



TRANSDISCIPLINARY METHODOLOGY FOR ADAPTIVE PROJECT

**Food Safety Hazards in the Pastoral Dairy Sector
under Climate Change**

ADAPTIVE (2024-2029)

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1.0 Introduction to the ADAPTiVE project

ADAPTiVE is a five-year research project (2024-2029) that is a collaborative research project between Jomo Kenyatta University of Agriculture and Technology (JKUAT), the University of Nairobi, the Kenya Agricultural and Livestock Research Organization (KALRO), the African Institute of Capacity Development (AICAD), Karare Women's Dairy Cooperative and the University of Copenhagen. It is a consortium of a wide range of scientists, development practitioners, policymakers and community actors dedicated to the creation of evidence-based solutions to food safety issues in a changing climate. The overall aim of the project is to explore ways of encouraging the uptake and long-term maintenance of climate adapted food safety practices in Kenyan pastoral smallholder dairy systems, but more specifically women owned pastoral dairy farms, which is a pillar of pastoral livelihoods that is often underestimated. The project is divided into four work packages (WP) themes to achieve a holistic impact in the region. These themes include are outlined as follows;

WP1: Food safety hazards in the dairy sector in the face of climate change

This theme seeks to answer the question, "how can climate change be expected to affect food safety performance and livelihoods of different actors in the Kenyan dairy sector?" The theme aims to map the most prevalent food safety problems from farm-to-fork in the Kenyan pastoral dairy sector and assess how these are influenced by climate change, whether value chain actors are aware of this and how livelihoods are impacted.

WP2: Smallholder dairy farmers' constraints and preferences for adaptation strategies

This theme seeks to answer the question, "what are the drivers and constraints for women dairy farmers' adaptation to climate change?" It focuses on understanding the constraints and preferences of smallholder pastoral women dairy farmers for adopting food safety practices adapted to climate change.

WP3: Design and evaluation of climate-robust food safety strategies for smallholder dairy farms

This theme seeks to answer the question, "which farm-level or community-level measures improve the food safety and livelihoods of smallholder women dairy farmers?" It aims at designing food safety strategies adapted to climate change and evaluates their impacts on food safety and livelihood outcomes, with particular focus on their applicability to women-led smallholder dairy farms.

WP4: Scalability of climate-robust food safety initiatives in Kenya.

This theme seeks to answer the question, "what institutional contexts and market conditions can support the use of effective climate change adaptation strategies?" It assesses consumers' and other stakeholders' preferences for food safety in dairy products and develops realistic and feasible guidelines and market infrastructures to increase farmers' adoption of climate-robust food safety strategies in ways consistent with sustaining livelihoods.

ADAPTiVE will apply a transdisciplinary approach, given the fact that food safety in climate stress conditions is a multidimensional problem at the interface of human behaviour, gendered labour relations, animal welfare, environmental change, and socio-economic limitations. This style will break the disciplinary boundaries and create knowledge with end-users collaboratively and incorporate scientific, experiential, policy, and cultural approaches.

1.1 Food safety hazards in the dairy sector in the face of climate change

Food safety has continued to be affected by climate change especially in pastoral communities in Africa (Magita 2024; Amenu et al., 2025). Increased temperatures, disrupted rainfalls, and frequent droughts lead to negative impact on availability of feeds, milk handling conditions, pathogen dynamics, and household vulnerability (Herrero et al., 2024; Kirui 2022). Heat stress in livestock reduces immune function and increases disease susceptibility, while water scarcity compromises hygienic practices and milk handling, leading to contamination (The East African 2024). The traditional interventions, which are not usually designed with a local context, do not always lead to sustainable adoption. However, they are also subjected to extremely susceptible environmental, infrastructural, and socio-economic conditions. Combinations of these challenges and an upsurge in livestock disease are changing the conditions of milk production as well as the routes through which food safety hazards enter and travel along the pastoral dairy value chain. Such climatic pressures are overlapped by structural constraints that have long existed, such as poor cold-chain infrastructures, overdependence on informal markets, lack of hygienic facilities and low access to extension services, all of which amplify the risks posed by microbial, chemical, and physical contamination (USAID-KAVES, 2014; Agong et al., 2022; Farmonaut, 2025).

It is against this backdrop that this Work Package attempt to respond to the main question: How can the climate change be predicted to impact on food safety performance, and the livelihoods of various actors in the Kenyan dairy industry? To tackle this, the Work Package

will attempt to (i) map the most common food-safety hazards along the pastoral dairy value chain from farm to fork (ii) examine the impact that climate variability and long-term climatic trends have on the occurrence and severity of these hazards, (iii) examine the level of awareness of the value-chain actors about the climate-related food-safety risks, and (iv) determine the impact that the identified risks have on the welfare of households, market participation and livelihood resilience. The major hazards that will be investigated are bacterial contamination, for instance, total viable count, coliforms, *Salmonella* spp., *Listeria monocytogenes*, zoonotic pathogens like *Brucella* spp., *Staphylococcus aureus* and *Escherichia coli* O157:H7 as well as chemical contaminants like aflatoxin M1 due to feed scarcity and inadequate fodder storage, and antibiotic residues due to the pressure of diseases in climatic stress (Grace et al., 2015; Kagira et al., 2020; Kiiru et al., 2022; Mutua et al., 2023). These risks pose a serious threat to public health as well as compromising the stability of incomes and the repetition of economic losses by pastoral households (FAO, 2019; Herrero et al., 2021).

This Work Package is important to the stakeholder participation. Marsabit pastoral dairy farmers, traders, processors, regulators, and service providers will be involved in research question co-creation, finding validation, and co-designing viable and context-specific interventions. Such engagement will make solutions, including better hygiene measures, low-cost cooling technology, better feed management to minimize aflatoxin contamination, and better institutional backing, socially acceptable, economically viable and environmentally friendly.

1.2 Scope and objectives

1.2.1 Main objective

To assess how climate variability, affect food safety risks and the livelihoods of actors across Kenya's pastoral dairy value chain.

1.2.2 Specific objectives

- I. To identify and map the most prevalent food safety hazards along the Kenyan pastoral dairy value chain.
- II. To examine how climatic factors, influence the occurrence, transmission and severity of food safety hazards.
- III. To analyze the knowledge, attitudes, motivations, constraints, perceptions and practices of different dairy value chain actors regarding food safety and climate related risks.
- IV. To assess how climate related food safety risks affect the economic wellbeing, resilience and livelihood strategies of pastoral households and other actors in the dairy chain.
- V. To co-design with stakeholders the appropriate strategies for reducing food safety risks and supporting pastoral dairy value chains to adapt to climate change.

Key Questions

1. What are the dominant microbial and chemical hazards present at each node; on-farm, aggregation centres, transport, Karare Women dairy cooperative?
2. How do climate stressors alter hazard emergence and transmission?
3. What is the distribution of knowledge, attitudes and practices (KAP) among actors about climate-food safety linkages and what are the incentives and barriers to adoption of risk-reducing behaviours?
4. What interventions are feasible and acceptable to stakeholders to reduce food safety risks without undermining livelihoods?

3.0 Transdisciplinary methods

Transdisciplinary research (TDR) offers a very strong system of applying a variety of scientific approaches alongside local knowledge and stakeholder interests to generate actionable and context-specific solutions together (Archibald et al., 2023; Pineo et al., 2021). Climate variability also changes the ecology and occurrence of important dairy hazards in the view of food science and technology. High ambient temperatures hasten microbial growth, increases the rate of spoilage and deteriorates the survival of pathogenic bacteria and informal dairy value chains where cold storage is limited. Studies show increasing concern about aflatoxin metabolite Aflatoxin M₁ (AFM₁) that is passed to milk by contaminated feeds; and climate-dependent increases in aflatoxin-producing fungi in drought-stressed crops increase the risk (Duchenne-Moutien et al., 2021; Kiambi et al., 2022). These hazards can be addressed by food-technology interventions, which include provision of appropriate storage of feeds, fast cooling, low-cost processing innovations and training farmers, but these interventions are hindered by cost factors, accessibility to equipment and contextual factors.

As anthropological studies have emphasized, the socio-cultural contexts of production and consumption of dairy cannot be handled through technological interventions without a thorough knowledge of the socio-cultural environment (Gebremichael, Didanna, & Ayza, 2025). Cultural norms and gendered systems of labour have a strong impact on dairy practices, risk perceptions, household roles and value-chain relationships. Women play pivotal roles in milking, managing and milk safety decisions at household levels in most of the East African contexts where Kenya is located. However, their views are often ignored in designing interventions. Ethnographic research shows that safety measures are implemented (or not at all) based on the perceptions of the purity of milk, beliefs in buyers and sellers, and the seasonal stresses of pastoral and agro-pastoral relationships (Zavala-Nacul et al., 2022; GAIN, 2020).

Economic aspects, such as price incentives, costs or financial constraints also play important roles for behaviour and conduct in the dairy value chain. Change of practices, production methods and product handling imply costs, extra time use or other inconveniences for those involved, and if they are not sufficiently compensated for via such costs e.g price premium, their incentives to undertake such efforts are limited. Implementation of safer methods of production or product handling may also require investments, but such investments can be hampered by lack of available financial resources.

Therefore, the enduring behavioural change requires participatory and gender-responsive strategies that recognize the local concept of quality, practices, and socio-economic reality.

Literature consistently underscores the importance of integrating food science, technology, anthropology, economics, and stakeholder-driven processes within an effective transdisciplinary system. This kind of integration will help researchers to study food safety hazards not only as biochemical phenomenon, but also as socio-technical issues conditioned by climate stress, lack of resources, market relations, and gendered roles. Transdisciplinary methods have been demonstrated to enhance the design, adoption, and sustainability of interventions, as they are technologically viable, acceptable, and economically feasible (Zhou et al., 2024).

In the ADAPTiVE project, the transdisciplinary methodology will be used to conduct a comprehensive study of the ways in which climate-adapted food safety approaches can be marketed and maintained in dairy farms operated by women in smallholder dairy farms in Kenya. The combination of laboratory analysis, field-based experimentation, economic analyses and participatory social research enables the project to be in line with the best practices worldwide in dealing with the intricate food-system issues in a shifting climate.

3.1 Relevance of the transdisciplinary method to the ADAPTiVE project

The ADAPTiVE Project will deal with the complex issues of climate change, food safety, and smallholder dairy production in Kenya and specifically focusing on women-led farming systems. These problems are multidimensional and complex in nature. These dynamics should be studied properly and thus a TDR methodology is necessary to come up with interventions that are scientifically sound and socially viable.

The transdisciplinary approach will facilitate the project to unravel the relationship between climate variability as a cause of food safety hazards proliferation and the relationship between these hazards and day-to-day practices, resource constraints, and cultural practices in smallholder dairy families. The approach will also make the interventions that will be formulated locally relevant and culturally appropriate (Figure 1). The ADAPTiVE Project will integrate the community priorities, gendered responsibilities, and economic realities into the food safety solution design and improvement process through participatory processes, such as the co-design workshops and the involvement of pastoral dairy farmers in Marsabit County. This is intended to raise the level of acceptability and practical relevance of the interventions hence raising the chances of meaningful uptake by women pastoral dairy farmers and other dairy value-chain actors.

It will also enhance co-production of knowledge through active engagement of stakeholders in various sectors in the formulation, testing and implementing interventions. The process of collaboration will also create definite connections between research, policy, and practice and make sure that the scientific findings produced by the project are translated into practical recommendations to the regulatory agencies, the county governments, and the national policymakers. This is important to formulate scalable long-term plans on how to enhance food safety in changing climatic conditions. Moreover, transdisciplinary research is iterative and adaptive which will facilitate constant learning over the 2024-2029 ADAPTiVE project period. Therefore, with the changing climate patterns, the market conditions change, and new data is provided by laboratory tests and field experiments, the TDR framework will enable the project to optimize the interventions and react to the new challenges in real time. This dynamic feedback process will enhance the sustainability of project outcomes by making sure the interventions are contextually relevant, technically viable and acceptable to society in different environmental and socio-economic contexts.

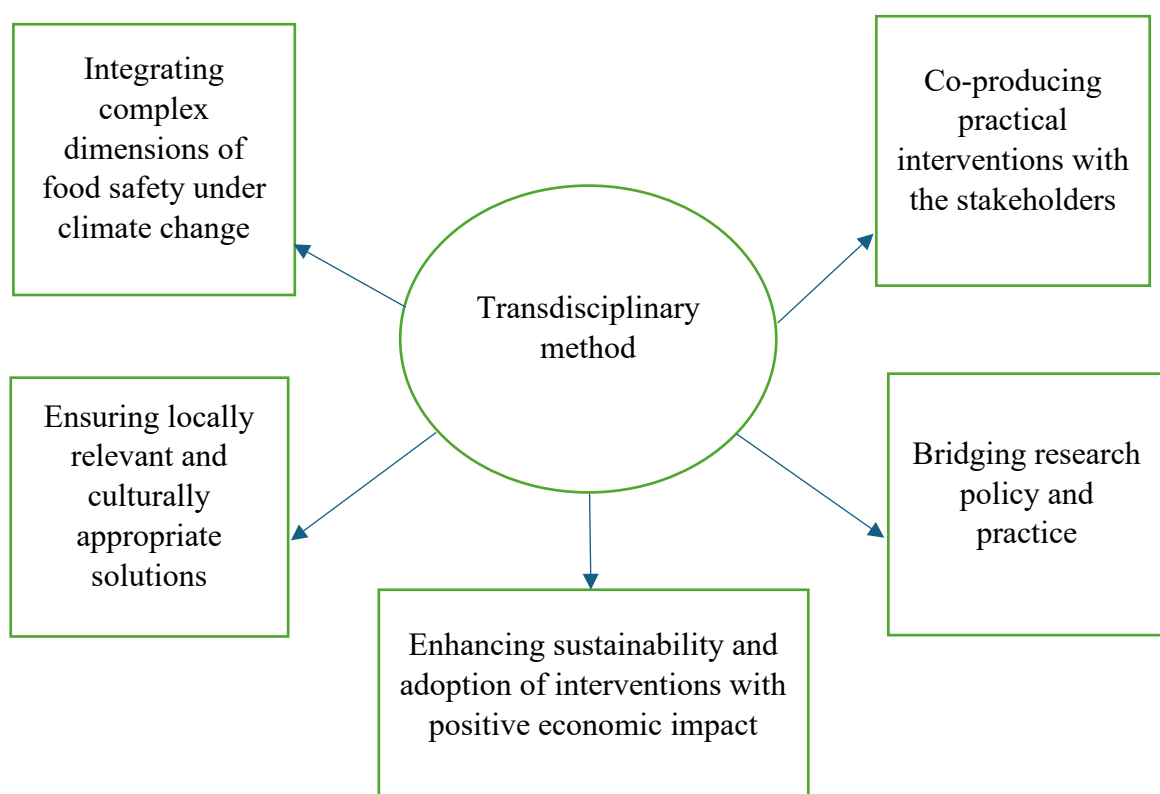


Figure 1: The importance of the transdisciplinary methods in the ADAPTiVE project

3.2 Participatory tools and methods

The participatory aspect of this project will be implemented in Marsabit County, Saku Constituency, Karare Ward. The following participatory tools will be used to co-produce information on food safety hazards, climate change, economic and livelihood outcomes, decision making and feasible solutions.

3.2.1 Power-Interest Grid

To analyze the different degrees of influence, vulnerability and decision-making power among players within the pastoral dairy value chain systematically, a power-interest grid will be used. County Public Health Officers, Dairy Board regulators and the governmental veterinary services are high-power actors that typically have strong regulatory authority and have the ability to implement regulations that have a direct impact on milk handling, transportation, and market entry. Their choices impact the general regulation of food safety and define the official regulations of the industry. On the other hand, actors with high interest level but low power such as pastoralist women who do the milking and hygiene, small scale transporters, informal vendors have huge day to day food safety responsibilities but have little impact on policy or official decision making. Climate variability usually affects these populations the most because the increased temperatures, lack of water, and long distances to the markets make the risk of contamination and spoiling worse.

3.2.2 Stakeholder mapping and engagement

The actors to be involved in this project will be a wide spectrum; pastoral smallholder dairy farmers, milk transporters, traders and vendors, Karare Women Dairy Cooperative, Marsabit County Public Health Departments, Kenya Dairy Board and Kenya bureau of standards, consumers, and the local non-governmental organizations to be involved will include PACIDA (Pastoralist Community Initiative and Development Assistance). Other stakeholders such as veterinary officers, extension agents, women group, youth representatives and community-based organizations will be introduced depending on the emerging needs as well as the revelations on the initial consultations. The process of engagement will begin with consultative discussions with the ministries and representatives of the key institutions. These ministries include; Ministry of Agriculture and Livestock Development, the Ministry of Health, Marsabit County Livestock and Veterinary Departments, and the agencies related to climate. These consultations are aimed at informing the authorities about the project, getting the required permissions, harmonizing the research activity with the current county or national programs, and defining the institutional expectations or possible collaboration areas.

The project will also hold a stakeholder meeting after these consultations which will involve the main players of the dairy value chain. The meeting will present the project goals, discuss the intended methodology, and offer a platform where the stakeholders will give their input concerning priority concerns and current challenges in the Karare Ward as the location of the study. Such a forum of interaction will promote trust, roles clarification, and communication channels that will facilitate continued involvement during the research. This will be followed by systematic mapping and analysis of stakeholders in the pastoral dairy system to determine the relationships, influence, interest, and capacity of actors in the system. The project will record the central stakeholders in food safety governance, the groups most at risk and where collaboration is likely to be most effective using influence-interest matrices, actor-linkage maps and participatory ranking. The mapping will assist in the recruitment of participants during fieldwork for focus groups and key-informant interviews to make sure that they represent all gender, age, socio-economic status, and value chain positions.

Mapping process findings will be used to make the study sites choice of the pre-test phase, as well as the entire field implementation. The location will be based on the ecological areas, movement of livestock, intensity of milk production, climate exposure profile, availability of infrastructure, access to market and security issues. Logistical accessibility and representativeness of larger pastoral dynamics will be used to select pre-test sites. The project will further continue with pre-test people such as those who will be used in focus group discussions (FGDSs) and key-informant interviews (KIIs). Sampling will be done among the pastoral households, milk traders, transporters, processors, public- health officers, extension workers, NGOs, and market actors. A purposive method of sampling shall be employed to create a balance between women, men, and the youth due to different roles and experiences with milk handling, food safety, and adapting to climate. In the pre-test period, the team will pre-test research instruments, such as KII guides, FGD guides, observation checklists, and informed-consent forms, to check their clarity, understanding, cultural sensitivity, relevance, flow, and length. Pre-test will be done to evaluate the ease of understanding the questions, whether the tools capture the desired information or not and whether there are any redundancies or ethical issues. The final research instruments will be refined based on the feedback of the participants.

Moreover, the research team will also engage the traditional elders and community leaders to have culturally-appropriate engagement and compliance with the local norms. Such consultations will be conducted on matters touching on community entry, benefit-sharing, the

preferred method of communication, timing of data collection concerning cultural or pastoral practices, and procedures of approaching vulnerable groups like women, youth and mobile herders. Gender issues will be incorporated in the entire process of engagement, given that the gendered nature of involvement in the production of milk as well as in its handling and decision making. The project will also focus on gender views on food safety, such as the role of women in milk hygiene, resource and training accessibility as well as the gendered effects of climate variability on food safety activities and livelihoods.

3.2.3 Livelihood mapping

In Karare Ward, the livelihood systems are highly interwoven with climate variability, mobility and gender roles that are entrenched in culture. The complexity of these pastoral livelihoods will be captured through livelihood mapping, which will involve recording the different household and community incomes that will rely on milk and livestock, and such activities. This instrument will shed light on how pastoral families create, diversify and earn incomes during the increasing climatic stress. The mapping exercise will allow seeing a comprehensive view of livelihood structures by analyzing milk sales, herd mobility, livestock trade, and small-scale vending. It will also demonstrate how the availability of resources, including water, grazing lands, financial capacity and market networks, affect food safety practices and agribusinesses stability of household income.

The mapping process will also shed light on the gendered aspect of labour in the pastoral dairy system whereby roles are allocated in the conventional way that greatly determines exposure to food safety risks. Women are usually the ones who handle milking, container cleaning, domestic storage and sales of milk in their area and therefore they are at the intersection of food safety and hygiene practices. Males in contrast, tend to herd, transport over long distances and negotiate livestock related incomes, they are thus placed in another position relative to climate induced risks like drought and pasture shortage. The livelihood mapping will illustrate the immediate impacts of climate variability on labour division, milk supply, and contamination risks by recording the changes in these roles in relation to seasonal changes. This tool will eventually give important insights on the intersection of gender, climate stressors, and livelihood strategies to determine food safety outcomes in the pastoral dairy value chain.

3.2.4 Attitudes towards food safety and climate change

The study will record the lived experiences, perceptions, and priorities of the people in the community in relation to food safety and climate-related issues within the Karare Ward using

a variety of Participatory Rural Appraisal (PRA) instruments. The PRA techniques will include community discussions, ranking exercises, and storytelling sessions that will allow the participants to express their awareness of the main food safety risks, such as bacterial contamination, food spoilage, adulteration, and the ongoing water shortage to ensure hygiene. The tools will also be used to reveal how pastoral families are viewing the emergent climate risks like extreme heat, extended droughts, longer travel distances to pasturelands, and the lack of stable cooling mechanisms, which lead to the increase in the risk of spoilage and contamination throughout the milk value chain. These participatory methods will provide the researcher with an understanding of how communities perceive the connection between variation in climate and food safety, and how these risks are perceived across various social groups, such as women, men, youth, and older people.

Also, PRA will help the researchers to determine and catalogue the adaptive measures that pastoralists already use in dealing with risks related to climate change and milk safety. They might involve the adoption of smoked gourds to slow down the growth of microbes, night or early-morning milking to prevent the heat of the day, shade-based storage, or shorter and safer transportation paths to retain the quality of milk.

3.2.5 Participatory Value Chain Analysis (PVCA)

Participatory Value Chain Analysis (PVCA) will form part of the key methodological tool to explain the overlap between food safety risks and climate risks along the pastoral dairy chain across Karare Ward (Table 1). PVCA is implemented using community workshops, transect walks and field-based engagements that enable researchers and local actors to map out the entire route of milk, starting with the kraal where animals are milked, through the homestead and local collection points all the way to the urban markets in Saku and the nearby towns. Through a collective tracing of this flow, the participants will identify the stages that are the most vulnerable to contamination or spoilage, which can be hand milking, storage in unclean containers, extended time spent in the heat during transportation, or time delay before reaching the market. These phases will be referred to as critical control points (CCPs) that need specific intervention. The process also helps to have a detailed insight into the cultural norms that influence the practices of milk-handling such as the use of traditional containers like gourds or plastic jerrycans, division of labour on the basis of gender, and ritual or symbolic practices that affect the behaviour of hygiene.

Besides the identification of hazards, PVCA will shed light on the way communities are already responding to climate stress by changing their milk-production and handling systems. Some of

the changes that the participants will describe and analyze includes changing the time of milking (afternoon to early morning) to prevent heat stress, replacing plastic with aluminium containers as they have better hygiene, or changing the transport routes as herds move further in pursuit of pasture during droughts.

3.2.6 Facilitation of the dialogue among stakeholder groups

The facilitated workshops will establish platforms in which pastoralist producers (both men and women) are able to freely express their experiences pertaining to milk handling, the risks of contamination, climatic stress and livelihood issues. Transporters, vendors and cooperative representatives will provide an input on the market dynamics, transport constraints, infrastructure constraints and the practical challenges that they face on ensuring that milk quality is upheld throughout the chain. Technical and policy views will be offered by county veterinary officers, food safety regulators, and the personnel of the public health explaining the current standards, gaps in enforcement, and ways to tighten the controls. NGOs like PACIDA who are more experienced in community development, resilience building and pastoralist advocacy will provide a wider contextual perspective of vulnerability, behaviour change and community mobilization. Community elders and youth groups are also very important and will be involved because they have cultural authority, local knowledge and emerging innovations that shape milk-handling practices and decision making.

Table 1: Outputs of the participatory value chain analysis

Output type	Description	Example
Value Chain Map	Visual diagram showing all stages, actors, flows, and risk points.	Milk flow: Milk move from kraal to women's cooperative to Saku market to restaurants.
Problem Ranking Matrix	Prioritized list of food safety risks and climate vulnerabilities.	Spoilage, long distances, water scarcity, poor containers.
Gendered Activity Profile	Documents who perform specific tasks and who controls resources and income.	Women handle milking and hygiene; men transport and negotiate prices.
Adaptation and Innovation Table	Captures indigenous and modern adaptations to climate variability.	Smoking gourds; shifting milking times; aluminium cans; home filtration.

3.2.7 Biological sample collection

To determine the prevalence and concentrations of major food safety hazards in milk and the related environmental sources, biological sampling will be conducted among pastoral dairy households and on milk value chain actors in Karare Ward. Sampling will be done at different dairy value chain stages to identify possible contamination routes associated with milk production, milk handling, milk storage, milk transportation and processing level. The primary biological samples will include raw milk samples from pastoral farms and aggregation centres, water samples used for cleaning milking containers, animal feed, and swabs collected from milking and storage containers. These samples will be collected following standard aseptic procedures and stored in sterile containers. To maintain sample integrity, collected samples will be transported under cold chain conditions to the laboratory for analysis.

The laboratory tests will be focused on identification and measuring of the major food safety hazards that are relevant to pastoral dairy systems. They will entail microbial contamination indicators like total bacterial counts and possible foodborne pathogens, as well as chemical hazards like aflatoxin M1 and antibiotic residues in the milk. The detection and quantification of chemical contaminants where necessary will be done using analytical methods and specifically High-Performance Liquid Chromatography (HPLC). Sampling will be done both in the dry and wet seasons to study the effect of climatic variability on the level of contamination and food safety risks.

3.2.8 Questionnaire surveys

Structured questionnaire surveys will be administered to pastoral dairy farm households and milk consumers in Karare Ward. For dairy farm households, the survey will collect quantitative information on milk production practices, food safety awareness, climate-related challenges, and livelihood characteristics. The questionnaire will provide baseline data on household demographics, livestock ownership, milk production volumes, milking hygiene practices, milk storage methods, and market participation. The survey will also explore perceptions of climate variability and its effects on dairy production and milk quality. Respondents will be asked to describe seasonal patterns in milk spoilage, livestock diseases, feed availability, and water scarcity. Such information will help contextualize laboratory findings and identify behavioral and environmental factors that contribute to food safety risks.

Moreover, the survey will collect data on production economics (economic outcomes from dairy production activities, other income sources, production costs, production methods), socio-economic data (including household income sources, gender roles in dairy production, income variability), access to veterinary services, and availability of extension support. These variables will help explain how structural constraints influence food safety practices within pastoral systems.

For consumer households, the survey will collect quantitative data on milk consumption, milk handling practices, perceived milk quality and safety, milk spoilage, and preferences for milk's attributes in terms of quality, safety and production methods.

The questionnaires will be administered through face-to-face interviews conducted in local languages where necessary to ensure clear communication and accurate responses. Prior to the main data collection, the questionnaire will be pre-tested with a small group of households to refine question wording and ensure cultural appropriateness. The structured survey will generate quantitative data that can be statistically analyzed and linked with biological sampling results to identify relationships between household practices, environmental conditions, and food safety hazards.

3.2.9 Discrete choice experiments

A Discrete Choice Experiment (DCE) will be conducted among dairy value chain actors (dairy farmers and milk consumers, respectively) in Karare Ward to examine how pastoral households make decisions regarding food safety improvements and milk handling practices. The DCE is an economic method used to evaluate preferences and trade-offs that individuals make when faced with different intervention options. In this project, the DCE will be integrated into the questionnaire survey and will present respondents with a series of hypothetical choice scenarios involving different milk production or handling strategies. Each scenario will include attributes related to potential food safety improvements such as improved hygiene practices, access to clean water, veterinary support services, milk storage technologies, and training on safe milk handling. These attributes will be presented at varying levels, along with associated costs or labour requirements.

Participants will be asked to select their preferred option from a set of alternatives in each choice scenario. The analysis of these choices will allow the estimation of the relative importance of different intervention attributes and the willingness of actors to adopt or invest

in food safety improvements. The attributes and levels used in the DCE will be identified through preliminary consultations with pastoralists, experts, and stakeholders, ensuring that the scenarios are realistic and relevant to the pastoral dairy system in Marsabit. The resulting data will be analyzed using econometric models such as multinomial logit or mixed logit models to estimate preference structures and variation among respondents. The results of the DCE will provide important insights into the economic feasibility and acceptability of different food safety interventions, helping to identify strategies that are most likely to be adopted by pastoral communities under conditions of climate variability.

3.2.10 Intervention study

A Randomized Controlled Trial (RCT) will be conducted in collaboration with Karare Women Dairy Cooperative to test specific strategies for improved food safety under climate change - strategies that will be developed on the basis of findings from qualitative and quantitative data as described in sub-sections 3.2.1-3.2.8. The RCT will be conducted to test the strategies in regard to their impacts on smallholder women dairy farmers' ability to adopt improved and climate-robust food safety practices. The RCT will consider two treatment groups and one control group of farmers (approximately 38 villages each with 20 farm households per group). Baseline data for the three RCT groups will be drawn from the microbiological sample collection (sub-section 3.2.6) and the questionnaire survey (sub-section 3.2.7). Additional data will be collected through intervention activity records during the intervention period, as well as through endline surveys focusing on food safety and livelihood outcomes.

3.3 Mixed methodology design

3.3.1 Scoping and system mapping

This forms Phase 1 of the project and it will take 1 to 3 months. It will form the basis of the study and will focus on generating an in-depth understanding of the pastoral dairy value chain and its susceptibility to food safety risks that are triggered by climate. In order to achieve this, the anthropological inquiry and the insights of food science and technology will be used to provide the baseline of further empirical and analytical actions. Anthropologically, the phase aims to document the lived life, practices as well as knowledge systems of the actors who work in the pastoral dairy industry. To do this, a set of Key Informant Interviews (KIIs) will be carried out with the representatives of the Ministry of Agriculture and the Kenya Dairy Board, governments in the sphere of the national health, non-governmental organizations working in

pastoral areas, and heads of local dairy cooperatives. Such interviews will offer invaluable information on the formal regulatory context, organizational issues, sectoral concerns, and the views of experts on how climate variability is influencing dairy production, milk quality, and the threat of food safety. The collected data will assist in placing the community-level practices in the frameworks of larger governance and policy. To supplement these institutional views, the study will include transect walks and participant observation in pastoral families. The pastoralists will be accompanied by members of the research team in their regular activities including herding, milking, filtering of milk and transportation to the collection points. These field studies will allow a first-hand evaluation of hygiene measures, handling, environmental factors, and access and utilization of key resources like water and shade. They will also help in building rapport with the community members hence building trust and thus securing deeper involvement during the later phases of the study.

Additional community-level information will be collected by conducting Focus Group Discussions (FGDs), which will be stratified based on gender and age category to depict the division of labour in the pastoral dairy system. Individual FGDs will be done among male pastoralists, female milk handlers and young herders. Such discussions will use a set of PRA instruments to create community-based analyses of the dairy system. Seasonal calendars will be created to track the variation of milk production, animal health, fodder availability, and incidences of human diseases that are sensitive to the climate like diarrhoea. The resource mapping exercises will map grazing grounds, water sources and milk collection points with spatial and temporal changes with respect to environmental stressors. Besides that, problem-tree analyses will be applied to assist the participants to detect and express the underlying causes and effects of such problems as milk spoilage, diseases in cattle, and lowered productivity. Together, these instruments will provide a dynamic interaction of climate variability and pastoral activities and livelihoods of households.

In line with the anthropological activities, the food science and technology aspect of Phase 1 will entail a scoping literature review and regulatory report to generalize the current knowledge on food safety hazards that are common in the Kenyan dairy industry. Focus will be on aflatoxin M1 contamination, bacteria, antimicrobial residues, and other risks recorded in the formal and informal market. The results of this review will be utilized in designing technical observation checklists that anthropologists will apply when they are on fieldwork. These checklists will help to gather information about the hygiene conditions, the types of containers and their cleanliness, the sources of water to clean them, the existence or lack of cooling

technologies, and how milk is exposed to high temperatures during transportation and storage. The observations will form a critical contribution to the identification of initial critical control points in the value chain.

This Phase will deliver the main deliverable in the form of a detailed and integrative system map of the pastoral dairy value chain. This map will also identify important nodes, actors, product flows, institutional arrangements and risk points and indicate initial connections between climate variability and food safety vulnerabilities as perceived by local actors and regulatory authorities. The system map will be used as an analytical and operational structure of sampling design, hazard assessment, and climate-risk modelling in the later stages of the research.

3.3.2 Data collection and analysis

3.3.2.1 Quantitative data collection

This phase will be dedicated to the empirical evaluation of food safety risks in the pastoral dairy value chain and will be between 4 to 8 months, which is a continuation of phase 1 system map and classifications of actors. The main aim of this step is to determine the quantitative value of contamination in microbes and chemicals in milk and related inputs and to compare the hazard profiles with the climatic variations and handling conditions in various value-chain nodes. This step will produce the scientific data that is needed in order to determine the effects of climate-related factors and daily practices on the milk safety of pastoral dairy systems.

With respect to food science and technology, the data collection plan will commence with the establishment of stratified sampling that will be informed by the system map created during Phase 1. The informal market vendors, stores, transport operators, farms, the aggregation centres will be selected purposely to cover the key nodes in the pastoral dairy value chain. Such stratification will allow making systematic comparisons among the risks of contamination at the production, handling, and distribution stages.

To capture the variability of season, the study will be carried out using longitudinal sample collection in two different seasons; dry season and wet season. Milk samples will be taken at each of the chosen nodes. Laboratory analysis will be done on all specimens according to the prescribed microbiological and chemical testing procedures. Microbial tests will involve metagenomics analysis to approximate the level of the total microbial load, and specific

pathogenic indicators like *Escherichia coli*, *Staphylococcus aureus*, *Listeria monocytogenes* and *Salmonella spp.* Chemical testing will be aimed at the detection of aflatoxin M1, a mycotoxin with high public health impact in Kenya, especially under drought and feed shortage conditions which favour the growth of moulds, and the presence of antibiotic residues in milk that are likely to increase in the climatic stress, owing to the disease pressure, the lack of water, and the possible use of the antimicrobials in the animal health care.

At the same time of collecting the samples, structured surveys will be given to the same actors who will give the samples. The questionnaires will be used to gather quantitative information on herd size and production, herd management, herd health history, feed sources and storage methods, water accessibility and quality, and specific milk handling, including cleaning schedule, access to cooling facilities, milk marketing and post-milking to market time. Furthermore, the survey questionnaires will include discrete choice experiments to disclose the value chain actors' preferences for alternative food safety strategies. This will be done by the economics researchers. The data will facilitate modelling of the relationship between the measured level of hazards and operation factors at every value chain node.

The anthropological input at this stage will make sure that the structured surveys are culturally acceptable, contextually acceptable and comprehensible by pastoral households. The design of the questionnaire will be assisted by anthropologists who will ensure that the questionnaire contains local terminologies, cultural norms, and knowledge systems to support milk production and handling. They will also ease the process of training data enumerators on culturally sensitive engagement techniques to establish trust and increase the accuracy of the responses when collecting data. This interdisciplinary cooperation makes sure that quantitative data is interpreted in a proper socio-cultural context, and the participation is ethical and respectful.

The major deliverable of this phase will be a detailed quantitative dataset that will establish the relationship between the levels of microbial and chemical contamination with particular value chain nodes, practices of handling, value chain actors' incentives and capacities and seasonal climatic conditions. This information will underline risk modelling and climate-impact analysis in Phase 3 besides the evidence in support of specific interventions to enhance food safety in the pastoral dairy system.

Data on consumers' milk consumption, milk handling practices and preferences for milk attributes (including preferences for safety-improving methods in milk production, as expressed in choice experiments) will be collected in a questionnaire survey and analysed using state-of-the art econometric techniques. Expertise from anthropology will be involved in interpretation of the data and results.

The RCT intervention study will commence after collection of the quantitative datasets (microbiological samples and farm questionnaire survey) and will use these datasets as its baseline measurement. Additional data from an endline data collection (microbiological samples, questionnaire data on economic and socio-economic outcomes) and from intervention activity records will be analysed using econometric methods and food science methods. Interpretation of the RCT findings will involve researchers from anthropology and food science researchers.

3.3.2.2 Qualitative data collection

This will be the third phase of the project and will occur between the 7 to 10th month. It will be used to further understand the quantitative results of phase 2 by addressing the lived, perceptions, and adaptive strategies of the actors in pastoral dairy value chain. The main point of this stage is to explain the meaning of certain food safety risks, gauge the state of risk awareness of the actors of the value chain and embody the overall livelihood consequences of food safety risks induced by climate change. It is a qualitative stage that uses anthropological questions, with technical contributions of food science and technology, to produce subtle explanatory knowledge.

The main part of this step will be the in-depth interviews (IDIs) with a purposely chosen sub-sample of the respondents that were involved in the quantitative sampling. Such interviews will offer a chance to introduce laboratory results, well-packaged in a non-stigmatizing and educative manner, and apply them as sources of reflective conversation. The respondents will be encouraged to make remarks on matters like causes of seasonal fluctuation in milk spoilage, limitations to ensuring hygiene or water shortage and animal health. As an illustration, interviewers can enquire about the perceived rise of microbial contamination in the rainy season and the practices, environmental settings or resource constraints that actors think are causing these results. The IDIs will shed light on the perception of risk, causality, and coping mechanisms of community members to the demands of climate and food safety.

Besides the interviews, case studies will be conducted to enable a thorough scrutiny of especially vivid or unusual cases that arise out of the quantitative data. These can be a pastoral family where the milk produced by them showed a high level of aflatoxin recurrently or a vendor where the samples were showing a high level of microbial quality even though the vendor had limited resources. Within the context of long-term engagement and observation, the individual case studies will address the particular practices, knowledge systems, cultural norms, and structural constraints that define food safety outcomes. These contextualized and rich accounts will assist in explaining the variability that is observed throughout the dataset and give understanding into the possible leverage points that can be used to intervene.

The qualitative inquiry will also be structured to include a livelihood impact assessment based on data gathered by the means of IDIs and previous FGDs. This evaluation will look into the multi-dimensional effects of food safety hazards and climate stress to pastoral livelihoods. The effects on the economy will be examined in terms of the income loss related to the spilled milk, the rise in the spending on animal treatment, and the fines related to low quality milk. The social impacts will be evaluated using the change in gender roles, intra-household duties or strains, and the change in social status associated with the capacity to deliver quality milk volumes. Self-reported occurrence of illnesses due to the use of milk in the house, healthcare expenditure, and perceived obstacles to embrace safer handling will be investigated as health effects. Such a comprehensive investigation will place food safety not just as a technical problem but as a determinant of the stability and well-being of the household as a critical one.

The food science and technology researcher will be used to support the communicated scientific findings in the interviews to be accurate and sensitive. This will involve coming up with simplified interpretations of the laboratory results, which is acceptable to be presented to the members of the community without any fear, stigma, and blame. In addition, food scientists and anthropologists will take part in a joint analysis to work together in interpreting the resultant qualitative narratives. Such sessions will assist in determining the compatibility or explanation of some of the hazard patterns identified during the Phase 2 by the practices outlined by actors, so that the interpretation is scientifically sound and based on the socio-cultural reality.

Economists will be central in the project in terms of interpreting the socioeconomic impacts of risks in food safety and climatic variability in the pastoral dairy value chain. Based on the results of Phase 2, including questionnaire surveys and discrete-choice experiments conducted quantitatively, economists will play a role in explaining how value-chain actors will develop decisions with regards to milk handling practices, risk-management strategies, and investments in food-safety improvements. At this stage, economists will also cooperate with anthropologists and food scientists to assess the role of economic incentives, market limitations and behavioral determinants in influencing adoption or rejection of safer milk production methods and handling practices. The findings on the discrete-choice experiments will help in explaining the preferences of the actors, their willingness to take risk-reducing action, and trade-offs between food safety, cost, labour, and market access. Such analyses will be complemented by qualitative information in terms of the in-depth interviews and case studies, thus, allowing to have a more subtle comprehension of the economic logic of household- and market-level decision-making. Moreover, the economics researchers will contribute to the livelihood impact assessment by examining the financial consequences of food safety hazards under conditions of climate stress. This will include evaluating economic losses associated with milk spoilage, veterinary costs, reduced market prices for poor-quality milk, and healthcare expenditures linked to foodborne illnesses. The integration of economic analysis with social and technical perspectives will enable the project to identify feasible and economically viable interventions that pastoral communities are more likely to adopt.

The main deliverable of this phase will be comprehensive, contextualized narratives which will give explanatory richness to the quantitative results. Such understandings will help in defining how climate variability relates with socio-economic conditions, cultural practices and resource endowment to influence food safety hazards in the pastoral dairy system. They will also provide information on the way actors view, negotiate, and deal with these risks, and the resultant impacts on their livelihoods and well-being. Such findings will be used directly in co-designing interventions.

3.3.3 Integration, validation and co-development of interventions

This will be the last phase of the project and will be between 11 to 12 months. Its aim will be to integrate the quantitative and qualitative results produced during the course of the project, confirm the outcome with the local and institutional stakeholders, and jointly develop viable and context-specific mitigation measures that would enhance climate adaptation and food

safety in pastoral dairy systems. It will combine scientific data, social intelligence, economic incentives and capacities, policy outlooks, and experience to make sure that the ultimate products are technically and locally sound. Structured workshops will be held in which the entire research team, food scientists, anthropologists, will collectively review and interpret the entire dataset. Such sessions will make it possible to triangulate across all the methodologies so that every finding is contextualized in both lived experiences and environmental realities.

3.3.3.1 The stakeholder validation workshops

The project will hold multi-stakeholder workshops within the study area to increase the levels of legitimacy and make the findings appeal to the people directly impacted. The targeted participants will be pastoralist families, milk traders, representatives of cooperatives, county public health officials, extension agents and the NGO partners involved. The results will be displayed in formats that are easy to understand and comprehend like visual diagrams, pictorial posters, simple stories, and interactive maps. Facilitation techniques that will be used in the workshops include the World Cafe method that will allow the use of small, rotating group discussions with guiding questions like; (1) Are these findings true to your experiences in life? (2) What are the most urgent identified risks? (3) What are the suggested changes that can be implemented in your present livelihood limitations?

3.3.3.2 Co-development of research findings and interventions

The research team will develop a set of outputs that are contextual using a collaborative approach based on the input of the stakeholders. These will include technical briefs of policymakers and regulators, practical pictorial manuals to pastoralists and small-scale vendors and academic publications

This last phase will come up with a tested and stakeholder approved model of the intricate interrelationships between climate variability, food safety risks, and livelihood risks in pastoral dairy systems. It will also provide co-created practical measures that aim at improving resilience in the household, value chain, and policy levels. The results of this will be the foundation of further scaling, policy discussion, and, possibly, piloting of climate-adaptive dairy solutions in the arid and semi-arid regions of Kenya.

4.0 Ethical considerations

According to the set project's data management plan (DMP), it will comply with internationally recognized ethical standards for research involving human participants. Ethical approval will be obtained from the relevant institutional ethics review committees in Kenya prior to the commencement of field activities in Marsabit county. Research authorization will also be acquired from the National Commission for Science, Technology and Innovation (NACOSTI). Participation in all research activities, including interviews, surveys, and participatory discussions, will be entirely voluntary. Participants will be informed about the objectives of the study, the procedures involved, and their right to decline or withdraw from participation at any stage without any negative consequences. The study will collect qualitative and quantitative data, including demographic information and interview recordings. To protect participants' privacy and confidentiality, all personal identifiers will be removed and replaced with anonymized codes during data processing and analysis. Data will be securely stored on password-protected institutional servers with access limited to authorized members of the research team. Data management procedures will comply with international data protection standards, including the General Data Protection Regulation (GDPR). Special attention will be given to respectful engagement with pastoral communities, ensuring culturally sensitive data collection practices and safeguarding the dignity, rights, and well-being of all participants throughout the research process.

4.1 Informed consent and voluntary participation

The study will inform all participants about the objectives, methods, possible risks, and expected benefits of the study. The consent procedure will involve both oral and written communication about the process of consent, in the most common local languages (Kiswahili, Rendille, Borana) depending on the dominant participants. In the case of low literacy participants, local enumerators and cultural brokers will assist in consent by making sure that the participants are meaningfully informed. The involvement will be completely voluntary, and the people will be told that they have the right not to answer certain questions or leave the study entirely at any time without any penalty.

5.0 Risks and benefits to participants

The project presents minimal risk to participants as it primarily involves interviews, surveys, and non-invasive biological sample collection from milk and environmental sources. However, potential concerns may arise regarding the disclosure of food safety practices or milk quality results that could be perceived as sensitive. To mitigate these risks, findings will be communicated in a non-stigmatizing and educational manner that emphasizes learning and improvement rather than blame. Participants may benefit indirectly from the study through increased awareness of food safety risks, improved understanding of safe milk handling practices, and access to knowledge generated through the research. The findings will also contribute to the development of contextually appropriate interventions aimed at improving food safety, livelihoods, and resilience among pastoral dairy communities in Karare Ward.

6.0 Community engagement and participation

Community engagement will be an integral component of the research process. Therefore, before data collection, the research team will engage with local leaders, community representatives, and relevant national and county stakeholders to explain the objectives of the study and seek their support. Moreover, continuous engagement with community members will ensure that the research is conducted in a culturally appropriate and respectful manner. In addition, participatory methods will be used to encourage dialogue with pastoral households and dairy value chain actors, allowing their knowledge, perceptions, and experiences to inform the interpretation of findings. Feedback sessions will also be organized to share key results with community members and local stakeholders, promoting transparency and facilitating the co-development of locally relevant food safety interventions.

7.0 Data sharing and open science

The project will follow responsible data sharing and open science principles while ensuring the protection of participant confidentiality. De-identified datasets and research outputs may be shared with the wider scientific community through secure data repositories and peer-reviewed publications. Any shared data will exclude personally identifiable information to ensure participant anonymity. Data sharing agreements will be established where necessary to regulate access and ensure compliance with ethical and legal requirements. The project will promote equitable access to research findings by disseminating results to participating communities,

policymakers, and relevant stakeholders in accessible formats that support evidence-based decision-making for improved food safety and climate adaptation in pastoral dairy systems.

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