier to investment in advanced biofuels.	0.0	0.0	9.1	9.1	81.8
Markets through mandates and targets:					
Policies affecting our business are stable and clear	36.4	45.5	18.2	0.0	0.0
Mandates and blending obligations for advanced biofuels should be strengthened by price mechanisms like rebates, tax credits, reduced tax rates, and a market value for carbon.	0.0	0.0	18.2	18.2	63.6
Eastern Africa renewable fuel targets are insufficient to encourage investments in advanced biofuel production	0.0	0.0	36.4	36.4	27.3
Eastern Africa biofuel markets are too fragmented, then more coherent central regulation is needed	0.0	0.0	45.5	54.5	0.0
Targets for expansion of advanced biofuels production are not sufficiently ambitious	0.0	0.0	0.0	81.8	18.2
Regulatory uncertainty impedes investments in biofuel production	0.0	0.0	0.0	81.8	18.2
Blending limits discourage investment in advanced biofuel production	0.0	0.0	0.0	81.8	18.2
Eastern African governments should increase blending ratios and introduce flexi-fuel vehicles even if it's at a small scale to create local market for biofuels	0.0	0.0	54.5	27.3	18.2
Import tariffs are needed to protect domestic investments in advanced biofuels	0.0	0.0	0.0	100.0	0.0
Import tariffs have a negative impact on eastern African biofuel operations	0.0	0.0	36.4	36.4	27.3
Consumer demand:					
Introduction of Flex-Fuel Vehicles (FFVs) in eastern Africa could inspire biofuel production in the region	0.0	0.0	0.0	54.5	45.5
The future of eastern Africa biofuels is dependent on the customer	0.0	0.0	36.4	36.4	27.3
Introduction of electric vehicles (EVs) in the developed world pose a serious threat for biofuels business even in eastern Africa	0.0	0.0	54.5	45.5	0.0
International agreements will eventually limit greenhouse gas emissions in transport by forcing them to use biofuels	0.0	0.0	0.0	81.8	18.2
Sales of biofuel by-products and co-products is a necessary part of business to increase profits and encourage more companies to invest	0.0	0.0	0.0	18.2	81.8
Environment and Social	0.0	0.0	0.0	0.0	0.0
Biofuel production will not increase GHG emissions, land use change and indirect land use change	18.2	27.3	54.5	0.0	0.0
Conflicts over land could be more prominent due to expansion of first generation biofuel feedstock	0.0	0.0	18.2	54.5	27.3
Smallholder farmers will not benefit from biofuel expansion due to small land holdings	27.3	72.7	0.0	0.0	0.0
Food-vs-Fuel debate continues to push advanced biofuels business forward.	0.0	0.0	0.0	54.5	45.5
Environmental advocacy groups have not helped advance the production of biofuel generation biofuels.	0.0	0.0	27.3	27.3	45.5
Biofuels production will result in increased poverty and food insecurity	45.5	27.3	27.3	0.0	0.0
Biofuels production could increase deforestation and increase environmental pollution	45.5	27.3	27.3	0.0	0.0

Note: Feed stocks issues: Key: SD (1) = Strongly Disagree; D (2) = Disagree; NAD (3) = Neither Agree Nor Disagree; A (4) = Agree; SA (5) = Strongly Agree

The use of first generation crops such as Jatropha, Croton, Sugar cane and Sweet sorghum were found to compete with food crop land. Further, those conventional feed stocks such as corn and sugarcane were not sufficient to supply the global demand of bioethanol production because they are also needed for food and animal feed, in the presence of low productivity of crops as Strongly Agreed by 18.2%, and Agreed by 63.6% of the respondents (Table 3).

The other mechanisms for addressing the challenges were; putting up policies that should facilitate/enable sustainable production of biofuel. The policies should address the environmental degradation (biodiversity loss) associated with clearing of vegetation. Furthermore, the policies should guide investments in ways that balance is secured between food security and livelihood of the communities.

The liquid biofuel especially biodiesel was found to be relatively new in the countries, and that most relevant issues around biofuel are unknown. The major problems that can arise with biofuel and other large-scale agricultural investments are connected with land rights, and create conflict as stated by 54.5% of the respondents.

Effect of liquid biofuel production on cropland, forest margins and food security

The biofuel investment affected cropland in different ways in all areas visited because it was largely not based on pre-assessment of land-use plans. The local people interviewed (Table 3) responded that water levels in streams were reduced after forest clearance for biofuel crop production. However, biofuel crop planting activity in degraded land improved the water resources because those biofuel crops protected the soil and conserved water. For example, jatropha plantation in Bati woreda in northern Ethiopia served as gully rehabilitation and reduced the water erosion.

In eastern Africa countries the biofuel investments were of project nature, with occasional project funds that supported farmers for the biofuel feedstock. During the project the local people shifted to paid jobs as their means of income source when they gave their land. However, this support was later stopped when the projects terminated. When the local people got the land back in short period of time they resumed the agricultural practice without impairing food security. Many of biofuel production initiatives had collapsed, and with biofuel crop planting having no long term food security effect.

In Kenya, the productivity of biofuel feedstocks or food crops per unit area was below the expected maximum due to low quality planting materials, and poor management. Biofuel investments were mainly made on grazing land, degraded land and other suitable marginal land. There was many years of land lease to investors. However, the biofuel investments in most cases were abandoned and the land areas replaced by bushes, shrubs or converted to agricultural land.

In Tanzania, farmers, environmentalist and NGO's prompted the Tanzanian government to suspend the allocation of arable land, processing any new applications for biofuel projects and eviction of farmers over biofuel projects, pending ratification of a law and establishment of a regulatory mechanism to govern the sector and monitor the biofuel industry. In Tanzania, initially farmers faced a trade-off between selling their food to the biofuel producing companies or retaining it as food. This happened when the price of the food crops was higher in bio-fuel producing area than selling or retaining it as food. This led to the shortage of food to the community. Experience from Action Aid (2010), reported the vulnerability of rising in food prices in rural households as the results food shortages linked to over selling.

The effect of biofuel production on crop and forest land was associated with displacement of land. In all parts of the study areas in eastern Africa farmers complained about the land taken for jatropha and castor bean production. The forests in western Ethiopia, Gambella and Benshangul Gumz were cleared for oil palm and jatropha cultivation. In eastern Ethiopia in Babile elephant sanctuary and surrounding districts about 10,000 ha of primary forest land was cleared for castor biofuel crop production. The forest was meant for unique elephant population that exists only in east Africa (BirdLife Africa Partnership, 2012), thus disrupting migration routes. The allocation of forest and agricultural land for liquid biofuel crop production caused conflict with local people. The investment also destroyed wild life habitat (Gebreegziabher *et al.*, 2014).

In Ethiopia, over 80% of biofuel developments were done in arable lands, forest lands and woodlands (MELCA Mahiber, 2008). A land use land cover change in one of the sugar factories of Ethiopia called Finchaa, which made expansion to produce additional sugarcane showed that cultivated land, settlement and sugar cane plantation increased at a rate of about 580 ha/yr, 140 ha/yr and 140 ha/yr, respectively, whereas wetland, forest land and bare land reduced by 600 ha/y, 330 ha/yr and 60 ha/yr, respectively, in 1987–2019 (Tolessa et al., 2021). The wet land and forest lands were the main victims of many of the biofuel investments in Ethiopia.

In Kenya, investments in biofuel production was said to be neither in forest land nor in settlement areas. Biofuel investment was mainly on grazing land, degraded land and other suitable marginal land. However, BirdLife Africa Partnership (2012) stated that in Kenya, over 20,000 ha of forests were deforested in Tana River Delta and Dakatcha woodlands for sugar cane plantation which are important bird areas, seasonal grazing lands and regulators of the flow of River Tana. Clearance of mountains for biofuel production raised complains and conflict with environmentalists. In Kenya, land covers change transitions between 1988 and 2017 as a proportion of land area was 0.86% ±0.47 mainly because of deforestation of dense forest (Bullock et al., 2021).

In Tanzania, clearing of natural vegetation such as miombo woodland and the montane forests resulted in loss of watersheds which are important sources of rivers. The consequences of clearing large areas of natural forest habitats to give way to biofuels resulted in loss of biodiversity and created a "carbon debt" by releasing significant GHG emissions (Markensten and Mouk, 2012) and blocked the route followed by wild animals. Biofuel development created biodiversity loss, land conflict, labor issues, and indigenous right issues in places in Tanzania (Hance, 2015). In Kisarawe District Coastal Forests which were important habitat for endemic and endangered bird species, endangered primate, and transit route for elephants and buffaloes, sources of edible wild plants, pottery soils and water were partly deforested for jatropha plantation (BirdLife Africa Partnership, 2012). A land cover change (LCC) study conducted in Tanzania revealed a significant increase in cultivated land, a decrease in forested land and encroachment into forest reserve from 1985 to 2011. The conversion of land used for crop production into jatropha farming caused direct and indirect LCC in the area. In Kisarawe district, bareland area was converted to 8613ha agricultural land because of the introduction of jatropha farming (Mwakapuja et al., 2017).

Eastern African countries have undergone extensive environmental change in the past three decades, largely driven by the expansion of cropland and the conversion of naturally vegetated land covers by factors like biofuel crops. From 1988 to 2017, the area of cropland and settlements increased and largely reduced in woody vegetation (Bullock et al., 2021). Open forest (natural and planted forest tree-covered areas with 15–40% canopy cover) commonly observed in eastern Africa countries when compared to dense forest (natural and planted forests tree-covered areas with over 40% canopy cover, Olson et al., 2001). Deforestation of open forest occurred most frequently in Tanzania. However, the exact effect of biofuel development on deforestation and land cover change was difficult to determine because the areas of biofuel investment in most cases was abandoned and the land areas was replaced by bushes, shrubs or agricultural crops.

Trade and competitiveness of eastern Africa biofuels in international markets

Increasing the growth of domestic and international biofuel markets depend on increasing availability of feedstocks because a major constraint to the growth of biofuel markets is development of biofuels feedstocks. In Ethiopia, ethanol demand has been growing for transport and household cooking, pharmaceutical and alcohol beverage industries. For example, Gaia Association (2014) estimated bioethanol for substitution of kerosene demand as 85 million liters per year in Ethiopia.

In all countries surveyed, there were considerable potential domestic and foreign markets for liquid biofuel because of large population size and external cooperation. Ethiopia, Kenya and Tanzania are members of the Common Market for Eastern and Southern Africa (COMESA), embracing 20 countries with a population of about 380 million, and have market access at preferential tariffs. East African countries also have potential accesses to the Middle East markets, European markets and US markets. The internal markets can play great role in the production of liquid biofuel by fueling demand. For example, in Ethiopia the blending for the transport sector from 2009 to 2015 was about 48,000.kiloliters of ethanol that saved the country $39.6 million to import fossil fuels. The highest earning was in 2011/12 at about $9.23 million ; however, after 2015 the blending was interrupted by insufficient production of ethanol in the sugar factories (Figure 3).

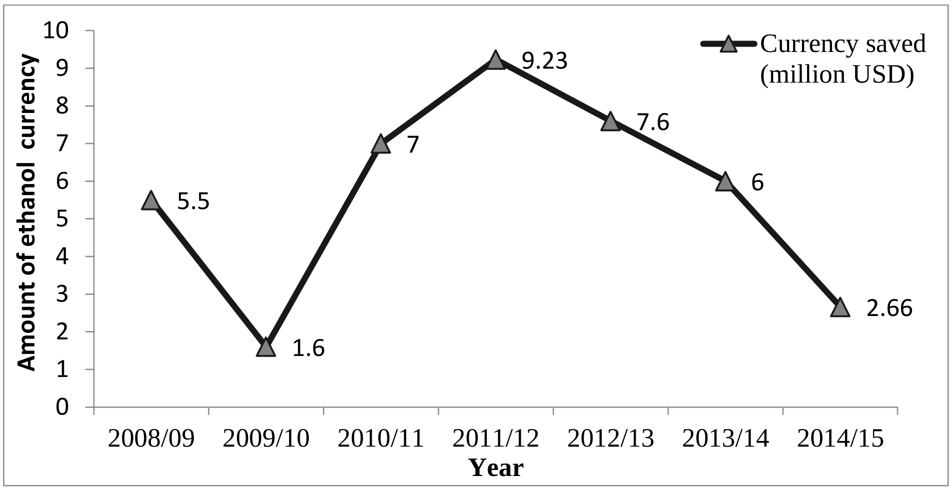

Figure **3**: Ethanol blending in Ethiopia, 2009 to 2015

During the initial stage of COVID 19 pandemic in March 2020 to February 2021 the demand of ethanol increased. The excise taxed ethanol was sold at USD 1.74 per litter which reduced demand.

In Kenya, bioethanol production emerged at the end of 2011 through the preferential trade terms on sugar agreed with other producers within the COMESA. Kenya had been using imported ethanol as cooking fuel for low income urban dwellers. The cost of bio-ethanol was inflated by 25% import tariffs and 16% value added tax (VAT) . If government of Kenya made bio-ethanol zero-rated for VAT and eliminated tariffs, it could displace charcoal and kerosene (Dalberg, 2018). The import could be from the neighbouring countries like Ethiopia. In Kenya, biofuel investment was socially acceptable because of job creation and reduction of unemployment, income increment, increasing energy supply and reducing soil erosion.

In Tanzania in 2007, *Jatropha Curcas* was labeled as one of the most exciting potential energy crops, but this potential was not realized a decade later. The cost of biofuel production was slowly declining as the price of petroleum was rising and increased awareness of renewable energy (UN, 2007). Furthermore, due to lack of regulatory framework for quality standards the study deduces, at this point in time that Tanzania biofuels, cannot compete in external markets. Tanzania had five main sugar mills in 2021, all of which had plans for investment and expansion. However, priority was given to sugar production (the country was a net importer) and better efficiency by clustering smallholder farms to improve agricultural practices and logistics management. Tanzania planned to import ethanol from Brazil in 2011 to reduce the cost of fuel by 10% but that was not achieved.

In eastern Africa, although investment in biofuels is currently not profitable, the market is projected to grow nationally and internationally with projected economic development and increased environmental awareness.

The quantity and quality of eastern African biofuels in the international markets

The eastern Africa countries has had bioethanol production and E10 (i.e. ratio of 90 to 10 of petrol and bioethanol respectively) blending program in early 1980’s in Kenya, and in 1979 in Ethiopia in their capital cities. The reduction in capacities of sugar factories and the low attention given to ethanol fuel production (because of drop in global fossil oil prices, and an increase in the price of beverage ethanol for alcoholic consumption), the ethanol had been sold for beverage factories within and out side the countries. Kenya was selling beverage ethanol to Uganda and Democratic Republic of Congo in the late 1980s.

After 2007 blending ratios planned to be issued by the Energy Regulator from time to time in Kenya, however, according to the Ministry of Energy the country hasn’t had a blending ratio issued. In Ethiopia, blending of ethanol and gasoline was commenced with the cooperation of Ministry of Industry and United Nations Industrial Development Organization (UNIDO) with the feasibility study conducted by the State Alcohol Monopoly of Finland Ltd. Then a French expatriate followed with a feasibility study of the production of yeast and bioethanol from molasses (Sugar Corporation, 2013). One of the sugar factories called Finchaa sugar factory was producing 6 million liters anhydrous ethanol annually since 2005 as a result of contract agreement entered with foreign, Italian company with an ex-factory price of \$0.202 per litre until the recent government decision that banned the export and to use for local gasoline blending (Tekle, 2008).

There was also information on the import of ethanol from USA and other countries and no document on the export of ethanol from Kenya. In Tanzania, there is no record of exporting ethanol and as it mostly depends on import activities.

Quality test of bioethanol was done by simple thermometer and alcohols meter. The quality of bioethanol was determined based on ISO certificate. The alcohol level of bioethanol for transport fuel was $\geqslant$99.9% (0.1% water) depending ISO standards. In Ethiopia, government was controlling oil distributing companies about the safety measures and operation to ensure the quality of the blended gasoline; however, there was no quality control system of the final blended gasoline at fuel stations and no quality standards because the fuel stations were operating in the already installed infrastructure of pure gasoline. Therefore, controlling the quality of gasoline requires modification to new infrastructure. Kenya Bureau of Standards (KEBS) was supposed to ensure quality of biofuels and set blending standards but not available in practice. In Tanzania, due to lack of regulatory framework for quality standards, there was no quality control.

In 2007 *Jatropha curcas* was labeled as one of the most exciting potential energy crops in Ethiopia, Kenya and Tanzania, but this potential has not been realized a decade later in 2020/21. Liquid biofuels were not available in the local market; therefore, the current study revealed that eastern African biofuels cannot compete in external international markets.

Policy and institutional frameworks for sustainable biofuel production in eastern Africa

In eastern Africa, regulations in biofuel investment forbid clearance of forest lands, while promoting feedstock production from degraded land that does not compete with food production. The focus of biofuel development is rural renewable energy development and climate change adaptation and mitigation. In Ethiopia the liquid biofuel policies include Biofuel Strategy of 2007, and Biomass Strategy of 2013, Biofuel Round Table of 2016 and others. In Kenya, the policies in liquid biofuel include *National Biofuels Policy (2010)*, the *Strategy for Developing the Biodiesel Industry (2008-2012) and biomass strategy 2013*. In Tanazania, a task force was formulated for the implementation of liquid biofuel investment. Key government bodies controlling investment in liquid biofuel sector are the Ministry of Water, Irrigation and Energy and Ministry of Agriculture in Ethiopia; Ministry of Energy, Ministry of Environment & Forestry, Ministry of Lands & Physical Planning and Ministry of Agriculture in Kenya and Ministry of Energy in Tanzania. However, all of these institutions lack clear mandate, and no follow up to sustain the liquid biofuel sector.

Currently, eastern Africa has no policies developed to aid sustainable production, transportation and consumption of liquid bio-fuels. The policies of the past failed because of lack of government support, as priority of energy shifted to hydro power in Ethiopian and Tanzania, and to geothermal energy in Kenya. The lack of policies hinders the development of biofuel companies as it limits them to small-scale (local) and bars access to more traditional fuel markets like gas stations and international markets. For example, in Tanzania, biofuels access to gas station market was hindered by lack of blending ratios (Table 4).

Table 4. Strengths and weaknesses of policies in development of liquid biofuel in eastern Africa countries of Ethiopia, Kenya and Tanzania

Country	Objective	Strength	Weakness
Ethiopia	• Produce adequate biofuel energy from domestic resources to substitute imported petroleum products and to export excess products, • Promote investment in forestry biomass • Ensure social and environmental sustainability of biofuel. • Planned expansion of ethanol production by constructing more sugar estates with ethanol mills attached • Planned to produce 450.3 million liters of biodiesel.	• Plan to reduce deforestation through and replacing firewood by renewable energies including liquid biofuel, • There was ethanol blending policy, E5 in 2008/2009, E10 in early 2011; and amendments to agricultural development and taxation policies were made to attract large-scale investments in agriculture including biofuels, • Planned to substitute fossil fuels in the transport sector.	• The institutions lack clear mandate on liquid biofuel sector. • Insufficient research information for biofuel policy to guide to grow bioenergy crops and to provide land • The energy policy of 2012 does not explicitly mention development of biofuels. • Lack of local people awareness creation.
Kenya	• Forbid clearance of forest lands, while promoting feedstock production from degraded land that does not compete with food production. • Strategies for promotion of collaboration with development partners; Mandates the government to facilitate the production of biofuels. It also directs KEBS to ensure quality of biofuels and set blending standards. • Provides instruments and tools for assessing proposed development activities on sustainbale basis.	• Formulation of policies lead to the establishment of research activities on liquid biofuels • Mandates the government to facilitate the production of biofuels. • Promotes strategies for preservation and conservation ecosystems. • Benefitted from Clean Development Mechanism (CDM) in the sugar industry using co-generation of electricity.	• All of the institutions lack clear mandate. • Insufficient research information for biofuel policy to guide to grow bioenergy crops and to provide land • No monitoring and evaluation
Tanzania	• Formulated guidelines for investments in the biofuel sector. • Project document on strengthening the policy, legal, regulatory and institutional framework for bioenergy development in Tanzania was prepared.	• Tanzania Investment Centre was the one stop centre for all biofuel investment in the country • Guideline and sustainability criteria developed by Task force. • liquid biofuels which include biodiesel and bioethanol can be blended with petroleum products at various ratios.	• Tanzania has no policies developed to aid sustainable production, transportation and consumption of liquid bio-fuels. • Both policies, legal and regulatory frameworks are in draft. • Lack of institutional memory on the reasons behind closure biofuel investment • TIC lost coordination efforts and lack

		proper implementation.

Problems in the biofuel related strategies and policies

The biofuel investment in eastern Africa countries was a kind of complain in 2007. The investment was abandoned without further generation of income on lands meant for local community. In Ethiopia the farmers lost trust on the local development agents and professionals because the promised income from the widely planted jatropha (more than 48 districts) and other biofuel crops was not realized. Similarly, large areas of jatropha, castor and croton planted in Kenya and Tanzania left without any significant income (Table 5 and Table 6).

The problems in liquid biofuel investment can be summarized as:

- Lack of sustainability and standards on producing, processing and consuming liquid biofuels in the value chain.
- Lack of consensus on definition of marginal land, which were planned to plant biofuel crops.
- Lack of clear mandate of the different ministries engaged, and regional offices to enforce regulations, such as land allocation, feedstock type selection, and licensing promoting investment.
- Lack of appropriate technologies in the different steps of liquid biofuel production and processing.
- In Ethiopia, and Tanzania there was principle of "one-stop-shopping" investment regulations that guided biofuel development which was abandoned .
- There was no private sector incentives to invest in biofuels. It is believed that incentives are necessary tools to encourage entrepreneurs into biofuel production.

Table 5. The strength and weakness of institutions for liquid biofuel industry in eastern Africa countries of Ethiopia, Kenya and Tanzania

Country	Institutions for biofuel development	Strength	Weakness
Ethiopia	• Ministry of Mines and Energy (Ministry of Mines, Petroleum and Natural Gases (MoMPNG), • Ministry of Water, Irrigation and Energy, and Ministry of Agriculture, • Regional energy offices, • Rural energy promotion center, • Ethiopian Institute of Agricultural Research and Ethiopian Environments and Forest Research Institutes	• Establishment of bioenergy directorate, • Introduction of renewable energy sources and technologies such as wind, solar, and biogas, • Initiation of the concept of liquid biofuel such as bioethanol, and biodiesel, • Conducting research on forestry, firewood and agricultural energy crops	• Lack of coordination, lack of monitoring and evaluation, lack of silvicultural and agronomic management lack of market identification for liquid biofuel feedstock production and lack of budget to conduct research, • The activities at federal, regional and investment offices were not clear and sometimes overlapping, in activities like land provision. • Frequent administrative structure changes that disturb attentive work,
Kenya	• Ministry of Energy (MoE), • Ministry of Environment & Forestry, • Ministry of Lands & Physical Planning and Ministry of Agriculture	• MoE has coordinated the formulation and development of many relevant policy and regulatory frameworks on liquid biofuels production and processing, • Formulation of policies to produce biofuels in nonresidential, and degraded lands	• All of the institutions related to biofuel lack clear mandate and no follow up to sustain the liquid biofuel sector.
Tanzania	• Ministry of Energy (MoE) by then Ministry of Energy and Minerals (MEM) • Ministry of Energy	• Tanzania Investment Centre is the one stop centre for all biofuel investment in the country	• All of the institutions related to biofuel lack clear mandate and no follow up to sustain the liquid biofuel sector because of lack of policies, lack of blending ratios, lack of institutional memory and lack of documentation to recall past events on biofuel, and all in all lack of biofuel coordination,

Policy directions

The eastern Africa countries faced failure of biofuel policies in the production period of 2007 to 2021. Then it is possible to deduce the need for additional policies that include updating the biofuel strategy, provision of incentives, institutional strengthening, development of directive, standards and guidelines, formulating biofuel development, monitoring and evaluation system. Therefore, policy directions are required depending on the problems and deficits identified. The policies need to have two dimensions namely political and strategic pillar. The political pillar deals on the institutional strength of the ministry on the authority, coordination, and promotion of different organizational level of biofuel production as well as the directorate through political actions. While the strategic pillar deals on developing strategic actions both in supply and demand side so that the biofuel market could be strengthened by establishing fixing prices, promoting high yielding varieties, and developing land-use planning protocols (Table 6).

Table 6. Political and strategic pillars of biofuel development sector in eastern Africa countries of Ethiopia, Kenya and Tanzania

Policy dimenstion	Ethiopia	Kenya	Tanzania
Poletical pillars	• Strengthening the authoritative body		• Strengthening the authoritative body
	• Strengthening institutional capacity	• The same as Ethiopia	• The same as Ethiopia
	• Coordinating among ministries		• Coordinating among ministries
	• Establishing international market	• The same as Ethiopia	• The same as Ethiopia
	• Carry out regional and international stakeholder analysis		• Carry out regional and international stakeholder analysis
	• Favourable policies and regulations		• Favourable policies and regulations
	• Assist small-scale producers		• Assist small-scale producers
	• Promote public private partnership		• Promote public private partnership
	• Collaborate with international actors		• Collaborate with international actors
	• Linking biofuel with emission reduction funding		• Linking biofuel with emission reduction funding
	• Promote local processing capacity by installing processing factories	• The same as Ethiopia	• The same as Ethiopia
Strategic pillars	• Establishment of national markets in addition to international market	• The same as Ethiopia	• The same as Ethiopia
	• Value chain analysis and GHG emission determination of the lifecycle of liquid biofuels utilization ,	• The same as Ethiopia	• The same as Ethiopia
	• Fixing the prices of feedstock, liquid biofuel and blended fuel.	• The same as Ethiopia	• The same as Ethiopia
	• Managing the environmental impacts		• Managing the environmental impacts
	• Carrying out capacity building	• The same as Ethiopia	• The same as Ethiopia
	• Developing land use planning		• Developing land use planning

	• Understanding interactions between biofuel crops and ecosystem dynamics	• The same as Ethiopia	• The same as Ethiopia
	• Mainstreaming research and development of biofuel crop	• The same as Ethiopia	• The same as Ethiopia
	• Promote high yielding varieties	• The same as Ethiopia	• The same as Ethiopia
	• Intercropping in agricultural farm plots		• Intercropping in agricultural farm
	• Avoiding use of basic food crops		• Avoiding use of basic food crops
	• Favoure biofuel with biodiversity		• Favoure biofuel with biodiversity
	• Demonstrating for small holder		• The same as Ethiopia
	• Research bio-fuel crop productivity	• The same as Ethiopia	• The same as Ethiopia

Conclusion

- Africa is reported to have biofuel development strategies since 2007 that targeted to increase the role of biofuel in reducing the import of petroleum; however, this has not borne much fruit in terms of an actual growth in biofuel industry due to several bottlenecks.
- Challenges in liquid biofuels production and utilisation include lack of enough trained people, non-mechanized system of feedstock production, lack of investment capital, lack of quality feedstock planting material and unclear land tenure systems. Other challenges include lack of multidisciplinary and holistic policies that encompass environment, agriculture and the community, and lack of local knowledge on liquid biofuel production.
- Some of the coping mechanisms to contain these challenges include facilitating access to credit from banks, as well as national governments providing incentives such as tax reduction, and subsidies in the form of enabling policies, friendly regulatory frameworks and active political support.
- The biodiesel development in eastern Africa was not successful because of lack of previous experience, lack of local people participation, lack of well-known biodiesel crops, lack of technology, insufficient research on many aspects of the industry, and insufficient land suitability analysis. Collaboration of smallholders farmers, private sector and government in liquid biofuel production was very low, therefore constraining sustainable production of biofuel.
- The involvement of foreign investors in eastern Africa for the production of biodiesel was not realistic, taking place without the knowledge of the need of local people, the type of soil and climate and crop type.
- Bioethanol production from sugar cane molasses in eastern Africa is viable with production of over 100,000 litres per day whereas viability and competitiveness of

biodiesel production require highly productive feedstock per unit area and per unit time higher than the currently utilized feedstocks such as jatropha, croton, castor, and oil palm. Bioethanol production relied entirely upon government efforts on sugar cane molasses. The efforts in sweet sorghum in Kenya and cassava in Tanzania were promising.

- The failure of the liquid biofuel investment resulted in policy direction towards research on biofuel crops, mixed model of small and large scale production of bioenergy crops on degraded lands.

The foreign large-scale plantations of biofuels might not always be a suitable mode of production, since they will involve taking up considerable land; something, if not done properly, could create considerable pressure on land in the near future that could lead into social conflicts as the population grows.

Recommendations

- Favorable economic situation in the countries and biofuel trade liberalization to private sectors and regional centers of private public partnership are highly important.
- There is need for policy and regulatory support such as subsidies on acquiring advanced technology for lignocellulosic ethanol and pyrolysis oil production in addition to well-structured institutional arrangements. Feedstock producers and processors need contractual agreements with guaranteed markets.
- Radical changes are required based on the international interest of climate policy that include right human and organizational capacity , right legal system and other frameworks to achieve biofuel sector green goals, and facilitate public, private sector, SMEs and researchers, and civil society organizations to engage in biofuel development.
- Policy incentives are crucial to make commercially driven biofuel successful for the formulation of common polices by neighbouring countries on pricing and blending to prevent cross border smuggling.
- Co-operation between stakeholders (government ministries, farmers, alcohol producers, oil marketing companies and car manufacturers), is highly needed for the elaboration and the implementation of the liquid biofuels projects.
- Establishment of long-term, stable and clear policies, regulations and incentives are highly needed for liquid biofuel investment.
- Initial price guarantee for biofuels (e.g. through fixed prices by the government) in order to secure return on investment in the biofuels sector; protection of local

manufacturers against biofuels imports in order to facilitate the build-up of a strong national biofuels industry; and establishment of revenue sharing mechanisms to ensure that small-scale farmers benefit from additional revenues generated through the production of biofuels should be practiced.

Conflicts of interest

There is no conflict of interest.

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Runs Of Homozygosity and Effective Population Size from Different Goat Genotypes in Kenya

Subtitle: Analysis of ROHs and Ne in Kenyan Goat Genotypes

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Abstract

Limited genetic information in most goat populations hinders the implementation of better breeding strategies for genetic conservation and improvement. Runs of Homozygosity (ROH) were used to analyse the distribution, inbreeding coefficients and effective population size (Ne) of different goat genotypes in Kenya. This was performed from 48808 Single Nucleotide Polymorphism (SNP) that were detected for analysis after quality control. The SNP data of four goat genotypes were used; Galla (n = 12), Alpine (n = 28), Saanen (n = 24) and Toggenburg (n = 30). Across the genotypes, 348 ROHs were detected with the highest number (180) observed in Toggenburg and lowest (22) in Galla. From the ROH length categories, the highest mean length was observed on the long ROHs category (>16 Mb) suggesting a recent inbreeding. The distribution of ROHs per chromosome was breed-specific without a clear pattern across the genotypes. Furthermore, 32 genomic regions with a high frequency of ROHs were detected. Sixteen genes (missense and synonymous) associated with various phenotypic functions were identified. High inbreeding coefficient values of > 0.1 were observed in all exotic genotypes suggesting continuous use of few breeding bucks. Toggenburg was found to be the most inbred genotype with the highest inbreeding coefficient of 0.68. The effective population size decreased over time across the genotypes. Galla, Saanen and Toggenburg at recent generation (13genAgo) recorded Ne of less than the recommended threshold (Ne = 100) population indicating a limited genetic diversity. The study outcome emphasize the need to use different lines of exotic goats, improved technologies, and/or sustainable implementation of controlled breeding programs.

Keywords: Goats, Genotype, Inbreeding coefficient, Runs of Homozygosity, Effective population size, Kenya

Introduction

Farmers at small and large scale practice goat production worldwide. In most African nations including Kenya, goat production helps in improving rural livelihood through the provision of meat, milk and income among other benefits (Monau *et al.* 2020a). Kenya is reported to have a diverse genetic structure of goats for both exotic and local genotypes used for genetic improvement programs (Kivila *et al.* 2018; Waineina *et al.* 2021). The shape of the animal genomic structure depends on factors such as geographical location, production and breeding systems that have the potential to increase or decrease genetic diversity (Bosse *et al.* 2012). Inbreeding leads to reduced genetic diversity and hence reduces the animal fitness. Inbreeding levels can be measured at both individual and population levels. Due to improvement in genomic technologies, the most effective way of measuring inbreeding in a population is through estimation of inbreeding coefficients from Runs of Homozygosity (ROHs) (Peripolli *et al.* 2017; Rebelato *et al.* 2018). The ROHs are continuous homogenous regions of the genome in an individual, which occurs due to the inheritance of identical alleles from parents (Ceballos *et al.* 2018). Unlimited artificial selection for beneficial alleles in a population can also increase homozygosity in genomic regions.

ROHs are either long or short and they usually follow specific distribution patterns in the animal genome (Zhang *et al.* 2015). Long ROHs indicate recent inbreeding whilst short ROHs, indicate ancient inbreeding implying the mating of closely related individuals which is not easily accounted for due to lack of pedigree information. The presence of ROHs patterns in specific genomic regions in selected individuals provides different information. For instance, ROHs distributional patterns have been used to describe the demographic history, gene mapping or differences between livestock genotypes among other genetic information (Upadhyay *et al.* 2017; Islam *et al.* 2019; Xu *et al.* 2019).

The effective population size (Ne) is defined as the size of an idealized population that undergoes the same genetic drift rate and inbreeding as the actual population under study (Falconer, 1996). Ne is an important genetic parameter that describes the genetic diversity level of a population and it is estimated by measuring pairwise Linkage Disequilibrium (LD) as a squared correlation coefficient (r^2). The LD refers to the non-random association of alleles which depends on the evolutionary history and the Ne (Deng *et al.* 2019). Changes in Ne over time in a population helps to measure population genetic diversity and implement conservation of important animal genetic resources.

Using Single Nucleotide Polymorphism (SNP) data, this study focused on genomic characterization of ROH distribution, inbreeding coefficients and the Ne among the exotic and local goat genotypes found in Kenya. Despite the genetic diversity and structure of Kenyan goat genotypes being known, information on various genetic parameters such as ROHs within the genotypes is still limited. This study information will enable farmers and livestock breeders to know the accumulated ROHs and inbreeding levels of goat populations in Kenya. Therefore, effective breeding strategies will be easily implemented to improve goat productivity and conservation of unique traits.

Materials and Methods

Sampling

A total of 96 goats from four goat genotypes obtained from 53 farms and one government breeding station in Kenya was used in this study. The goats were purposively selected in different ecological zones of Kenya, namely; Nyeri (Mukurweini Sub-County), Meru (Central Imenti Sub-County) and Homa Bay (Homa Bay town) located in the Central (wet-dry), Eastern (wet) and Western regions (wet area) respectively. The selected areas are some of the entry points of exotic breeds in the country. The goat genotypes that were investigated included; Saanen (n = 24), Alpine (n = 29) and Toggenburg (n = 31) sampled from members of goat farmer associations across the selected Counties and Galla (n = 12) from Naivasha, Sheep and Goat government station. Number of goats varied between the breeds and within the sampled households which led to variations in sample size across the genotypes. Blood samples were collected at each selected farm. A member with two does only one doe was used and where there were more, the relationship of the does was confirmed by the farmer to avoid selecting full and half siblings. For Galla goat, pedigree information was used to ensure sampling of unrelated goats.

DNA extraction and genotyping

Blood samples were collected at each selected household by a qualified veterinary officer. The animals were constrained during blood collection and all FAO protocols for sampling of blood for DNA were observed. The blood were collected into Ethylenediaminetetraacetic acid (EDTA) tubes from the Jugular vein and stored at -20^{O}C for two months before genomic extraction. Blood sample duplicates were also collected and kept separately.

DNA extraction was done using the Qiagen DNeasy Blood and Tissue Kits. Purified DNA quality and quantity were validated using the Qubit dsDNA BR (Broad-Range) Assay Kit on the Qubit 2.0 and Nanodrop Spectrophotometer (Nanodrop ND-1000). Genotyping was conducted using the Illumina goat SNP50 Bead chip developed by International Goat Genome Consortium (IGGC). Quality control procedures of SNPs were done in PLINK v 1.9 (Chang *et al.* 2015). Standard parameters of SNP filtering were applied: all SNPs < 95% call rate, < 0.05 Minor Allele Frequency (MAF < 0.05), Hardy-Weinberg Equilibrium (<0.001) and more than 10% missing genotypes were removed. The study protocol was approved by the Egerton University Research Ethics committee and it occured in strict accordance with the recommendations of the institute of Primate Research (IPR) Ethical guidelines on Animal care and use of Laboratory Animals.

Statistical analysis

Distribution of runs of homozygosity

Total number, frequency and length distribution of ROHs (Mb) were identified per individual and per genotype in PLINK v1.9 (Chang *et al.* 2015). Homozygosity in this study was defined based on the following parameters; having a minimum number of 15 consecutive homozygous SNPs, a minimum physical length of 1 Mb, 1 maximum missing genotype and 1 heterozygous call were allowed within the ROHs for genotyping errors (Kumar *et al.* 2018; Islam *et al.* 2019). For the chromosomes, the percentage of chromosomes covered by ROHs was calculated by dividing the mean ROH length of chromosome by their respective chromosome length multiply by 100 (Al-Mamun *et al.* 2015). ROHs length was categorized into four classes; 2–4 Mb, 4–8 Mb, 8–16 Mb and > 16 Mb.

Estimation of inbreeding coefficient

The inbreeding coefficient was estimated per individual and genotype. Runs of Homozygosity inbreeding coefficients (F_{ROH}) was determined by dividing the total length of ROHs (L_{ROH}) in an individual genome with the autosomal genome length (L_{AUTO}) of goats (2399.4 Mb), (Islam *et al.* 2019).

Genomic Regions with high ROH frequency

The percentage of SNP occurrence was determined by calculating the number of times each SNP occurred in the ROHs throughout the populations. The top 10% of ROHs observed in each genotype were identified as genomic regions with high-frequency ROHs which were extracted using vcftools. The ROHs were then uploaded in the ENSEMBL goat *Capra hircus* using the Variant Effect Predictor (VEP) for functional annotation.

Effective population size

The SNeP v1.1 was used to estimate Ne among the genotypes based on LD (Barbato *et al.* 2015). This followed the formula described by (Sved, 1971);

$$E(r^2) = \frac{1}{[1/(1+4N_e c)]}$$

Where;

Ne is the effective population size,

c is the genetic distance between SNPs in Morgans

$E(r^2)$ is the expected correlation between allele frequencies of two loci.

The estimated Ne were plotted against the past 1000 generations to determine its trend.

Results

Detection of ROH and ROH patterns

348 ROHs were detected across the goat genotype with a mean of 4.703 per individual. Table 1 shows the descriptive statistics of ROHs per genotype among the studied populations. The number of ROH per genotype according to length category shows more short ROHs than long ROHs (Table 2). Additionally, ROHs detected per chromosome vary according to genotype in all the 28 chromosomes (Fig 1).

Table 1. ROH Descriptive statistics per genotype

Genotype	No. Of ROHs Detected	No. Of individuals with ROH	Mean No. Of ROH	Stdev. of ROH	ROH length (Mb)	Mean ROH length
Alpine	54	20	2.7	29.77	554.92	27.75
Gala	22	5	4.4	14.9	211.17	42.23
Saanen	92	22	4.2	29.41	846.67	38.49
Toggenburg	180	27	6.7	36.86	1631.53	60.43

Table 2. Total number of ROH, Total number of individuals with ROH and mean sum of ROH length (Mb) according to ROH categories across the genotypes.

ROH length category	Gala			Toggenburg			ALP			SAA		
	ROH No.	No. Of Indv.	Mean Length	ROH No.	No. Of Indv	Mean Length	ROH No.	No. Of Indv	Mean Length	ROH No.	No. Of Indv	Mean Length
2-4Mb	0	0	0	0	0	0	0	0	0	0	0	0
4-8Mb	12	5	6.13	102	27	5.99	30	17	6.33	50	22	5.91
8-16Mb	8	5	12.02	59	22	10.45	16	12	12.02	32	14	10.68
>16Mb	2	2	20.76	19	13	21.25	8	4	24.84	10	8	20.95

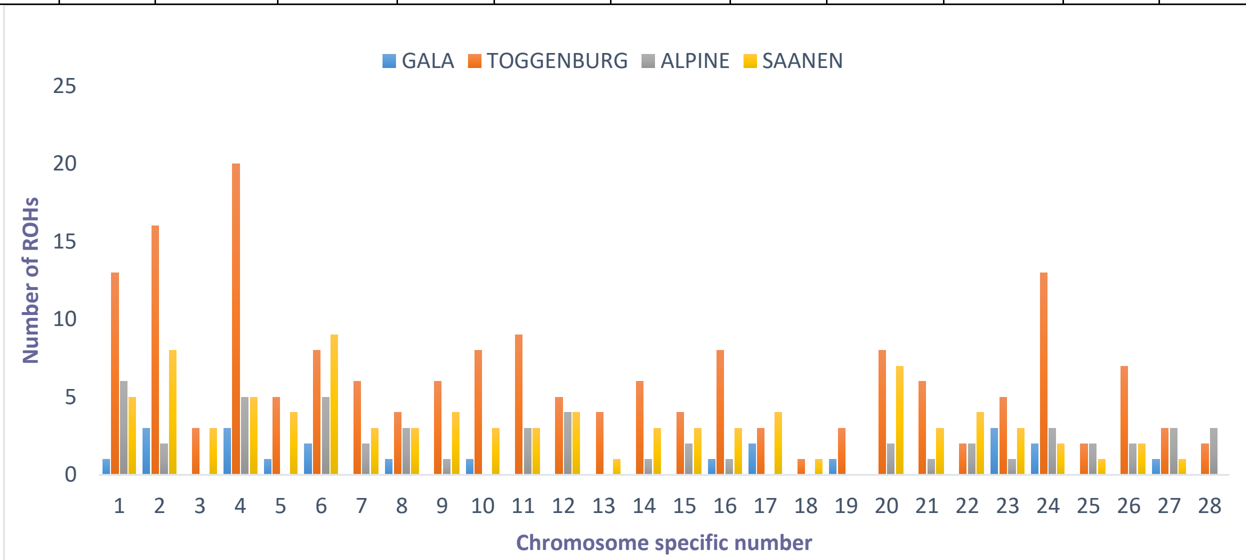

Figure 1. ROHs identified per chromosome per genotype

Inbreeding coefficients

The overall inbreeding coefficients calculated from runs of homozygosity in this study were 1.35. The variations of inbreeding per genotype are presented in table 3 where Tottenburg shows the highest inbreedin levels (0.68) compared to other genotypes in the study.

Table 3. Inbreeding coefficients per genotype

GENOTYPE	GALA	TOGGENBURG	ALPINE	SAANEN	TOTALS
Inbreeding coefficient per genotype	0.09	0.68	0.23	0.35	**1.35**
Mean Range	0.02	0.03	0.01	0.02	
Total ROH length	211.17	1631.53	554.92	846.67	
Mean ROH length	42.234	60.427	27.746	38.485	

Genomic regions with high frequencies of ROH

Runs of homozygosity islands and SNP percentage were evaluated in all the four goat genotypes where 34 genomic regions were identified. Sixteen genes were identified from the genomic regions with missense and synonymous effects.

Table 4. Genomic regions with the high frequency of Runs of Homozygosity (ROH), genes identified and their consequences

Genotype	CHR	START	END	GENES	CONSEQUENCES
TOT	2	121194945	127160014	ZSWIM2, FSIP2,	Missense
TOT	2	122540040	127934583	ZSWIM2	Missense
TOT	2	29975669	35490029	ABCA12	Missense
SAA	8	103492446	112591777	MYT1L, MEGF9	Missense
GAL	17	50496599	55334347	NAA15	Synonymous
SAA	17	24404597	28958842	PIWIL1	Missense
TOT	17	23941309	28606126	PIWIL1	Missense
TOT	21	39316366	46004536	EAPP, AKAP6	Missense & Synonymous
TOT	21	40245597	47248076	EAPP, AKAP6	Missense & Synonymous
SAA	23	35428109	40516154	PNPLA1, ZNF76,	Synonymous
SAA	24	56109867	61291762	ATP8B1	Missense
ALP	27	3855715	10045474	RARB, TOP2B	Missense
SAA	27	1051338	7735492	RARB, TOP2B	Missense
TOT	27	600400	10512553	KAT6A, RARB, TOP2B	Missense
ALP	28	39181	5758953	C10orf71	Missense

CHR = Chromosome

Effective population size (Ne)

The estimates of ancestral effective population size (Ne) over past generations obtained in this analysis are presented in fig 2. As the number of generations increases, effective population size across the genotypes also increased at a different increasing rate. Effective population size for Alpine tends to increase rapidly compared to all other genotypes in this study. At the most recent 13th generation, the Ne for Alpine, Gala, Saanen and Toggenburg was 109, 49, 81 and 93 respectively indicating little genetic pool for all the genotypes except Alpine. The Ne for the furthest distant generation was 3709, 2428, 7515 and 2548 for ALP, GAL, SAA and TOT respectively, Supplementary file 1.

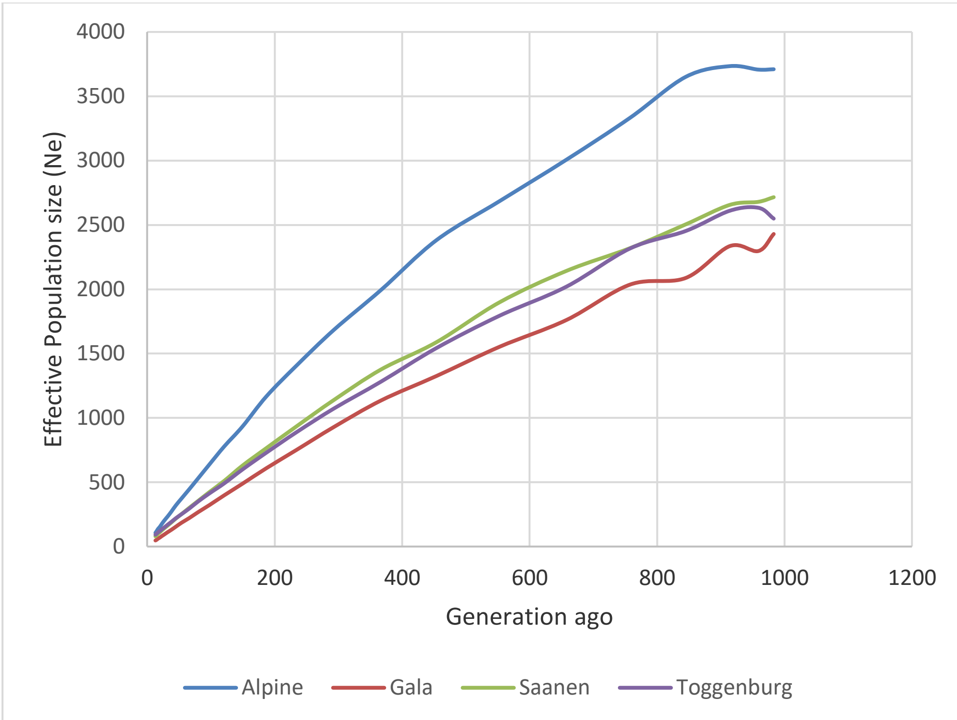

Figure 2. The effective population size of Kenyan goat genotypes

Discussion

Runs of homozygosity

The descriptive statistics of ROHs per genotype (Table 1) show differences among the studied populations. Generally, all genotypes in this study have ROHs in their genome whose presence varies in terms of the total number, length and distributions. These findings are similar to the distribution of ROHs observed in Italian goat populations and cattle breeds of Poland (Szmatola *et al.* 2019; Mastrangelo *et al.* 2021). According to Bosse *et al.* (2012), the formation of ROH in a population is a factor of demographic events and recombination rate. The mean ROH length tends to be higher in Galla compared to Alpine and Saanen which recorded low numbers of ROHs. A similar trend was also observed in domestic Greek goat breeds (Michailidou *et al.* 2019).

Results for the analysis of ROHs per different length categories varied across the genotypes as indicated in table 2. Xu *et al.* (2019), reported that different length categories of ROHs provide information on genetic variations between genotypes. The highest mean length of ROH coverage across genotypes was observed in long ROHs > 16 Mb which suggests recent inbreeding. Similar observations were made in Asian pig and Italian goat populations (Bosse *et al.* 2012; Mastrangelo *et al.* 2021). This result can be attributed to management and breeding systems applied in these populations such as uncontrolled breeding, artificial selection of best breeding bucks or the presence of few replacement stocks for breeding in the population. Furthermore, ROHs were more common in short ROHs (4 – 8 Mb) than in long ROHs (> 16Mb) contrary to what was observed in related ROH studies of goats and sheep (Purfield *et al.* 2017; Onzima *et al.* 2018). Generally, the majority of the mean ROH coverage was reported at the length of >16Mb suggesting recent inbreeding across the genotypes. This information is important for planning better breeding programs since most deleterious variants are reported to be carried in the long ROHs (Szpiech *et al.* 2013). The ROHs detected per chromosome varied according to genotype in all the 28 chromosomes (Fig 1). The distribution pattern of ROH per chromosome across the genotypes was non-specific concurring with the fact that the distribution of ROH per chromosome is breed-specific (Mastrangelo *et al.* 2017). The highest number of ROHs in chromosome 4 of Toggenburg suggested continuous transfer of ancestral genes specific for chromosome 4.

Inbreeding coefficient

The observed individual genomic inbreeding coefficients calculated from ROHs were generally low (0.00 to 0.07) indicating non-inbred individuals. For instance, the inbreeding levels per individual for Alpine goats were below 0.05. This concurs with the findings of other scholars in related studies who concluded that Kenyan Alpine goats are not inbred and they suggested the implementation of a controlled breeding system to avoid future inbred populations (Marete *et al.* 2011). A population with low inbreeding levels must have inbreeding coefficient levels of less than 0.1. In this study, only local Gala recorded F_{ROH} value of 0.09 which corresponds with the observed low numbers of ROHs. This suggests that the genetic material for this genotype is at least well managed in the government farm but measures must be implemented to maintain recommended inbreeding levels at both at the controlled farms and farmer levels. The variations of inbreeding per genotype show that exotic genotypes were most inbred with inbreeding levels of 0.68, 0.39 and 0.23 for Toggenburg, Saanen and Alpine, respectively, as presented in table 3. This observation is in agreement with the inbreeding coefficient values of goats observed from different geographical locations by Bertolini *et al.* (2018). It can therefore be eluded to the extensive use of exotic bucks for breeding in goat populations since these genotypes were brought in Kenya to improve local goat productivity.

Genomic regions with the high frequency of ROH

From the genomic regions associated with the high frequency of ROHs, more missense genes (12) were identified compared to synonymous genes (4) as shown in table 4. This observed missense and synonymous genes were reported to be associated with genetic disorders or diseases, reproduction and general body immunity. However, evaluation of the identified genes in the goat population is limited compared to other mammal species.

Effective population size

The Ne for all the genotypes at the very distant past (983 generations ago) was high with Ne values of above 2000 across the genotypes. Over time until the recent present, a decrease in the Ne was observed (Fig 2). This trend was also observed in local swiss sheep (Bertolini *et al.* 2018), Australian and Canadian boar goat (Brito *et al.* 2015), Buffalo populations (Deng *et al.* 2019) and local South African goats (Monau *et al.* 2020b). To ensure the long-term viability of any livestock population, the effective population size must reach a threshold of Ne = 100 (Meuwissen *et al.* 2009). However, at the 13th generation, ago recent Ne for all the genotypes except Alpine did not meet the required Ne threshold (Ne = 100) indicating limited genetic diversity. Similar results were also obtained at 13th generation ago in two goat populations of china (Islam *et al.* 2019). Measures such as exchange of breeding bucks or use of artificial insemination can be implemented in Gala, Saanen and Toggenburg to ensure the required levels of diversity are sustained. It is important to ensure that populations of local genotypes have high genetic variations at all times since they are a source of many genetic materials adaptable to the local environment (Monau *et al.* 2020b). In the 20th generation ago, the Ne for all exotic genotypes was above the threshold of Ne = 100 with 156, 113 and 122 for Alpine, Saanen and Toggenburg. These results are comparable with Ne observed in the same goat breeds at 20th generation ago (Brito *et al.* 2015).

Conclusion

Accumulations of ROHs have been confirmed in the goat population of Kenya with high numbers of ROHs and inbreeding levels observed in exotic goat genotypes compared to the local genotype. This indicates uncontrolled breeding among the studied goat population, which causes an increase in homozygosity and affects the effective population size. Therefore, strategic breeding should be a priority in these populations to avoid a reduction in genetic diversity which can lead to loss of important genetic materials and accumulation of undesirable genes. Therefore, special considerations should be made to have different lines of exotic goat genotypes, use of improved technologies such as Artificial Insemination and/or implementation of controlled breeding programs to ensure effective genetic improvement and conservation.

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Modern Technology Techniques for Adoption of Agriculture; An Implementation Review for Developed and Developing Countries Using the CCE Model Approach

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Abstract

The main focus of this paper is to give an introduction review of the modern technology techniques, their value, usage and contribution to better agriculture. In the recent past, the basic agricultural technologies such as machines has changed; as much as the modern technologies, harvesters and planters perform better or are slightly altered from their predecessors. The current US$250,000 combine harvester still cuts, threshes and separates grains as always was being done in the past. However, modern technology is transforming the ways humans operate the machines, GPS Systems Locators, as computer monitoring systems and self-driven software allow advanced tractors and other equipment to be more accurate and economical in the use of fuel, seeds or fertilizer. This study aimed at establishing the value and contribution of using modem technology techniques in the adoption of Agriculture. Content analysis was done on selected developing and developed countries using purposive sampling on the content covered. The data extracted from the content analysis was analyzed quantitatively. It was established that countries that have embraced modern technology in their Agricultural practices have more output in Agricultural production and are more food-stable as opposed to those countries that have not fully embraced the use of modern technology techniques in Agriculture. Therefore, the study concluded that as technology becomes more advanced and complex, in future, there is likely to be a mass production of driverless tractors and other agricultural machinery which will likely be required to make use electronic sensors and GPS maps, requiring less human intervention with greater agricultural output.

Key words: **C**ritique, **C**onfigure, **E**xtend, Modern Technology, Pesticides, Crop Sensors, Gross Domestic Product, Biotechnology and Inorganic Fertilizers

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Introduction

In the recent few years, development measures in agricultural sector and policies have been set in successfully while emphasizing on external inputs so as to increase production of food (Niels & Jules, 2023). Thus, leading to growth in consumption of pesticides, inorganic fertilizer, animal feeds, tractors and other machinery. These and other inputs have been replaced with natural resources with new processes, rendering them less powerful. Pesticides have replaced with cultural and biological methods mainly for control of pests, weeds and diseases. Inorganic fertilizers have best been substituted with manure in composts and nitrogen fixing crops. The main challenge of sustainable agricultural practice is to ensure better use of these internal resources. This will ensure the overall minimizing of inputs used externally, by regenerating internal resources more effectively. It is clearly evident that technologies and practices which are developmental and resources conserving can bring both environmental and economic benefits to farmers, communities and nations (Eva & Matin, 2018).

The modern technologies used in agricultural sector can substantially increase the agricultural production and sustainability. For example, best management practices for advancement of agriculture are extensively used nowadays, (Abdul *et al.,* 2017). New disease resistant hybrids, reduced pesticide use, biological pest control, cultural practices which can reduce the incidence of pests and diseases. Insect-specific chemicals and biological insect controls are now being applied, instead of broad-spectrum pesticides, which actually reduce the number of sprays needed and therefore its capitals. GIS, Crop models and remote sensing can provides information to farmers for attaining precision agriculture, which is done by matching inputs as per all actual yields of different portions on the field. These tools play an important role and also allow the industry to manage land for both agriculture and wildlife. (Rajendra & Sunsanee, 2016)

For increasing food production the evidence comes from some countries of Africa, Latin America, and Asia where farming has been largely untouched by the modern technology (Niels & Jules, 2023). There are three common elements in which these have success. They are using resource conserving technologies like as integrated pest management, soil and water conservation, nutrient recycling, water harvesting and

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waste recycling. Some groups and communities are helping farmers in becoming experts at managing farms as ecosystems; they also have supportive and enabling external government and non-government institutions, which have realigned their activities to focus on local capabilities and needs. Most policies still actively encourage farming that is dependent on external technologies and inputs. (World Bank, 2023).

Objectives of the study

The study will be guided by the following objective:

1. To establish the contribution of modern technology techniques towards the improvements of Agriculture.

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Materials and Methods

Content analysis on selected developing and developed countries was performed to assess the food and agricultural production levels. This was done in respect to the use of Modern technology techniques for adoption of Agriculture. This helps to quantify and analyze the presence of relationships, patterns and concepts (Kathryn Reis, 2023).

Purposive sampling was applied in the selection and drawing boundaries for what will be included in the analysis followed by the procedures for extracting a sample of content from the population. This follows an overview of these procedures used in a systematic quantitative analysis (Pavelko *et al.,* 2017)

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Results and Discussions

Modern Agricultural Technology and Machinery Usage

Modern technology and machinery usage in agriculture as employed today is as below with details.

Autopilot Tractors

New GPS tractors and sprayers machines can accurately drive themselves through the field with no drivers. Using Configured onboard computer system, a user draws width of a path a given piece of equipment will cover as he drives a short distance setting A and B points to make a line (Vibhav Mittal, 2018). The GPS system will have a track to follow and it extrapolates that line into parallel lines set apart by the width of the tool in use. The tracking system is tied to the tractor's steering, automatically keeping it on track freeing the operator from driving. This allows the operator to keep a closer eye on other things. Guidance is great for tillage since it eliminates human error from overlapping, saving equipment hours and fuel (Matthew Digman, 2021).

Crop Sensors

Programmed crop sensors will help the use of fertilizer in a very effective manner, maximizing uptake (André & Rob 2018). Sensing how your crop is feeling and reducing potential leaching and runoff into ground water. This is taking variable rate technology to the next level. Instead of making a prescription fertilizer map for a field before you go out to apply it, crop sensors tell application equipment how much to apply in real time. Optical sensors are able to identify how much fertilizer a plant needs based on the amount of light reflected back to the sensor (André & Rob 2018).

Fig 1: Cover Crops, Sensors, and Food Security (*source: Mogoi, OB*)

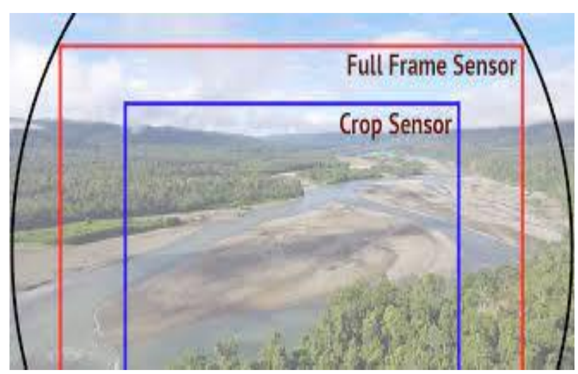

Fig 2: Crop Sensors (*source: Forward-Thinking Ideas for the USDA's Agriculture Innovation Agenda*)

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VRT and Swath Control Technology

Through Variable Rate Technology (VRT) and swath control technology, guidance begins to show returns on investment. Swath control is just what it sounds like. The farmer is controlling the size of the swath a given piece of equipment takes through the field (Vibhav Mittal, 2018). The savings come from using fewer inputs like seed, fertilizer, herbicides, etc. Since the size and shapes of fields are irregular, you are bound to overlap to some extent in every application. The GPS mapping the equipment in the field already knows where it has been and swath control shuts off sections of the applicator as it enters the overlap area. VRT works in a similar fashion. Based on production history and soil tests a farmer can build a prescription GPS map for an input (Vibhav Mittal, 2018).

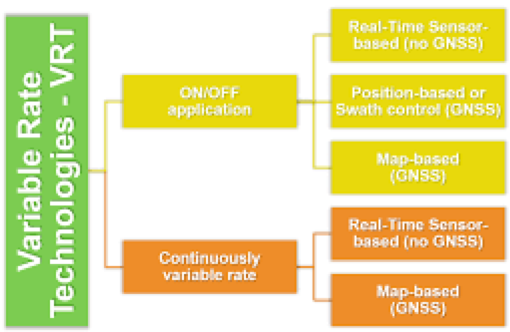

Fig 3: Site-specific management using Variable Rate Technologies (*source: Mogoi, OB*)

Fig 4: Variable Rate Technology (*source: Mogoi, OB*)

Fig 5: SWATH Control *Carnahan & Sons, Inc.*)

Fig 6: Spinner spreaders swath control (*source:*

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Monitoring and Controlling Crop Irrigation Systems via Smartphone

Mobile technology is playing a vital role in monitoring and controlling crop irrigation systems. With this modern technology, a farmer can control his irrigation systems from a phone or computer instead of driving to each field. Moisture sensors in the ground are able to communicate information about the level of moisture present at certain depths in the soil (Leo B., 2023). This increased flexibility allows for more precise control of water and other inputs like fertilizer that are applied by irrigation pivots. Farmers can also combine this with other technologies like VRT to control the rate of water applied (Vibhav Mittal, 2018). Critically. it's all about more effective and efficient use of resources.

Fig 7: Smart Irrigation Technology and System (*source: www.renke.com*)

Fig 8: Smart Irrigation (*source: Mogoi, OB*)

Biotechnology

Biotechnology or Genetic Engineering (GE) is not a new technology, but it is a principal technology with much more potential yet to be unleashed (Hossam S., 2023). The practice of Genetic Engineering that most people have probably heard of is herbicide resistance. Crops can be made to yield toxins which control particular pests. Many employ toxins that are similar to those found in some organic pesticides. It means farmers will not need to make a pass through their fields to apply pesticide (Margarida S., 2023). This not only saves on pesticide, but fuel, wear on equipment and labor too. Another ways to look at it would be that farmers who irrigate their crops can cut back on water use and not see yields suffer. Nitrogen use efficiency is similar to this except you are doing it with fertilizer instead of water (Prabhu G. *et al.,* 2023).

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Fig 9: Plant Biotechnology (*source: www.plantlet.org*)

Fig 10: Applications of Plant Biotechnology (*source: Mogoi, OB*)

Documentation of Fields via GPS

Due to programmed on-board monitors and configured GPS, the power of document yields and application rates are becoming easier and more precise every year. In fact farmers are getting to the point where they have so much good data on hand and able figure out what to do with all of it. The favorite form of documentation of every farmer is the yielding map and it sums up a year's worth of planning and hard work on a piece of colorful paper. These equipment of harvesting roll through the field and they calculate yield and moisture as they go tying in with GPS coordinates (James A. Taylor, 2023). The field is printed when finished with a map of yield. These maps are usually called heat maps. Now the farmers can see the varieties that had the best, worst, or most consistent yield over varying conditions. Maps like these can tell a farmer how well a field's drainage system is working (Kateryna Sergieieva, 2022).

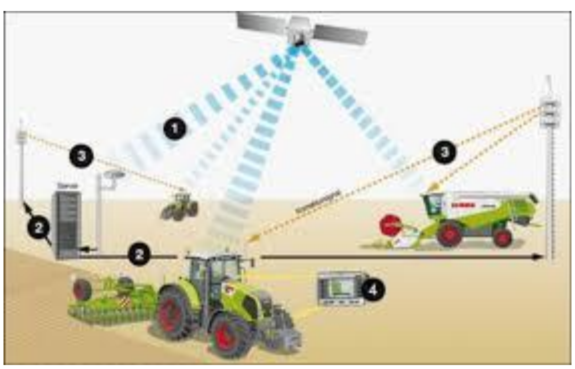

Fig. 11: GPS in agriculture (*source: Mogoi, OB*)

Fig. 12: GPS-controlled Optical plant growth (*source: Mogoi, OB*)

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Ultrasounds for Livestock

Ultrasound is not only for checking on baby animals in the womb, also can be used to discover what quality of meat might be found in an animal prior to going to the market (Jamie Lynn Stewart, 2022). Testing of DNA helps producers to identify animals with good pedigrees and other desirable attributes. For improving the quality of the herd, these information can be used to help the farmer to improve quality (Alexandre G. *et al.,* 2021).

Fig. 13: Animal Biotechnology (source: www.whichcollege.ie)

Fig. 14: Veterinary Ultrasound Scanner Kit (source: WOERD)

Usage of Mobile Technology and Cameras

Mobile technology and cameras are playing a big role for farmers and ranchers are using all the social media sites for all types of reasons. Some are using apps like foursquare to keep tabs on employees. Putting up cameras around the farm is a new trend catching on.

Livestock managers are securing their barns, feedlots and pastures with cameras that send images back to a central location like an office or home computer in real-time. They can keep a closer eye on animals when they are away or home during the night.

Fig. 15: IoT in agriculture (*source: Mogoi, OB*)

Fig. 16: Real-time farm monitoring (*source: Mogoi, OB*)

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Table 1 below shows Ten Countries African using Modern Agricultural Technology with Agricultural Outputs in 2021 with GDP in million USD.

Table1: Africa's Top 10 most food-secure countries (*source: IOA*)

#	Country	ACBR Food security score
1	Tunisia	68.20
2	Mauritius	67.33
3	Morocco	64.38
4	Algeria	63.86
5	Egypt	60.03
6	Gabon	58.81
7	South Africa	57.88
8	Ghana	53.57
9	Senegal	52.16
10	Namibia	51.42

Table2: Top 5 Agricultural Producing Countries in the World (*source: Our World in Data*)

Country	Exports (in billions)
United States	$118.30
Netherlands	$79
Germany	$70.80
France	$68
Brazil	$55.40

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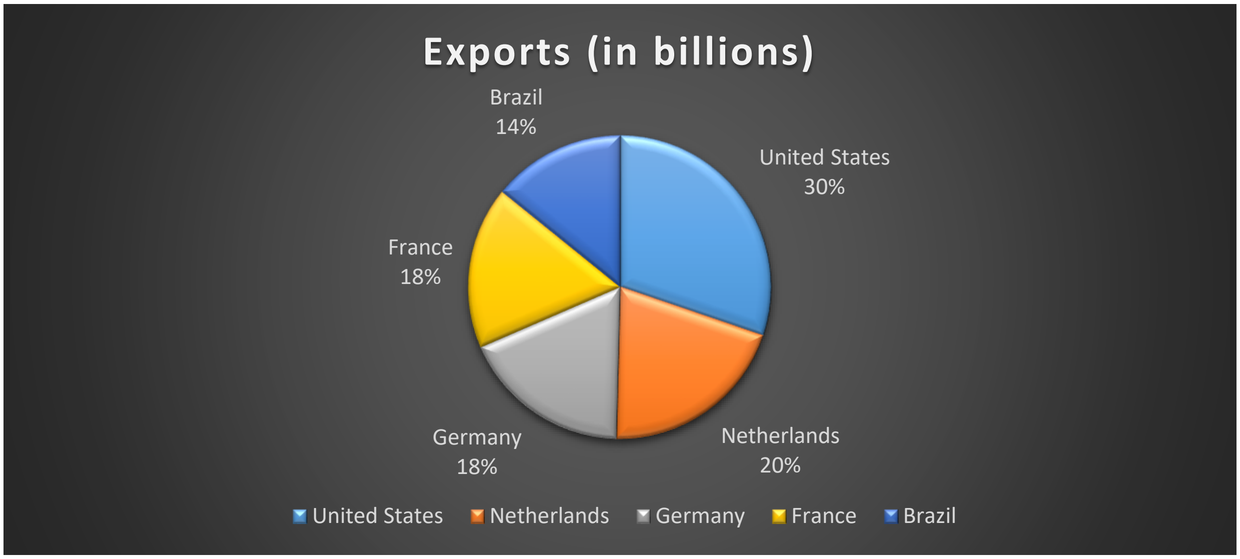

Fig 15: Top 5 Agricultural Producing Countries in the World (*source: EarthDaily Agro*)

Table3: Top 6 Staples Export in the World (*source: Visual Capitalist*)

Commodity	**Leading country**	**% of Global Exports**
Corn	United States	26% ($7.6 billion)
Fish	China	9.2% ($6.6 billion)
Palm Oil	Indonesia	51% ($10.4 billion)
Rice	Thailand	34.5% ($6 billion)
Soybeans	United States	50.5% ($16.5 billion)
Wheat	United States	18% ($5.4 billion)

Conclusion

Modern agricultural technology has been developed with keeping two important things in mind: first thing is to obtain the highest yields possible and second thing is to get the highest economic profit possible. To achieve these goals, six basic and important practices have come to form the backbone of production in agriculture: application of inorganic fertilizer, irrigation, intensive tillage, monoculture, chemical pest control and enatic manipulation of crop plants. Autopilot tractors, crop sensors, VRT and swath control technology, monitoring and controlling crop irrigation systems via smartphone, documentation of fields via GPS, biotechnology and ultrasounds in livestock as the backbone in production and its use for its individual contribution to productivity. All these combined are

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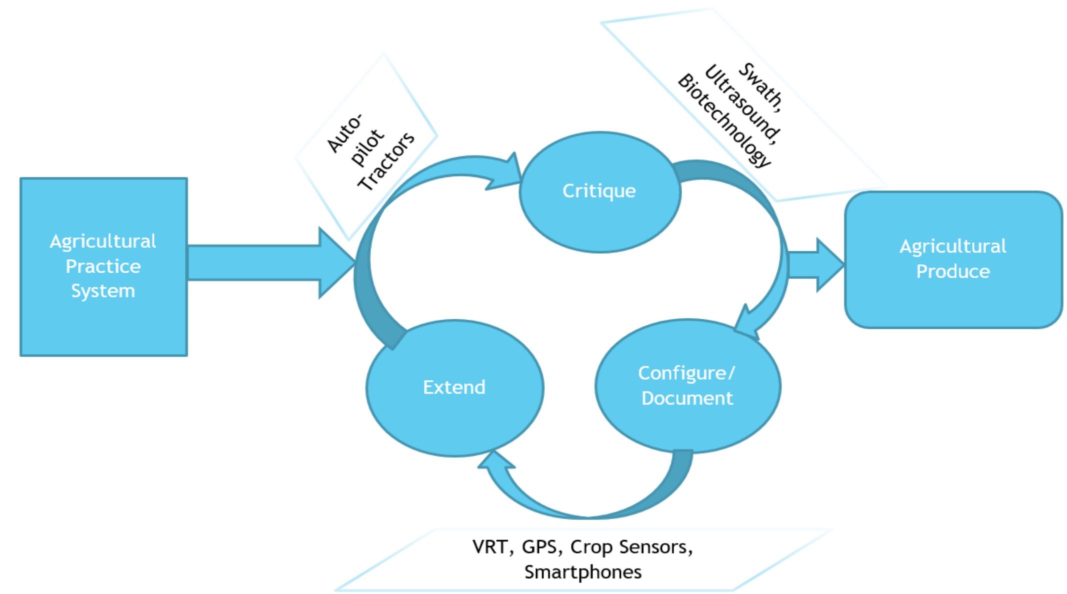
promising much less-human-intervened Agriculture with maximum agricultural output. The CCE Adoption Model principles in the use of Technology include Critique, Configure and Extend. Using the three CCE Model key principles in the use and implementation of Technology in any field, the diagram below summarizes how technology can be applied in Agriculture for maximum production.

- **The Agricultural Production Practice Model (CCE)**



Recommendations

It is recommended that as technology is becoming more advanced and complex, countries, governments, both private and public corporations should modernize their practice in agriculture and use of modern technology to improve on agricultural outputs. For food stability to be achieved, use of modern technological techniques is inevitable. This study also recommends further research on the use technology in farming and agriculture, impact and their relevance.

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Exploration of the Status of Fish Farming Enterprises among Farming Communities in Nyandarua, Nakuru, and Nyeri **Counties of Kenya**

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Abstract

Understanding the status of fish enterprises is vital for developing policies to enhance their productivity and economic growth. This study assessed the status of enterprises raising three main farmed fish species: Nile tilapia (*Oreochromis niloticus*), African catfish (*Clarias gariepinus*), and rainbow trout (*Oncorhynchus mykiss*), among farming communities in Nyandarua, Nakuru, and Nyeri counties in Kenya. The study selected these Kenya Climate Smart Agricultural Project (KCSAP) priority counties because these regions offer ideal conditions for fish farming and they represent promising areas for developing climate-smart fish farming. Using a snowball sampling procedure, the study identified 34 fish farms. Descriptive analysis was employed to examine socio-economic factors, production objectives, rearing methods, labour, markets, and marketing practices. Results showed that farmers aged 30-49 were most engaged in fish farming (23.5%). Family and family-hired labour were the most common sources. The majority (81.2%) of fish farmers preferred male labourers. Over 71.9% practiced commercial fish farming, primarily to generate income, and most emphasized producing table-size fish. The rearing period for tilapia, catfish, and trout fish were approximately 10.4, 10.2, and 12 months, respectively, with harvested average weights of 326.76 grams, 1357.14 grams, and 555 grams, respectively. Nile tilapia farmers mostly produced table-size fish, unlike trout and catfish farmers who targeted fingerlings, brooders, table-size fish, and fillet production. Prices for fingerlings, raw, and processed (value-added) fish ranged from 9.7 to 28 Kenyan shillings (KES), 335 to 650 KES, and 700 to 1200 KES, respectively. Farmers sold mature table-size fish at average prices of 335 KES, 540 KES, and 650 KES for tilapia, catfish, and trout, respectively. The price for value-added tilapia, catfish, and trout were 700 KES, 700 KES, and 1200 KES in that order. In conclusion, fish farming in Nyandarua, Nakuru, and Nyeri counties generates cash income, creates employment opportunities, ensures food and nutrition security, and contributes to societal empowerment for these communities.

***Keywords**:* African catfish, enterprises, Nile tilapia, rainbow trout, Kenya

Introduction

Aquaculture farming is currently the world's fastest-growing animal food producing sector, with an average annual growth rate of 8.6% (FAO, 2014, 2018). It provides livelihoods for many people and is a good alternative source of income for rural communities (World Bank, 2013). Fisheries and aquaculture are a vital source of essential nutrients, supporting the livelihoods of 10-12% of the world's population and accounting for over 17% of globally consumed animal protein (FAO, 2014, 2018). Africa has enormous potential for aquaculture expansion, but currently contributes only 2% of total global aquaculture production (FAO, 2020). Egypt is a major African producer, while Sub-Saharan Africa contributes only 0.6% (FAO, 2014, 2018). Smallholder aquaculture production accounts for 95% of the total, with Nile tilapia farming contributing 40% (Omasaki et al., 2016). In Kenya, aquaculture is practiced by small-scale farmers using semi-intensive earthen ponds. This system is characterized by low inputs and diverse farming conditions in terms of income level and market objectives (Omasaki et al., 2016). The main farmed fish species include Nile tilapia (*Oreochromis niloticus*), common carp (*Cyprinus carpio*), African catfish (*Clarias gariepinus*), and rainbow trout (*Oncorhynchus mykiss*) (Opiyo et al., 2017). Aquaculture farming has increased steadily in Kenya since the government's national fish farming enterprise productivity program launched in 2009. The program provided farm subsidies, established new hatcheries, and revived and expanded existing ones. Consequently, the number of fish farmers increased dramatically, from 4,742 to 49,050 (Nyandat & Owiti, 2013). Land dedicated to aquaculture farming expanded from 722 hectares in 2008 to 3,500 hectares in 2018 (Opiyo et al., 2018). Production levels also increased significantly, from 4,452 metric tonnes in 2008 to 24,096 metric tonnes in 2014. In 2020, fish outputs increased by 7.6%, from 18.5 thousand tonnes in 2019 to 19.9 thousand tonnes. Currently, fish farming contributes 16.1% to the total fish production in Kenya (Economic Survey, 2021). Fish farming has emerged as a significant contributor to food security, income generation, and rural development in several regions in Kenya. While studies have documented the status of fish farming around Lake Victoria and the western regions, information on the sector in the Mount Kenya region remains limited. This lack of data hinders effective planning, resource allocation, and the development of targeted support programs for fish farmers in this area. Therefore, this study aimed to address this gap by assessing and documenting the status of fish farming among fish farming communities in Nyandarua, Nakuru, and Nyeri counties within the Mount Kenya region.

Materials and Methods

Study area

This study was conducted in three priority counties for the Kenya Climate Smart Agricultural Project (KCSAP) in Kenya: Nyandarua, Nakuru, and Nyeri. A total of nine sub-counties and 14 wards were sampled (Table 1).

Table 1: Sampled Kenya Climate Smart Agricultural Program (KCSAP) priority counties, sub-counties and wards

County	Sub-counties	Wards
Nakuru	Gilgil	Gilgil
	Naivasha	Hells gate, Maeilla
	Nakuru Town East	Menengai
	Kinangop	Gathara, Githioro, North kinangop
Nyandarua	Kipipiri	Kipipiri
	Ndaragwa	Kiriita, Shamata
	Oljoroorok	Weru
	Olkalou	Rurii
Nyeri	Kieni East	Kabaru, Naromoru

Survey design

The study employed a snowball sampling procedure, involving a total of 34 fish farms (Table 2). KCSAP county coordinators and county livestock officers identified the initial participants in the sampling process. Through snowball sampling, these initial farmers then identified other fish farmers in their network. To be included in the study, farmers had to meet the defined criteria of raising fish species like tilapia, catfish, or trout. Baseline information was collected from fish farmers using a pre-tested, semi-structured questionnaire loaded onto Open Data Kit (ODK) software. This questionnaire covered socio-economic characteristics, production systems, rearing practices, labour, markets, and marketing practices. The data collected from farmers was entered and analyzed using the Statistical Package for Social Sciences (SPSS) version 20. Descriptive statistics such as means, relative frequencies, and percentages were employed to achieve the study's objectives.

Results and discussion

Socio-economic characteristics of fish farmers

Among the respondents, the gender distribution was 71% male and 29% female. Their educational backgrounds were primarily post-secondary (38.2%) and secondary education (26.5%). The majority of the fish farmers (47.1%) owned their land, while 23.5% farmed on family-owned land. Table 2 presents the age distribution of fish farmers in the study area. Farmers in the 30-49 age brackets were the most engaged in fish farming (23.5%), which aligns with the prime working age range for humans. Conversely, participation was lowest among respondents in the 20-29 and 50-59 age groups. This finding suggests that despite the high returns associated with fish farming and the significant youth unemployment rate (over 7.27% for 18-35 year olds in Kenya as of 2020) (ILO, 2020), few young people are actively involved. Our data shows that a majority (58.6%) of the farmers in the study area are older (between 40 and 60 years or above), compared to only 40% who aged 20-39 are. These results support the United Nations Development Program's (UNDP, 2011) observation that Kenya's agricultural sector is experiencing an aging population due to a lack of appeal among younger generations. Consequently, there's a need to train and educate young people about the potential of fish farming for job creation.

Table 2: Age structure of the respondents in the three study counties

Age group	Frequency	Percent
20-29	6	17.6
30-39	8	23.5
40-49	8	23.5
50-59	5	14.7
>60	7	20.6
Total	34	100.0

Labour preference

Family labour most common in fish farms

Table 3 details the sources of fish farm labour and gender preferences across the studied counties. Family labour is the dominant source (31.3%), followed by hired labour (25%) and a combination of family and hired labour (25%). Communal and group labours are the least preferred options. Financial constraints are a key reason for the prevalence of family labour, as many fish farmers lack the capital to hire external workers. Family members offer a readily available and potentially lower-cost alternative. Additionally, fish farming requires close attention and coordination, and using trusted family members can facilitate better communication and pond management, especially for smaller farms with limited resources.

Gender disparity in fish farming

Gender plays a significant role in aquaculture. Females comprise only 18.8% of the workforce compared to 81.3% males (Table 3). The preference for male labourers stems from a combination of factors. Traditional gender roles often associate physically demanding tasks with men, and fish farming involves activities like pond construction, hauling nets, and handling heavy equipment. Limited access to education and technical training for women in these regions further disadvantages them for these perceived strenuous roles. Cultural norms might also influence the perception of aquaculture as a male domain, discouraging women's participation. This creates a cycle where the lack of female involvement reinforces the idea that fish farming is unsuitable for women, potentially hindering its adoption by younger women and women in general.

Breaking down barriers for women in aquaculture

While the importance of women's inclusion and gender equality in fish farming is increasingly recognized, their roles are still limited by low literacy levels and inadequate technical knowledge on pond management. These challenges are not unique to this study and are faced by women in aquaculture globally, across various segments of the value chain (Butt et al., 2010; Ndanga et al., 2013). To address this imbalance, specific efforts are needed to increase women's participation in training programs, improving their understanding of fish farming practices. Furthermore, having more female extension agents could be beneficial, helping to overcome cultural barriers and encourage more women to pursue careers in fish farming (FAO, 2014). Ultimately, by promoting women's involvement in aquaculture production and various fish farming activities, the sector can achieve its full potential for enhanced productivity.

Table 3: Source of labour and gender preference of labourers across the three counties

Source of labour	Frequency	Percent
Family	10	31.3
Hired	8	25.0
Communal	2	6.3
Others	2	6.3
Family and hired	8	25.0
Group members	2	6.3
Total	***32***	***100***
Gender preference of labourers		
Male	26	81.2
Female	6	18.8
Total	***32***	***100***

Fish Species and Production objectives

Table 4 details the purposes (commercial, subsistence, and others) and specific commercial goals (table size, fillet, fingerling, or brood stock production) for different fish species raised by the farmers. The majority (71.9%) engage in commercial fish farming, primarily for income generation. Nile tilapia farmers predominantly produce table-size fish (14%), while trout and catfish producers have more diverse goals, including fingerling, brood stock, table-size, and fillet production. Across all surveyed households, the commercial focus varied depending on the fish species. The weight of fish at harvest is a significant factor for both fish producers and consumers (Blonk et al., 2010; Trọng et al., 2013). Most farmers prioritize producing table-size fish. Heavier fish at harvest command higher market prices, explaining the preference for this size category. A smaller number of farmers focus on fingerling production. Our observations suggest that this group may have a higher level of knowledge and resource endowment. Sevilleja (2001) supports this notion, reporting that fingerling production and management generally require more resources, skills, and technology compared to rearing fish to grow-out size.

Table 4: Purpose and commercial purpose of Tilapia, catfish and trout fish species farmed

Purpose of rearing	Frequency	Percent
Commercial	23	71.9
Subsistence	1	3.1
Others	1	3.1
Commercial and subsistence	7	21.9
Total	***32***	***100.0***
Fish commercial purpose Tilapia		
Table size	14	58.3
Table size and fillet production	3	12.5
Fingerling and Table size	4	16.7
Brooders, table fish and fillet production	2	8.3
Total	***24***	***100.0***
The commercial purpose of Catfish		
Table size	4	44.4
Table size and fillet production	2	22.2
Fingerling, brooders, table size and fillet production	2	22.2
Fingerling and table size	1	11.1
Total	***9***	***100***
The commercial purpose of Trout		
Fingerling, Table size and fillet	3	50.0
fingerlings, brooders, table size	3	50.0
Total	***6***	***100.0***

Rearing period and harvest weights variations

As shown in Table 5, the rearing period for tilapia, catfish, and trout averaged approximately 10.4, 10.2, and 12 months, respectively, with corresponding harvested average weights of 326.76 grams, 1357.14 grams, and 555 grams. These figures highlight variations in growth period and harvest weight across different counties. Growth rate, size at harvest, and feed conversion efficiency are key factors influencing species selection for aquaculture. Fish demonstrating superior performance in these areas typically reach market weight faster. The culture period can also be influenced by factors like targeting harvests for festive seasons or limited fish feed availability, which can impact the total quantity and value of fish harvested (Raufu et al., 2009).

For tilapia, standard aquaculture practices typically target a harvest weight of around 300 grams (Okechi, 2004). However, some farmers strategically harvest tilapia at higher weights (500-700 grams) despite the longer rearing time, aiming to capitalize on market demands. This trend is reflected in the observed harvest size range of 250 grams to

1 kilogram. Farmers harvesting at 500 grams achieved higher average prices compared to those harvesting at 300 grams. This aligns with Kawarazuka's (2010) observation that larger fish are often sold to meet daily market needs, while smaller fish might be consumed domestically.

Fish marketing

Table 5 presents the farm-gate prices (KES) for fingerlings, table-size fish, and value-added fish products. Average prices for tilapia, catfish, and trout fingerlings were KES 9.7, KES 15, and KES 28.3, respectively. Mature table-size fish prices averaged KES 335 for tilapia, KES 540 for catfish, and KES 650 for trout. The price of table-size fish is influenced by species, weight, size, and thickness. Generally, trout fetched higher prices compared to other species. Heavier fish, believed to have more flesh (Omasaki et al., 2017), typically command premium prices, as observed in this study. Farmers often extended their rearing periods to achieve heavier fish, maximizing market returns. Value-added products commanded even higher prices, with tilapia, catfish, and trout averaging KES 700, KES 700, and KES 1200, respectively. However, majority of farmers were aware of value-addition and the extent of their involvement in this process was limited. Despite the potential for higher profits, fish value addition remains limited among Mount Kenya region fish farmers. This is attributed to several factors, including a lack of knowledge and skills in processing techniques, limited access to equipment like filleting machines or proper storage facilities, and infrastructure challenges in maintaining cold chains for chilled or frozen products in rural areas. These constraints hinder farmers from transforming their product and capturing a larger share of the value chain.

Results from this study highlight the crucial role of fish farming in the studied counties' rural household economies. Fish sales and value addition in fish farming serve as a powerful engine for rural development. They generate income for fish farmers, contribute to food security by providing a source of protein, and empower communities economically. Value addition practices further enhance these benefits by increasing product shelf life, marketability, and overall value, leading to higher profits and reduced post-harvest losses. By promoting fish sales and value addition, we can create a sustainable and thriving aquaculture sector that empowers rural communities and contributes to poverty reduction.

Table 5: Rearing period, harvesting size and prices for raw and value-added tilapia, catfish and trout across the three counties

Rearing period in months				
Fish species	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Tilapia	6.00	12.00	10.40	2.16
Catfish	6.00	12.00	10.25	2.49
Trout	8.00	16.00	12.00	3.27
Harvesting size in grams				
Tilapia	250.00	400.00	326.76	55.87
Catfish	700.00	2500.00	1357.14	789.21
Trout	250.00	1000.00	555.00	406.36
Fingerling prices in Kenya shillings (KES)				
Tilapia	4.00	15.00	9.7143	3.19970
Catfish	15.00	15.00	15.0000	0.00000
Trout	13.00	45.00	28.2500	16.60070
Prices for raw table size fish in Kenya shillings (KES)				
Tilapia	200.00	600.00	335.00	149.16
Catfish	250.00	800.00	540.00	277.04
Trout	300.00	1000.00	650.00	404.15
Price of value-added fishin Kenya shillings (KES)				
Tilapia	700.00	700.00	700.0000	0.0000
Catfish	700.00	700.00	700.0000	0.00000
Trout	1000.00	1400.00	1200.0000	282.84271

Conclusion

This study investigated fish farming practices in Nyandarua, Nakuru, and Nyeri counties of Kenya, targeting Nile tilapia, African catfish, and rainbow trout. Commercial fish farming dominated, with most farmers aiming to produce table-size fish for income generation. However, production objectives and rearing methods varied by species. The rearing period and price also differed by processing stage, with fingerlings fetching the lowest prices and value-added products commanding the highest. These findings offer valuable insights for promoting sustainable and profitable fish farming practices in Kenya.

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Conflict of interest

The author declares that there is no conflict of interest.

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