The role of the integrated soybean-maize-chicken value chains in sustainable food systems in the Southern Highlands of Tanzania

W.C. Wilson 2023

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Wilson Charles Wilson

Propositions

1. A linear presentation of agri-food value chains underplays the role of smallholder farmers.
   (this thesis)
2. Increasing soybean production in Tanzania concurrently needs the strengthening of local processing facilities.
   (this thesis)
3. Bridging the missing middle in agri-food systems is the key to achieving zero hunger (SDG 2).
4. The societal deliverables of a PhD program are more important than its scientific output.
5. The recent food crisis in developing countries calls for improved local production.
6. Climate change adaptation needs similar budgets as currently allocated to military operations to have any chance to succeed.

Propositions belonging to the thesis, entitled

The role of the integrated soybean-maize-chicken value chains in sustainable food systems in the southern highlands of Tanzania

Wilson Charles Wilson,

Wageningen, 14 June 2023

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Thesis

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This thesis is dedicated to the lovely superwomen, my grandmother Medrine Mndalila, mum Elizabeth and Pendo Mndalila, and the entire family of the late Rev. Patrick Mndalila.

This thesis is also dedicated to my lovely daughter Lisa Wilson!

Abstract

Tanzania is among the sub-Saharan African countries experiencing food insecurity due to high rates of malnutrition in many forms, largely attributed to a lack of dietary diversity among disadvantaged urban and rural households. Surprisingly, Tanzania's breadbasket regions important for food production have high rates of micronutrient deficiency, partly due to limited dietary diversity. This thesis focused on exploring the potential of soybean-maize-chicken value chains to support the sustainable production of diversified diets and to identify entry points for value chain integration in the Southern Highlands of Tanzania. We first employed fuzzy cognitive mapping (FCM) to understand the current soybean, maize, and chicken value chains, highlight stakeholder relationships, and identified entry points for value chain integration to support nutritious diets in three regions in the Southern Highlands. The study revealed the importance of networks of value chains in domestic markets, whereby soybean-maize-chicken value chains are interconnected particularly at smallholder farming systems and at processing facilities. Chicken feed was an important entry point for integrating the three value chains, as maize and soybean meal are chickens' main sources of energy and proteins. Unlike maize, the utilization of soybean in chicken feed was very low, mainly due to inadequate processing of soybean grain into meal. As a result, the soybean grain produced is primarily exported to neighbouring countries for processing, and soybean meal is imported at relatively high prices. We proposed enhancing local sourcing and adequate processing of soybean coupled with strengthening the integration of smallholder farmers with other soybean-maize-chicken value chain actors to improve access to nutritious food for people.

In a next step, we conducted a cross-sectional survey to understand the diversity of chicken farming and to explore the intensification gradient in the production systems in urban and rural areas in the Iringa region. This study is the first to explore the diversity of chicken farming and the underlying production constraints based on the subdivision of the production systems refined by adding the size of the flocks to highlight variations in the scale of operations. The findings show that the degree of intensification of chicken production systems was increasing with the number of improved crossbred and exotic chickens raised at medium to large scale intensive systems, in both urban and rural locations. These chickens were fed with homemade and/or commercial feeds. Understanding the diversity of chicken farming systems allowed a diaf problems targeting interventions for different production systems. We found for instance that development of small-scale poultry systems is hampered by limited access to quality feed whereas medium to large scale systems were constrained by limited supply of one-day-old chicks.

The study further explored the current feed gap and how this gap can be closed by comparing the actual feed quantity and quality supplied to dual-purpose chicken with the recommended standards. Combining surveys, physical measurements of chicken and eggs, sampling of feed and laboratory analysis on micronutrient content and mycotoxin contamination, we found the need for a stronger focus on feeding strategies and ensuring the availability of affordable, suitable and safe feed formulations. In line with the Tanzania Livestock Master Plan, the study highlighted the importance of closing feed gaps (both with regard to quantity and quality) to meet the increasing demand for chicken meat and eggs.

Lastly, the study assessed land requirements to produce sufficient food of adequate nutritional quality for the current and the anticipated doubled population of the Iringa region by 2050 based on macro secondary data, and micro primary data. The actual and potential yield of the food crops grown in the region were extracted from the Yield Gap Atlas, a global open-access database. For actual chicken production, we used our own data and potential yields, and feed requirements were based on values provided by poultry breeding companies. The findings of this thesis revealed that with actual yields for crops and poultry and a doubling in population size, even the total area of land suitable for agriculture is not enough to produce sufficient food and feed. Cultivating unused suitable or unsuitable land with the actual yields leads to food-feed competition in most scenarios and with the increasing population, food exports will be strongly reduced or no longer possible. To meet the increasing demand for food, the present study strongly recommends focusing on sustainable intensification options aiming to reduce the yield gaps in crop and poultry production. Otherwise, with the current yield, it will not be possible to produce sufficient diverse food for the current and future population without further expansion of agricultural land.

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Chapter 1

General introduction

1.1. Background

By 2050, the global human population is projected to reach 10 billion people with a major increase expected in sub-Saharan Africa (SSA), where the food supply is already under great stress (UN, 2022). The continuing increase in the human population in SSA implies that the demand for major cereals will triple while that of animal-sourced food (ASF) will double by 2050 (Thornton, 2010; Van Ittersum et al., 2016; Weber and Windisch, 2017). Attaining food security is important to ensure that all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and preferences for an active and healthy life (FAO, 1996). In 2015, all member states of the United Nations pledged joint support for 17 Sustainable Development Goals (SDGs), with the second goal (SDG2) targeting ending hunger, achieving food security and improved nutrition and promoting sustainable agriculture by the year 2030 (UN, 2015). Although initiatives are taking place to achieve the SDG2, food insecurity and micronutrient deficiencies are still alarming in SSA (Liu et al., 2015). Tanzania is among the SSA countries experiencing food insecurity due to high rates of malnutrition in many forms, largely attributed to a lack of dietary diversity among disadvantaged urban and rural households (Alphonce, 2017). With the increasing population and urbanisation, the demand for ASF chicken meat in Tanzania is projected to increase by 148% while that of beef, goat and mutton, pork and milk increase by 87%, 71%, 88%, and 108%, respectively from the mid-2000s to 2030 (Baker et al., 2016b; FAO, 2011).

1.2. The need for local production and sustainable food systems

Smallholder rain-fed agriculture is the backbone of food security in Tanzania and employs about 69% of the labour force and contributes to 29% of the country's Gross Domestic Product (NBS, 2017). Currently, the agricultural sector in Tanzania is constrained by low yields due to the sparse use of inputs and low adoption of improved agricultural technologies and practices (Kassie et al., 2013). As a result, the country has a large gap between food production and healthy consumption (De Bruyn et al., 2018), which articulates in micronutrient deficiencies, including those of vitamin A, iron and iodine. Consequently, the country has high rates of chronic undernutrition (as indicated by stunting), underweight and wasting among children as indicated by 34, 14 and 5% of the population, respectively. It is currently estimated that one out of ten child deaths under the age of 60 months is due to vitamin A deficiency, while 45% of women aged 15-49 are anaemic, resulting in one in five deaths during pregnancy (Ministry of Health et al., 2016; Temu et al., 2014).

To attain SDG2, a diet should be sustainable in all matters. Besides dietary diversity, food should, for example, be produced without further expansion of its natural resources e.g. agricultural land. According to the FAO, sustainable diets are "diets with low environmental impacts which contribute to food and nutritional security and to a healthy life of present and future generations" (Burlingame and Dernini, 2012). Currently, food production impacts the environment via its emissions to air, water, and soil (Foley et al., 2011; Krausmann et al., 2013). Worldwide food production causes for example 25% of the global anthropogenic greenhouse gas (GHG) emissions (Tilman and Clark, 2014) and the majority (60%) of this originates from livestock production (Gerber et al., 2013). In Tanzania, the environmental impacts are related to land use and land use change and poor agricultural practices, resulting in depleted soils and poor agricultural yields (Kassie et al., 2013). Therefore, the dual challenge is producing sufficient diverse diets for the population while reducing the environmental impacts. To achieve this, we need sustainable innovations within the whole food system. Food systems encompass the entire range of actors and their interlinked value-adding activities from the point of production ('the field'), aggregation, processing, distribution to ultimate consumption ('the table') and disposal of food products, and parts of the broader economic, environmental and societal aspects of which they are embedded (FAO, 2018).

1.3. Nutrition-oriented farming systems

Innovations that embrace the whole food system will lead to synergies in terms of dietary diversity and environmentally sustainable production of food. An example of an innovation applied in Tanzania is the integration of grain legumes such as common bean, soybean, groundnut, cowpea, chickpea and pigeonpea in the cereal-based farming systems. Of all grain legumes, the common bean *(Phaseolus vulgaris)* is the most widely grown, whereby the country ranks 7th in global bean production (Ronner and Giller, 2013). Recently, the N2Africa project funded by the Bill & Melinda Gates Foundation invested in "research-in-development" projects focussing on putting nitrogen fixation to work for smallholder farmers growing legume crops in SSA, including Tanzania (Dontsop-Nguezet et al., 2019). In recent years, supported by the N2Africa project, soybean production has gained ground in Tanzania, particularly in the Southern highland regions (Nijbroek and Andelman, 2016). The increase in soybean production is mainly driven by increasing demand for edible oil for human consumption and soybean meal used in the formulation of animal feed, particularly for poultry (Baijukya, 2022; Mgeni et al., 2019; Murithi et al., 2014). Unlike other grain legumes, the utilization of soybean for human consumption requires processing i.e. roasting, fermentation and germination to reduce the anti-nutritional factors and toxin proteins (Martin et al., 2010). Currently, a small quantity of the locally produced soybean is processed to soy flour (fortified flour), mostly carried out by small and medium enterprises while little is known on processing of soybean into other nutritious soy products i.e. soy sauce, soybean curd, soy drinks and milk (Martin et al., 2010; Wilson et al., 2021). Research shows that soybean-maize rotations and intercropping have significant advantages in improving resource-use efficiency, weed, pest and disease control, and increased yield of subsequent maize, respectively (Rurangwa et al., 2018; van Vugt et al., 2018).

Nutrition-sensitive interventions including that of soybean may contribute to improving access to sustainable diets. Although the introduction of soybeans is promising, so far little information is available on its contribution to dietary diversity and the environmental impacts of the farming system. For example, does an increase in the production of soybean in the end result in improved dietary diversity at the regional level? Can dietary improvement be expected from efficient utilization of soybean as poultry feed which may contribute to increased production of meat and eggs? Animal-sourced food (ASF) contains essential amino acids and multiple micronutrients (particularly zinc, iron, vitamin A and B12) that are less dense and less (bio)available in plant-sourced food or even absent. Especially these nutrients are important in reducing malnutrition, and helping to improve growth and cognitive development of children (Leroy and Frongillo, 2007). Increasing the production of chickens, therefore, may help to increase dietary diversity, as well as improve the income of farmers through sales of surplus eggs and meat, especially if you realise that it is the most affordable livestock species kept by the vulnerable communities in the country, mostly under the traditional free-range system (Goromela, 2009; Michael et al., 2019).

The demand for chicken meat and eggs in Tanzania exceeds domestic production and supply, with average per capita consumption of one egg per week and one chicken per year (MLDF, 2019). In the past decade, the demand for animal-sourced food including that of chicken has increased and triggered the increase in chicken population from 30 million to 93 million chickens (MLDF, 2006; URT, 2022) with the major increase reported in improved breeds. The possibilities for increased production of soybean and consequently increased domestic chicken production and its environmental impact is so far unexplored. We can wonder, for example, if soybean is the most environmentally friendly crop in terms of land use compared to other grain legumes, or if its inclusion in poultry diets outweighs that of fish meal, in view of food-feed competition? Minimizing land use while securing dietary diversity can, for example, help to improve the environmental impact as land use is a central concern as it is associated with critical processes affecting the functioning of the planet, such as climate change, biosphere integrity and biochemical flows (Newbold et al., 2016; Rockström et al., 2009; Steffen et al., 2015).

1.4. Study rationale and objectives

In order to assess the contribution of the introduction of soybean to dietary diversity and environmental impacts, it is important to understand the maize-soybean-chicken value chains. The intervention through agri-food value chains may incorporate different actors and activities to ensure the provision of nutritious food to consumers in both urban and rural locations. The agri-food value chain approach is primarily focusing on food marketing chains and related economic benefits from the point of production to consumption (Allen and de Brauw, 2019). Currently, the existing maize-soybean-chicken value chains in the Southern highland regions are inter-connected at a certain point but seem to have different series of activities from the first point of production to final consumption. A small proportion of maize produced in the country is exported to neighbouring countries (Diao and Kennedy, 2016), while the current amount of soybean is mainly marketed in the domestic market (Wilson et al., 2021). On the other hand, the informal value chains dominate for local chicken producers in the rural areas, while the formal value chain is gaining grounds in the semi-intensive and intensive farming systems in urban areas (Oleke and Isinika, 2011; Wegerif, 2014).

Understanding the structure and stakeholders involved in the existing value chains is required to identify the entry points for future interventions to improve dietary diversity for rural and urban consumers. Effective maize-soybean-chicken value chains may provide opportunities for the implementation of sustainable intensification practices and increase agricultural productivity and involvement of different stakeholders throughout the chain (Ampadu-Boakye et al., 2017). Thus, the need arises for further empirical studies to understand the functioning of the value chains, policy gaps, incentives, institutional barriers, and opportunities that may contribute to finding local solutions to achieve SDG 2 in Tanzania. Therefore, the aim of this study is to explore the potential of soybean-maize-chicken value chains to support sustainable production of a diversified diets, identifying important entry points for value chain integration. To achieve this general aim, the following specific objectives were addressed:

i. To understand the current maize, soybean, and chicken value chain(s), stakeholders involved, their roles and networking, and identifying points for value chain integration
ii. To understand chicken farming diversity and constraints underlying chicken production in Tanzania
iii. To analyse feed gaps in chicken production both in feed quantity and quality
iv. To explore potential scenarios to design food systems that provide sustainable diets and their land-use needs to feed the current and future population at the regional level while minimising land expansion.

1.5. Study area and research methodology

The study was conducted in three regions in the Southern Highlands (SH) of Tanzania i.e. Iringa, Njombe and Ruvuma. The three regions are among the major breadbasket regions important for food production in the country with large opportunities for intensification. Surprisingly, the regions are most vulnerable to undernutrition mainly due to limited dietary diversity, where diets display high consumption of maize and other carbohydrate-rich staples (Ministry of Health et al., 2016). The regions were involved in the N2Africa project, focussing on dissemination of legume technologies of smallholder farmers. The three regions contribute about 25% of Tanzania's total maize production mainly produced by smallholder farmers (Suleiman and Kurt, 2015).

1.6. Thesis outline and research methods

This thesis consists of six chapters (Figure 1). Chapter 1 is a general introduction, followed by four research chapters (Chapter 2 to 5) and a general discussion (Chapter 6). In the second chapter, I employed fuzzy cognitive mapping to understand the current soybean, maize and chicken value chains, highlight stakeholder relationships, and identified entry points for value chain integration to support nutritious diets in the three regions based on the information collected during household interviews and participatory workshops.

For the third chapter, I assessed chicken farming diversity and explored the intensification gradient in the production systems and the underlying constraints limiting production in urban and rural areas. Data were collected in Iringa region where 121 chicken farming households were interviewed using semi-structured questionnaires, followed by a problem tree analysis.

In the fourth chapter, I present feed gap analysis, where I explored the current feed gap and how the feed gap can be closed. I did this by comparing the actual feed quantity and quality supplied to chicken with the recommended standards for improved dual-purpose crossbred chicken, and exotic layers and broilers. I focus particularly on farms keeping indigenous and improved dual-purpose crossbred chickens raised for both meat and eggs under semi-intensive and intensive systems whereby 101 farmers in the Iringa municipality were interviewed by using a semi-structured questionnaire. Furthermore, the study involved physical measurements of chickens and feed, and nutritional quality analysis of the feed using Near-Infrared Reflectance Spectroscopy (NISRS) and aflatoxin contamination using the AccuScan Gold III reader.

In Chapter 5, I present the potential scenarios to design food systems that provide sustainable diets to feed the population in Iringa region, while minimizing land expansion based on both macro secondary data and micro primary data used in Chapters 2 to 4. Starting from the actual yield of the current crops grown aiming at providing sufficient plant-based diet in the region, I built feasible scenarios (including adding chicken and eggs produced within the region) to analyse different diets in terms of nutritional value. Next, I evaluated these scenarios on production and land requirement to produce sufficient food for the actual population and the anticipated double population by 2050. Chapter 6 synthesizes the research findings of this thesis into the broader context, highlights overlaps and synergies between the thesis chapters, and draws conclusions from the main findings.

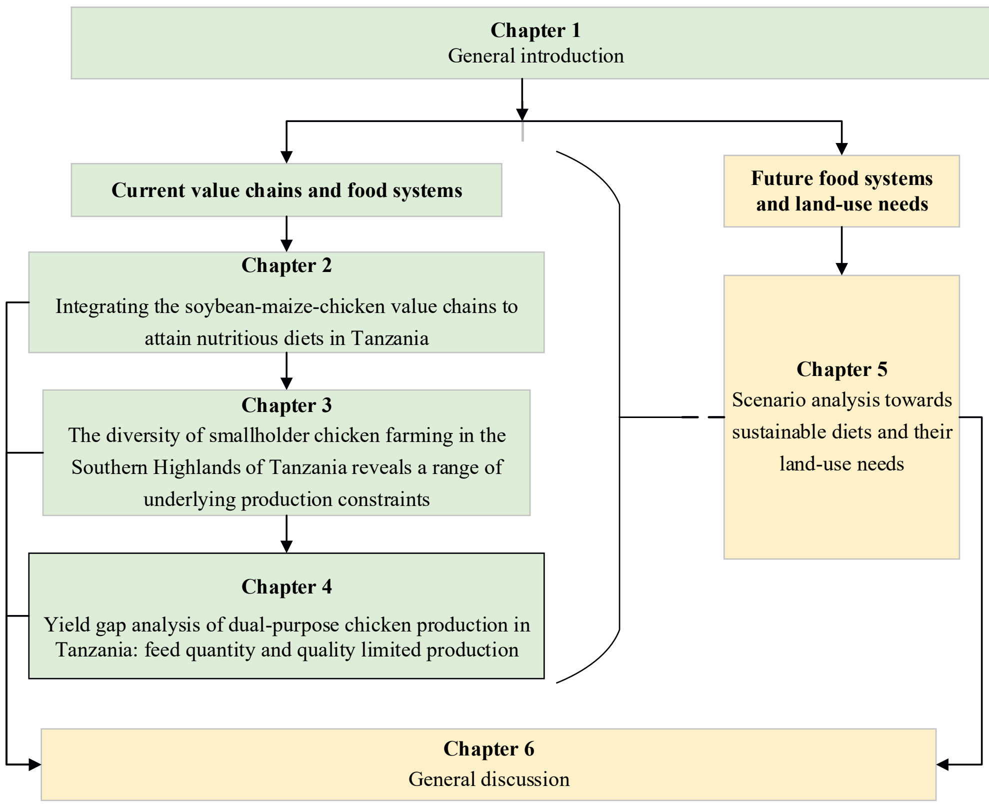

Figure 1.1. Thesis framework

Chapter 2

Integrating the soybean-maize-chicken value chains to attain nutritious diets in Tanzania

This chapter is a modified version of the following publication:
Wilson, W. C., Slingerland, M., Baijukya, F. P., van Zanten, H., Oosting, S., & Giller, K. E. (2021). Integrating the soybean-maize-chicken value chains to attain nutritious diets in Tanzania. *Food Security, 13*(6), 1595-1612. https://doi-org.ezproxy.library.wur.nl/10.1007/s12571-021-01213-4

Abstract

In Tanzania, diets are dominated by starchy staple crops such as maize, levels of malnutrition are high and largely attributed to lack of dietary diversity. We employed fuzzy cognitive mapping to understand the current soybean, maize and chicken value chains, to highlight stakeholder relationships and to identify entry points for value chain integration to support nutritious diets in Tanzania. The fuzzy cognitive maps were constructed based on information gathered during household interviews with 569 farming households, followed by a participatory workshop with 54 stakeholders involved in the three value chains. We found that the soybean, maize and chicken value chains were interconnected, particularly at the level of the smallholder farming systems and at processing facilities. Smallholder farming households were part of one or more value chains. Chicken feed is an important entry point for integrating the three value chains, as maize and soybean meal are the main sources of energy and protein for chicken. Unlike maize, the utilization of soybean in chicken feed is limited, mainly due to inadequate quality of processing of soybean grain into meal. As a result, the soybean grain produced by smallholders is mainly exported to neighbouring countries for further processing, and soybean meal is imported at relatively high prices. Enhancing local sourcing and adequate processing of soybean, coupled with strengthening the integration of smallholder farmers with other soybean, maize and chicken value chain actors offers an important opportunity to improve access to nutritious diets for local people. Our method revealed the importance of interlinkages that integrate the value chains into a network within domestic markets.

Keywords: dietary diversity, food security, SDG2, feed, integrated value chains, fuzzy cognitive map

2.1. Introduction

Member states of the United Nations pledged their joint support in 2015 for 17 Sustainable Development Goals (SDGs), with the second goal (SDG2) aiming to 'end hunger, achieve food security and improved nutrition and promote sustainable agriculture' by the year 2030 (UN, 2015). Achieving SDG2 in sub-Saharan Africa (SSA) is a major challenge, as the rapid human population growth implies that the demand for major cereals will increase three-fold while that of animal-sourced food (ASF) will double by 2050 (Thornton, 2010; Van Ittersum et al., 2016). Further, there is a 'missing middle' in terms of the lack of the globally-defined goals and local actions, and particularly a lack of connection between food production and consumption (Veldhuizen et al., 2020). The alarming incidence of food insecurity and undernutrition due to micronutrient deficiency in SSA is associated with limited dietary diversity among households (Rajendran et al., 2017). Tanzania is a typical example of a country facing challenges where limited dietary diversity is common among disadvantaged urban and rural poor households (Alphonce, 2017; Chegere and Stage, 2020; Wenban-Smith et al., 2016).

In Tanzania, dietary diversity is surprisingly limited in the "breadbasket" regions which are key for food production, including Iringa, Njombe, Mbeya and Ruvuma (Altare et al., 2016). The incidence of stunting among the under-five children in these regions is above 38% against the national prevalence of 35% (Ministry of Health et al., 2016). Dietary data revealed that the main dishes in these regions have low content of essential micronutrients, vitamins and amino acids that are critical especially in children's diets (Ministry of Health et al., 2016; Temu et al., 2014; Wandel and Holmboe-Ottesen, 1992). Inadequate diversity in diets is in part related to the high dependence on maize and other carbohydrate-rich staples including rice, sorghum, millet, roots and tubers (cassava, sweet potato and Irish potato), banana and plantain.

Tanzania has set several policies, programs and projects to achieve SDG2 (Alphonce, 2017). Among these, the Agricultural Sector Development Plan phase II (ASDP II 2017-2028) and the Tanzania Livestock Master Plan (TLMP) both target the improvement of livestock productivity and the functioning of the value chains to contribute to improving household income and nutritional security (Michael et al., 2018). Poultry products, both meat and eggs, could contribute to increased dietary diversity. Hence, the TLMP highlights the potential of maize and soybean to provide quality chicken feed, which is a major constraint to expansion of chicken sector production (Andrew et al., 2019; Nandonde et al., 2017). Currently, processed chicken feed is comprised largely of cereal grain/bran (mainly maize), and fish meal (mainly sardines) which could be directly consumed by humans, implying food-feed competition (Mkunda et al., 2020; Tacon and Metian, 2009). As a result, commercial chicken feed rations are expensive (particularly the protein sources), and contribute about 70% of the production costs (Mutayoba et al., 2011).

Agricultural diversification with legumes, fruits, vegetables and animal-sourced food (ASF) has significant potential to improve dietary diversity (De Bruyn et al., 2018). The protein from ASF contains the essential amino acids and multiple micronutrients (particularly zinc, iron, vitamin A and B12) in a form readily absorbable in the human body compared with smaller quantities with lower bioavailability in plant-sourced foods (Gibson, 2007; Perignon et al., 2018). These nutrients are particularly important in reducing malnutrition, helping to improve growth and cognitive development of children (Leroy and Frongillo, 2007). The demand for chicken meat and eggs in Tanzania exceeds domestic production and supply, with average per capita consumption of one egg per week and one chicken per year (MLDF, 2019). With increasing urbanization, economic growth and increasing affluence, the demand for chicken is projected to increase by 148%, while that of beef, goat and mutton, pork and milk will increase by 87%, 71%, 88%, 42% and 108%, respectively, by 2030 (FAO, 2011).

Between 2014 and 2018, the International Institute of Tropical Agriculture in collaboration with Wageningen University (through the N2Africa Project) and Catholic Relief Services (CRS) (through the *Soya ni Pesa* Project), promoted soybean production in the Southern Highlands of Tanzania (SH) aiming to improve household nutrition and cash income, and to enhance soil fertility. The increase in soybean production in Tanzania is primarily driven by increasing demand for animal feed, and as a fortifier in human foods under small to medium-scale processing (Martin et al., 2010; Murithi et al., 2014; Wilson, 2018). The utilization of soybean in animal feed has increased and could substitute fish meal which is currently unsustainable in terms of quality and availability. Nevertheless, soybean production, processing and supply cannot meet the current demand. As a result, Tanzania imports soybean meal from India and neighbouring countries (Leonardo et al., 2018; Mbwambo et al., 2016).

To assess the integration of soybean in the maize-based farming systems and its potential inclusion in chicken feed, it is important to understand the functioning of existing value chains. The agri-food value chains incorporate different actors and ranges of activities from initial production, processing and distribution to consumption (Allen and de Brauw, 2019). Understanding the functioning of the value chains is important since they may interact with each other and/or with other components in a wider food system (Veldhuizen et al., 2020). Attaining dietary diversity requires a value chain framework that incorporate different stakeholders and activities from production to consumption to enhance access to diverse diets (Fanzo et al., 2017; Gelli et al., 2017). The aim of this study was therefore to understand the soybean, maize and chicken value chains, the key stakeholders involved and to identify opportunities and constraints in the functioning of the chains to support diverse diets in the Southern Highlands of Tanzania.

2.2. Methodology

2.2.1. Study area

The present study was conducted in three regions in the Southern Highlands (SH) of Tanzania; Iringa, Njombe and Ruvuma (Fig. 2.1). The regions are found between latitude 7.7° S and longitude and 36° E. The altitude ranges from 400 m in the lowlands of Ruvuma region to above 2200 m asl in the highlands of Iringa and Njombe region, with a much of the area at 1600 masl. The mean minimum and maximum temperature is 13 and 22ºC in the highlands and 22ºC and 31°C in the lowlands (Mhagama, 2020; SAGCOT, 2015). The rainfall pattern is unimodal with mean annual rainfall ranging from 600 mm in the lowlands to 2600 mm in the highlands, starting in November and ending in May, followed by a cooler dry season from June to October. Soils are highly leached and weathered. The regions contribute about 25% of Tanzania's maize which is mainly produced by smallholder farmers (Suleiman and Kurt, 2015). Other food crops include wheat, legumes (mainly common bean, chickpeas and soybean), Irish potato, cassava, sunflower, horticultural crops, tea and timber. The main livestock species include traditional and improved chickens (cross-bred dual-purpose, layers and broilers), cattle (beef and dairy), pigs and small ruminants (sheep and goats) (Bisanda et al., 1998; SAGCOT, 2015).

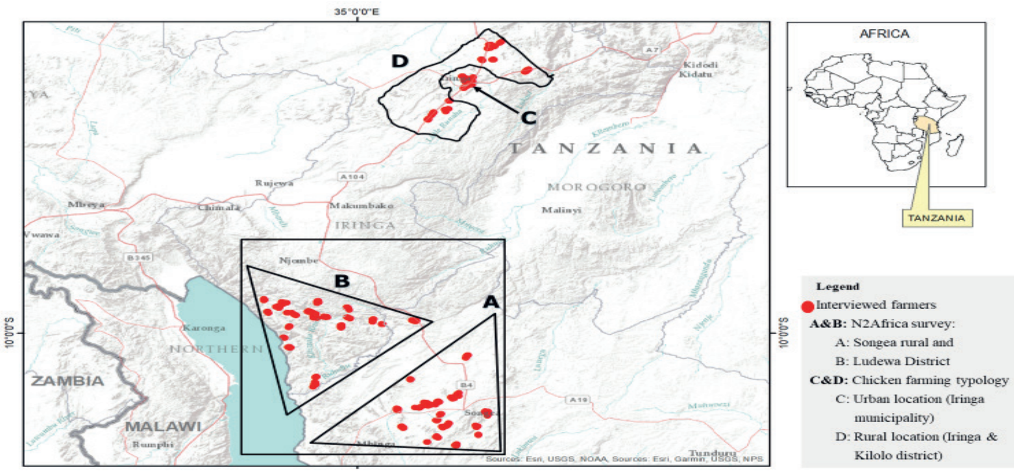

Fig. 2.1. Location of study regions and three clusters of farmers interviewed in Ruvuma (A), Njombe (B) and Iringa urban (C) and rural (D) regions in the Southern Highlands of Tanzania.

2.2.2. Data collection

To understand the production and value chain development in the current soybean, maize and chicken value chains, we collected secondary and primary data in three steps:

i. Aggregating and analysing secondary data on soybean and maize production and utilization.

ii. Collecting and analysing primary data on chicken production and management in urban and rural areas.

iii. Conducting a participatory workshop on value chain mapping and stakeholder analysis in the soybean, maize, chicken value chains.

Soybean and maize production and utilization

Data on production and utilization of soybean, were available from a survey conducted in September 2018 which examined production and utilization of soybean among 448 farming households in Ruvuma and Njombe (Baijukya et al., 2019) (Table A1). The data were retrieved from the N2Africa Open Data Kit aggregate platform, sorted, cleaned and analysed. The data on production and productivity of maize was obtained from Tanzania Annual Agriculture Sample Survey 2016/17 (NBS, 2012), (Table A1).

Characterisation of chicken production systems

Information on diversity of chicken production systems in urban and rural locations, was obtained from semi-structured interviews with 121 chicken farmers in the Iringa region from November to December 2018. Three administrative districts were involved, namely Iringa Municipality with urban farmers and Kilolo and Iringa with rural chicken farmers (Table A2).

Value chain mapping and stakeholder analysis

Generally, "value chain" denotes a range of value-adding activities required to bring a product and services from the point of production i.e. procurement of inputs, physical transformation and value addition, transportation and distribution to consumers. As such, value chains describe all the vertically and horizontally linked processes and diverse actors and their dynamic relationships from the point of initial production to consumption (Ayele et al., 2012; Kilelu et al., 2017; Webber et al., 2009). In the literature value chain integration is often used to describe the integration between links within a value chain (e.g. Papazoglou et al., 2000). Such integration is articulated in for instance governance of flows of goods and information between producers, processors, retailers and consumers**.** Some authors emphasize integration of smallholders into value chains (Barrett, 2010; Kissoly et al., 2017b;

Ros-Tonen et al., 2019) as timely sourcing of sufficient volumes of products of adequate quality from multiple small scale producers is a challenge, which is especially highlighted in global value chains literature. In the present study, value chain integration is used differently. It is used to explain how different domestic value chains are connected with each other at one or more nodes for example at production and processing.

To complement the information from the surveys, we used Fuzzy Cognitive Mapping (FCM) for value chain mapping and stakeholder analysis after pre-testing the approach through a focus group discussion (FGD) with four stakeholders involved in the chicken value chain. FCM is a semi-quantitative modelling tool used to structure stakeholder knowledge and views in a diagrammatic format, whereby the system components and relationships between the components are defined based on the stakeholder views and opinions (Jetter and Kok, 2014; Özesmi and Özesmi, 2004). The stakeholders involved in the FGD included two livestock extension workers, an animal-feed specialist and an integrated farmer, raising different species of poultry and also engaged in egg collection from other farmers and marketing. During the FGD, the participants were asked to identify the main components constituting the value chain from the point of production to consumption.

Within our methodological approach of FCM, we define a connection as a causal relationship between components. The components are of three categories:(1) indicators of value chain functioning, (2) variables affecting value chain functioning and (3) drivers determining value chain functioning (see section 2.3 for more details). The direction of the influence of components on each other can be positive or negative. They are positive when a component provides opportunities for the development or growth of another component and negative when a component constrains another component (see section 2.4 for more details). The strength of the positive or negative connection is an indication of the strength of this influence as assessed by the stakeholders.

In a next step, the stakeholders defined the strengths of the causal relationships between the identified components by filling a matrix based on seven categories as applied by Verkerk et al. (2017) i.e. no connection (0) very strong positive (+++), moderate positive (++) or weak positive (+) pointing at the strength of the connections between value chain components; and strong negative (---), moderate negative (--) and weak negative (-) pointing at levels of constraints and weak connections. The exercise took about four hours for the whole process, leading to problems with stakeholder engagement by the end of the session. We therefore adjusted and simplified the methodology and organised a multi-stakeholder workshop with 54 stakeholders involved in the value chains as explained in the next section.

Multi-stakeholder workshop

A participatory workshop was organised in May 2019 comprising 54 stakeholder-representatives including farmers, input suppliers, government agencies and non-governmental organisations (NGOs) involved in soybean, maize and chicken value chain development. The objective of the workshop was to map the current soybean, maize and chicken value chains, the stakeholders involved and to identify important entry points for integrating the three value chains.

The stakeholders were divided into three working groups based on their involvement in each value chain, with 21, 18 and 16 participants working on soybean, maize and chicken value chains, respectively. The participant groups were first asked to identify the actors involved in the value chain from production to consumption. Next, the stakeholders defined the strengths of the relationships between the identified value chain actors by connecting them on a map using arrows of thickness, relative to their importance in the value chain. The rapporteurs from each group presented the developed value chain and stakeholders involved to all participants for further discussion. Subsequently, each group listed the opportunities and critical constraints limiting the functioning of the value chains, followed by ranking the most important ones. The final exercise was a plenary assessment to identify important entry points for integrating the three value chains for food and feed production based on the expert views and further discussion among all stakeholders.

2.2.3. Fuzzy Cognitive Mapping

We developed the FCMs based on the primary data collected during the household interviews and a multi-stakeholder workshop (described in section 2.2.4 above) as well as expert knowledge. In the first step, we grouped the value chain actors into nine (9) classes based on the stakeholders' views during the participatory workshop i.e. (i) producers (smallholders, medium and large scale farmers for maize, soybean and chicken); (ii) agricultural input suppliers; (iii) extension service providers (government and private); (iv) government agencies and regulatory bodies (e.g. seed certification, National Bureau of Standards, Food and Drugs Control Authority, Ministry of Trade (import-export control), policymakers etc.); (v) agricultural research and development organisations (local and international); (vi) marketing and trading agencies (local and export); (vii) processors (medium scale millers, feed processors); (viii) financial institutions; and (ix) consumers (food and feed). The output indicators of the three value chains included household income and access to diverse diets through own-production and purchase.

In Fig. 2.2, we provide an example of stepwise construction of the FCM for the soybean value chain where we categorised the FCM components into three types of variables i.e. transmitter, receiver and ordinary variables (Gray et al., 2012). The same approach was applied in developing FCMs for the maize and chicken value chains. The transmitter variables are those having a significant influence on the system and affect other variables (and are not affected by other variables), while the receiver variables are affected by other variables but do not affect other variables. The ordinary variables are nodes in between the transmitter and receivers (Gray et al., 2012; Malek, 2017). The FCM component may also act as a central driver especially when its inclusion or exclusion strongly impacts the model (Sperry and Jetter, 2019). In the current study, the fuzzy cognitive maps were developed by defining the value chain indicators, variables and drivers following the protocol by Kokkinos et al. (2018) and Murungweni et al. (2011) based on the following steps:

(i) Defining the indicators of the functioning of the value chains i.e. (a) household production/harvest (soybean, maize and chicken), (b) household food availability (diverse diets), (c) feed availability for the chicken and (d) cash from surplus produce.

(ii) Defining the variables in the functioning of the maize, soybean and chicken value chains based on the constraints identified by the stakeholder groups during the participatory workshop.

(iii) Defining the drivers determining the functioning of the value chains i.e. the presence of research and development initiatives, availability of extension services, government policies, presence of farmer groups/platform, financial institutions and microfinance, market availability (traders, processors and the end users (food and feed).

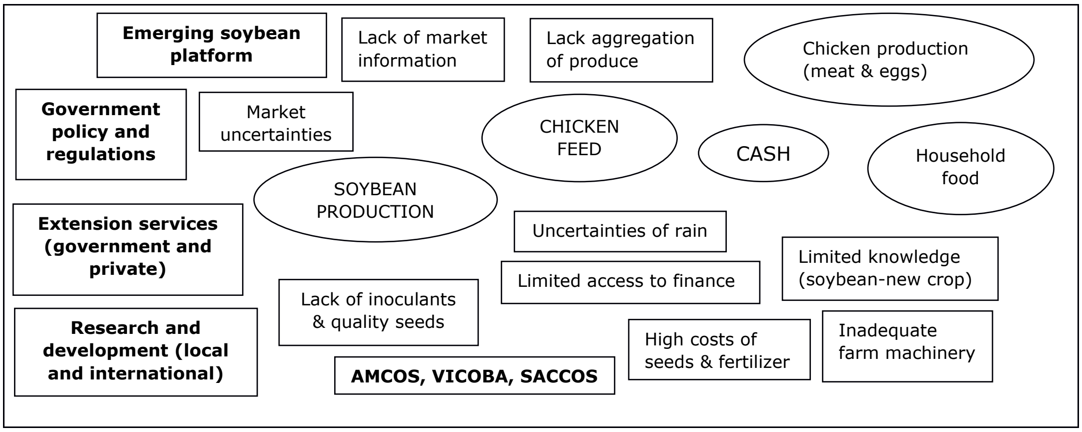

Fig. 2.2. FCM framework in the case of soybean value chain mapping and stakeholder relationship based on the approach applied by (Murungweni et al., 2011). The steps involved: (A) Defining the indicators in the functioning of the value chain components (circles); (B) defining the variables affecting the functioning of the value chain (boxes with plain text); (C) the drivers determining the functioning of the value chain (boxes with bold text). AMCOS stands for Agricultural and Marketing Cooperative Societies while VICOBA and SACCOS sands for Village Community Banks and Savings and Credit Cooperative Societies, respectively.

2.2.4. Data analysis

The quantitative data from the surveys were analysed using Statistical Package for Social Sciences (SPSS) version 25 to obtain the descriptive statistics to find frequencies and mean values that describe the household demographics and socio-economic activities. The significance of the mean differences was assessed using Analysis of Variance (ANOVA) and Chi-square tests. Furthermore, to understand the current maize production and productivity in different regions, we computed means and percentages based on the secondary data from the annual agricultural sample survey 2016/17 (National Bureau of Standards 2017).

The qualitative information collected during the interviews, participatory workshop, documentation and experts' views were entered into the online modelling software "Mental Modeller", where FCM graphs were generated based on the pre-defined indicators, variables and drivers following the protocol by Kokkinos et al. (2018) and (Murungweni et al., 2011). The value chain components were linked by attaching weights, where the following aspects were calculated:

i. Total number of value chain components
ii. Total number of connections between the value chain components (positive and negative)

iii. Indegree and outdegree of each value chain component calculated based on the column and row sum of the absolute values of the variables, respectively. The indegree presents the strength of the variables (incoming connections) while the outdegree (out-going connections) is a measure of influence between the variables FCM (Papageorgiou and Kontogianni, 2012).

iv. Number of connections per value chain component

v. Type of value chain component (transmitter, ordinary or receiver components)

vi. Total number of connections divided by the number of variables.

vii. Structural density: number of all identified connections divided by total number of all possible connections between variables in the FCM (Malek, 2017).

viii. Complexity score: the ratio between receiver variables and transmitter variables.

ix. The centrality of the nodes in the model i.e. the sum of the out-going and incoming connections.

Following the FCM modelling, we developed the graphs with + and – signs indicating the direction of the connections and arrows of different thickness indicating the strength of the connection (Figs A1-A3), and red fonts indicating negative strength. In the next step we further transformed the developed FCM into simplified diagrams using Microsoft Visio 2010 following the protocol in section 2.4 as depicted in Figs 2.4, 2.5 and 2.6. The numbers in between lines in the developed figs were retrieved from the FCM matrix where the model generates the values between -1 and +1 indicating the strength of the connections between value chain components. We assigned the values into the model based on the constraints and opportunities identified by the stakeholder groups during the participatory workshop using the modified FCM framework applied by Verkerk et al. (2017). In the modified framework, the strength of connection between value chain components were classified into strong positive (>+0.7), moderate/medium (+0.5 to +0.7), weak positive (+0.1 to +0.4); and strong negative (>-0.7), moderate negative (-0.5 to -0.7) and weak negative (-0.1 to -0.4) pointing at levels of constraints and weak connections; and zero (no connection).

2.3. Results

2.3.1. Crop production and utilization

Crop production and utilization Maize is grown by smallholder farmers in the Southern Highlands (SH) for household consumption and sale. According to the Annual Agricultural Sample Survey 2017, the average yield of maize in the SH during the 2016/17 growing season was 1.7 t/ha; slightly above the national average of 1.2 t/ha (Table A1) (NBS, 2017). In the same period, the SH produced 1.7 million t of maize, contributing to about 30% and 31% of the total maize produced and sold in the country, respectively. Based on the N2Africa survey, we found that most households in the SH grew legumes as a sole crop (81%) while 19% intercropped legumes mainly with maize (95%) and other crops (5%) (Table A1). There was a large variation in the choice of legume produced among households. Of all respondents, 65% grew legumes, mainly common bean (41%) and soybean (15%). Other legumes grown were groundnut grown by 25% of the farmers and cowpea only by one farmer. The average maize production was 1070 kg per household (range from 54-7000 kg). Value addition was mainly done on staple crops whereby 83% of the respondents milled maize flour locally for household consumption. Soybean was grown as a cash crop, with only 1% of the respondents reporting that they processed it for food. Other crops were processed in a very small proportion by the households.

2.3.2. Characterisation of chicken production systems

Three systems of chicken production were identified in the study area i.e. extensive, semi-intensive and intensive systems. The extensive system was comprised of indigenous chicken breeds raised under the low input-output system. The intensive systems raised specialized breeds under high input-output systems with commercial broilers, layers and improved dual-purpose crossbreed (mainly Sasso and Kuroiler breeds). Within urban locations, most farmers raised chicken under the intensive system (75%), while in rural chickens were raised under semi-intensive (37%), free-range production (38%) and intensive system (49%) (Table A2). The households interviewed in urban locations raised much larger numbers of chickens, produced more eggs and consumed more ASF than those in rural locations. Some of the farmers produced chicks themselves, while others purchased one-day old chicks from small-scale (local) and/or from large-scale hatcheries and brooders, mainly through selling agents.

2.3.3. Chicken feeds and feed ingredients

The urban farmers fed their chickens on purchased local feed rations/feed ingredients from local stores and market (69%) and commercial feed (40%), while those practising free-range and semi-intensive systems relied on a combination of scavenging and kitchen-waste (21%). On the other hand, chicken farmers in rural locations relied on both locally made feed rations (48%), scavenging (36%) and commercial feed rations (22%). The most common feed ingredients used in chicken feed formulation in the region were maize (grain/bran) and sunflower seed cake (Fig. 2.3), mainly sourced from local millers and middlemen at grain market and stores. Fish meal and soybean were also important sources of protein in chicken feed, particularly for the improved chicken breeds.

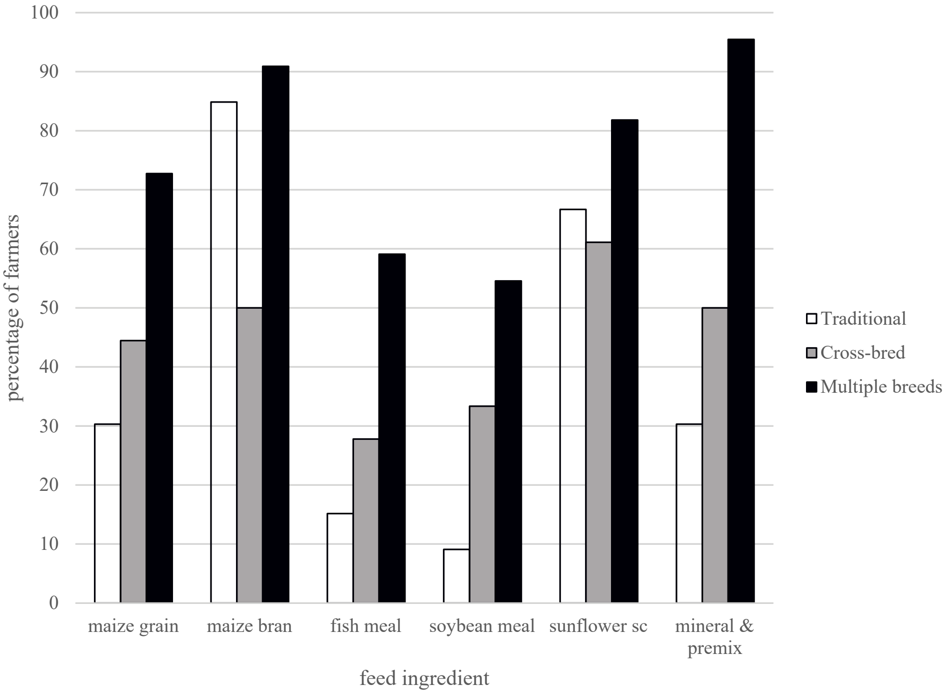

Fig. 2.3. The main ingredients used in locally-made feed rations for different types of chicken based on farmer interviews.

2.3.4. Soybean value chain development and stakeholder's analysis

Soybean is an emerging crop in the SH, mainly grown as a cash crop for export to the neighbouring countries and for animal feed and small-scale fortified baby food processing. The stakeholders in the soybean value chain identified during the participatory workshop included agricultural input suppliers, smallholder and mid-scale farmers, farmer groups/networks, traders, marketing agents, service providers (machine hiring), extension service providers (government and NGOs), research organization (government and international research organisations), wholesalers, retailers and supermarkets and financial institutions (Fig. A1).

2.3.5. Constraints and opportunities in the soybean value chain development

The soybean value chain was underdeveloped, where we found a negative connection between soybean farmers and processors (with a weak connection of -1), mainly constrained by high uncertainties in the output market (-1) and inadequate processing facilities (-1) in the country (Fig. 2.4). The uncertainties in the soybean market were mainly associated with lack of market information, weak linkages between producers and buyers, weak farmer organisation and lack of aggregation of the produce. As a result, traders collected soybean from individual farmers in the region. On one hand, soybean farmers complained that there was no market for their produce, while on the other hand traders complained that they could not collect the small amounts of produce from disaggregated farmers. Similar findings were observed during the N2Africa end line survey, where 26.6% of the interviewed farmers engaged in farmer groups and/or cooperatives (Table A1).

Other challenges limiting the growth of the soybean value chain included lack of improved quality seeds, limited availability of inoculants, high costs of inputs (quality seeds, fertilizers), inadequate labour-saving technologies (i.e. planters, harvesters, threshers), limited access to finance and lack of awareness of farmers on soybean production as a new crop. The government and private extension service providers contributed to improving awareness of farmers in soybean production. However, there were insufficient extension staff in the region, leading to a medium connection (+0.6) connection between farmers and extension service providers in the FCM (Fig. 2.4).

There were strong positive connections (+1) between soybean farmers and NGO's, agricultural research and development institutes (local and international) in the region mainly related to the initiatives in promoting the development of the agricultural sector i.e. the Southern Agricultural Growth Corridor (SAGCOT) initiatives, the N2Africa project and local initiatives on soybean research and dissemination of best-bet technologies to smallholder farmers. Furthermore, the government policy of promoting industrialization has a positive impact on promoting soybean production (+0.75) and processing (+0.5) that could ultimately contribute to the development of the soybean value chain. Nevertheless, soybean was processed locally using mechanical extraction facilities with inadequate processing capacity, resulting in poor quality soybean meal with a large residual oil content. When used in chicken feed formulation this has a negative effect on the growth of chickens leading to a negative relationship between processors and chicken producers (-0.75) and limited extraction of soy oil for household consumption (-0.5). A large quantity of soybean was exported to neighbouring countries for processing, with imports of soybean meal. Chicken farmers preferred the imported soybean meal despite the higher prices due to its good quality compared to the locally processed soybean meal resulting in medium connections between chicken farmers, feed processors and the import agents (+0.5). Other opportunities for the growth of soybean value chain indicated by the stakeholders during the workshop included: supportive policy environment for private sector investment in soybean production and processing, Value Added Tax (VAT) removal on animal feeds, the existence of Agricultural and Marketing Cooperative Societies (AMCOS), the existence of Village Community Banks (VICOBA), Saving and Credit Cooperative Societies (SACCOS), emerging soybean platform in improving access to input, output market and information and the growing demand for soybean meal as chicken feed.

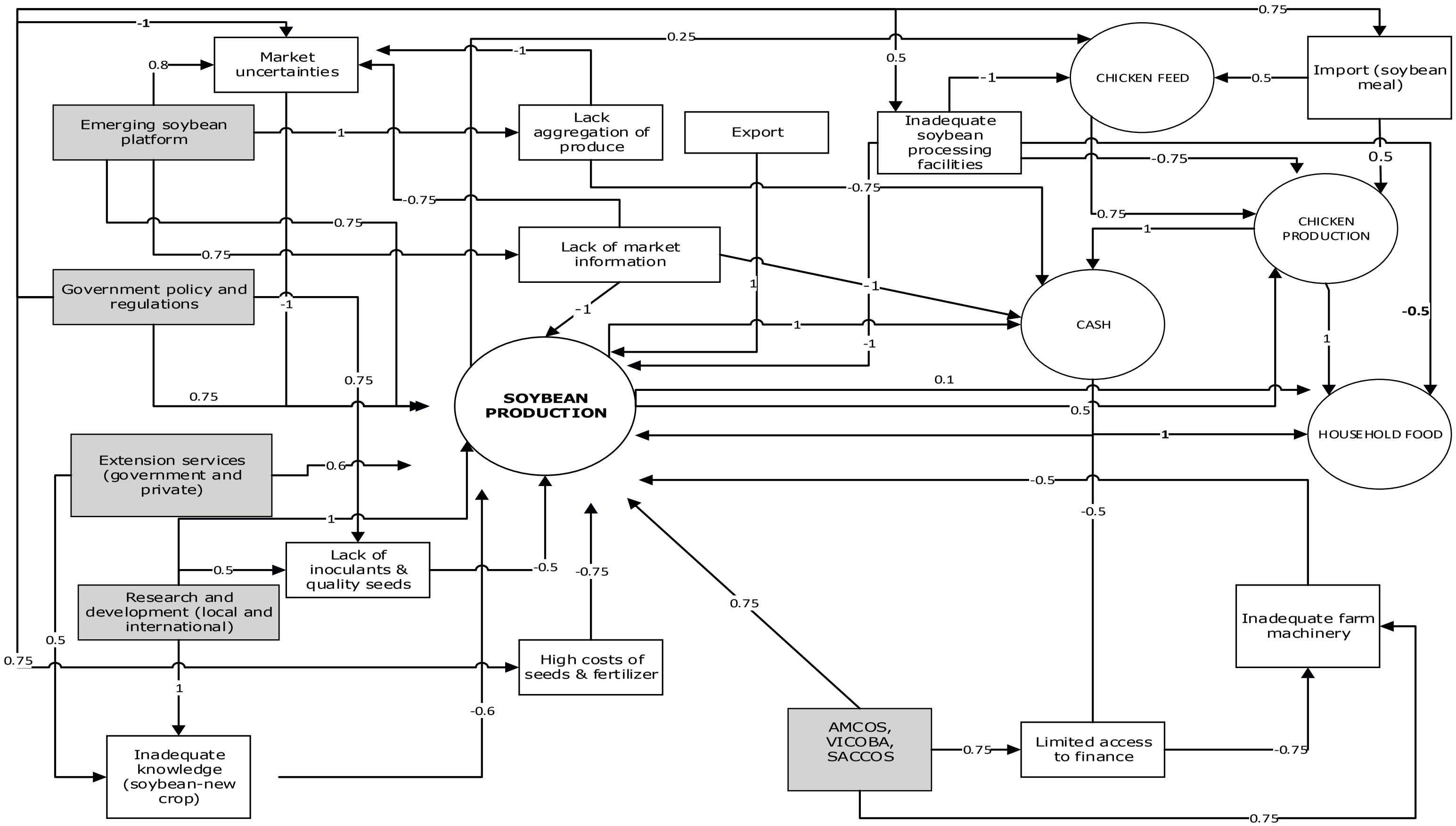

Fig. 2.4. A Fuzzy Cognitive Map of the soybean value chain in the SH of Tanzania. The white circles are the key indicators of the functioning of the value chain; the grey boxes are value chain drivers and white boxes are variables. AMCOS stands for Agricultural and Marketing Cooperative Societies while VICOBA and SACCOS sands for Village Community Banks and Savings and Credit Cooperative Societies, respectively. The numbers in between lines (between -1 and +1) indicates the strength of the connections between value chain components.

2.3.5. Maize value chain mapping and stakeholder analysis

Maize was grown as both a food and a cash crop. The surplus produce was traded mainly as dried grain through the informal value chain whereby middlemen were involved in grain collection from the farms and selling on to large grain traders. The grain traders were connected to the consumers through sale of maize grain to the urban market, supply to the grain millers for further processing into various products for consumers within the region and/or export outside of the region (Fig. A2). Some consumers would also access the maize flour/dehulled maize grain from small-scale processing units (hammer mills) located throughout the region. The mid and large-scale processors produced quality maize products using roller milling machines while following quality standard procedures i.e. sorting, cleaning, milling and packaging. The main products produced by mid and large-scale maize millers included the dehulled maize, white/brown maize flour and fortified flour that was supplied to consumers (within and outside the region) through the distributors selling agents, wholesalers, and retailers. The by-product (maize bran/maize bran with germ) was an important animal feed or ingredient in feed formulation, mainly for chicken. Besides dried corn, sale of green maize cobs was an important source of income for smallholder farmers, particularly those with access to irrigation during the off-season.

2.3.6. Constraints and opportunities in maize value chain development

Despite the significant importance of maize production and supply to neighbouring countries, the maize value chain was poorly coordinated, mainly dominated by middlemen/traders operating in the informal value chain leading to low profitability for producers. There were inadequate storage facilities and warehouse services, contribute to periodic oversupply and low prices of maize in the market particularly during the harvesting season (Fig. 2.5). The functioning of the maize value chain at producer level was mainly constrained by limited access to finances, high costs of inputs, inadequate farm machinery and implements. Other challenges highlighted by stakeholders included the effects of climate change (i.e. changes in annual rainfall patterns and prolonged dry seasons), declining soil fertility and soil organic matter due to continuous maize monocropping with few inputs. On the other hand, in 2017/18 the Tanzanian government banned the export of maize to ensure food security for the citizens, which led to a medium strength to the household food (+0.5) and increased availability of chicken feed (+1). On the other hand, the export ban had negative effects on producers as it led to a decrease in the price of maize and household income (-1).

The increasing demand for maize in the chicken feed industry creates a potential market opportunity leading to a strong connection between maize and chicken farmers (+1). The households producing both maize and chicken can utilize the grains in chicken feed formulation and improve the production of meat and eggs for the household at low cost and obtaining income from surplus produce (+1).

Other drivers in the functioning of the current maize value chain included promising agricultural policies and programmes i.e. Agricultural Sector Development Programme (ASDP II), SAGCOT, the establishment of National Food Reserve Agency (NFRA), Tanzania Investment Bank (TIB) and Tanzania Agricultural Development Bank (TADB) as well as the country's industrialization policy in promoting local production and processing. Besides, the existence of agricultural research and development institutes (local and international) and NGOs contributed to the development of the value chain through training and enhanced access to inputs and best-bet technologies and practices aimed at improving maize productivity (e.g. climate-smart agriculture - CSA). Additionally, the initiatives on providing extension services (government and NGOs), contributed to the dissemination of the CSA initiatives (+1).

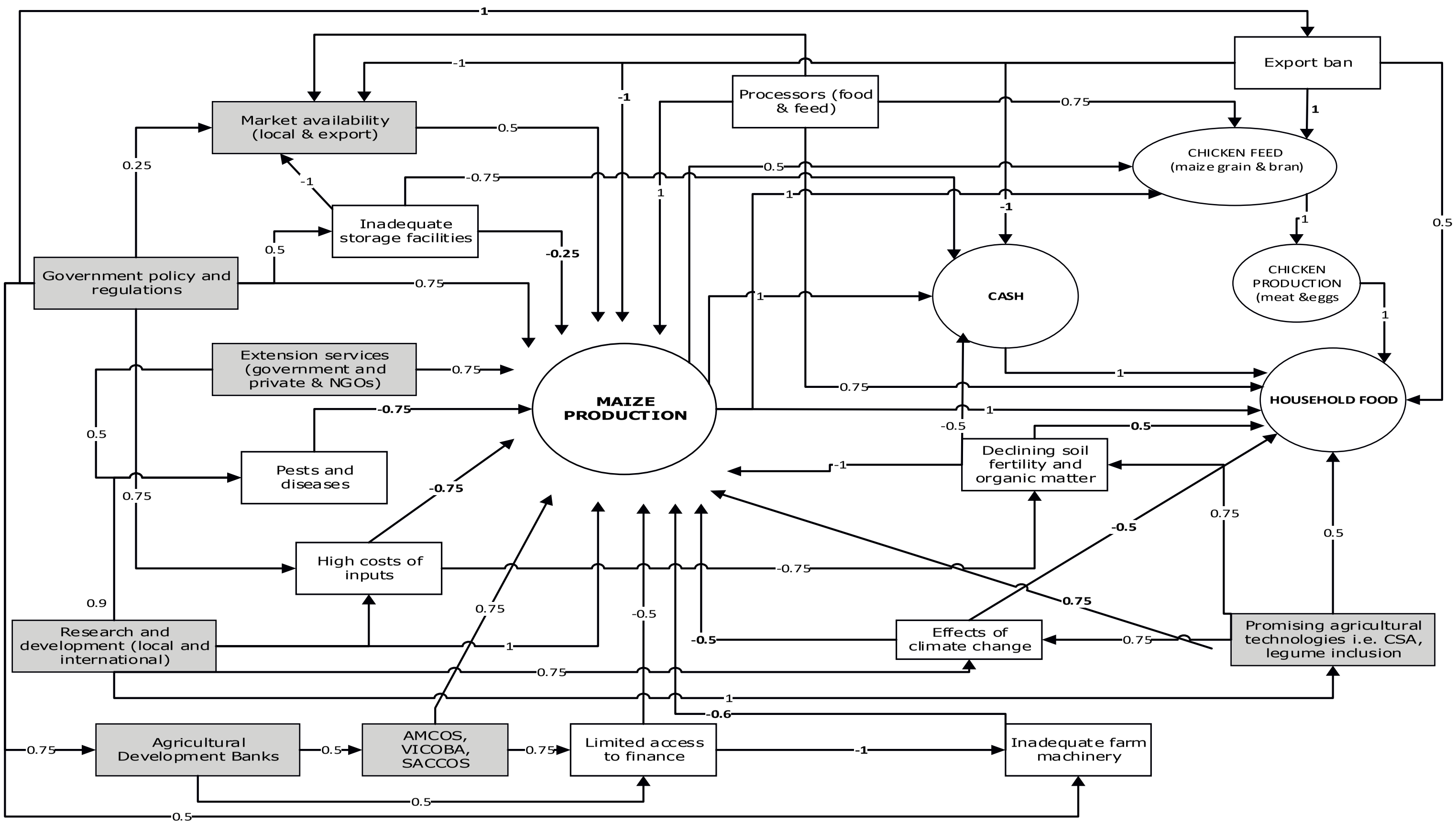

Fig. 2.5. Fuzzy cognitive map of the maize value chain in the Southern Highlands of Tanzania. The white cycles are the key indicators of the functioning of the value chain; the grey boxes are value chain drivers and white boxes are variables. AMCOS stands for Agricultural and Marketing Cooperative Societies while VICOBA and SACCOS sands for Village Community Banks and Savings and Credit Cooperative Societies, respectively. The numbers in between lines (between -1 and +1) indicates the strength of the connections between value chain components.

2.3.7. Chicken value chain mapping and stakeholder analysis

The informal value chain dominated the chicken value chain, whereby chicken farmers could sell live chickens and eggs to middlemen and traders in different channels where various stakeholders are involved (Fig. A3). These included, the households' own-production and consumption, selling live chickens and eggs to neighbours, slaughtered/processed chickens sold to hotels, restaurants and catering services, live chickens sold to middlemen/primary market (village level) and ultimately transported to the secondary market (district/municipality). Live chickens from secondary market or mid and large-scale farms, were sold to the informal middleman/agent to process and supply to consumers, hotels, restaurants, catering services, mini supermarkets etc. On the other hand, chickens from secondary markets were either sold to consumers within the region (live chickens/slaughtered) and/or transported from secondary markets to tertiary markets outside the region, mainly Dar es Salaam. The eggs produced on farm were sold to middlemen, selling agents and/or directly sold to markets, local shops, restaurants, and hotels and/or exported to other regions after being collected by traders.

2.3.8. Constraints and opportunities in the integrated chicken value chain

During the workshop, stakeholders indicated that limited access to quality feeds and feed ingredients were among the major constraints limiting the development of the chicken sector. Despite having feed processors in the region, the commercial chicken feed ration was expensive and mostly not available in small packages, leading to a weak relationship between smallholder chicken producers and commercial feed processors (+0.25 in Fig. 2.6). Most smallholder chicken farmers were unable to purchase bulky feed while some farmers under intensive and semi-intensive system partly fed their chicks with commercial feed rations during the early stages of growth and ultimately switched/combined locally made and commercial feed rations to reduce the cost of production.

Soybean meal and fishmeal were the important protein sources used in chicken feed rations by farmers in the SH regions. Notwithstanding, fishmeal was scarce and expensive. Soybean meal could either be accessed from local processing facilities within the region or through import. The latter option was expensive but mostly preferred by farmers due to the good quality of the imported meal. Imported soybean meal was sold at almost three times the price of whole soybean grain produced in the region. The local soybean meal was produced using mechanical extraction, with inadequate capacity to extrude oil from the grain which limited its value as chicken feed. Other challenges limiting the development of chicken value chain included the inadequate supply of day-old chicks (particularly for broilers and local chickens), lack of market infrastructures and disorganized marketing systems for chickens. Besides, there was a prevalence of chicken diseases mainly associated with limited access to veterinary and extension services, equipment, drugs and vaccines particularly for control of Newcastle disease.

The opportunities envisaged in the chicken value chain included organizing farmers into groups to enhance mass vaccination of chickens, the introduction of small packages of vaccines and drugs for smallholder farmers and promoting chicken out-grower schemes. The government, NGOs and international development organisations have significant opportunities to improve chicken production through improved awareness of smallholder farmers on efficient management practices and assisting farmers to organise into groups. Furthermore, the local presence of hatcheries (i.e. Silverlands and Mkuza Chick), and the ongoing chicken projects focusing on genetic improvement including the African Chicken Genetic Gain initiative and the involvement of Hendrix genetics, provided opportunities to improve access to high producing and well-adapted chicken breeds.

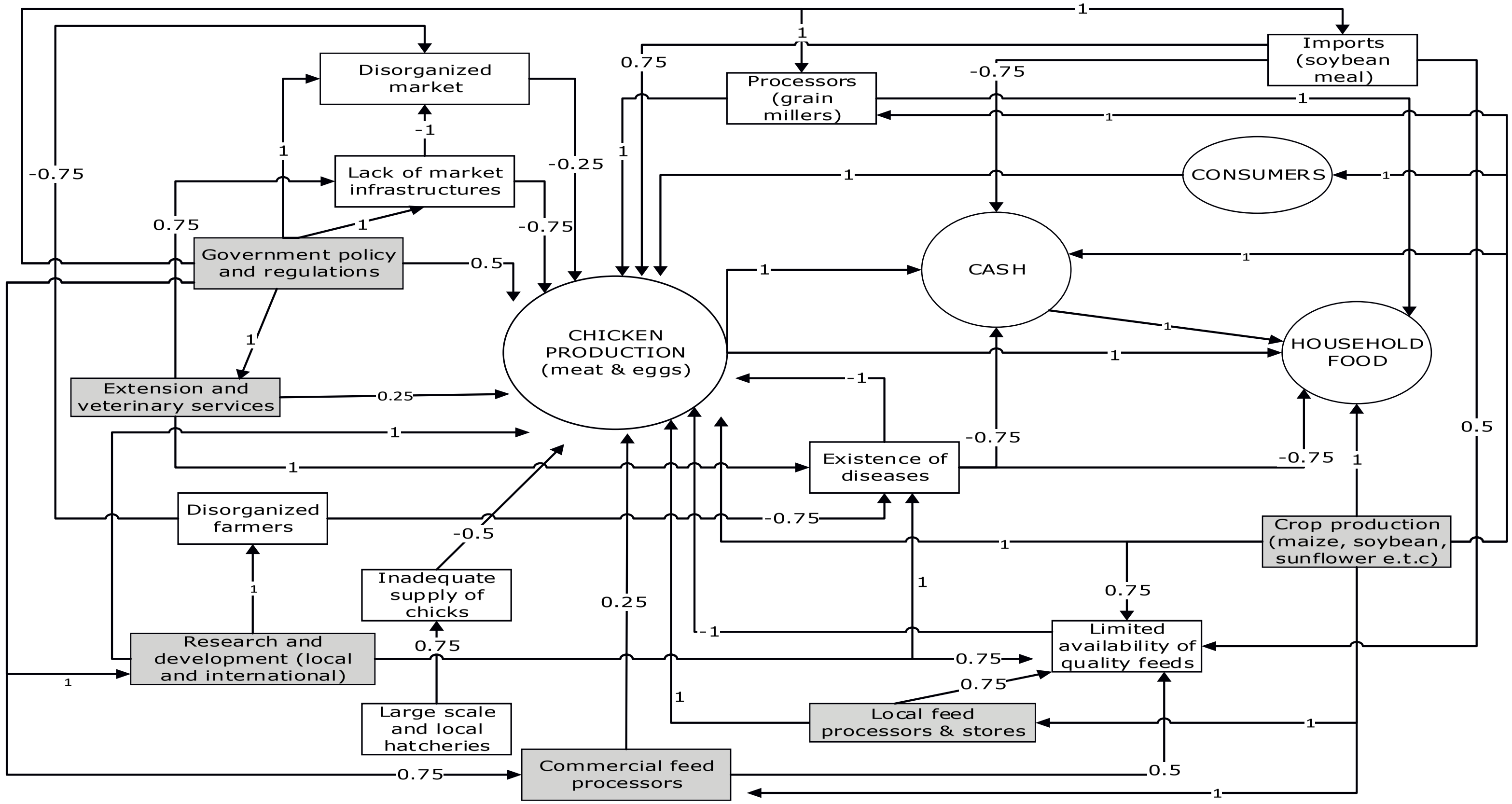

Fig. 2.6. Fuzzy cognitive map of the chicken value chain in the Southern Highlands of Tanzania. The white cycles are the key indicators of the functioning of the value chain; the grey boxes are value chain drivers and white boxes are variables. The numbers in between lines (between -1 and +1) indicates the strength of the connections between value chain components.

2.3.9. Integrating the soybean-maize-chicken value chains within the agri-food-feed system

The stakeholder workshop highlighted that the three value chains were interconnected, particularly at the point of production and of processing (Fig. 2.7). A smallholder chicken farmer could also be a maize and/or soybean farmer and benefit from own production and consumption of chicken meat and eggs as well as from maize and soybean for home consumption. The maize and soybean farmers would also sell the surplus produce to chicken farmers, mainly through middlemen and selling agents and ultimately being customers of chickens and eggs from chicken farmers. At the farm level, the household has to make decisions on resource allocation (i.e. their land, capital and labour) if they decide to produce soybean, maize and/or chicken. At the processing level, maize and soybean could be processed into diverse food products based on consumer preferences. On the other hand, the animal feed processors could use maize and soybean (the grain or by-products) as energy and protein source in livestock feed formulation, mainly for chicken.

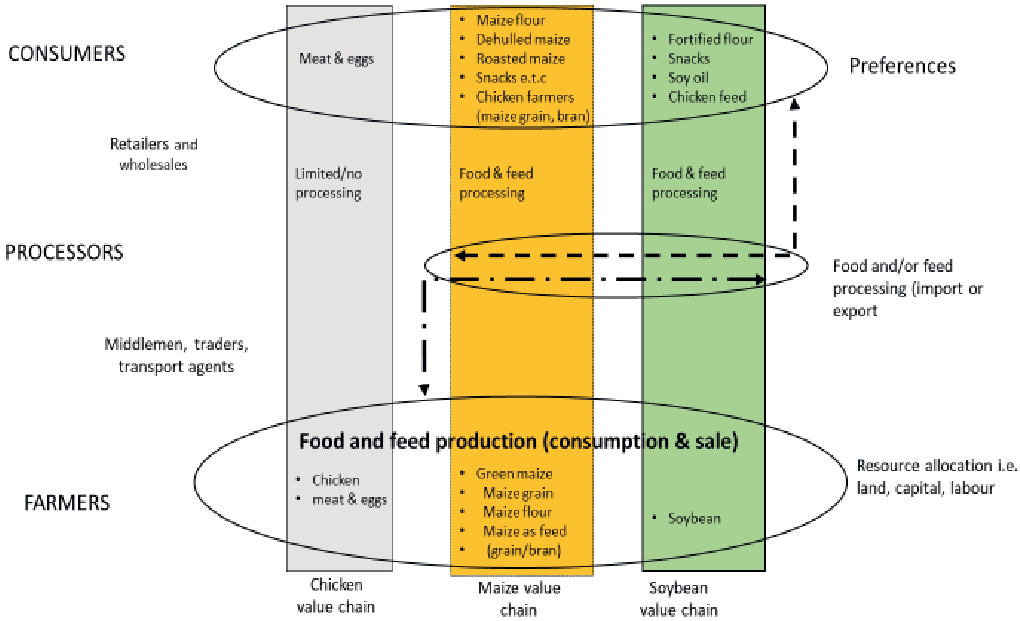

Fig. 2.7. Key influencers in integrating the soybean-maize-chicken value chains

Value chain integration using the FCM

Unlike the individual chains, the integrated soybean-maize-chicken value chains constituted a network of 29 FCM nodes (ordinary variables) connected by 117 connections, of which 66% were positive connections (Table 2.1). Also, the large number of nodes (29 nodes) in the integrated value chains indicated a strong connection between the value chain components compared with the individual chains. Using an integrating value chain lens showed that improving access to diverse diets for the household and other consumers was the most important aspect in the functioning of the value chain (receiver component) (Table A3 and Fig. A3). The main drivers in the individual and integrated value chain included the existence of supportive government policies, research and development organisations contributing to finding solutions to the existing challenges and promoting best-bet agricultural practices, organising farmer into groups, providing agricultural training to smallholder farmers and value chain actors. Another driver to integrate the chains included the existence of large scale and local hatcheries to meet the demand for day-old chicks. When looking at the values of indegree and outdegree in the FCM (Table A3), we can derive a picture of the importance of different value chain components. For instance, the variables with positive indegree and zero outdegree mostly received input from other value chain component “considered as receivers” while the variables with zero in-degree and positive outdegree are considered as senders.

Table 2.1. Key characteristics of the fuzzy cognitive maps on soybean, maize, chicken and the integrated value chains in the Southern Highlands of Tanzania

FCM properties	Value chain type			
	Soybean value chain	Maize value chain	Chicken value chain	Integrated chicken-soybean-maize value chains
Total components	21	22	19	33
Total connections	50	56	53	117
Number of positive connections	30	35	40	77
Number of negative connections	20	21	13	40
Density	0.12	0.12	0.17	0.11
Connections per components	2.33	2.55	2.80	3.55
Number of driver components (influential)	5	3	4	3
Number of receiver components (dependent)	1	1	1	1
Number of ordinary components	15	18	14	29
Complexity score	0.2	0.33	0.25	0.33

2.4. Discussion

Using FCM, we realize that there are complicated fuzzy networks within and among the components of the three value chains. The analysis provided insights on the opportunities to integrate the three value chains which in turn could contributing to improving access to quality nutrient-dense feed for chickens and ultimately improve access to diverse diets (meat and eggs) for people. To the best of our knowledge, the current study is the first to apply FCM method in value chain mapping based on stakeholder views and opinion. Previous studies applied FCM in modelling agricultural systems and assessing socio-ecological sustainability in agroecosystem (Aravindakshan et al., 2021; Kok, 2009), livelihood vulnerability assessment (Murungweni et al., 2011), climate change adaptation (Verkerk et al., 2017), food security assessment (Aliyev et al., 2017), sustainable food consumption (Morone et al., 2019) and healthy diet assessment (Wang et al., 2016).

The complex network amongst value chain components identified by our FCMs shows a number of constraints in input supply and market infrastructure, pointing at inefficiencies in the value chains and potentially increasing transaction costs (Lee et al., 2012). The network also shows that smallholders can be integrated in one or more domestic maize, soybean and chicken value chains, as producers, consumers, or both. In the present study, we found that the soybean, maize and chicken value chains are particularly inter-connected at two levels: at the smallholder farming system level and at the level of processing facilities. The production of maize, soybean, chicken can directly contribute to a diverse diet or household income through sale of surplus produce. Smallholder farming households can be producers in one or more value chains (Leonardo et al., 2018) while they could also benefit directly from their own production and consumption. Dissa et al (2021) have shown that using different outlets and coordination structures between smallholders and buyers allowed smallholders in Southern Mali to obtain inputs and services for maize via the cotton supply chain. It also allowed them to pursue different income sources over the year. They balance flexibility by selling maize to spot markets, and security by transactions of cotton for predetermined prices with a monopolist buyer. In Tanzania, maize production can directly benefit from soybean production to increase soil fertility and replace some fertilizer costs. Maize is both consumed directly and sold at spot markets while soybean is a cash crop, sold to traders collecting it for animal feed mills or even for seed companies as soybean seed is still rather scarce. Storage of soy is possible without quality loss and farmers can wait for better prices when they have access to market information. Using different outlets and different moments in time to sell their produce provides farmers with more stability in income. On the other hand, the farming household can access diverse diets through the income-food purchase pathway (De Jager et al., 2017), whereby the crop farmers in our case study could access chicken meat and eggs with the cash generated through sales of maize and soybean.

Diversification through legume-cereal intercrop and/or rotations have significant advantages in improving resource-use efficiency, weed, pest and disease control (Ojiem et al., 2014), and increased yield of subsequent maize in soybean-maize rotations (Rurangwa et al., 2018; van Vugt et al., 2018). Despite diversification in the farming system, we found that there is a high variation in grain production among households. This variability in crop production reflects the heterogeneity in the socio-economic status of the farming household in terms of land, labour and capital endowments, as well as biophysical factors, whereby the resource-poor farmers are most vulnerable (van Vugt et al., 2018).

Diversifying diets by including animal sourced foods is an important means to improve growth, development and cognitive responses in young children, particularly during the first 1000 days of life (Stark et al., 2020). In Tanzania, chickens are mostly managed and/or owned by women (De Bruyn et al., 2017; Galiè et al., 2015) who are mainly responsible for household diets (Ochieng et al., 2017). Therefore, improving the productivity of chickens could provide a direct route to improve access to nutritious diets in the household and thus to reducing undernutrition.

Diets may also be improved through other interventions related to maize and legumes. Ongoing initiatives, including the introduction and promotion of Quality Protein Maize (QPM) that has an additional amount of essential amino acids (lysine and tryptophan) (De Groote et al., 2010; Krivanek et al., 2007) may also contribute to higher quality diets for people. The efficient utilization and dissemination of maize flour fortified with soybean could have a significant potential for reducing malnutrition through provision of essential nutrients and vitamins. Furthermore, the efficient utilization of QPM and soybean in chicken feed could reduce the costs of production and ultimately improve chicken productivity to meet the increasing demand for quality eggs and meat (De Groote et al., 2010; Panda et al., 2011).

Diversification in the farming systems is an important indicator of household dietary diversity particularly for poor rural households (Pellegrini and Tasciotti, 2014; Timler et al., 2020) and have been considered as a coping strategy on the effects of global climate change (McCord et al., 2015). Relying on maize monocropping could have a risk on the household income and food security due to market uncertainties. The export ban in Tanzania in 2016/17 is a vivid example of the risk that farmers could encounter while relying on maize monocropping. Short-term export restrictions of agricultural commodities have been frequently imposed by developing countries in response to price fluctuations and ensuring domestic food supply (Diao and Kennedy, 2016; Porteous, 2017). Despite the benefits of the export ban in ensuring food security in developing countries, research shows that the rural and urban poor communities are benefited from the decrease in the maize price while at the same time this hurts farmers who rely on growing maize as a cash crop (Diao and Kennedy, 2016).

The increasing intensification of the chicken sector in Tanzania implies that the demand for major cereals in the animal feed industry will increase. The emerging chicken feed industry is an important entry point for integrating the three value chains, whereby maize (grain/bran) and soybean meal could be used as the main sources of energy and protein for chicken, respectively. The intensification in chicken production implies a greater need for feed resources such as maize and soybean which could also be used for human consumption, implying food-feed competition (Van Zanten et al., 2018). Increasing the resource use efficiency in the current farming systems through sustainable intensification may contribute to reducing the yield gap through increased crop productivity per unit of resource invested (Tittonell and Giller, 2013) and help to reduce such food-feed competition.

Soybean is mainly grown as a cash crop by smallholders in Tanzania where only few farmers were involved in value addition. Boosting legume production in rural communities might improve access to diverse diets particularly for the rural poor through production followed by own consumption (De Jager et al., 2017). Unlike other grain legumes, soybean is not a staple food, and its utilization requires processing or longer cooking times. Therefore, education on home processing would be required promote use of soybean to improve food and nutritional security (Khojely et al., 2018). Since soybean is currently grown as a cash crop, its utilization as chicken feed does not raise major issues of food-feed competition.

The emerging animal feed industry is the main driver of soybean demand in Tanzania. Currently, the annual demand for soybean in Tanzania is more than 128,000 t compared to the current production of about 8,000-10,000 t (SAGCOT, 2019). Soybean outweighs other plant protein sources due to its high nutritive value in terms of crude protein and energy contents (Medic et al., 2014). Nevertheless, its utilization in chicken feed requires proper processing to reduce the effects of the antinutritional factors and oil content (Dozier et al., 2011; Rada et al., 2017). As a result, most animal feed processors source soybean meal rather than the whole soybean grains due to their limited extrusion capacity and associated high investment costs. In 2019, only three out of forty commercial animal feed processors in Tanzania, registered under Tanzania Animal Feed Manufacturers Association (TAFMA) have solvent extraction with a processing capacity of 6,000 t of soybean per year (SAGCOT, 2019). These three animal feed processors include Silverlands Co Ltd, Interchick Co Ltd and Tanfeeds Ltd, located in Iringa, Dar es Salaam and Morogoro, respectively. The latter was the main company processing soybean for sale of soybean meal (and soy oil) while others produced soybean meal for their own use. The recent expansion of solvent extraction facilities at Tanfeed is expected to increase the demand for soybean (SnP, 2015) and might also contribute to meeting the increasing demand for edible oil (Mgeni et al., 2019) and soybean meal required in the chicken feed industry (Mbwambo et al., 2016).

The integration of smallholder farmers with other value chain actors is an important pathway to improving the functioning of the soybean, maize and chicken value chains that might contribute to achieving food security and welfare of the farmers (Kissoly et al., 2017a). During the implementation of the N2Africa project, a Soybean Innovation Platform was formed in 2015 to facilitate the dissemination of the latest soybean technologies and practices to smallholder farmers (Odhong, 2018; SnP, 2015). The platform is comprised of the representatives from both public and private sectors i.e. local and international research institutes, district extension officers, village-based agricultural advisors (VBOs), farmer associations and agro-input suppliers and other stakeholders involved in the value chain. While this platform is a means to connect actors within the soybean value chain, similar initiatives may be needed to integrate well with the maize and chicken value chains. Efficient functioning of the integrated value chains requires both public and private sector partners (Bitzer et al., 2013), value chain collaboration (Kissoly et al., 2017a) and promoting of innovation platforms (Kilelu et al., 2017). Whereas, most studies to date have explored the integration of smallholder farmers in value chains of export-oriented and high-value cash crops (Barrett et al., 2012; Challies and Murray, 2011), our study focused on domestic agricultural value chains to reduce the need for imports of soybean meal.

2.5. Conclusion

To meet the increasing demand for nutritious diets in Tanzania, the soybean, maize and chicken value chains all have important roles to play. The emerging chicken feed industry is an important market outlet for smallholders producing maize and soybean in the country providing them with an income to buy nutritious food items. Efficient processing of soybean has a great potential to increase the local availability of soybean both for human food and animal feed. Further, domestic production and processing of soybean is expected to reduce the cost of chicken feed that currently relies on expensive fish meal. To realise the promise of integration of these three value chains, the inefficiencies identified in the soybean chain require effort to strengthen producer groups, to enhance joint marketing of their produce and to enhance private sector investment in appropriate soybean processing facilities.

Acknowledgement

We thank NWO-WOTRO for funding through “The Missing Middle project: Food system transformation pathways to link actions at multiple levels to Sustainable Development Goals (SDGs) particularly the SDG 2, 12, 13 and 15 in Tanzania and Vietnam” and through the Netherlands-CGIAR Scientific Expert Programme (Grant number W07.303.109). The Bill & Melinda Gates Foundation provided funding fieldwork and data collection in the Southern Highlands of Tanzania through the N2Africa project (www.N2Africa.org), led by Wageningen University and the International Institute of Tropical Agriculture (IITA). We extend our gratitude to the households which participated in our research and the agricultural and livestock extension offices for facilitating the fieldwork in the study area. Special thanks to the enumerators and all stakeholders involved in the participatory workshop in the study area. We are grateful to Kasper Kok and Chrispen Murungweni for insights on the Fuzzy Cognitive Map (FCM) method.

Conflict of Interest: The authors declare no conflict of interest.

Chapter 3

The diversity of smallholder chicken farming in the Southern Highlands of Tanzania reveals a range of underlying production constraints

This chapter is a slightly modified version of the following publication:

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Abstract

The poultry industry in Tanzania has grown steadily over the past decade. We surveyed 121 chicken farming households along an intensification gradient from backyard to semi-intensive and intensive production systems based on rearing system and assumed purpose and poultry breed in the Iringa region. About 30% of households had more than one breed and/or rearing system combination. The subdivision of poultry systems was refined by adding the size of the flocks to highlight variation in scale of operations. On this basis we distinguished three main types: 1) subsistence small-scale free-range chicken production; 2) market-oriented small to medium scale semi-intensive and 3) small to medium-large scale intensive systems. 'Intensification' involves the transition from keeping indigenous chickens to improved dual-purpose and exotic breeds driven by greater productivity and potential for income generation. The more intensive the production system, the more the intensity and diversity of diseases identified by farmers as their main problem, which was partly attributed to the greater sensitivity of the improved breeds, poor veterinary measures, and the high chicken density facilitating disease spread. Based on the survey we constructed a problem tree to classify the underlying constraints and their interrelations, and to identify common root causes, based on which we propose practical solutions to improve chicken production. Development of medium-large scale systems is particularly constrained by a limited supply of one-day-old chicks and theft. By contrast, intensification of small-scale systems is constrained by limited access to quality feed, vaccines and medicines, capital, and lack of a reliable market, partly due to the absence of farmer organization. These constraints can be addressed through formation of producer groups and promotion of outgrower and enterprise development models. Enterprise development appears to be the most promising business model for smallholder chicken farmers given that it allows farmers more freedom in decision-making and management while strengthening linkages with input suppliers and output markets to ensure a viable and profitable business.

Keywords: farm diversity, chicken feed, intensification, poultry management, problem tree

3.1. Background

Driven by rapid urbanization (Africapolis, 2019), economic growth, and change in consumer's affluence, the demand for animal-sourced food (ASF) in Tanzania, particularly chicken meat is projected to increase by 148%, while that of beef, goat and mutton, pork and milk will increase by 87%, 71%, 88% and 108%, respectively from the mid-2000s to 2030 (Baker et al., 2016a). Currently, the demand for chicken meat and eggs in Tanzania already strongly exceeds domestic production and supply, mainly due to low production and productivity of indigenous chicken breeds and limited availability of quality feed (Naggujja et al., 2020). Policy interventions taken to improve the poultry sector in Tanzania include the genetic improvement of the indigenous chickens raised under a low-input free-range system (Michael et al., 2018). As a result, improved dual-purpose chickens have been introduced in various regions of the country over the past decade (Sanka et al., 2020). In the same period, the number of commercial layers and broilers raised under high input-output intensive systems has been increasing, particularly in urban areas (Mushi et al., 2020; Sindiyo et al., 2018).

Chickens are important sources of animal-sourced food in Tanzania for numerous reasons. Firstly, 86% of the livestock keeping households in the country own chickens (MLDF, 2019). About 80% of the chicken are owned by women who have control over decisions on sales and consumption of chicken meat and eggs (Galiè et al., 2015; Shapa et al., 2021; Tavenner et al., 2019). Secondly, chickens are sold alive and do not necessarily need central slaughterhouses and cold chains. Thirdly, a chicken is a unit fit for rural household consumption compared with ruminants which generate too much meat to be consumed in one meal. Chicken eggs are also appropriate units for daily consumption and can be stored for some days without cooling. Fourthly, managing a chicken enterprise is relatively easy, requiring a small capital investment with promising income generation within a short period of time and hence, attracting more women and youth (Hundie et al., 2019; Ngongolo and Chota, 2021). White meat including that of chicken is considered a healthier food than red meat, and therefore, the trend of consumption is expected to increase steadily (Weber and Windisch, 2017). In addition, chickens play important roles in satisfying religious and social cultural needs in most rural communities in the country (Akinola and Essien, 2011).

From a regional perspective, the Southern Highlands of Tanzania have great potential in food production and are considered to be the country's breadbasket (Altare et al., 2016). Despite the potential of the Southern Highlands in food production, there are high rates of stunting among under-five children, mainly associated with limited dietary diversity among households (Ministry of Health et al., 2016). Previous research on chicken production in the Southern Highlands focused on the characterization of the indigenous chicken breeds (Guni and Katule, 2013; Guni et al., 2013; Mwambene et al., 2019); and, more recent on the performance evaluation of the newly introduced crossbred namely Sasso and Kuroiler, implemented by the African Chicken Genetic Gain project (Andrew et al., 2019; Pius and Mbaga, 2018). These aforementioned studies focused on chicken production raised under rural outset, with scant information on the intensification gradient, dynamics and constraints in different production systems.

We set out to understand chicken farming diversity and explore the intensification gradient from backyard, semi-intensive and intensive production systems and the underlying constraints limiting production in urban and rural areas. The findings will suggest relevant innovation options to improve the domestic production of meat and eggs in the identified systems that will contribute to improving access to animal-sourced food to support diverse diets among households in Tanzania.

3.2. Methodology

3.2.1. Description of the study area

To understand the current chicken production systems and challenges faced by farmers, we conducted a household survey in the Iringa region, SH of Tanzania from November to December 2018. Differences in farming system development between rural and urban areas were expected in line with recent research in East Africa (Migose et al., 2018; van der Lee et al., 2020). Therefore, in the present study data was collected from both urban and rural poultry producers. For the representation of urban and rural locations, three administrative districts were selected from the Iringa region namely Iringa municipality with urban farmers and Kilolo and Iringa districts with rural chicken farmers (Figure 3.1). The districts were selected based on the intensification gradient we observed earlier in urban and rural areas, potential in the commercialization of chicken production, the existence of grain millers, feed processors and hatcheries established over the past decade (Wilson et al., 2021). The three districts comprised sixty administrative wards in urban and rural, respectively. Based on the government designations on urbanization, population density and economic advancement the wards located in Iringa Municipality were considered as the representatives of the urban location when compared to Iringa rural and Kilolo districts (Africapolis, 2019; Wineman et al., 2020).

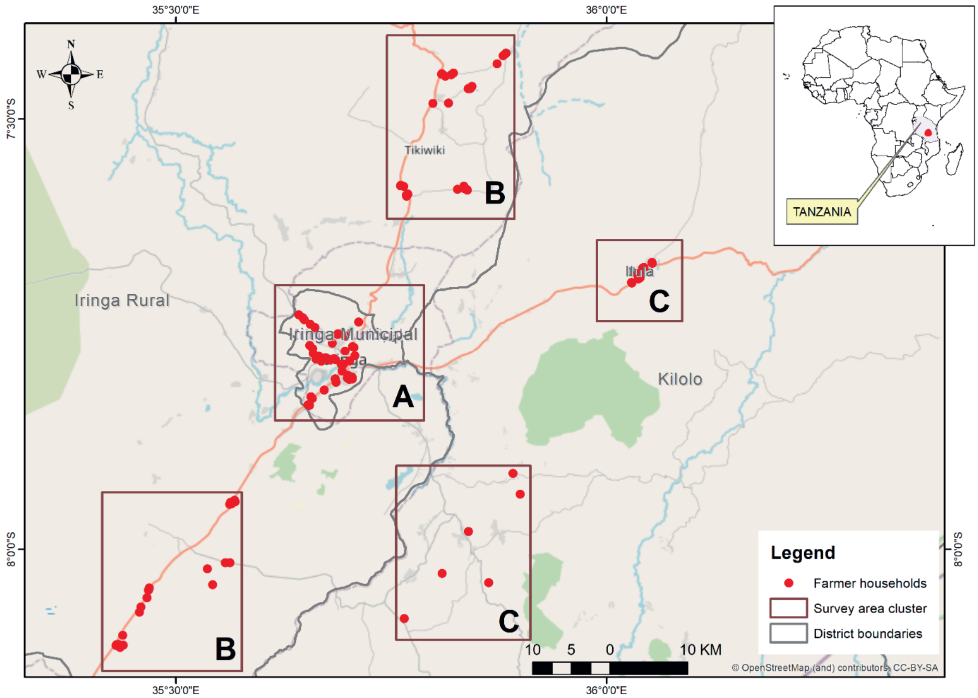

Figure 3.1. Location of 121 chicken farming households interviewed in Iringa Municipality (A) Iringa rural (B) and Kilolo districts in the Iringa region.

3.2.2. Sampling Framework and Data Collection

In total, 121 poultry farmers were interviewed in urban and rural locations (Figure 3.1) using semi-structured questionnaires that were programmed using Open Data Kit (ODK). Seventeen out of sixty wards were purposively selected from the three districts based on having a relatively high number of chickens according to the district statistics and on discussions with the respective district extension offices. Since the exact number of farmers keeping chicken in the respective wards was not available, the farmers were randomly sampled from the list provided by the respective ward extension officers and interviews conducted depending on their availability and willingness to participate. In total, 48 and 73

chicken farming households were interviewed to explore the diversity in the farming systems in urban and rural locations, respectively. The households interviewed were keeping indigenous, improved crossbred and/or exotic chickens. Preliminary backyard, semi-intensive and intensive systems were distinguished based on a gradient of increasing controlled environments in terms of housing, feeding and veterinary care (see also Wilson et al. 2021) to check whether all types were represented in our sample.

To characterize the different farm types, a semi-structured questionnaire was administered collecting information on (i) general characteristics of the household i.e. demographics and socio-economic activities, farm size; (ii) chicken production and management practices; (i.e. housing, feeds and feeding, health, disease and parasite control), chicken breeds and types, flock size, egg production per week, experience in keeping chicken, rearing systems, sources of chicken flock; (iii) product handling, marketing and consumption; and (iv) challenges limiting chicken production. The interviews were conducted in Kiswahili by six enumerators.

3.2.3. Data Analysis

The quantitative data resulting from the interviews were analyzed using Statistical Package for Social Sciences (SPSS) version 25 to obtain descriptive statistics (frequency counts, median, maximum and minimum numbers) of the surveyed sample which were used to characterize the farm types (Table 3.1). The significance of the mean differences in number of chicken and productivity in urban and rural was assessed using Analysis of Variances (ANOVA) and Chi-square test (Table B1). After data analysis it appeared that there were no statistical differences between urban and rural locations, and hence, after a system description, this distinction between rural and urban was dropped in the rest of the chapter. The farming system were primarily grouped into backyard/free-range system, semi-intensive and intensive systems based on the rearing systems i.e. housing and feeding (Chaiban et al., 2020). Backyard is scavenging outdoor, semi-intensive is partly indoor and fed, intensive is permanent indoor and fed. The farm types were further subcategorized based on the breeds of chicken (indigenous, improved cross and exotic), and purpose of keeping chicken (meat, meat and dual-purpose (meat and eggs)). In the next step, the predefined farm types were further subdivided into small-scale, medium-scale, medium-large scale production based on the number of chickens as partly applied by Chaiban et al. (2020). We categorized small scale semi intensive systems as having less than 50 chickens and only indigenous chickens and we labelled as intensive small scale types with less than 150 chickens. Semi-intensive and intensive systems with larger numbers of improved breeds up to 500 chickens are called medium scale. As individual intensive systems may have up to 5700 chickens, we add call them medium to large scale system.

The constraints faced by chicken farmer based on the household interviews were coded and grouped into three major categories, i.e. financial, technical, and institutional constraints using the analytical framework (Figure 3.2) of (Gale et al., 2013). The financial constraints are those related to the factors determining the total farm/firm size (Ringo and Lekule, 2020), while the technical constraints relate to farmers knowledge on chicken production and management i.e. veterinary measures, feed and feeding practices (Justus et al., 2013; Mapiye et al., 2008; Mutua et al., 2019). Other technical aspects investigated included knowledge and awareness of farmers on record keeping, entrepreneurship and marketing skills and gender roles in different managerial aspects at the household level. The institutional aspects included the public support services and physical infrastructures (i.e. roads, water supply, communication technology, energy), market infrastructures, finance and credit facilities (Mapiye et al., 2008).

In a next step, we constructed a problem tree analysis by classifying the constraints in the three earlier identified categories (recognizable by color) and assessing the relations between the identified constraints and their consequences. The problem tree distinguishes between the more immediate and root causes of low chicken production. Finally, the problem tree allowed to find practical solutions to increase chicken production at each of these levels and in each of the three earlier-mentioned categories.

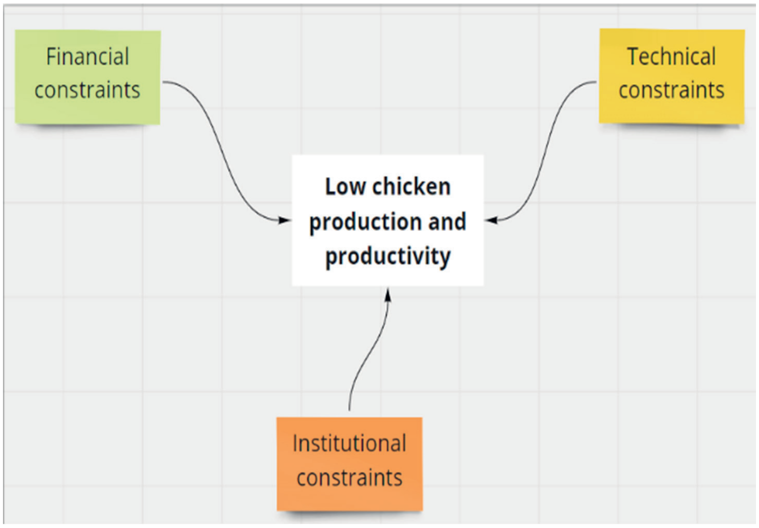

Figure 3.2. The conceptual framework for analyzing constraints in chicken production and productivity categorized into financial, technical, and institutional constraints indicated by green, yellow and orange boxes, respectively.

3.3. Results

3.3.1. Chicken Production System Types in Urban and Rural Locations

We confirmed the existence of the three main production systems that had been initially proposed (Wilson et al., 2021); i.e. free-range/extensive production, semi-intensive and intensive systems both in urban and rural locations. Nevertheless, we felt the need to make subdivisions within these types based on the outcome of our survey. Characterization of the farming systems was primarily based on the rearing system (housing and feeding), breed of chicken, the purpose of keeping chickens and flock size (Figure 3.3 and 3.4. We found that 85% of the interviewed households raised indigenous chickens both for meat and eggs while fewer households raised the improved cross (28%) and exotic breeds (15%) for meat or eggs. Irrespective of the systems the flock size varied significantly between urban and rural locations *($P<0.05$)* with larger numbers of chickens produced and consumed in urban locations (Table B1). Indigenous chicken flocks consisted of chicks hatched at the farm and/or purchased from neighbours while the improved cross and exotic one-day-old chicks were purchased from selling agents and hatcheries in the region.

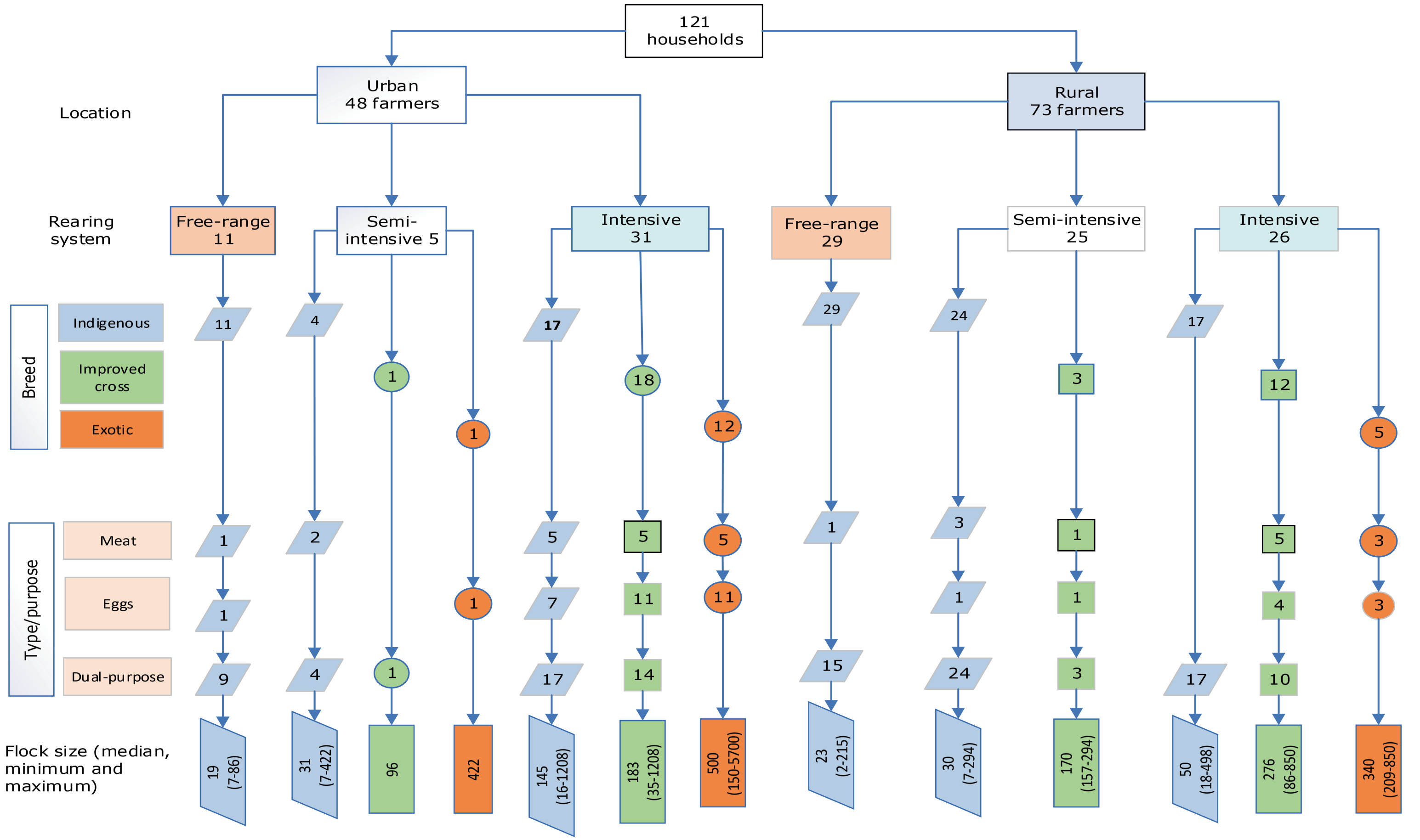

Figure 3.3. Subdivisions of the farm types identified in urban and rural, Iringa region. N.B: Some households raised multiple breeds of chicken/rearing systems.

Type 1: Free Range: Small-Scale Systems (40)

The first type comprised smallholder farms raising indigenous backyard chicken in urban (23%) and rural (40%) locations. The farming households within this farm type had small flock sizes of about 19 and 23 chickens in urban and rural, respectively (Figure 3.3). In free-range farms, chickens rely on scavenging for their feed (Figure 3.4b). Chickens were raised for both eggs and meat, producing about 12 and 16 eggs per week in urban and rural, respectively. In an urban location, 42% of the produced eggs were sold and 33% were retained for home consumption. In rural locations, 31% of the produced eggs were sold and 22% were retained for home consumption. The remaining eggs were left for natural hatching. On average, the farming households sold about two chickens and consumed one chicken per month in both urban and rural.

a. Boxplot: flock size vs rearing system in urban and rural

b. Boxplots: flock size, rearing system and the primary feed sources

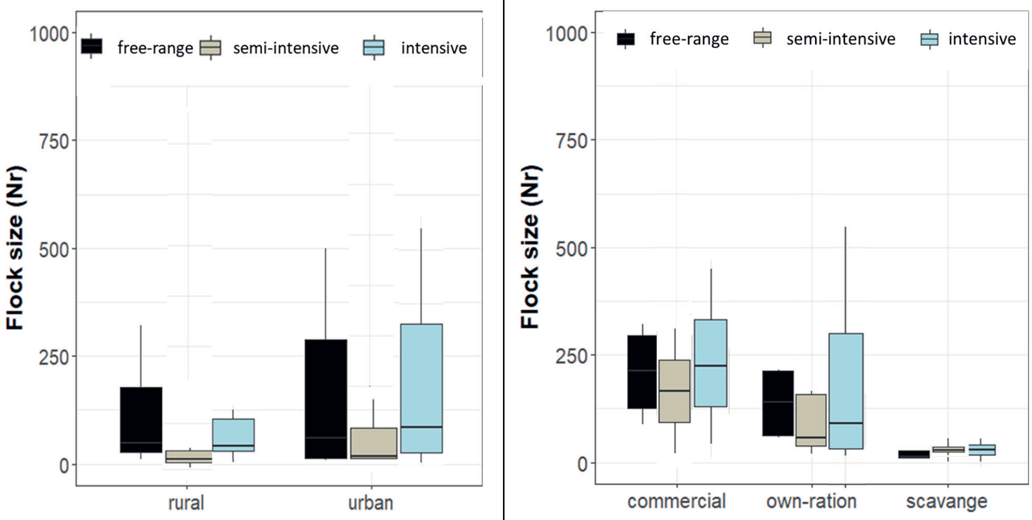

Figure 3.4. Boxplots of the quantitative (instant flock size (mean ± SE)) and qualitative variables farm location (a) and rearing system and primary feed sources (b).

Type 2: Semi-Intensive

Small-Scale Semi-Intensive Systems (28) This category constitutes farms raising, on average, 30 indigenous chickens, mainly in rural locations (86%) (Figure 3.3; Table 3.1). These chickens were partly scavenging outdoors and partly supplemented with own-made feed rations (Figure 3.4b). In this system, chickens were raised for both eggs and meat, producing about 17 eggs per week, of which

59% were sold and 24% retained for home consumption. Despite the chickens being supplemented with homemade feed, the production and productivity were the same as for farm type 1 above. On average, both urban and rural farming households sold and/or consumed about two chickens per month.

Medium-Scale Semi-Intensive System (4) This category constitutes the farms raising, on average, 170 improved cross-bred chickens, mainly in rural locations (75%). Chickens were partly raised outdoors and fed with commercial and/or homemade feed rations (Figure 3.4b). In this system, chickens were raised for both eggs and meat, producing about 205 eggs per week, of which 85% were sold and 11% retained for home consumption. On average, a medium-scale semi-intensive farming household sold about 20 chickens and consumed two chickens per month (Table 3.1).

Type 3: Intensive Systems

Small-Scale Intensive Systems (34) An equal number of small-scale intensive farming households were interviewed in both urban and rural locations. Farms keep indigenous dual-purpose chickens with a flock size of about 50 and 145 chickens in rural and urban locations, respectively (Table 3.1), raised for both meat and eggs. Chickens were raised and fed indoors whereby the small-scale intensive farms in rural locations fed their chickens with homemade feed rations while those in urban locations relied on a combination of homemade and commercial feed (Figure 3.4). Chickens were more productive in urban locations producing a large number of eggs per household per week (five times higher compared to rural locations (Table 3.1). The number of eggs sold and consumed per week was also greater in urban households compared with rural ones.

Medium-Large Scale Intensive Systems (47) This sub-category is comprised of farms keeping the improved cross-bred and exotic chickens in urban and rural locations. The mean flock sizes for the improved cross-bred were 183 and 275 in urban and rural, and 500 and 340 for the exotic chickens in urban and rural locations, respectively (Table 3.1). Chickens were raised indoors and fed with commercial and/or homemade feed (Figure 3.4b). 71% of the interviewed farmers that were keeping exotic chickens were in an urban location with the majority raising exotic layers (65%). The farms

keeping the improved cross-bred chickens produced about 250 and 350 eggs per week in urban and rural while the farms keeping the exotic layers produced about 381 and 405 eggs per week in urban and rural locations, respectively. The farms were run commercially where most eggs were sold and about 14 and 20 eggs were retained for household consumption per week in urban and rural locations, respectively. The households keeping the exotic chicken in rural areas retained five chickens for home consumption per month, compared with two chickens in all other farm types.

Households keeping multiple breeds of chickens in one or more rearing systems (38) out of the 121 interviewed households, 31% raised multiple breeds/types of chickens in one or more rearing systems in both urban and rural (Table B1). We found that the more intensified the system the more the diverse breeds of chickens were raised for both meat and eggs. The first sub-category, constitute seven small-scale farms keeping indigenous dual-purpose chickens in multiple systems i.e. free-range and semi-intensive system (four farms), free-range and intensive system (three farms). The second sub-category constitutes four medium-scale farms keeping improved crossbred chickens under medium scale and a small number of traditional dual-purpose chickens under the semi-intensive system, both for meat and eggs. The third subcategory constitutes medium-large scale intensive farms raising the improved crossbred and exotic chickens in combination with other breeds in multiple systems. Out of 30 households raising the improved dual-purpose chickens under the intensive system, 20% raised a large number of exotic chickens and 97% raised a small number of indigenous dual-purpose chickens under the free-range system (48%), semi-intensive (10%), and intensive systems (33%) both for meat and eggs. Out of 17 households raising exotic chickens under the intensive system, 53% raised indigenous and/or improved dual-purpose chickens both for meat and eggs.

Table 3.1. Description of the households sampled and interviewed for the characterization of chicken farming typology in urban and rural, Iringa region

Farm location		Urban (n=48)							Rural (n=73)					
Households interviewed per dominant rearing system*		Free-range (*n*=11)	Semi-intensive (*n*=5)			Intensive (*n*=31)			Free-range (*n*=29)	Semi-intensive (*n*=25)		Intensive (*n*=26)		
Chicken breed		Indigenous	Indigenous	Improved cross	Exotic	Indigenous	Improved cross	Exotic	Indigenous	Indigenous	Improved cross	Indigenous	Improved cross	Exotic
Number of systems found		11	4			17			29	24		17		
				1			18				3		12	
					1			12						5
Purpose of keeping chicken	Meat	1	2			5	5	5	1	3	1		5	3
	Eggs	1			1	7	11	11		1	1		4	3
	Meat and eggs	9	4	1		17	14		28	24	3	17	10	
Flock size per system[1]		19	31	96	422	145	183	500	23	30	170	50	276	340
		(7-86)	(7-422)			(16-1208)	(35-1208)	(150-5700)	(2-215)	(7-294)	(157-294)	(18-498)	(86-850)	(209-850)
Number of chickens sold/month[1]		2	2			9	10	20	2	2	20	4	15	57
		(0-12)	(1-2)			(3-167)	(3-167)	(150-5700)	(0-12)	(0-30)	(20-28)	(0-53)	(0-64)	(10-64)
Number of chickens retained for home consumption/month[1]		1	1	1	1	1	2	2	1	2	2	1	2	4
		(0-2)	(0-1)			(0-18)	(1-4)	(0-167)	(0-2)	(0-2)	(1-2)	(0-4)	(1-5)	(1-5)
Number of eggs production/week[1]		12	15		20	150	250	381	16	17	205	30	350	405
		(5-50)	(7-25)			(7-2170)	(7-2170)	(86-11970)	(0-140)	(7-130)	(130-280)	(5-559)	(0-2940)	(0-2940)
Number of eggs sold/week[1]		5	5		2	95	240	185	5	10	175	10	310	280
		(0-45)	(2-20)			(0-735)	(0-1500)	(0-11940)	(0-60)	(0-196)	(100-250)	(0-350)	(0-2900)	(0-2900)
Number of eggs retained for home consumption/week[1]		4				10	14	15	4	4	23	5	20	19
		(0-6)	(0-5)			(4-30)	(0-30)	(0-30)	(0-10)	(0-30)	(15-30)	(0-30)	(0-30)	(15-30)

[1]median, minimum and maximum, * one household may have more than one rearing system and/or breed

3.3.2. *Constraints Limiting Chicken Production*

The major constraints limiting chicken production identified during the household interviews include chicken diseases, poor availability of day-old chicks, theft and limited access to quality feed and/or feed ingredients (Figure 3.5). Other challenges include limited knowledge on managerial practices, market availability, predators, limited access to vaccines and medicines, lack of capital and limited extension services. Some of the constraints varied among the production systems as further explained below.

Health Management We found that the more intensive the system, the more farmers highlighted disease problems, and also more types of diseases as their main problem (Figure 3.5 and 3.6). Newcastle disease (NCD) was the most prominent disease reported in the intensive (37%), free-range (30%) and semi-intensive systems (20%) followed by coccidiosis (13%), fowl pox (8%) and fowl typhoid (6%), each mostly reported in the intensive system. Other diseases included salmonellosis (4%), gumboro (3%) and infectious coryza (2%).

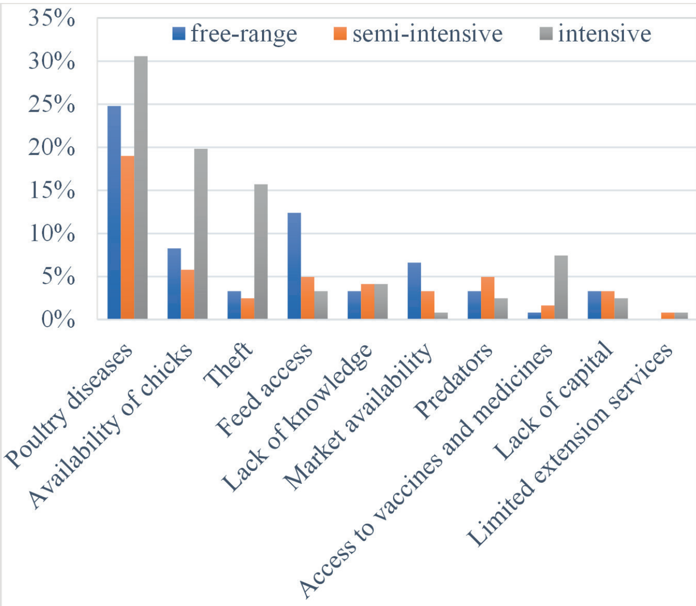

Figure 3.5. Constraints limiting chicken production in the Iringa region based on the household interviews.

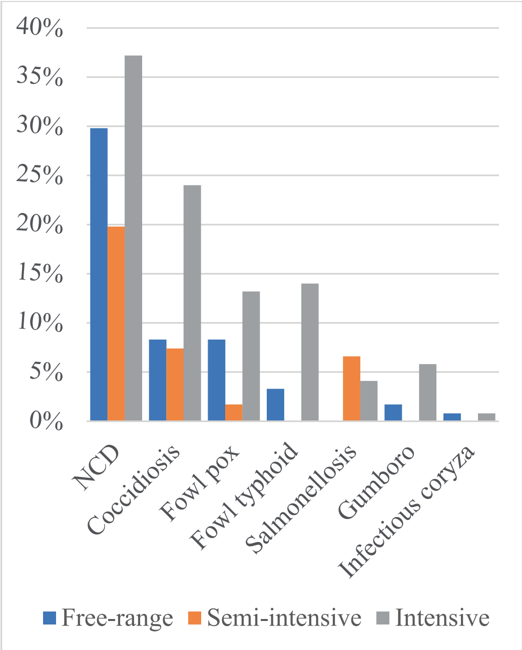

Figure 3.6. Occurrence of chicken diseases in the different production systems. NCD stands for Newcastle disease.

Access to Chicken Feeds and Feed Ingredients Limited access to quality feed was among the technical constraints limiting the free-range scavenging system partly related to the farmers' lack of knowledge on how to formulate their own feed rations, limited access to feed ingredients (less available or too expensive) and lack of capital to buy the 50 kg packages of commercial feed. The primary sources of feed were strongly determined by flock size and the rearing system, whereby large flocks (>50 chickens) were fed on either commercial or locally-made feed rations under free-range, semi-intensive and intensive systems. On the other hand, small flocks relied on scavenging in the small-scale free-range and semi-intensive systems (Figure 3.4b).

Some of the feed ingredients used in formulating own-feed ration were produced within the region and sold at low prices including maize bran, maize grain and sunflower seedcake, sold at 238, 259 and 349 Tanzania Shilling (TZS) per kg, respectively. Other feed ingredients imported from other regions/countries were expensive including the premixes, fishmeal, soybean meal, salt, bone meal, limestone and cottonseed cake sold at TZS 3639, 1824, 1801, 1000, 733, 655 and 325 per kg, respectively. Soybean was produced within the region, but the local processing facilities rely on crushing which results in a poor quality feed with a large oil content which is not suitable for chicken. As the result, the soybean grain produced was exported to the neighbouring countries (sold at around

TZS 800 per kg) for processing whereas soybean meal was imported at more than double the price of TZS 1801 per kg. Some of the major feed ingredients used by farmers, such as maize and maize bran and sunflower seedcake, were mainly available on a seasonal basis leading to an increase in feed prices and costs of production particularly during the rainy season.

Breeding and Access to Day-Old Chicks Farmers indicated that they experienced limited availability of day-old chicks, particularly for broilers, since they had to wait for a long time to receive them after placing their orders to the hatcheries through their agents in the region. This problem was mostly faced by commercial medium-large scale intensive farms as they work in cycles replacing all adult chickens at the same time. Despite the consumer demand for indigenous chickens, there were no hatcheries specialized in providing a large number of indigenous day-old-chicks.

Access to Market for Chicken and Chicken Products The market for eggs and meat of the dual-purpose chicken was available throughout the year (Figure 3.7). However, there were seasonal fluctuations in selling the products from the exotic breeds (layers and broilers) from January until August. The peak market for all products was reported in December mainly related to the end of the year celebrations, and the worst market for broiler and layer's meat reported from January to July. Limited access to market for the small-scale free-range farmers (Figure 3.5), was partly associated with lack of farmers organizations to aggregate their produce. Chicken manure was also among the important outputs from the chicken farm, with larger market demand from mid-September to December, mainly applied in own-farms.

Based on the field visits and interviews, we found that there were no proper marketing infrastructures in the region, with no professional hygienic chicken slaughtering and storage facilities within the regional market. Chicken customers could buy a live chicken and slaughter it at home and/or have it been slaughtered at the marketplace in urban locations, where there was poor infrastructure with a high risk of contamination.

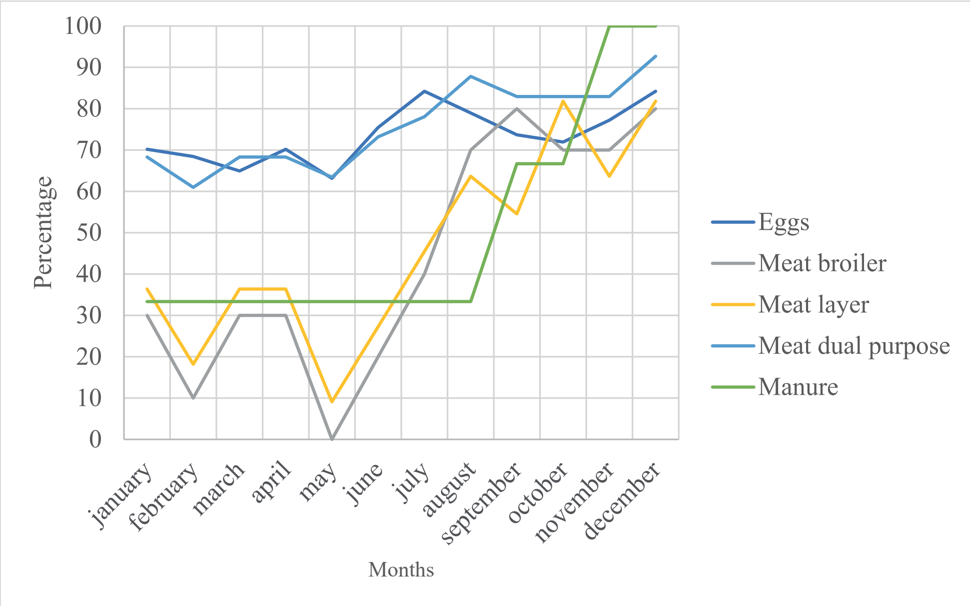

Figure 3.7. Percentage of the respondents that agreed that live chicken and their product markets were readily available in different months in the Iringa region.

Options for Improving Domestic Production of Meat and Eggs in The Identified Systems

The relationships among, and consequences of, the identified financial, technical and institutional constraints were further explored by building a problem tree (Figure 3.8). This also allowed us to identify missing links. The final analysis was used to identify options to improve domestic production and productivity of chickens in the different farm types in the region. The identified constraints led to more general advice for the respective farm types. We found that the development of the chicken industry is constrained by high costs of production and low productivity of chickens. These two problems lead to limited access to chicken meat and eggs and low income for the farming household. The core causes of the identified problems were categorized into three clusters namely technical, institutional, and financial. The technical constraints limiting the development of the chicken industry link to both institutional and financial constraints. These include limited access to quality feeds associated with lack of capital, seasonal availability of feed ingredients and limited knowledge to formulate feed rations using the locally available ingredients, particularly for the smallholder farmers. Other technical constraints included high mortality of chickens due to poor managerial practices, lack of knowledge, lack of farmer groups, limited extension services and high costs of vaccines and medicines. The institutional constraints limiting access to quality feeds were partly related to the lack of suitable feed processing facilities for soybean grain in the region.

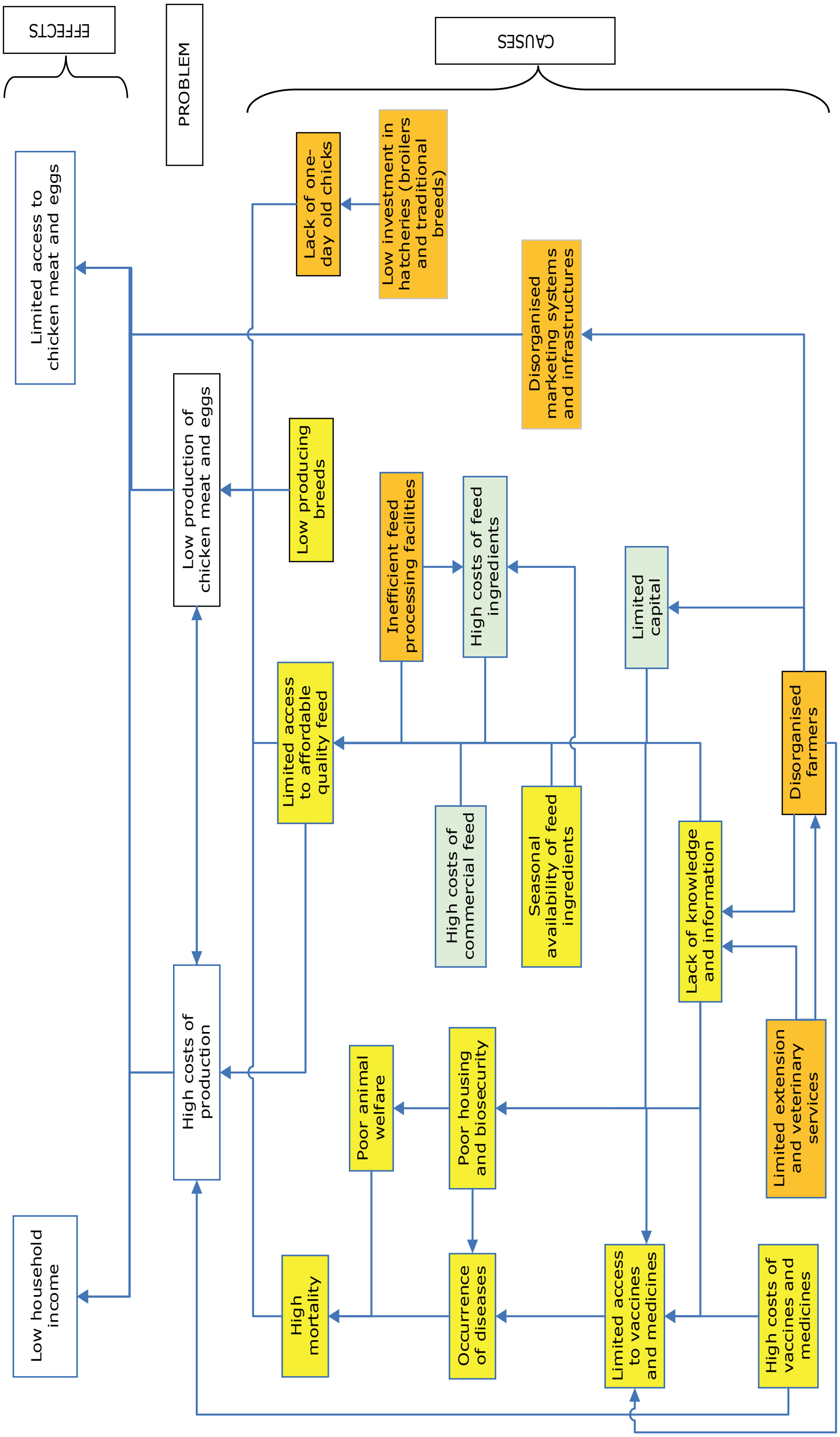

Fig 3.8. Constraints limiting chicken production in Iringa region categorized into financial, technical and institutional constraints indicated by green, yellow and orange boxes, respectively.

3.4. DISCUSSION

3.4.1. Chicken Farming Diversity

Numerous authors have characterized chicken farming under extensive production systems, but with limited differentiation and sub-division of farm types in urban and rural locations (de Glanville et al., 2020; Guni et al., 2013; Haoua et al., 2015). In the past two decades, studies in Tanzania have described chicken production systems but have not investigated or addressed the challenges that different farmers face that limit productivity and production. Most of the challenges reported were related to the existence of diseases and low production and productivity of chickens, limited access to feeds, markets, extension and veterinary services (Buza and Mwamuhehe, 2000; Msami et al., 2006; Ngongolo and Chota, 2021). Our study confirmed an intensification gradient in chicken farming systems ranging from free-range/extensive production to semi-intensive and intensive systems in Tanzania. To better understand chicken farming diversity and associated constraints limiting production in urban and rural locations we first made sub-divisions within these farm types.

The subdivision of the farms in this study revealed differences in the degree of intensification from subsistence small-scale production to more market-oriented systems. The specific characteristics linked to intensification were based on the breed of chicken raised by farmers (indigenous, improved cross-bred and exotic breeds), rearing system (housing and feeding), flock size (instant number of birds), the purpose of keeping chicken and their productivity (meat and/or eggs). As a result, five farm types were identified in the region i.e. small-scale free-range, small-scale semi-intensive, medium-scale semi-intensive, small-scale intensive and medium-large scale intensive farms. The subdivision of different farm types in the current study allows us to differentiate which of the observed technical, institutional and financial constraints are most relevant for each farm type and further increases our ability to identify relevant intervention options for improvement in each of the farm types.

The intensification of chicken production systems in the Iringa region partly involved diversification through keeping multiple breeds of chicken in one or more rearing systems in the farming household. The households keeping exotic broilers and layers also raised the indigenous and/or improved crossbred both for meat and eggs. Diversified chicken systems have the potential for income generation through keeping the exotic and improved cross-bred with high productivity (Wolfgang, 2020) and meeting the household preferences for eggs and meat from the indigenous chickens (Naggujja et al., 2020). Diversification of chicken systems in the Iringa region is mostly found in the mid-large scale intensive system both in urban and rural locations where we found a large number of chickens and eggs both sold and retained for household consumption.

3.4.2. The Intensification Gradient: From Subsistence to Medium-Large Scale Farming Systems

We found that the indigenous breed of chickens dominates the Iringa region, and that this breed was found even in the more intensive production systems. Nevertheless, the productivity of indigenous breeds was very low resulting in a small amount of the products (meat and eggs) retained for household consumption and/or sold to generate income. We found a transition from keeping indigenous chickens under the small-scale free-range system to both small-scale semi-intensive and intensive systems in rural locations. By contrast, in urban areas the transition is mainly towards the intensive system, partly related to limited space in urban areas as was also found in the capital city, Dodoma by (Ngongolo and Chota, 2021). Andrew et al. (2019) found that in Tanzania the indigenous chickens are mostly preferred by the highly risk-averse farmers due to their resistance to diseases and high survivability while raised with low costs. Furthermore, indigenous chicken meat and eggs are preferred by consumers compared with the meat from broilers and eggs from exotic layers in the country (Naggujja et al., 2020). Despite the strong consumer preference of indigenous chicken meat and eggs and the change from free-range to more intensive systems with indigenous breeds, it is challenging to meet the current demand through domestic production and supply (MLDF, 2019), because of the low productivity of the indigenous breeds.

In Iringa, we found that the degree of intensification is increasing with the number of improved crossbred and exotic chickens raised under the medium-large scale intensive systems and fed with homemade and/or commercial feeds in both urban and rural locations. We also found that intensive farms in urban locations raised quite a substantial number of indigenous chickens compared to the backyard and semi-intensive systems. This may be due to the assumed increased need of care for exotic breeds compared with indigenous breeds because of their greater susceptibility to diseases or because of their higher management costs (Andrew et al., 2019). The farms under this typology were commercially-oriented whereby most of the produce was for sale. These are typical characteristics of commercial mid-large scale production systems in East Africa (Chaiban et al., 2020). Recent studies show that in Tanzania there is a transition to keeping improved dual-purpose breeds under semi-intensive and intensive systems mainly driven by high egg and meat production, high consumer appreciation of the products (Naggujja et al., 2020), high growth rate and high potential for income generation (Wolfgang, 2020).

Thus, in Iringa on one hand, the small-scale farms own small flocks under a low input-output system while relying on scavenging and/or partial feeding and producing their own chicks using natural hatching as for most developing countries (Pius et al., 2021). On the other hand, the medium-large scale farmers buy feed and feed ingredients as well as the one-day-old chicks from the feed companies, hatcheries and/or selling agents (Wilson et al., 2021). Based on the subdivision of the farming systems, we found that while the intensification of small-scale farming systems is highly constrained by limited access to quality feed, the development of the medium-large scale farms is constrained by a limited supply of one-day-old chicks. Despite higher degree of management, more intensive systems reported more disease problems (Figures 3.5 and 3.6) which may be due to the larger number and density of chickens, uniform in age and indoor housing in one farm compared with the extensive systems where more disease-resistant chicken freely scavenge outdoors.

3.4.3. Linkages between the Constraints in Different Production Systems and Practical Solutions

Based on the problem tree analysis we found that we need to consider multiple options at the same time when addressing the constraints limiting the growth of the chicken industry in Tanzania. Clustering the technical, institutional and financial challenges explored possible solutions that might contribute to reducing the costs of production and ensuring a profitable chicken enterprise for each farm type and meeting the increasing demand for chicken meat and eggs (MLDF, 2019). The technical and institutional packages identified in the current study include investing in research on improving the genetic potential of the indigenous breeds of chickens, increasing the capacity of local hatcheries to reduce the shortage of one-day-old chicks, particularly for the medium-scale semi-intensive and medium-large scale intensive farmers who keep the improved and exotic breeds of chickens.

Since 2016, Tanzania has banned the importation of chicken and poultry products but allowed the import of parent line (both fertilized eggs and day-old chicks) for the local hatcheries to reduce the risk of spreading avian influenza into the country (Naggujja et al., 2020; Wilson, 2015). The import ban in one hand have stimulated investment in strengthening the capacity of local hatcheries within the country and have contributed to reducing dependency on imports over the past five years (Ringo and Lekule, 2020).

Moreover, it should be noted that the genetic strain of chicken is strictly linked with feed quantity. High performance chickens need high quality feed energy and protein, in particular. Thus, the use of the improved crossbred chickens could be more useful to smallholder farmers since they have lower nutrient requirements and more disposed to use alternative feed sources compared to the exotic breeds. The recent introduction of the improved dual-purpose chickens (Sasso and Kuroiler breeds) has enormous potential due to their high genetic potential and adaptability in semi-scavenging systems (Guni et al., 2021; Sanka et al., 2020) that might be affordable for resource-poor farmers. The establishment of local hatcheries in the Iringa region is of great advantage to ensure a reliable supply of day-old chicks (Wilson et al., 2021). Nevertheless, there is a need to increase their capacity to reduce the seasonal lack of day-old chicks, including the exotic broilers serving the peak market from mid-September to December that we observed in the present study.

Feed costs account for up to 70% of the total costs of production in chicken farming (Mutayoba et al., 2011). Chickens are fed with highly nutritious and digestible energy and protein feeds including maize and fish meal (mainly sardines) which could be part of human food, implying food-feed competition (Wilson et al., 2021). Maize is produced by almost all smallholders in Tanzania and is readily available for chicken farmers. On the other hand, fish (sardines) and other protein sources were imported from other regions at high prices and their inclusion in chicken feeds was limited and contributed to high costs of production.

Improving access to affordable quality feed is an important pathway to reduce the costs of production and contribute to stimulating the commercialization of small-holder free-range production systems. Research is needed to explore options to reduce the seasonal feed shortages and find alternative feed sources that are not consumed by humans i.e. alternative proteins including soybean meal, insects and insect larvae (Van Huis et al., 2020). Furthermore, research and training are crucial on proper feed formulation for diverse types/groups of chicken using the locally available feed ingredients. Soybean is produced in the region, but its use is hindered by limited processing facilities. And therefore, investing in efficient soybean processing facilities is of immense importance to improve the local availability of quality protein which is currently expensive in the region. Addressing the challenges related to feeds and feeding might contribute to ensuring a profitable chicken enterprise that would attract more youth and women to the poultry business (Hundie et al., 2019; Ngongolo and Chota, 2021). In turn, this would contribute to improving dietary diversity in the farming households through own-production and consumption and/or through purchase. Packages with smaller quantities could also improve access to commercial feeds that were also expensive and packed in 50 kg bags.

The technical and institutional packages for reducing the occurrence of chicken diseases and mortality include strengthening the extension and veterinary services and training farmers on proper managerial practices and veterinary measures. For the intensive system, there is also a need to improve access to finance to enhance the construction of proper housing systems to accommodate large flock sizes while ensuring veterinary measures. We found that most vaccines were both expensive and packed in large doses that are less affordable for chicken farmers. An option would therefore be to invest in small doses of vaccines that might be affordable by smallholder and mid-scale farmers. Another option is to facilitate collective vaccination allowing large vaccine packages to be shared by more producers.

3.4.4. Establishment of Farmer Groups and Contract Farming in Relation to Input-Output Markets

During the interviews, when asked about constraints, poultry farmers did not identify the lack of farmer organisation as a direct problem related to chicken production but access to feed, vaccines and markets were mentioned (see Figure 3.5). When asked about farmer organisation, farmers agreed there was a lack of organisation in general. Farmers were apparently not aware that farmer organisations might assist in addressing these problems. Hence they did not independently identify a lack of organisation as an underlying problem. In the problem tree analysis, we saw that a lack of farmer organization was identified by stakeholders as a core cause of multiple constraints (Figure 3.8). We found that chicken farmers in our study were disaggregated and that most did not engage in farmer groups in both urban and rural locations contributing to the limited access to input and output markets. Since most vaccines are sold in large doses, and need cold chain transportation, organizing the smallholder farmers has the potential in reducing costs when a large number of chickens are vaccinated in one go (Campbell et al., 2019). Organizing farmers into groups can also strengthen group initiatives i.e. access to soft loans from microfinance and access to improved inputs (i.e. resilient breeds of day-old-chicks and/or point of lay hens, housings, medicines), training and extension services on proper management practices, and access to information (Beesabathuni et al., 2018). Organizing farmers into groups may also shorten the marketing channels through direct sales of chickens and eggs to consumers and increase their equity and bargaining power in getting better prices of their products (Aklilu et al., 2007).

Many business models exist, related to the development of smallholder chicken farming systems in low and mid-income countries (LMICs) with an emphasis on the aggregation of smallholder farmers to enhance trading partnerships and engage them with diverse actors i.e. the NGOs, private business companies, microfinance institutions. The models also emphasize the training of farmers on proper management, feed processing, group marketing and large-scale rearing of chickens to ensure viable and profitable business. The viable business models implemented in LMICs include micro franchising with small capital investment for smallholder backyard farmers with small margins; microfinancing and cooperative farming both targeting the commercialization of backyard farmers to raise more chickens and aggregating farmers into small groups (Beesabathuni et al., 2018).

Other business models proposed for the growth of smallholder farmers in LMICs include the outgrower and enterprise development (Beesabathuni et al., 2018; Reji, 2013; Sanyang, 2012; Sikenyi, 2017; Thompson and MacMillan, 2010). For the enterprise development model, the input supplier is responsible for organizing smallholder farmers into groups and coordinating the enterprise development. The support services provided by the input suppliers include the training, input packages on credit and organizing markets for the produce. In this model, farmers are encouraged to sell eggs to the local community and hence contribute to improving dietary diversity. Farmers are also aggregating the excess produce and transporting them to urban markets using the trucks used in delivering feeds in rural areas. In this model participating chicken farms may be of diverse types and may decide to select amongst the services provided and the pace at which they develop their business. On the other hand, the outgrower model has the same capital investments for the farmer and for the company. This model involves a formal contract between a commercial entity and an independent farmer or farmer group managing ≥5000 chickens. The commercial entity supplies day-old-chicks, extension and veterinary services, input packages including feed, regular farm visits and monitoring of the farm. They can also select the local parties to whom they sell their products (Beesabathuni et al., 2018). The outgrower model was partly implemented in the southern highlands of Tanzania (Mugittu, 2016). Unfortunately, little is known yet about the progress and output of the project.

3.5. CONCLUSION

Our study revealed a large diversity of chicken production systems in Tanzania, beyond what had been described previously. We found that the indigenous breed of chickens was dominant in the region and was found even in the more intensive production systems. We also found that about 30% of farms had multiple chicken production systems alongside each other. The intensification gradient in chicken production from subsistence small-scale production to more market-oriented semi-intensive and intensive systems was confirmed. Intensification involves the transition from keeping indigenous chickens to the improved dual-purpose chickens driven by high egg and meat production, high consumer appreciation of the products, high growth rate and a high potential for income generation. The subdivision in production systems and the problem tree analysis revealed different constraints limiting chicken production depending on the types which open the door to propose relevant packages for improving the production of meat and eggs for the household and other consumers. Despite a greater management input, more intensive systems reported more disease problems implying that there should be training on improved housing and veterinary measures, particularly for the farmers intensifying to the medium to large scale production systems. Apart from the existence of chicken diseases in all the systems, the development of the medium-large scale systems is highly constrained by a limited supply of one-day-old chicks and theft, while the intensification of small-scale systems is constrained by limited access to quality feeds, vaccines and medicines, capital, and reliable output market, partly associated with lack of farmer organization. There is therefore a need for institutional support to organize producers into groups and/or cooperatives with emphasis on training them on proper management, low-cost feed processing, group marketing and large-scale rearing of chickens. The enterprise development might be the most promising business model for the growth of smallholder chicken farming since farmers have more freedom in farm management and decision making while they will be linked with the input suppliers and output markets to ensure a viable and profitable business.

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DISCLOSURES

The authors declares no conflict of interest toward development, submission and publication of this manuscript.

Chapter 4

Feed gap analysis of dual-purpose chicken production in Tanzania: feed quantity and quality limited production

This chapter has been published as:
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Abstract

The demand for chicken meat and eggs exceeds what can be produced in Tanzania, largely due to low productivity of the sector. Feed quantity and quality are the major factors determining the potential production and productivity of chickens. The present study explored the yield gap in chicken production in Tanzania and analyses the potential of increased chicken production as a result of closing the feed gaps. The study focused on feed aspects limiting dual-purpose chicken production in semi-intensive and intensive systems. 101 farmers were interviewed using a semi-structured questionnaire and the amount of feed provided to chickens per day was quantified. Feed was sampled for laboratory analysis and physical assessments were made of weights of chicken bodies and eggs. The results were compared with the recommendations for improved dual-purpose crossbred chickens, exotic layers, and broilers. The results show that the feeds were offered in insufficient quantity compared with the recommendations for laying hens (125 g/chicken unit/day). Indigenous chickens were fed 111 and 67 while the improved crossbred chickens were fed 118 and 119 g/chicken unit/day under semi-intensive and intensive systems, respectively. Most feeds fed to dual-purpose chickens were of low nutritional quality, particularly lacking in crude protein and essential amino acids in both rearing systems and breeds. Maize bran, sunflower seedcake and fishmeal were the main sources of energy and protein in the study area. The study findings show that the important feed ingredients: protein sources, essential amino acids, and pre-mixes were expensive, and were not included in formulating compound feeds by most chicken farmers. Of all 101 respondents interviewed, only one was aware of aflatoxin contamination and its effects on animal and human health. All feed samples contained a detectable concentration of aflatoxins and 16% of them exceeded the allowed toxicity thresholds (>20 μg/kg). We highlight the need for a stronger focus on feeding strategies and ensuring the availability of suitable and safe feed formulations.

Keywords: productivity, feed ingredient, feed quantity, aflatoxin

4.1. Introduction

In Tanzania, human nutrition can be improved through the consumption of affordable locally produced poultry products. Chickens are the predominant poultry species in Tanzania raised by 86% of livestock-keeping households, supporting livelihoods, and providing nutrient-dense animal-sourced protein and income along the value chain (MLDF, 2019). Most consumers in Tanzania prefer indigenous chicken meat and eggs to products from exotic broilers and layers (Naggujja et al., 2020) due to the perception that they taste good and are nutritious and that they come from chickens which are raised organically (Muhikambele, 2019; Sanka and Mbaga, 2014). Producers also prefer indigenous breeds because of their resilient nature to diseases and to harsh conditions which result in less need for veterinary drugs (Kapella et al., 2022; Muhikambele, 2019). The demand for chicken meat and eggs is already high in Tanzania, and it is projected to increase. It is challenging to meet the increasing demand through domestic production (MLDF, 2019; Naggujja et al., 2020) due to the low production capacity of indigenous breeds and limited access to quality feeds.

Over the past decade, the chicken industry in Tanzania intensified, involving the transition from keeping a small number of free-range indigenous chickens to keeping improved dual-purpose crossbred and exotic layers and broilers in semi-intensive and intensive systems (Ringo and Lekule, 2020; Wilson et al., 2022). Hence, chicken production systems in Tanzania are categorized into three rearing systems i.e. free-range, semi-intensive, and intensive. These different rearing systems are primarily defined by the housing and feeding systems. Free-range is scavenging outdoors, the semi-intensive system is partly indoors and fed with home-made feed, while in the intensive system the chickens are permanently indoors and fed with commercial or home-made feed or both (Wilson et al., 2022).

Feed quality and quantity are major aspects determining the production and productivity of chickens. The theoretical concepts of production ecology have been applied in assessing the potential, limited, and actual crop and animal production (Van de Ven et al., 2003; van der Linden et al., 2015). When applied to animal production, potential production is defined by the growth-defining factors i.e. genotype and climate, while limited production is defined by the growth-limiting factors i.e. feed quantity and nutritional quality (van der Linden et al., 2015). The actual production is defined by growth-reducing factors i.e. diseases and parasites, and feed contamination (for example by a mycotoxin such as aflatoxin). Using this approach, the yield gap, which is the difference between the actual and limited yield or potential yield can be estimated. Moreover, in practice, research on yield gap analysis shows that is not feasible in practice or cost-effective to close the yield gap fully (van Ittersum and Cassman, 2013). The exploitable yield gap in crop and livestock production is therefore between 75 to 85% of potential production (van der Linden et al., 2015; van Ittersum and Cassman, 2013).

The Tanzania Livestock Master Plan (TLMP 2017-2022) highlights that limited access to quality feeds and feed ingredients is among the major constraints to the development of the poultry sector in the country (MLDF, 2019; Nandonde et al., 2017) and hence is a major contributor to the yield gap. The TLMP further highlights the potential of maize and soybean as local sources of energy and protein, respectively in chicken feed, providing an opportunity for growth of the chicken industry in the country. Despite the low maize and soybean yield in Tanzania (as for most sub-Saharan African countries), there is enormous potential to reduce the yield gap through improved agronomic practices (Giller et al., 2021; Van Loon et al., 2018). Moreover, the country potentially has about 44 million hectares of land suitable for crop production, of which only 24% is being used for farming at present. So, extra land can be made available for food and feed production while considering sustainable land use strategies (Dunstan Gabriel, 2013; Msofe et al., 2019).

Chicken feed accounts for about 70% to the production costs in Tanzania (Mutayoba et al., 2011). Commercial feeds are expensive and mostly not available in quantities small enough to be affordable to smallholder chicken farmers (Wilson et al., 2021). Moreover, most farmers rely on local feeds and feed ingredients from local stores and markets. Often, the quality of these locally-available feeds is questionable, and the prices, particularly of the protein sources used (e.g. fish meal), are high (Andrew et al., 2019; Nandonde et al., 2017). Quality control of chicken feed and feed ingredients along the supply chain is limited, whilst there is no labelling of feed packages by processors showing the nutrient contents of feeds (Geerts, 2014). Moreover, there is little compliance with recommended feed standards due to lack of awareness, and weak extension services (Longo et al., 2019; Matrona et al., 2022). There are recent reports of high mycotoxin contamination in feeds and feed ingredients, which arises during crop production and storage (Agape et al., 2021; Suleiman et al., 2017; Temba et al., 2021), posing risks to chicken and human health (Shephard, 2008). Therefore, feed availability and quality are major contributors to the feed gap in poultry production in Tanzania.

In the present paper, we focus on this specific component of yield-gap analysis, namely an analysis of the so-called “feed gap”. A feed gap analysis is the comparison of the actual feed quantity and quality supplied to chickens with the recommended standards for improved dual-purpose crossbred chickens, and exotic layers and broilers. We explore the current feed gap and how this feed gap can be closed. The study focuses particularly on farms keeping indigenous and improved dual-purpose crossbred chickens raised for both meat and eggs under semi-intensive and intensive systems in the Southern Highlands of Tanzania.

4.2. Materials and methods

4.2.1. The Study Area

The study was conducted in Iringa municipality in the Iringa region, Southern Highlands of Tanzania. The municipality covers urban and peri-urban locations with limited land for crop production and is characterized by semi-intensive and intensive chicken production systems (Wilson et al., 2022). Furthermore, the municipality has potential for commercialization of the chicken industry due to presence of hatcheries, grain millers and feed processors established over the past decade.

4.2.2. System Boundaries

Yield gap analysis in the present study was done at the farm level. A farm is defined as an entity comprised of a farming household with a chicken production unit and cropland or garden. The studied farms in urban and peri-urban areas relied on external inputs, i.e. one-day-old chicks, feed or feed ingredients, water, medicines and vaccines, and extension services (Figure 4.1) (Wilson et al., 2022). Some farms produced chicks themselves and had access to chicken feed from their own cropland or garden. The farming household members provided labor to manage both the chicken production unit and cropland. Chicken meat and eggs were both consumed within the farm and sold. Chicken manure in small-scale farms is mainly used within the farms while some mid-large-scale farms sell manure to crop farmers. On the other hand, excess manure from landless farms is dumped in the garbage area.

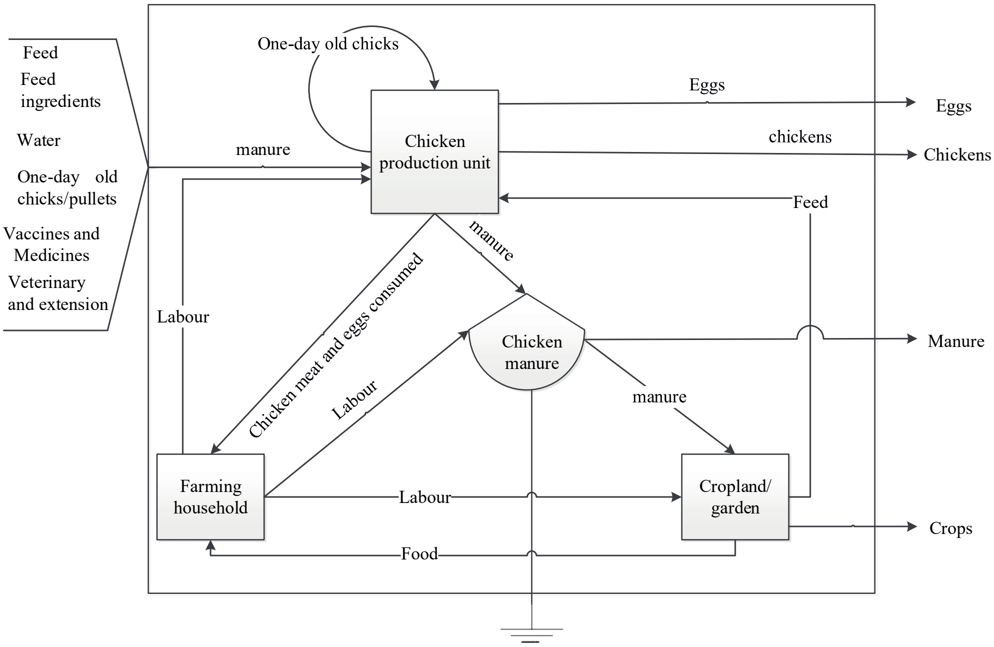


Figure 4.1. System description for farms raising dual-purpose chickens in urban and peri-urban locations, Iringa region, Tanzania.

4.2.3. Sampling Framework and Data Sources

Primary Data

The actual production and feed quantity and quality (status quo) were primarily assessed by a cross-sectional survey, physical measurements, quantification of feed offered to chickens during a farm visit and feed quality assessment by laboratory analysis.

A cross-sectional survey was executed in the Iringa Municipality from November to December 2020 whereby 101 farmers keeping dual-purpose chickens were interviewed using a semi-structured questionnaire programmed using Open Data Kit (ODK) software (https://opendatakit.org/). A stratified sampling of farms was conducted in fourteen Wards in the municipality. The wards were purposively selected based on having high number of dual-purpose chickens according to the extension office statistics. To better understand the diversity of chicken production and feeding practices, the wards within the municipality were subdivided based on the location of the farming household along the urban-peri-urban gradient i.e. the urban sub-location (Group I: < 5 km from the town center) constituting of eight Wards, and the peri-urban sub-location (Group II: ≥ 5 km from the town center), constituting of six Wards. A random sample of farms keeping dual-purpose chickens was selected from the two sub-locations based on the list provided by the extension office, resulting in 45 and 56 farms in urban and peri-urban sub-locations, respectively. The interviews were conducted by trained enumerators. The interviewees were adult respondents directly involved in chicken management. Chicken production systems were grouped into two pre-defined rearing systems i.e. semi-intensive and intensive systems, primarily based on housing, and feeding system (Wilson et al., 2022). The majority of farmers raised chickens in semi-intensive systems (81%) and a minority were practicing intensive systems (19%). Of all farms, 64% raised indigenous and 36% improved crossbred chickens (Table 4.1), while 5% raised multiple breeds of chicken in one or more rearing systems. The questionnaire included questions about the management of chickens, type of feed and feed ingredients used in formulating chicken feed, sources of feed, feed availability, prices of feed and feed ingredients, and the quantities and prices of the products produced and marketed (i.e. meat, eggs, and manure).

Table 4.1. Distribution of interviewed poultry farmers and feed sample collection in Iringa municipality

	Rearing system		Total number of farms
	Semi-intensive	Intensive	
Indigenous breed	54	11	65
Improved crossbred	28	8	36
Total	82	19	101

During the farm visits, physical measurements were taken for assessment of the performance of chickens. Measurements taken include live body weight and egg weight, recorded using a digital weighing scale in grams; and shank length and circumference measured using a tailoring and a digital vernier caliper, respectively. Shank length and thickness or circumference are important parameters in measuring the skeletal development of chickens and they also have a direct relation with growth and body weight (Mutayoba et al., 2012; Yakubu et al., 2009). Physical measurements were done in all 101 farms interviewed whereby 4-5 chickens and eggs were randomly selected for physical measurements in each farm, depending on the flock size and number of eggs at the moment of farm visit. In total, 401 hens and 462 eggs were selected for physical measurements.

Feed quantity and quality were also assessed during the farm visits. The quantity of feed fed to chickens per day, feed formulation practices and storage, and seasonal availability of different feed ingredients used in feed formulation were recorded. The feed offered was estimated based on a measurement of the total amount fed to the whole flock on the day of the farm visit. The production parameters assessed included the number of laying hens per farm, the number of eggs per hen/week and the body weight of chickens.

Feed quality characteristics i.e. nutritional quality and aflatoxin content were assessed in feed samples (one sample from each farm, sampled from the whole mixed ration) which were collected from semi-intensive (78 farms) and intensive systems (19 farms) and analyzed for dry matter (DM), crude protein (CP), crude fat, crude fiber (CF), ash, metabolizable energy (ME) and essential amino acids (lysine, methionine, and tryptophan). Of the 101 interviewed farms, four farms had already fed the last feed portion to chickens on the day of the farm visit and were not sampled for laboratory analysis. The nutritional quality of feed was done using Near-Infrared Reflectance Spectroscopy (NISRS) at the Tanzania Veterinary Laboratory Agency (TVLA) animal feeds laboratory, by exposing the feed sample to an electromagnetic scan over a spectral wavelength range of 1100 to 2500 nm (Corson et al., 1999). 32 feed samples constituting 23 samples from semi-intensive and 9 samples from intensive farms were analyzed for aflatoxin contamination using an AccuScan Gold III reader, a single-step lateral flow immunochromatographic assay at the International Institute of Tropical Agriculture (IITA) pathology laboratory in Dar es Salaam, Tanzania.

Secondary Data

Secondary data were gathered about feed quantity, quality, and chicken production. The quality and quantity of the feed supplied to indigenous and improved dual-purpose crossbred chickens were compared to the recommendations in the Hendrix Genetics guidelines (Hendrix Genetics, 2022). The recommendations for layers and broilers differed slightly between sources. We therefore averaged the recommendation from the East Africa Community Standards (TBS, 2020), Feed Calculator App (FeedCalculator, 2022), and Lohman breeder (for layers' feed) (Thiele and Pottgüter, 2008) and PoultryHub recommendations (for broiler finishers' feed) (PoultryHub, 2022), respectively (Table 4.2). The number of chickens were expressed as Chicken Units (CU), defined as the equivalent of a mature chicken of 1800 g.

4.2.4. Data Analysis

R package 4.2.1 was used to analyze the effects of the rearing system and breed on production parameters i.e. maturity age, body weight, weekly lay %, egg weight, and physical parameters of shank length and circumference (Table 4.3), and the differences in feed quantity (per CU) and quality (Table 4.4). Weekly lay % as an indicator for laying hen productivity was computed by dividing the number of eggs produced in the farm per week divided by the number of laying hens in the flock at that farm divided by seven (Ibrahim et al., 2019). The Generalized Linear Model (GLM) was used to test the effects of the rearing system (semi-intensive and intensive), breed (indigenous and improved cross bred), location type (peri-urban and urban) and interactions at a 5% level of significance. During data analysis, no significant differences were found between peri-urban and urban sub-locations, and therefore the sub-location effect was not included in the results presented in the current article. The following statistical model was used to analyze the effects of the rearing system and breed of chicken on the performance of chickens (physical parameters):

$$Y_{ijk} = \mu + R_i + B_j + L_k + R_i \times B_j + R_i \times L_k + B_j \times L_k + R_i \times B_j \times L_k + e_{ijk}$$

Where:

Y_{ijk} = an observation for a given variable

μ = overall mean

R_i = effects of the ith rearing system (1=semi-intensive, 2=intensive)

B_j = effect of jth breed (1=indigenous, 2=improved cross bred)

L_k = effect of k^{th} location (1=urban, 2=peri-urban)

$R_i \times B_j \times L_k$ = the interaction between the rearing system (i), breed (j) and sub-location (k)

e_{ijk} = residual error term

In the next step, feed quantity and quality per farm were plotted against the recommended values using the *ggplot2* package in R. The potential weekly lay % was assumed to be 95% weekly lay at peak production (25 to 26 weeks) for the improved crossbred Sasso chickens (Hendrix Genetics, 2022), illustrating the flock size with the actual and potential egg production per flock per week. In practice, a realistic potential weekly lay % is probably between 75-85% of the potential production. Therefore, in the current study, the realistic potential weekly lay % (as an indicator of egg productivity) was assumed to be between 80% (van der Linden et al., 2015).

Secondly, the actual quantity of the feed (per CU) and nutritional quality were compared with the recommendations for the improved dual-purpose crossbred, exotic layers and broilers. Furthermore, the average levels of aflatoxins of the feeds were calculated per system and breed (Table 4.4) and compared with the recommended limits (Table 4.2).

4.3. RESULTS

4.3.1. General Characteristics of the Chicken Farming Household

Overall, 61% of the interviewed respondents were women and 39% were men. The majority of the respondents had attained secondary education (62%), while others attended tertiary education i.e. college or university (24%) and primary school education (13%). The most important sources of household income were poultry business (65%), off-farm informal businesses (12%), crop farming

(5%), off-farm formal business (4%), and income from salaries (2%). Of all 101 farmers interviewed, 11 were involved in farmer groups, mainly for joint marketing, for accessing information and training about chicken management, and for accessing loans.

4.3.2. Flock Size, Reproduction and Production Characteristics

The overall flock size was 100 chickens per household on average without significant differences between breed and rearing system (Figure 4.2a and Table 4.3). The total number of laying hens in the flock was influenced by the rearing system and breed of chickens *($P < 0.05$)*, where we found that the households that keep improved breeds under the intensive system had more laying hens than households keeping indigenous breeds *($P < 0.05$)*. Of the 101 interviewed farms, 64% raised indigenous breeds while 36% were keeping the improved crossbred chickens (Table 4.1). We found that the improved crossbred chickens attained maturity (assessed as the perceived age at first lay) earlier than the indigenous chickens *($P < 0.05$)*, irrespective of the raising system (Table 4.3).

Of 401 chickens and 462 eggs sampled for physical measurements, 52% and 21% met the recommended weight for matured crossbred chicken (≥1800g) and egg (≥52 g), respectively (Table 4.2). The body weight of chickens and egg weight were higher ($P < 0.05$) for the improved crossbred than for the indigenous chickens. The number of eggs and weekly percentage lay were influenced by the rearing system and breed of chickens ($P < 0.05$), where we found the largest flocks in households that keep the improved crossbred chickens under the intensive system (Table 4.3). 60% of the interviewed farming households that keep crossbred chickens reported low weekly lay (Figure 4.2b), under the intensive and semi-intensive systems. Shank length and circumference were not significant different between production systems and breeds (Table 4.3).

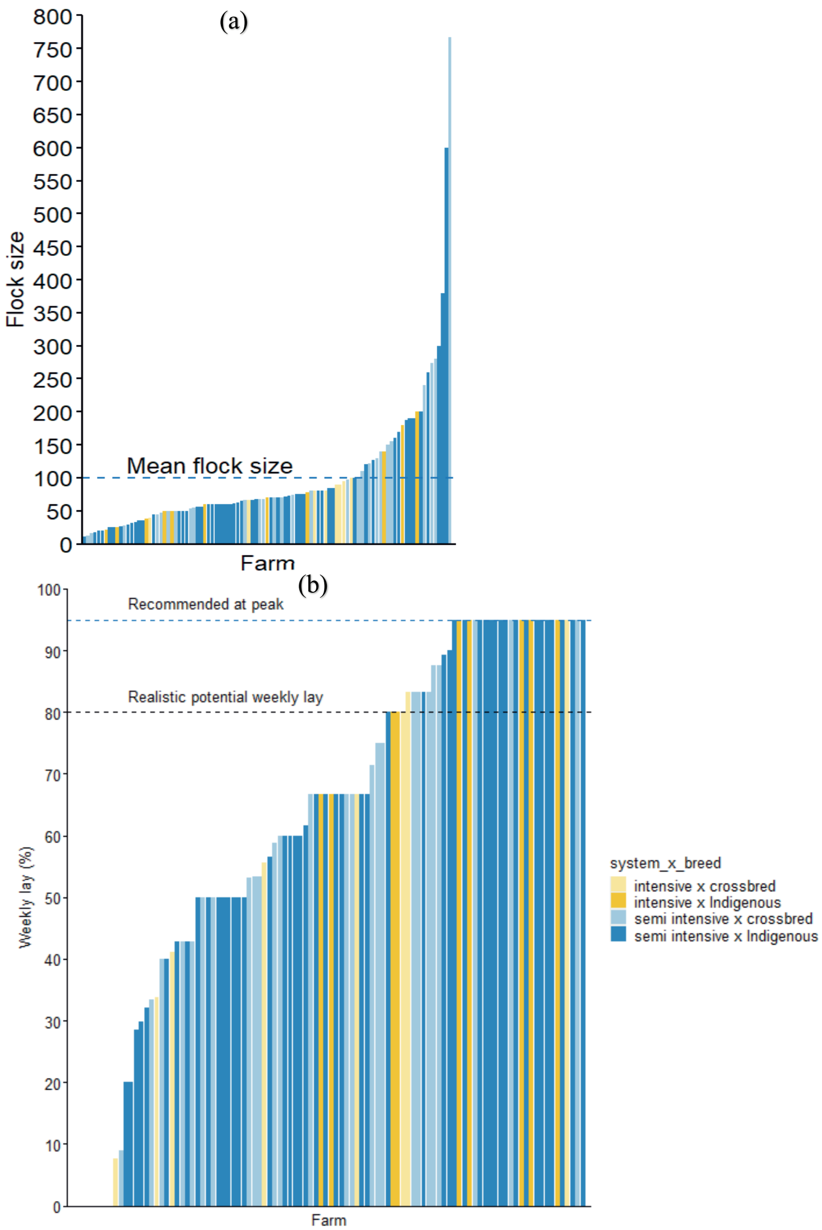


Figure 4.2. Flock size distribution (a) and weekly lay and weekly lay per laying hens (b) at poultry farms. The recommended percentage at peak (95%) was based on the recommendations for improved crossbred chickens at 25-26 weeks (Hendrix Genetics, 2022) while the realistic weekly lay percentage is taken to be 80% of potential production (van der Linden et al., 2015).

Table 4.2. Nutritive value of chicken feed based on the East African Standards, Feed Calculator App, Hendrix Genetics guidelines (for Sasso breeder chickens), and Lohmann layer standards.

	Moisture (%)	Crude Fat (%)	Crude Protein (%)	Crude Fibre (%)	Lysine (%)	Methionine/Cystine (%)	Tryptophan (%)	ME (kcal/kg)	Aflatoxin (µg/kg)
East Africa standards guidelines[1]									
Broiler Finisher Feed	12	10.9	18.0	7.5	1.0	0.8	1.25*	3000	<20
Layer Feed	12	7.9	16.0	7.5	0.7	0.6	1.25*	2650	<20
Feed calculator App guidelines									
Standard broiler finisher		9.5	19.0	6.6	0.9	0.7		2750	<20
Standard layer feed		7.1	16.5	6.5	0.6	0.5		2600	<20
(c) Breeding company's guidelines									
Sasso breeder[2#]		>3.5	17	<6	0.7	0.6	0.16	2750	<20
Poultry hub[3]			20		1.1	0.8	0.2	3225	
Lohmann layer[4]			17.5		0.9	0.7	0.18	2800	<20
Average broiler finisher $((a_1+b_1+c_2)/3)$	12	10.2	19	7.1	1.0	0.8	0.2	2992	<20
Average layer feed $((a_2+b_2+c_3)/3)$	12	7.5	17	7.0	0.7	0.6	0.18	2683	<20

[1]Source: Tanzania Bureau of Standards (TBS, 2020). * Extreme high compared to the recommended threshold from breeding companies (excluded in calculating the average recommended value for tryptophan)

[2]25th week age (peak production), egg weight 52.3 g, BW= 1820 g, weekly lay 95%, Feeding g/♀/day = 127 g. Source: Hendrix Genetics breeding manual for SASSO chickens (SA51A)[1]. Source: Hendrix Genetics (Hendrix Genetics, 2022– - https://africa.sasso-poultry.com/documents/853/SASSO_Traditional_Poultry_Breeders_SA51A.pdf

[3]Broiler finisher (8 weeks age), BW=3700 g (hens), cumulative feed intake = 8200 g and 100 g/day. Source: (PoultryHub, 2022) - https://www.poultryhub.org/all-about-poultry/nutrition/nutrition-requirements-of-meat-chickens-broilers.

[4]21-22 weeks (layers in phase 1 of laying), egg weight 53-62.7 g, BW= 1730 g, weekly lay 92-94%, Feeding g/ ♀/day = 125 g). Source: Lohmann Layer, (Thiele and Pottgüter, 2008).

NB; Particular environments, sanitary conditions, geographic location, or equipment might require adaptations that have not been taken into consideration in these general recommendations.

[#]Matured improved crossbred Sasso chicken of 1800 g, at peak egg production (25-26 weeks) and 95% weekly lay (Hendrix Genetics, 2022).

Table 4.3. Production parameters used in assessing the production of the dual-purpose chickens in the Iringa region (mean and standard deviation).

Rearing system	**Semi-intensive (*n*=82)**		**Intensive (*n*=19)**		***P-values*²**		
Breed	Indigenous (*n*=54)	Crossbred (*n*=28)	Indigenous (*n*=11)	Crossbred (*n*=8)	System	Breed	System × Breed
Flock size (number of chickens)	98.6±117	100±71.7	117±165	92.5±61.2	0.86	0.69	0.66
Number of laying hens	11.2±11.8	17.3±26.1	6.6±5.8	53.3±26.5	0.00	0.00	0.00
Perceived average maturity age of hens (weeks)*	23.7±0.4	21.8±0.5	23.6±0.9	21.3±0.9	0.47	0.00	0.25
Body weight (g)	1702±385	2479±517	1732±308	2924±819	0.05	0.00	0.09
Egg weight (g)	43.0±5.5	50.0±7.1	42.7±8.2	55.00±12.5	0.18	0.00	0.14
Egg production /flock/week	47.7±48.1	82.1±110	35.8±36.1	208±130	0.00	0.00	0.00
Weekly lay (%)/flock/week	8.0±6.3	13.8±14.0	6.4±3.8	35.7±17.1	0.00	0.00	0.00
Weekly lay (%)/laying hens in the flock/week	59.9±32.1	61.3±29.3	59±23.9	87.8±10.9	0.10	0.05	0.08
Shank length (cm)	6.1±0.1	6.3±0.1	6.2±0.1	6.3±0.1	0.29	0.06	0.19
Shank thickness (mm)	13.2±5.9	13.4±8.2	11.8±13.7	13.6±15.4	0.52	0.38	0.72

*Perceived maturity age of hens (age at first laying) based on the interviews (farmer's memory)

²P-values in boldface indicate a statistically significant difference

Table 4.4. Mean and standard deviation values and P-values for nutritional quantity and quality of chicken feed in the study area.

Rearing system	**Semi-intensive**		**Intensive system**		***P-values***		
Breed	Indigenous (*n*=54)	Crossbred (*n*=28)	Indigenous (*n*=11)	Crossbred (*n*=8)	System	Breed	System × Breed
Feed quantity (g/chicken unit)	111±59	118±60	67±32	119±52	0.14	0.1	0.13
Metabolisable energy (kcal/kg feed)	2735±147	2674±184	2723±162	2671±90	0.86	0.17	0.91
Crude protein (%)	11.9±1.17	12.6±1.13	12.5±1.53	12.7±1.06	0.39	0.19	0.45
Crude fat (%)	8.1±1.31	7.8±0.88	8.4±1.03	8.0±0.81	0.38	0.28	0.84
Crude fiber (%)	5.7±1.38	5.8±1.05	5.8±1.02	5.3±0.66	0.57	0.53	0.27
Lysine (%)	0.69±0.07	0.72±0.06	0.71±0.09	0.72±0.06	0.40	0.18	0.47
Methionine/cystine (%)	0.51±0.05	0.54±0.05	0.53±0.06	0.54±0.05	0.43	0.17	0.50
Tryptophan (%)	0.14±0.01	0.15±0.01	0.15±0.02	0.15±0.01	0.61	0.28	0.43
Moisture content (%)	10.9±1.21	10.7±1.05	10.4±1.43	10.3±0.61	0.12	0.63	0.77
Aflatoxins (μg/kg)[1]	13.1±7.73	8.4±2.87	14.4±11.28	14.6±6.84	0.32	0.54	0.52

[1] the sample size for aflatoxin was 32 farms (23 semi-intensive and 9 intensive systems)

4.3.3. Chicken Feed Ingredients and Feeding

The most common feed ingredients used in formulating compound feeds among farms included maize bran and sunflower seedcake, reported by 95 and 93% of the interviewed farmers, respectively. Other feed ingredients reported by farmers (percentage of farmers using the ingredient) included fish meal (68%), limestone (66%), bone meal (60%), di-calcium phosphate (54%), premixes (46%), salt (42%), sorghum (29%), soybean meal (16%), maize meal (11%), rice polishings (10%), blood meal (10%), lysine (2%), and methionine (2%). The use of feed ingredients was determined by price and availability and farmers indicated that the most expensive feed ingredients were less frequently used in formulating feeds. The essential amino acids (methionine, lysine) were mentioned as the most expensive feed ingredients followed by premixes and di-calcium phosphate, but farmers appreciated that they were sold in small quantities (≤0.5 kg). Protein sources, including fish meal and soybean meal, were also expensive: both were sold between 0.7 to 0.9 USD per kg (Figure 4.3).

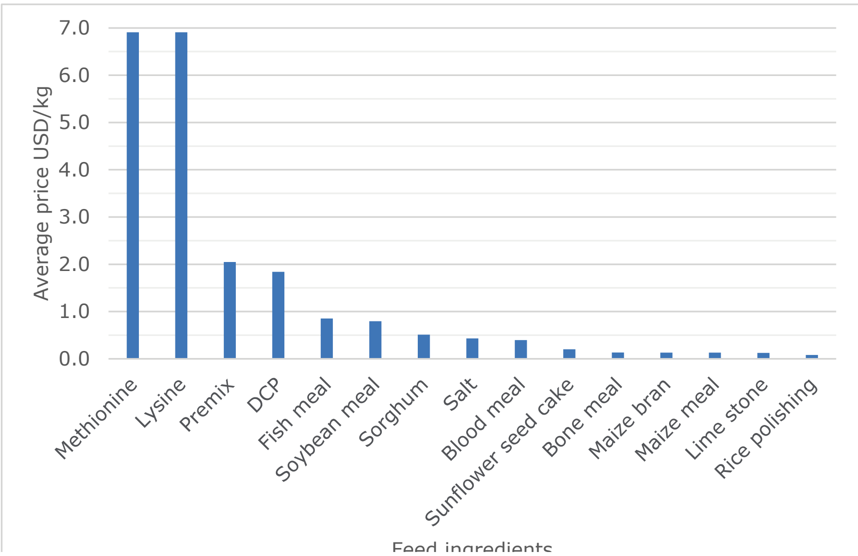


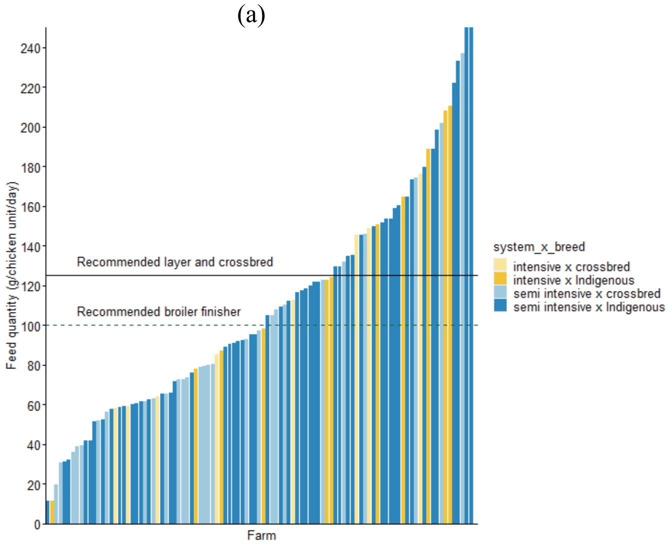
Figure 4.3. Prices of feed ingredients used for chicken feeding. DCP = di-calcium phosphate.

Feed Quantity

When considering the concept of CU, 40% of the interviewed households met the optimum recommendations of ≥125 g of feed required for a CU (mature laying hen) per day (Figures 4.4 and 4.5). Within the intensive system, 50% of farmers supplied above the average of the recommended feed ration for mature laying hens. When considering the quantity of feed required for broiler finisher chickens, 50% of the households met the requirements as recommended by the breeding company

(100 g/CU per day). All farms with ≥200 chickens fed their chickens less than the recommended quantity of feed (125 g/CU per day) for layers and crossbred chickens (Figure 4.5).

(a)



(b)

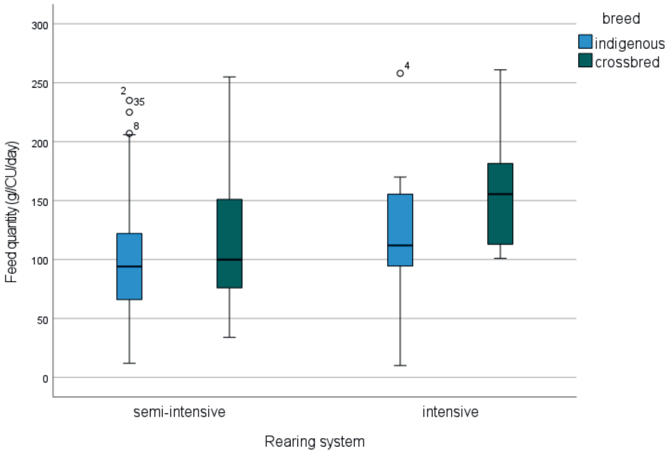


Figure 4.4. Comparison of feed quantity recommended for broiler, layers and improved crossbred (a) and the quantity of feed fed to indigenous and improved crossbred chicken units per day under semi-intensive and intensive systems (b) in Iringa municipality.

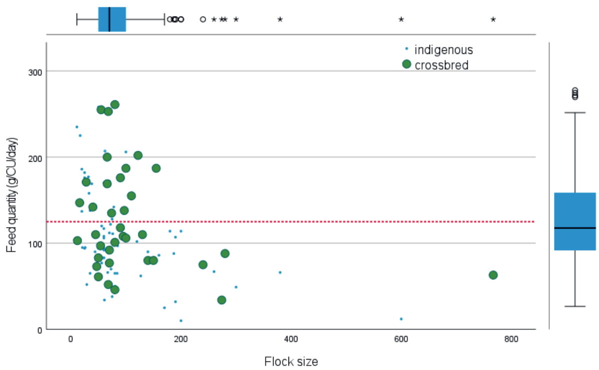


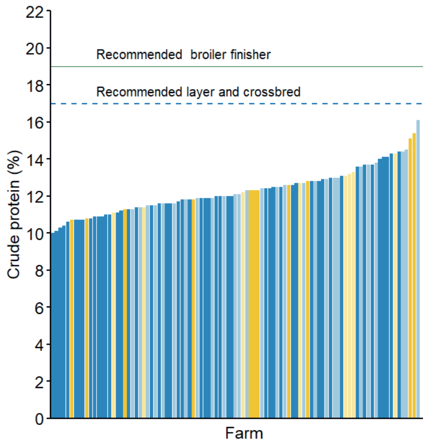
Figure 4.5. Relationship between feed quantity and flock size (chicken unit). The optimum recommended feed quantity for a matured chicken is provided in a red dotted line (≥125 g/day). The box plots indicate the mean flock size and feed quantity, respectively.

4.3.4. Feed Nutritional Quality

Overall, none of the feed samples analyzed met the recommended nutritional standards for crude protein for broilers, layers and improved crossbred chickens while 60% and 47% of the samples had the recommended metabolizable energy content for layers and improved crossbred chickens (Figure 6). When considering the recommendations for broiler finisher feed, none of the feed samples had the recommended metabolizable energy and crude protein content. For the essential amino acids, 48% and 10% of the samples had the recommended lysine and methionine or cysteine concentrations for layers and improved crossbred chickens, respectively.

When considering the recommendations for broiler finisher feed, none of the feed samples reached the recommended concentration of the essential amino acids (Figure 4.7). When considering the recommendations for layers and improved crossbred feed, 3% and 19% of the feed samples reached the minimum tryptophan concentration, respectively (Figure 4.7 and Table 4.2).

(a)



(b)

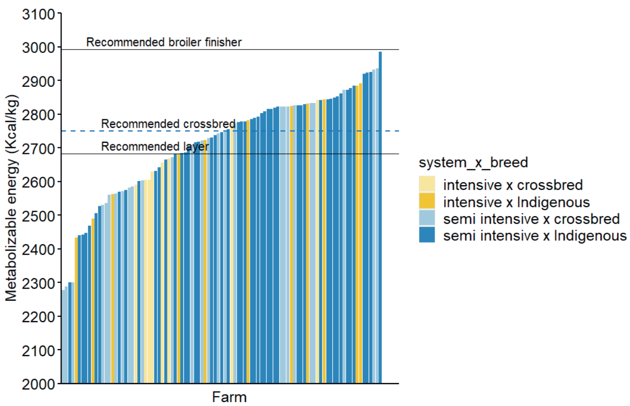


Figure 4.6. Nutritional quality of the feed samples from the study area in terms of crude protein (a) and metabolizable energy (b) based on the laboratory analysis and the comparison with the average recommended values from the East African Standards, feed calculator App and international breeding companies.

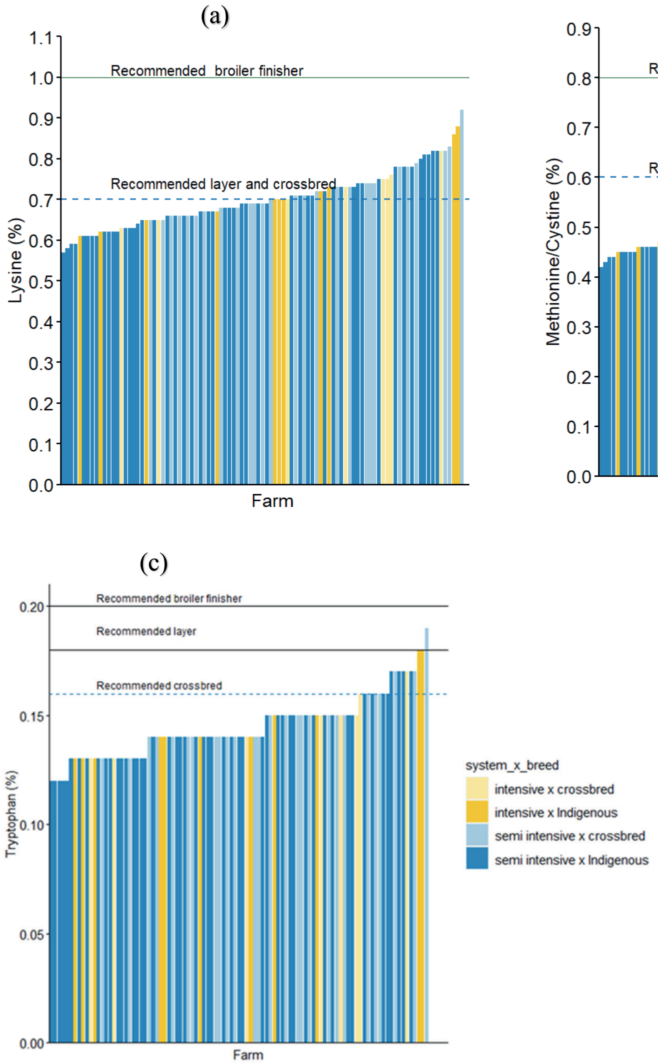


Figure 4.7. Essential amino acids concentration of the feed samples i.e. lysine (a), methionine/cystine (b) and tryptophan (c). The horizontal lines indicate the recommendations from the Tanzania/East African Standards, feed calculator App and international breeding companies.

4.3.5. Aflatoxin and Moisture Content

Of all 101 respondents interviewed, 1% was aware of aflatoxin and its effects on animal and human health. All feed samples analyzed contained a detectable concentration of aflatoxins of which 16% exceeded the East Africa Community standards of 20 µg/kg. The highest concentrations of aflatoxins were observed in feed samples collected from farms raising indigenous chickens in both semi-intensive and intensive systems, with 32.5 µg/kg and 26.6 µg/kg, respectively (Figure 4.8). 12% of the collected samples had excess moisture content in the semi-intensive and intensive systems.

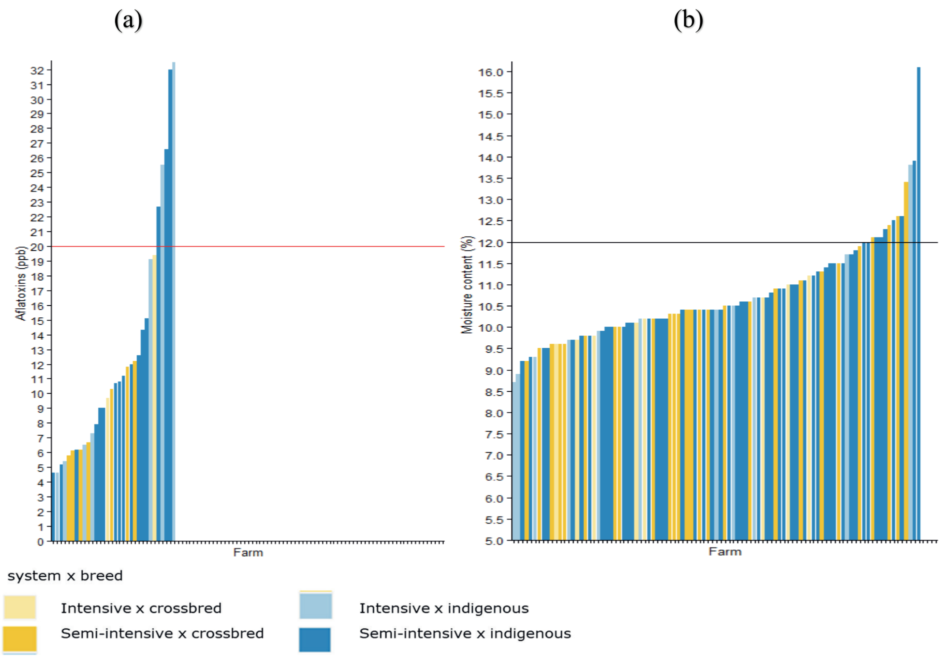


Figure 4.8. (a) Aflatoxin and (b) moisture content assessment in relation to the maximum limits (horizontal lines) set by the Tanzania/East African Standards, respectively.

4.4. Discussion

The intensification of the poultry industry in Tanzania involves the transition from keeping small numbers of free-range indigenous chickens per farm to large flocks of multiple breeds or improved breeds of chickens under semi-intensive and intensive systems (Wilson et al., 2022). The newly introduced crossbred i.e. Kuroiler and Sasso breeds have shown potential in the highlands and lowlands of Tanzania (Guni et al., 2021; Sanka et al., 2020). The present study explored a major component of the yield gaps in the poultry industry in Tanzania by first analyzing the effects of rearing system and breed of chickens and interaction effects on production parameters (body weight and egg production). In the next step, we analyzed the effects of the rearing systems and chicken breed and their interaction effect on feed quantity and quality. To the best of our knowledge, there are no relevant simulation models for estimating the potential production of chickens which would be needed to estimate the yield gap (Van de Ven et al., 2003; van der Linden et al., 2021; van Ittersum and Cassman, 2013). Considering the crucial importance of feed in closing the yield gap in chicken production, we focused on the yield that could be attained by closing feed gaps (both quantity and quality).

Most chicken farmers keeping dual-purpose chickens in Tanzania prefer locally-made feeds or feed ingredients to reduce the costs of production and evade expensive commercial feeds, which are mostly not available in small quantities (Wilson et al., 2022). Our results show that the feeds are indeed of low quality for all breeds but provided in inadequate quantity, especially for indigenous chickens, suggesting differentiated improvements to feeding practices are required to reach the potential production of dual-purpose chickens of both breeds, and hence reduce the yield gap. Several studies reported limited access to high-quality feed and feed ingredients as the major constraint limiting chicken production and productivity in Tanzania (Enahoro et al., 2021; Longo et al., 2019; Naggujja et al., 2020), but they did not describe local feeding strategies in different production systems in detail. In comparison with the East African standards and international breeding companies' recommendations, we found that most dual-purpose chickens in the study area received feeds particularly low in crude protein and essential amino acids. Research shows that a well-managed flock of improved dual-purpose crossbred chickens may reach 1800 g body weight and egg production potential of about 95% (weekly lay/flock, laying eggs of ≥52g) at peak lay (Hendrix Genetics, 2022). Nevertheless, when considering the realistic potential weekly lay percentage (80%) that can be attained by most farmers (van der Linden et al., 2015), our findings show that only 50% of the interviewed farms attained the potential body weight of mature chickens and 40% of the farms met the potential weekly lay %, in major part due to the poor quantity and quality of feed provided.

Our findings show that the poor quality of the feed provided is partly due to the prices of feed ingredients, as the most important ingredients i.e. the protein sources, essential amino acids, and premixes are expensive. We found that maize bran, sunflower seedcake and fishmeal are the main sources of energy and protein in the study area. Soybean cake is also an important source of protein produced within the region, but its utilization in chicken feed formulation is limited due to a lack of efficient processing facilities (Wilson et al., 2021). As a result, the locally produced soybean grain is exported to the neighboring countries for processing and soybean meal is imported at prices that are not affordable for most chicken farmers.

Apart from feed quantity and quality, attaining the potential production requires proper animal breeding and a favorable environment i.e. proper housing (clean, well-ventilated, and with regulated temperature) (van der Linden et al., 2015). There is also a crucial need to consider the acceptable levels of animal welfare and growth-reducing factors such as water quality, housing, disease and parasite prevalence and feed contamination (aflatoxin). Only feed samples collected from the farms raising indigenous chickens exceeded the maximum aflatoxin limits (>20 μg/kg) in both systems, posing high risks to chicken productivity and human health. Despite low moisture content observed in feed samples from most farms, there are dangers of aflatoxin contamination due to limited awareness of farmers on the presence, effects and control of aflatoxins. The most common feed ingredients used in formulating chicken feed include maize and sunflower seed cake, which are among the feeds that are prone to aflatoxin contamination (Mwakosya et al., 2022). Research shows clear evidence of the effects of aflatoxins on depressed laying performance, feed intake, eggshell thickness, and egg hatchability, along with the deposition of aflatoxin residues in eggs and meat (Al-Ruwaili et al., 2018; Coppock et al., 2018; Jia et al., 2016). We did not observe a significant relationship between aflatoxin content and egg production (weekly lay %) in the present study, perhaps due to the small sample size. Free range chickens are more exposed to aflatoxin contamination than semi-free range chickens since they rely on scavenging with exposure to contaminated feeds (Tarus, 2019). Therefore, since most consumers in Tanzania prefer products from indigenous free-range chickens (Naggujja et al., 2020; Sanka and Mbaga, 2014), there is a need for interventions in chicken management and feed quality management to reduce aflatoxin residues in chicken meat and eggs.

Alternative protein sources including insects and insect larvae have been proposed as replacements for fish meal in tropical countries, particularly in monogastric feeds (Oosting et al., 2021; Vernooij et al., 2019). Recently, some companies have invested in processing city waste into valuable proteins through black soldier fly production (BSF) in major towns and cities (Isibika, 2022; Limbu et al., 2022; Vernooij et al., 2019), but the scale at which it could contribute to the growing-chicken industry in Tanzania is unclear. The advent of open-access feed-calculator mobile applications (e.g. FeedCalculator, 2022) provides an opportunity for small-scale chicken producers to design better feeds for their chickens. Further improvements of the tool should focus on the inclusion of alternative protein sources and locally produced feed ingredients.

4.5. Conclusion

In line with the Tanzania Livestock Master Plan, our findings reveal a large feed gap in current chicken production. Despite the recent intensification of the chicken industry in Tanzania through the introduction of improved and exotic breeds, there is a high yield gap in chicken production. Our results highlight the importance of closing feed gaps (both quantity and quality) to meet the increasing demand for chicken meat and eggs.

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Disclosures

The authors declare no conflict of interest toward the development, submission, and publication of this manuscript.

Chapter 5

Scenario analysis towards sustainable diets and their land-use needs: the case of the Iringa region, Southern Highlands of Tanzania

This chapter will be submitted as:
Wilson, W. C., Dastoum, S., Oosting, S., Giller, K. E. Baijukya, F. P., & Slingerland, M. Scenario analysis towards sustainable diets and their land-use needs: the case of the Iringa region, Southern Highlands of Tanzania

Abstract

The increasing human population in sub-Saharan Africa (SSA) implies that the demand for major cereals will triple while that for animal-sourced food will double by 2050. The present study explored scenarios to provide sustainable diets to feed the population in the Iringa region, in the Southern Highlands of Tanzania. It does so by assessing land requirements to produce sufficient food of adequate nutritional quality for the current and the anticipated doubled population of the Iringa region by 2050. The study involved macro secondary data, and micro primary data collected in the region between 2018-2020. The actual and potential yield of the food crops grown in the region were extracted from the Yield Gap Atlas, a global open-access database. The region has about 1,556,465 ha of arable land suitable for crop and livestock production, of which only 37% is currently used for farming, providing an opportunity for the growth of the agricultural sector. With actual crop yields, half of the current land use is needed to produce a plant-based diet for the present population of Iringa. The rest of the land produces for export to other areas of Tanzania and neighbouring countries. Improved diets to be achieved with actual yields of crops and poultry for the current human population size in the Iringa region, would require about 521,826 ha of land for food and feed. This means that all land currently used for food crops needs to be utilized, plus an additional 175,865 ha of suitable land not yet cultivated. With actual yields for crops and poultry and a doubling in population size, a total land use of 1,043,696 ha is needed. Hence, even the total area used for agriculture is not enough to produce sufficient food and feed. An additional 697,559 ha needs to be transformed from suitable land not yet cultivated when current land use for cash crop production and grazing is maintained. Such scenarios show that large food-feed competition will occur in the region, and then probably the poultry sector cannot be served with locally grown feed. Furthermore, in multiple scenarios, cultivation of food (maize) for export will be strongly reduced or no longer possible. To meet the increasing demand for nutritious food, the present study highlights the need for sustainable intensification options focusing on reducing the yield gap in the region. Otherwise, with the current yields, producing sufficient food and feed will not be feasible without further expansion of agricultural land.

Keywords: nutritious diet, attainable yield, food-feed competition, expansion, intensification, breadbasket

5.1. Introduction

In 2015, the United Nations (UN), developed the 2030 Agenda for Sustainable Development and outlined 17 Sustainable Development Goals (SDGs) which all member states committed to achieving. The food system is at the core of a number of these SDGs. In particular, the second of the SDGs, Zero Hunger – is to end hunger, achieve food security and improved nutrition and promote sustainable agriculture (UN, 2015). Food Security exists when all people, at all times have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life (FAO, 1996). By 2050, the global human population is projected to reach 10 billion people with a major increase expected in sub-Saharan Africa (SSA), where the food supply is already under great stress (UN, 2022). The increasing human population in SSA implies that the demand for major cereals will triple while that of animal-sourced food (ASF) will double by 2050 (Thornton, 2010; Van Ittersum et al., 2016; Weber and Windisch, 2017). Tanzania is among the SSA countries experiencing food insecurity due to high rates of malnutrition in all its forms, largely attributed to a lack of dietary diversity among disadvantaged urban and rural households (Alphonce, 2017).

Over the past decade, Tanzania’s population increased from 44.9 to 61.7 million people, with a growth rate of 3.2% per annum (NBS, 2022). By 2050, the population is projected to have doubled, with the major growth projected in towns and cities that are largely depending on the food supply from rural areas (Cohen, 2006; Wenban-Smith et al., 2016). The local diets in the country are dominated by carbohydrate-rich staples, low in minerals and vitamins (Ochieng et al., 2017). The starch staple diets provide dietary energy to households but require to be consumed together with micronutrient-rich foods i.e. poultry meat and eggs, milk, beef, fish, fruits and vegetables to meet the dietary needs (Herforth et al., 2020; Ochieng et al., 2017). Currently, the demand for animal-sourced food is already higher than the domestic production in Tanzania (MLDF, 2019). As a result, per capita consumption of animal-sourced food is very low, contributing to high rates of undernutrition and micronutrient deficiency, particularly among women and children (Wang et al., 2022). Surprisingly, the breadbasket regions important for food production, the Southern Highland regions, in particular, are most affected by malnutrition, partly due to limited dietary diversity (Altare et al., 2016; Ministry of Health et al., 2016).

Tanzania is continually working on improving food and nutritional security through domestic production, despite obstructions by internal and external factors including prolonged droughts, global economic downturn, and fuel, fertilizer and food price hikes (Bumb et al., 2021; MLDF, 2019; URT, 2017). The country is endowed with diverse natural resources including 44 million ha of arable lands suitable for crop and livestock production and extensive rangelands (MLDF, 2019). Despite these resources, agricultural productivity has increased more slowly in Tanzania than in most other SSA countries. Large yield gaps have been reported for the major cereals i.e. maize and rice (Giller et al., 2021; Kwesiga et al., 2020; Ten Berge et al., 2019), and grain legumes (Van Loon et al., 2018), due to poor soil fertility and agronomic practices. Moreover, large yield gaps have been reported in the livestock sector i.e. dairy (Hawkins et al., 2021; Notenbaert et al., 2020) and poultry (Wilson et al., 2023) mainly due to limited access to quality feed and low production capacity of indigenous breeds (MLDF, 2019).

To attain SDG 2, a diet should be produced in a sustainable way, for example, be produced without further expansion of agricultural land and with minimal environmental impacts (Foley et al., 2011; Van Zanten et al., 2018). The main challenge is how to produce more food to feed the growing population in a sustainable and healthy way, all during the time of global climate change and prolonged dry seasons (Fróna et al., 2019). Currently, agricultural production impacts the environment via its emissions to soil, air and water (Foley et al., 2011; Krausmann et al., 2013). It contributes, for example, 25% of the global anthropogenic greenhouse gas emissions with the majority (60%) originating from livestock production (Gerber et al., 2013; Tilman and Clark, 2014). In Tanzania, the main environmental impacts related to food production include land use change (LUC) due to the expansion of agricultural land for crop production and grazing, which accounts for 66% of the estimated 319 Mt of total annual CO_2-eq emissions (Doggart et al., 2020; Hawkins et al., 2021). Based on the Paris Agreement, the Tanzania government has committed to reduce greenhouse gas emissions with between 30-35% relative to the business-as-usual scenario by 2030 (URT, 2021). The dual challenge is improving agricultural yields to provide enough diverse and nutritious food for the growing population without further expanding agricultural land use. The objective of this study was therefore to explore potential scenarios to design food systems that provide sustainable diets to feed the population at the regional level while minimizing land expansion in the Southern Highlands of Tanzania. We developed scenarios to analyse different diets in terms of nutritional values and then estimated production and land requirements for these scenarios.

5.2. Methodology

5.2.1. The study area

The study focused on the Iringa region which is in the Southern Highlands of Tanzania. The total area of the region is 35,743 square kilometres. It holds strategic importance in the country's economy, as it is one of the major breadbasket regions important for food production in the Tanzanian mainland because it is generally endowed with rich soils and resources for food crops and livestock production for the growing population (CIAT and CARE, 2019). The region occupies part of the southern plateau of Tanzania, and can be divided into three zones i.e. lowland, midland and highland, where temperature ranges from about 10 ^{0}C in May/June to 28 ^{0}C in October. The highland zone, towards the east of the region, lies at an altitude between 1600-2300 m above sea level (masl). The area is characterised by red/yellow, well drained, with highly leached and weathered clay soils. The rainy season is between November and May with annual precipitation ranging from 500–1,500 mm. The midland zone, in the central part of the region, lies at an altitude of 1,200–1,600 masl and receives annual rainfall between 600–1,000 mm. The area is characterised by moderately drained and leached soils. The lowland zone lies at an altitude between 900–1,200 masl, and is endowed with highly fertile red brown loam soils. Most of the farmlands are on sandy loams while the black cotton soils hosts acacia woodland. The area receives between 500–600 mm of rain per annum (NBS, 2013).

Agriculture is the mainstay of Iringa's economy accounting for 85% of its Gross Domestic Product. The region has 3,303,280 ha of land of which 47% (1,556,465 ha) is arable land suitable for crop and livestock production. Currently, only 37% (575,892 ha) of the total arable land is used for crop and livestock production, providing an opportunity for the growth of the agricultural sector (NBS, 2013). Food crops occupy about 60% of the cultivated land (346,137 ha) while cash crops occupy about 10% (56,870 ha). Maize is the dominant food crop grown in the region, occupying about 245,000 hectares (71%) of the cultivated land under food crops, followed by beans (16%), rice (4%), sunflower (2.4%), wheat (2%), sorghum (2%), Irish potato (2%), sweet potato (0.6%), cassava (0.4%) and finger millet (0.1%) (Table 5.1a). Iringa is one of the six regions which the government identified as having a potential of massive maize production and it contributes about 25% of Tanzania's total maize production, mainly produced by smallholder farmers (Suleiman and Kurt, 2015). Sunflower is also grown as a cash crop in the region. Other cash crops grown in the region are tea, tomatoes and onions, tobacco, groundnuts, and coffee (Table 5.1b) (NBS, 2013). The livestock species raised in the region are traditional and improved chicken (cross-bred dual-purpose, layers and broilers), cattle (beef and dairy), pigs, and small ruminants (sheep and goat) (Bisanda et al., 1998; SAGCOT, 2015). Despite being among the regions important for food production in the country, dietary diversity in Iringa is surprisingly limited. Diets contain high levels of maize and other carbohydrate-rich staples such as rice, millet, cassava, sweet and round potatoes, and low levels of animal-sourced foods, fruits and vegetables (Ministry of Health et al., 2016).

Table 5.1. Estimated area (ha) under major food and cash crops in Iringa region.

(a) Estimated area (ha) under major food crops

Crop	2009/10	2010/11	2011/12	Yearly Average	Percent
Maize	247,363	232,105	255,333	244,933.7	70.8
Beans	53,831	52,897	60,438	55,722.0	16.1
Paddy rice	12,192	13,636	16,201	14,009.7	4.0
Irish potatoes	6,491	6,479	7,632	6,867	2.0
Wheat	4,897	6,204	6,295	5,798.7	1.7
Sorghum	11,052	3,109	5,753	6,638.0	1.9
Sweet potatoes	2,013	2,088	2,092	2,064.3	0.6
Cassava	1,473	942	1,371	1262.0	0.4
Millet	674	470	306	483.3	0.1
Sunflower	8,481	7,930	8,664	8358.3	2.4
Regional Total	348,467	325,860	364,085	346,137.3	

(b) Estimated Area (ha) under major cash crops

Sunflower	39,499	34,367	45,918	39,927.8	70.2
Tea	5,997	5,756	6,065	5,939.5	10.4
Tomatoes	5,065	5,207	4,402	4,891.3	8.6
Groundnuts	1,909	2,486	2,637	2,344	4.1
Tobacco	1,739	2,240	2,466	2,148.3	3.8
Onion	677	1,231	1,376	1,094.7	1.9
Coffee	398	405	354	385.7	0.7
Pyrethrum	137	100	178	138.3	0.2
Regional Total	55,421	51,792	63,396	56,869.6	

Source: Iringa region, compiled data from districts councils (agriculture departments), 2013 (NBS, 2013)

5.2.2. Data collection

The study involved both macro secondary data and own micro primary data. The data on dietary requirements, diet and food composition, bio-availability and bioconversion, demographics, and crop production were derived from secondary sources as further explained in the next sections. The data on crop and livestock production were partly derived from own data sources collected during household interviews aimed at characterisation of chicken production systems, feed assessment and performance evaluation in Iringa region carried out between 2018 and 2020 by the first author (Wilson et al., 2023; Wilson et al., 2022).

Crop production

Production data of most food crops were obtained from surveys and routine data from the Iringa regional social economic profile (NBS, 2013), and from the Tanzania Annual Agriculture Sample Survey 2019/20 (NBS, 2021). In addition, National dietary survey data (NNS, 2019) were matched with the UNComtrade and the FAOstat databases to estimate the quantity of food produced within the country, for each food item consumed in Tanzania. Average actual yield (Ya) and water limited potential yield (Yw) per crop were extracted from secondary data to calculate the amount of land used for the target production of maize, rice, wheat, sorghum and millet (GYGA, 2022), Irish potato (Shaaban and Kisetu, 2014; Waarts et al., 2016), sweet potato (Ngailo et al., 2019), cassava (Senkoro et al., 2018), and sunflower (CIAT and CARE, 2019; NBS, 2013) (Table 5.2). The soybean yield was based on the average yield of rainfed common bean in the country (GYGA, 2022). In practice, it is not realistic to reach water limited potential yield by 100%, for instance, because producing the highest yields may have too high economic costs, whereas also weather variability may lead to interannual fluctuations that are difficult to manage. Therefore, we assumed the attainable yield (Yt), defined as the yield that can be achieved by farmers using the best farm management practices i.e. using quality inputs, with timely sowing under average climatic conditions, and given the ratios of input/output prices (Singh et al., 2015; van der Linden et al., 2018; Van Ittersum et al., 2013). The attainable yield in this study was assumed to be 80% of water limited potential yield (Yt= 80%Yw), and the yield gap (Yg= Yt-Ya) is the difference between attainable and actual yield (Singh et al., 2015; van der Linden et al., 2018; Van Ittersum et al., 2013). All defined yield levels plus the defined yield gap are calculated for the crops that supply food for the diets in Tanzania and the results of these calculations are presented in Table 5.2.

Table 5.2. Actual (Ya), water limited potential (Yw), attainable yield (Yt) and yield gap (Yg =Yt-Ya) of the food crops produced in the Iringa region

Crop type	Yield category	Zone 1: lowland (t/ha)	Zone 2: low midland (t/ha)	Zone 3: Mid-lowland (t/ha)	Zone 4: Mid-highland (t/ha)	Zone 5: Highland (t/ha)	Average yield (t/ha)	Reference
Maize	Actual Yield (Ya)	1.5	1.0	1.2	1.6	1.9	1.4	(GYGA, 2022)
	Potential Yield (Yw)	8.0	6.0	12.8	4.4	15.8	9.4	
	Attainable yield (Yt)	6.4	4.8	10.2	3.5	12.6	7.5	
	Yield Gap (Yg)	4.9	3.8	9.0	1.9	10.7	6.1	
Rice	Actual Yield (Ya)	2.8	1.8	2.8			2.5	(GYGA, 2022)
	Potential Yield (Yw)	8.3	8.5	7.1			8.0	
	Attainable yield (Yt)	6.6	6.8	5.7			6.4	
	Yield Gap (Yg)	3.8	5.0	2.9			3.9	
Wheat	Actual Yield (Ya)	1.1	1.4		1.3	1.8	1.4	(GYGA, 2022)
	Potential Yield (Yw)	2.3	3.2		4.8	6.2	4.1	
	Attainable yield (Yt)	1.8	2.6	0.0	3.8	5.0	3.3	
	Yield Gap (Yg)	0.7	1.2	0.0	2.5	3.2	1.9	
Sorghum	Actual Yield (Ya)	0.8	0.7	1.0			0.8	(GYGA, 2022)
	Potential Yield (Yw)	2.8	3.2	3.9			3.3	
	Attainable yield (Yt)	2.2	2.6	3.1			2.6	
	Yield Gap (Yg)	1.4	1.9	2.1			1.8	
Millet	Actual Yield (Ya)						1.0	(GYGA, 2022)
	Potential Yield (Yw)						2.7	
	Attainable yield (Yt)						2.2	
	Yield Gap (Yg)						1.2	
Common bean	Actual Yield (Ya)	0.7	0.5	0.6	0.6	0.9	0.7	(GYGA, 2022)
	Potential Yield (Yw)	3.2	3.1	3.0	2.6	3.4	3.1	
	Attainable yield (Yt)	2.6	2.5	2.4	2.1	2.7	2.4	
	Yield Gap (Yg)	1.9	2.0	1.8	1.5	1.8	1.8	

Sunflower	Actual Yield (Ya)						0.6	(NBS, 2013)
	Potential Yield (Yw)						4.8	
	Attainable yield (Yt)						3.8	
	Yield Gap (Yg)						3.2	
Irish potato	Actual Yield (Ya)						2.5	(Shaaban and Kisetu, 2014; Waarts et al., 2016)
	Potential Yield (Yw)						25.0	
	Attainable yield (Yt)						20.0	
	Yield Gap (Yg)						17.5	
Cassava	Actual Yield (Ya)						6.2	(Senkoro et al., 2018)
	Potential Yield (Yw)						32.7	
	Attainable yield (Yt)						26.2	
	Yield Gap (Yg)						20.0	
Sweet potato	Actual Yield (Ya)						5.3	(Ngailo et al., 2019)
	Potential Yield (Yw)						21.7	
	Attainable yield (Yt)						17.4	
	Yield Gap (Yg)						12.1	
Tomato	Actual Yield (Ya)						2.2	(GYGA, 2022)
	Potential Yield (Yw)						27.5	
	Attainable yield (Yt)						22.0	
	Yield Gap (Yg)						19.8	

Dietary Requirements

The dietary requirements data (Table 5.3) were compared with dietary intake data to assess the adequacy of intakes of different demographic groups. We used the Estimated Average Requirement (EAR) for a specific group (IOM, 1998). We selected a Harmonized Nutrient Reference Values approach as proposed by Allen et al. (2020) to demonstrate how current recommendations from different sources can be used to adjust these core nutrient reference values (NRV), and to generate an EAR that can be applied on a global scale to assessing intakes across populations. The use of these NRVs across regions and countries allows a global comparison of nutrient adequacies and inadequacies. The NRVs were selected from standards set by the European Food Safety Authority (EFSA), which is the most recent and scientific basis for formulating different requirements, and by the Institute of Medicine (IOM) (for the United States and Canada) (IOM, 2001), where we prioritised the most recently published study (Allen et al., 2020).

When individual dietary data are not available, it is recommended to use Adult Equivalent (AE) to assume that food is allocated within households according to members' proportional energy and nutrient requirements relative to an average adult (Monteiro et al., 2015). To determine the AE reference scale, we estimated the mean energy and nutrient requirements for men and women from 25 to 50 years of age, in East African countries (FAO and WHO, 2004) (Table 5.3 and Table C1). In the demographic information (NBS, 2012; NNS, 2019), the population distribution is reported as male, female and children ≤17 years old. In this regard, all the children ≤17 years old were considered as 0.78 AE. Women and men had an AE of 0.82 and 1.0, respectively.

Diet and food composition

We obtained the data on diet and food composition from the National Sample Survey of Consumption Expenditure in Tanzania (NBS, 2018). We selected the 14 food crops with the highest per capita supply from the National Food Balance Sheets Report 2014-2017 (NBS, 2019). Food supply during the reference period is the total quantity of foodstuffs produced in the country plus the total quantity imported and adjusted to any change in stock that may have occurred since the beginning of the reference period (FAO, 2017). We calculated the daily availability of each food product according to per capita supply and assumed this to be the quantity consumed. We assessed the nutritional value of these food crops and additionally of eggs and chicken meat to develop scenarios with adding two different animal source foods to the current diet to fulfil daily micronutrient requirements (Table 5.3). The energy content (kcal), protein (g) and the micronutrients of Iron (mg), Zinc (mg), Calcium (mg), Vitamin B12 (µg) and Vitamin A (µg) in daily diets were collected (Table 5.4) to allow comparison with daily nutritional requirements (Table 5.3), because these nutrients are important in children's and adults' diets and deficiencies of these nutrients have been reported in Tanzania (Mrimi et al., 2022; NNS, 2019). The USDA FoodData Central has been used as the main source to provide nutrient composition data in different food items (McKillop et al., 2021).

Bioavailability and bioconversion

Human nutrient uptake from a plant-based diet greatly depends on the bio-availability of nutrients (Hurrell, 2003; Sandberg, 2002) and has consequences for nutrient requirements of the diet (Hambidge et al., 2010). Despite the high iron and zinc content of legumes and some vegetables, the bioavailability of these nutrients is low due to the high content of anti-nutritional components that can drastically limit the uptake of these nutrients (Hurrell, 2003; Sandberg, 2002). In plant-based foods consumed by young children, iron was assumed to have a 5% bioavailability (Nair and Iyengar, 2009). In agreement with the International Zinc Nutrition Consultative Group (iZiNCG), the estimated average requirements (EAR) for zinc was also adjusted to 15% bioavailability for unrefined cereals based diets (Brown et al., 2004). Therefore, for iron 5% bioavailability and for zinc 15% bioavailability have been considered in the nutrient supply by the plant-based diets. For animal sourced food, iron and zinc are assumed to be fully bioavailable.

For calcium bioavailability in plant-based food we considered medium levels of dialysable (11-18%) calcium which has been found in young and mature cooked soybean and some leafy vegetables, both of which had low levels of oxalate and medium levels of phytate (290–400 mg/100 g) (Kamchan et al., 2004). For vitamin A (retinol) many precursors such as β-carotene can be found in plant-based diets. These precursors need to be converted to retinol to be used by the human body. The vitamin A equivalency ratio for β-carotene to vitamin A is currently estimated as 12:1, by weight (12 μg β-carotene is equal to 1 μg retinol), for plant sources of β-carotene in a mixed diet. The ratio is based on ∼17% absorption of β-carotene from a mixed diet (6 μg plant β-carotene = 1 μg pure β-carotene) and a conversion ratio to vitamin A of 2:1 (2 μg β-carotene = 1 μg retinol) (IOM, 2001). For animal-based products conversion is not needed as they contain retinol. Therefore, the total vitamin A has been calculated as retinol activity equivalent (RAE) by the sum of retinol and 1/12 β-carotene (FAO, 2012) in plant-based diets. For our study we aimed to meet the minimum dietary requirements for energy, protein, iron, zinc, calcium, vitamin B12 and vitamin A.

Table 5.3. Daily nutritional requirements for men and women (form Allen et al, 2020)

Daily recommendation	Energy (kcal)	Protein (gr/kg BW/day)	Iron (mg)*	Zinc (mg)$	Calcium (mg)	Vitamin B12 (μg)	Vitamin A (μg,RAE) #
Source	EFSA	EFSA	EFSA	EFSA	EFSA	IOM	EFSA
Men (age 25-50)	2500	0.66**	6-22.4	6.2-12.7	750-860	2	490-570
Women (age 25-50)	2000						

**Ranges between 59-114 g/day or about 12 to 20% of total energy intake for both sexes (EFSA, 2017).

*Assumed high absorption (6-7), moderate absorption (9.6-11.2) and low absorption (19.2-22.4)

$ Assumed highly refined (6.2-7.5) semi-refined (7.6-9.9) and unrefined (10.2-12.7)

Vitamin A is measured in Retinol Activity Equivalents (RAE) to account for the different bioactivities of retinol and provitamin A carotenoids (IOM, 2001).

Demography

The demographic data were extracted from the national census 2022, national sample census of agriculture 2019/2020, and the Iringa Region Socio-economic profile 2012 (NBS, 2013, 2021, 2022). In 2022 the total population size of Iringa was 1,192,728 with 618,415 women and 574,313 men (NBS, 2022). The Population and Housing Census reported a population of 455,631 in the group of 0-17 years old and 485,607 in the adult ≥17-group, the latter divided into 261,757 women and 223,850 men. We assumed that this proportional distribution over age class was similar in 2022. The average household size was 4.2 in 2012 (NBS, 2012) and we assume it was the same in 2022.

5.2.3. Scenarios

The study used both primary and secondary data in developing baseline and improvement scenarios in order to provide the diets for the population of Iringa region. We calculated the energy and micronutrient content in different diets and translated these data to the crop and chicken production needed to reach those diets and calculated their associated land use requirements. We first calculated energy and micronutrient composition of the current and improved diets (Table 5.4). Then we calculated land requirements for current diets (Table 5.5) in scenario 1a,b,c,d (Figure 5.1). Next, we targeted a diet adequate in micronutrients by adding one egg and 100g chicken meat per day to the diets. We calculated then feed needs and land use for the chicken produce only, in scenarios 2a,b,c,d. Finally we added the land requirements for the food production plus for feed production in scenarios 3a,b,c,d which represent micronutrient adequate diets, which we then compared to land availability and current land use (Table 5.7).

	Scenario	Ya	Yt	CYa	CYt	Pop 1	Pop 2
F	1a	x				x	
O	1b	x					x
O	1c		x			x	
D	1d		x				x
F	2a	x		x		x	
E	2b	x		x			x
E	2c		x		x	x	
D	2d		x		x		x
B	3a	1a + 2a					
O	3b	1b + 2b					
T	3c	1c + 2c					
H	3d	1d + 2d					

Figure 5.1. Characteristics of the scenarios used in this study. Ya = actual yield for crops, Yt = attainable crop yield, CYa = actual chicken yield, CYt = attainable chicken yield, Pop1 = current population, Pop2 = future double population.

For data analysis, we used Microsoft Excel and Statistical Package for Social Sciences (SPSS version 29) for our calculations. In the next sections the scenarios are further explained in detail.

Scenarios 1a,b,c,d : Current (largely vegetarian) diet

For the first scenario (1a), we used the Tanzania National Food Balance Sheets as a reference for the current diet. It is reported in the Food Balance Sheet that the daily supply of calories per person was 2,259 kcal in 2017, while the contribution of plant-based food items to the total per capita dietary energy supply was 2128 kcal (NBS and OCGSZ, 2019).

We have chosen 14 food products according to their ranking of per capita supply in Tanzania, and together they contribute 1800 kcal of dietary energy supply (DES). The animal products, sugar and sweets, spices and alcoholic beverages were excluded from this list as the contributions of each to the diet are small. These 14 food products all fall within the plant-based category and include sub-categories of cereal and grains, starchy roots, pulses, vegetable oils, vegetables, and fruits. Within each sub-category, we have chosen the most important products with the highest per capita supply. Maize, rice, wheat, sorghum, and millet have been chosen as the main and most consumed grains. We calculated the energy and micronutrient contents for each per 100 grams of grain. We chose to consider the energy and micronutrients from maize flour instead of those of maize grain because of high consumption of maize flour in the country (Aaron et al., 2017; Teachout et al., 2021). Maize is the main staple in Tanzania, contributing about 59% of the caloric supply, with a per capita consumption of 72 kg per year, followed by rice (21%) and wheat (12%) (NBS and OCGSZ, 2019). For the vegetable oil category, we considered sunflower oil and imported palm oil because of their considerable participation in daily energy intake, but we excluded them from the micronutrient calculation. The Tanzanian Food Balance Sheet does not provide detailed data for the vegetable category; therefore, we have chosen tomatoes and onions as representatives for vegetables. In the fruits category, we selected three: oranges, bananas, and plantains.

We used USDA, FoodData Central as a reference for nutritional composition for each one of these 14 products. We estimated a daily consumption proportional to the reported data from the Food Balance Sheet 2016 (NBS, 2019). The daily dietary energy and micronutrient intake from each crop were calculated according to the daily consumptions of the product times the nutrient concentration (Table 5.4). Per capita daily consumption of these 14 crops were based on National Food Balance Sheets Report 2014-2017 (NBS, 2019) to calculate an estimation about the daily consumption of these food products per AE. For this purpose, we calculated the target production through multiplying the recommended daily intake of different food items per capita to the population of Iringa and estimated an average amount of production for each crop. We developed the following equation to calculate the amount of land required for food production for the target production.

$$L = \frac{Spc}{Y} \quad (1)$$

$$Spc = \frac{C.P}{1000} \quad (2)$$

Where (L) is the required land area in hectares, (Spc) is the total supply in tons and (Y) is the yield per hectare in tons (Table 5.2). The information and data on actual and attainable yield for each crop was extracted from the Yield Gap Atlas (GYGA, 2023). For crops with missing data, we used the average yields from other data sources and/or assumed yields from comparable crops (de Jager et al., 2022). To calculate the target production, we multiplied per capita supply in kg (C) with the population of the region (P), divided by 1000 to get the production in tons.

Considering the anticipated increase in human population by 2050 (i.e. a doubling), we further calculated the amount of land (Table 5.5) required to feed the current and twice the current population of Iringa region while considering the actual (scenario1a, 1b) and attainable yield (scenario 1c, 1d).

Scenario 2: Land use calculations for chicken production

For promotion of egg consumption, the Poultry Association of Tanzania (PAT) conducts an "egg week day" every year to coincide with the annual Poultry Expo. This "egg week day "implies that during this one week, eggs are distributed to several schools. Eggs are contributed by poultry stakeholders. The motto is "An egg per child every day" (Ringo and Lekule, 2020). This is promoted by the Tanzania Layer Farmers Association (TALFA) and is expected to create impact on egg consumption. Introduction of eggs as complementary feeding to diets of infants elsewhere (in Somalia and Ecuador) resulted in high compliance, low attrition, and infant feeding policy change (Iannotti et al., 2017). Use of social marketing techniques, like those in this initiative, could be key for scaling up food-based interventions in Tanzania and beyond (Ringo and Lekule, 2020). Therefore, for our second scenario, we analysed, the direct and indirect impact of adding one egg and 100 g of chicken meat per person per day to an individual's diet in terms of micronutrient intake. The nutritional composition of an egg (cooked) and chicken meat (cooked) was derived from USDA, FoodData Central (Table 5.4).

We calculated the chicken feed requirements to produce an adequate amount of eggs and meat for the target population in Iringa. The actual daily feed intake was 125 g/day for improved dual-purpose chicken and the actual chicken production level (CYa) was 1800 g body weight of chicken, producing 4.83 eggs per week weighing 50 g each (Wilson et al., 2023). In the next step, we calculated the amount of land (Table 5.5) required to produce sufficient feed for these chickens to provide food for the current (Pop1) and the future double size of the population in the region (Pop2), while considering the actual crop yields (Ya) as presented in Table 5.2.

For the attainable egg production (CYt), we considered the weekly lay percentage of 80% (5.6 eggs per week) of the potential production of 7 eggs per week and we compared this with the actual production (CYa) explained in the previous section (van der Linden et al., 2018; Wilson et al., 2023). For attainable body weight (CYt) we assumed the average attainable body weight of improved crossbred chickens i.e. 2,175 g at 20 weeks based on the recent research findings on performance evaluation of Kuroiler and Sasso crossbred chickens in Tanzania (Guni et al., 2021), and compared this with actual body weight (CYa) of 1800 g for current dual purpose crossbred chicken. We calculated the amount of land required to feed attainable production of chicken (CYt egg and meat) using attainable crop yields (Yt, Table 5.2) for the current (Pop1) and the future double population (Pop2) size (Table 5.6)

To assess the chicken feed needs for each scenario, we formulated chicken feeds using the most common feed ingredients used in Iringa region (Wilson et al, 2023) by using the FeedCalculator mobile app which calculates the least cost ration that meets the nutritional composition requirements

(FeedCalculator, 2022). The feed ingredients include maize bran, sunflower seedcake, fish meal, limestone, bone meal, di-calcium phosphate, premixes, salt, sorghum, and soybean meal. Other ingredients include maize meal, rice polishings, blood meal, lysine, and methionine. A standard diet for laying hens was formulated for a flock with about 100 laying chickens, constituting 16.5% CP and 2600 kcal/kg Metabolisable Energy (Figure C2). Fish meal was excluded in the ration to reduce the costs of production and ensuring maximum utilisation of the plant proteins produced within the region. Land requirement for feed production was computed for maize and soybean, the two main components of the poultry feed. We have also included sunflower since the seed cake was often used by farmers as a source of protein (Wilson et al., 2023), and it is available because of its production of edible oil. We calculated the required area to produce adequate feed for chickens (Table 5.6) based on yield data of the mentioned crops (Table 5.2). In table 5.7 we compare all scenario outcomes with actual land use and land availability.

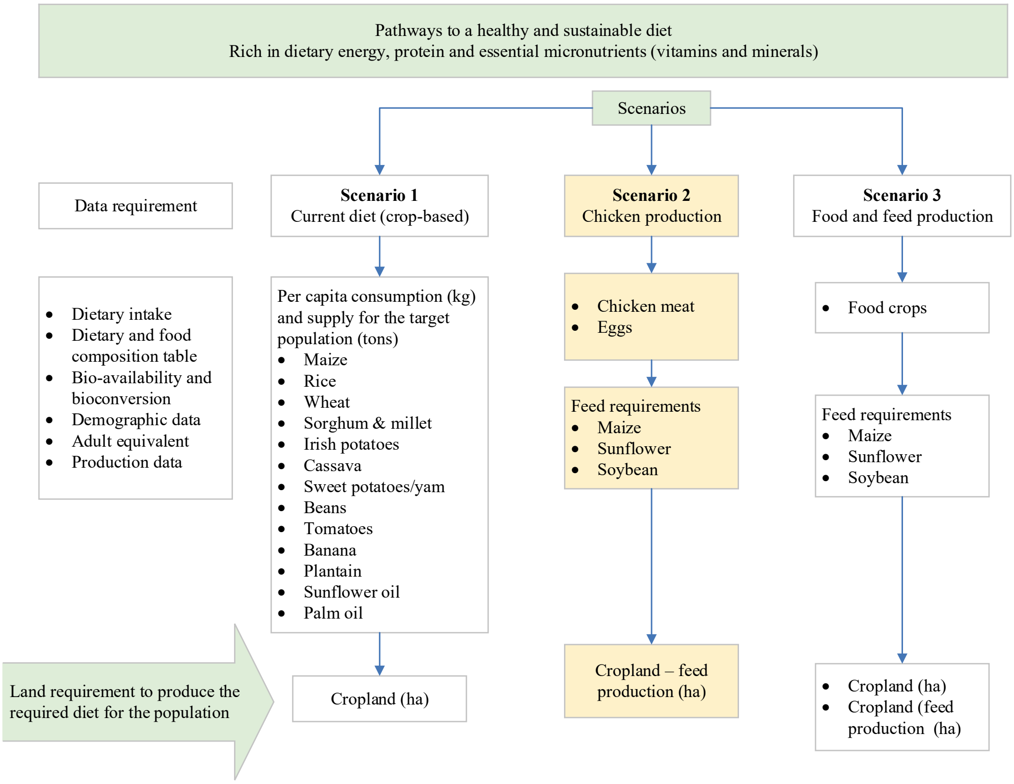


Figure 5.2. An analytical framework on different scenarios for sustainable diets, land requirement in the Iringa region.

5.3. Results

5.3.1. Scenario 1a: crop-based diet for the current and future population

Table 5.4 represents the actual daily diet composition of the population of Iringa based on the available amount of food items per year, month and day derived from Food Balance Sheet (FAO) and their nutritious value derived from USDA, FoodData Central. With the actual crop yield (Ya) in scenario 1a, a total land area of 192,125 ha (Table 5.5) is needed to produce the minimum daily energy value of 1812 kcal per adult equivalent (Table 5.4) for the current population of 1,192,728 people in Iringa region. The estimated land is for production of the 14 food crops in the region without considering food losses and waste. This total land need would be equivalent to an average farm size of 0.68 ha per household, considering a household size of 4.2 Adult Equivalent (NBS, 2013) and the actual yield (Ya) per crop (Table 5.2). When considering the attainable (Yt) yields, the land requirement to produce sufficient food for the current population of Iringa decreases to 53,821 ha equivalent to 0.19 ha per household. Considering doubling the population of Iringa by 2050 (2,385,456 people), with the actual yield, a total land of 384,249 ha will be required to produce 1812 kcal per adult equivalent for the 14 food crops produced in the region. The total land is equivalent to farm size of 1.35 ha per household. Considering the attainable yield (Yt), less land (107,642 ha) will be required to produce the food crops sufficient for the double population size (Pop2), equivalent to 0.38 ha per household.

Currently, food crops occupy 346,137 ha, which is about 20% of the total arable land suitable for agriculture (1,556,465 ha) (NBS, 2013). Large yield gaps were found in all food crops produced in the region (Figure 1, Table 2). For the vegetarian diet all food production can be accommodated in currently cultivated land for food crops (Scenarios 1a, 1c, 1d). These scenarios free up land currently used for food production (154,012, 292,316 and 238,495 ha for scenarios 1a, 1c and 1d, respectively) for producing cash crops or surplus food crops for export (Table 5.7). When the anticipated doubling of the population by 2050 will indeed occur, with the actual yield (Ya), an additional 38,157 ha need to be cultivated on top of the current land used for food crops with no export of food crops (Scenario 1b). In this scenario, food crops can replace cattle grazing or cash crop in the current land used for agriculture but opening 38,157 ha of land in area suitable for cultivation is also possible and prevents competition for land in currently cultivated area.

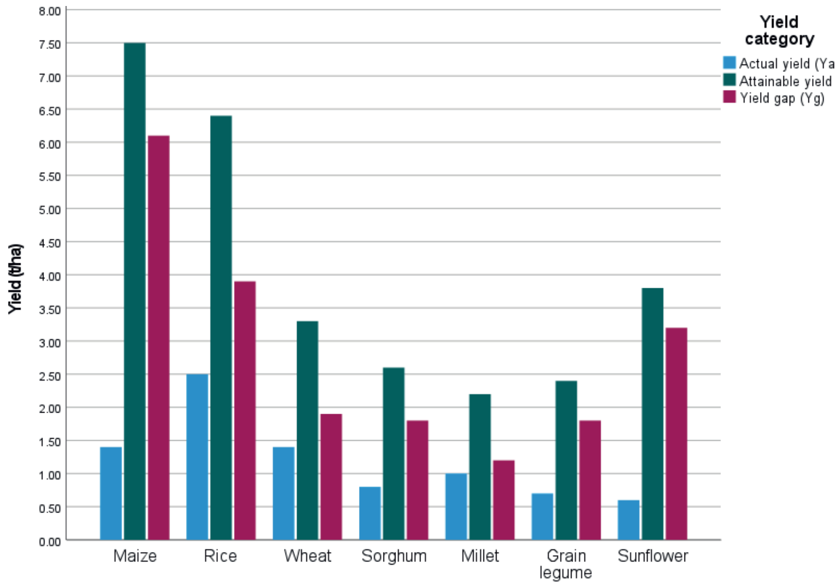
Table 5.4. Per capita daily nutrient supply based on food balance sheet & USDA FoodData Central

	Annual per capita supply kg	Per month kg	Per day gr	Energy kcal for per capita	Protein gr	Iron mg	Zinc mg	Calcium mg	Vitamin B12 µg	Vitamin A µg RAE
Maize and product	72	6	200	722	13.8	4.8	3.4	14	0	22
Rice	35	2.92	97	126	2.6	1.2	0.5	9.7	0	0
Wheat	16	1.42	47	157	4.5	1.7	1.4	15.6	0	0
Sorghum+ millet	10	0.83	28	105	3.1	0.8	0.5	2.2	0	0
Potatoes	23	1.92	64	61	1.7	0.6	0.2	11.5	0	1
Cassava	47	3.92	131	209	1.7	0.3	0.4	20.9	0	12
Sweet potato/ yam	31	2.58	86	78	1.7	0.6	0.3	32.7	0	0
Beans	27	2.25	75	107	6.8	1.5	0.7	34.5	0	0
Tomatoes	10	0.83	28	5	2.5	0.1	0.2	2.8	0	12
Oranges	9	0.75	25	12	0.2	0	0	10.8	0	3
Banana	26	2.17	72	64	0.7	0.1	0.1	3.6	0	2
Plantain	10	0.83	28	43	0.4	0.1	0.1	0.8	0	13
Sunflower oil	2	0.17	6	49	0	0	0	0	0	0
Palm oil	3	0.25	8	74	0	0	0	0	0	0
Total (a)				1812	40	12	7.6	159.1	0	64
Egg (50g)	18	1.5	50	73.5	6.2	0.84	0.62	24	0.51	90
100 g meat	36.5	3.04	100	158	32.1	0.49	0.96	6	0.2	0
Total (b)				231.5	38.3	1.325	1.58	30	0.71	90
Total (a + b)				2043	78	13.2	9.1	189.1	0.71	154
Requirements				2000-2500	59-114	6-22.4	6.2-12.7	750-860	2	490-570
% of the minimum requirements met				100%	100%	100%	100%	25%	36%	31%

Table 5.5. Required land for plant-based diet production for the current and future population of Iringa

Food crop		Scenario 1(a): actual yield (Ya), actual population		Scenario 1(b): actual yield (Ya), double population		Scenario 1(c): attainable yield (Yt), actual population		Scenario 1(d): attainable yield (Yt), double population,	
Food crop	Per capita consumption (kg)	Total food requirement (tons)	Required land (ha)	Total food requirement (tons)	Required land (ha)	Total food requirement (tons)	Required land (ha)	Total food requirement (tons)	Required land (ha)
Maize	72	85876	61,340	171753	122,681	85,876	11,450	171,753	22,900
Rice	35	41745	16,698	83491	33,396	41,745	6,523	83,491	13,045
Wheat	16	19084	13,631	38167	27,262	19,084	5,783	38,167	11,566
Sorghum+ millet	10	11927	11,927	23855	23,855	11,927	8,519	23,855	17,039
Potatoes	23	27433	10,973	54865	21,946	27,433	1,372	54,865	2,743
Cassava	47	56058	9,042	112116	18,083	56,058	2,644	112,116	5,289
Sweet potato/ yam	31	36975	6,976	73949	13,953	36,975	2,175	73,949	4,350
Beans	27	32204	46,005	64407	92,010	32,204	8,051	64,407	16,102
Tomatoes & onions	10	11927	5,421	23855	10,843	11,927	542	23,855	1,084
Banana	26	31011	4,430	62022	8,860	31,011	4,430	62,022	8,860
Plantain	10	11927	1,704	23855	3,408	11,927	1,704	23,855	3,408
Sunflower oil	2	2385.5	3,976	4770.9	7,952	2,385	628	4,771	1,256
Palm oil	3	3578.2	-	7156.4	-	3,578	-	7,156	
Total land (ha)			192,125		384,249		53,821		107,642

(a)



b)

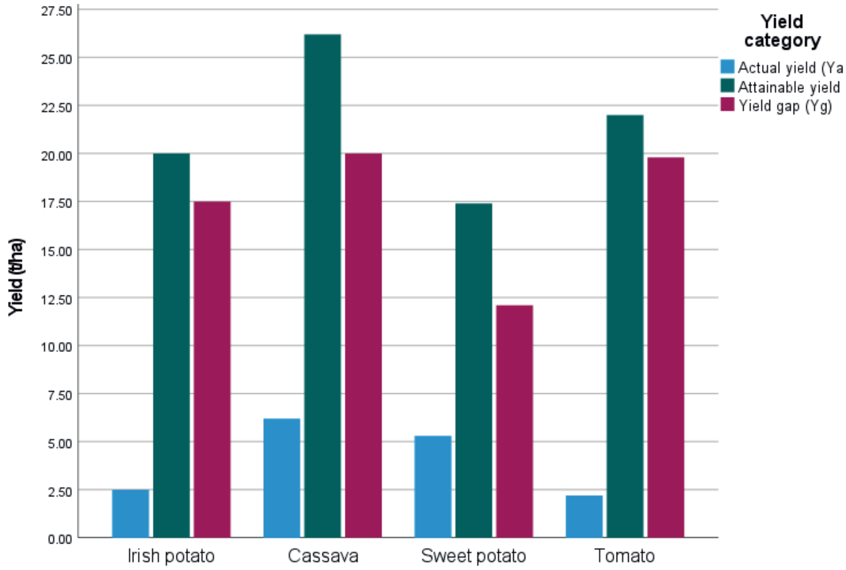


Figure 5.2. Actual, water limited potential grain yield and yield gap for different cereals, grain legume and sunflower (a), roots, tubers and tomato (b).

5.3.2. Scenario 2: Poultry production

The results from scenario 2 show that adding 1 egg per day in the diet can build up the amount of 77.5 kcal energy, 6.3 g protein, 0.6 mg of Iron, 0.5 mg of zinc, 25 mg of calcium, 0,5 mg of vitamin B12 and 74,5 mg vitamin A in an individual's diet (Table 5.4). Consumption of 100 g of meat per day build-up 158 kcal energy, 32.1 g protein, 0.49 mg iron, 0.9 mg zinc, 6 mg calcium and 0.2 mg vitamin B12. Micronutrients from animal source feeds are fully bioavailable (Table 5.4). The added animal-sourced foods contributed to closing the micronutrient gap but there is still large deficiency for vitamin A and B12, and also calcium is not provided in sufficient quantities.

Based on the actual chicken productivity (CYa) in Iringa (1.8 kg BW/20 weeks, 4.8 eggs/chicken/week), a total of 9,302,259 dual-purpose chickens are needed to produce 43,535 t of meat and 333,765,052 eggs for the entire population of the region per year (Table 5.6). These chickens require an amount of 424,416 t of feed per year based on the average daily feed intake of 125 g/chicken. When considering the actual yield of maize, soybean and sunflower (Ya Table 5.2), the total land required to produce this chicken feed is 329,701 ha (scenario 2a). This can entirely be produced in area suitable but currently not used for agriculture (980,573 ha) (Table 5.7), thus keeping current land use for agricultural production unchanged. When it needs to be produced in currently cultivated agricultural land, almost all land used for food production will need to be used for feed production, while the land currently allocated for cash crop production and grazing will be maintained. This implies food-feed competition.

When population will double (Pop2) and crop (Ya) and chicken yields (CYa) remain similar to actual yields (Scenario 2b), the flock size will have to double to produce sufficient chicken meat and eggs. The total amount of land needed for chicken feed will be 659,402 ha. This implies that, all land used for agricultural production plus additional 83,510 will be needed just to produce feed. In that case neither food nor cash crops or grazing will be possible. Fortunately, there is still suitable land not yet used for agriculture (980,573 ha) and the entire feed production could fit there, without compromising current food and cash crop production and grazing. When current food production would be used as chicken feed, then an additional 313,265 ha of suitable land not yet used for agriculture needs to be cultivated, maintaining current land use for cash crop production and grazing. However, this would imply food-feed competition.

When considering the attainable yields of maize, soybean and sunflower and the attainable yield of chickens (scenario 2c, 2d), the flock size required to produce sufficient meat and eggs for the current population (Pop1) decreases to 7,695,591 chickens. These chickens can produce 43,535 t of meat and 320,136,571 eggs per year. Furthermore, when both crops (Yt) and poultry (Cyt) would reach attainable yields, even with doubling of population size (Pop2), the current agricultural land will be enough to produce chicken feed (scenario 2c, 2d), without compromising food and cash crop production. It can partly replace grazing or other activities (172,866 ha). When current land use needs to be maintained it can easily fit in the large available area of suitable land not yet cultivated (980,573 ha)

Table 5.6. Chicken meat and eggs requirements and land requirements to produce these with actual chicken (CYa) and crop yields (Ya), attainable chicken (CYt) and crop yields (Yt) and current (Pop1) and double (Pop2) population sizes.

	Scenario 2(a): actual yield (Ya & CYa), actual population	Scenario 2(b): actual yield (Ya & CYa), double population	Scenario 2(c): attainable yield (Yt & CYt)), actual population	Scenario 2(d): attainable yield (Yt & CYt), double population
Per Capita kg meat requirement (100 g/day)	37	37	37	37
Meat requirement for the target population/year (t)	43,535	87,069	43,535	87,069
Number of chickens to be slaughtered per year (1.8 and 2.18 kg BW)	9,302,259	18,604,518	7,695,591	15,391,181
Estimated egg production per year (0.69 and 0.8 eggs/day)	333,765,052	667,530,104	320,136,571	640,273,143
Feed tons	424,416	848,831	351,111	702,223
Maize - 63.4% of the diet (t)	269,079	538,159	222,605	445,209
Soybean - 20.6% of the diet (t)	87,430	174,859	72,329	144,658
Sunflower - 2.8% of the diet (t)	7,561	15,122	9,866	19,732
Area for maize (ha)	192,200	384,399	29,681	59,361
Area for soy (ha)	124,899	249,799	18,082	36,164
Area for sunflower (ha)	12,602	25,204	2,596	5,804
Area for chickens m^2	18,604,518	37,209,036	15,391,181	30,782,363
Area for chickens (ha)	1,860	3,721	1,539	3,078
Cultivated area (needed for feed)	329,701	659,402	50,359	101,329
Total area ha (for feed and housing)	331,561	663,123	51,898	104,408

Table 5.7. Land requirements based on the outcomes of each of the scenarios fitted in the current land for food crops, total agricultural land, total land suitable for agriculture and total available land (ha)

		Vegetarian diet land requirements (ha)				Poultry Feed land requirements (ha)				Land requirements for diet with poultry products (ha)			
		YaPop1	YaPop2	YtPop1	YtPop2	YaCYaPop1	YaCYaPop2	YtCYtPop1	YtCYtPop2	YaCYaPop1	YaCYaPop2	YtCYtPop1	YtCYtPop2
	Scenario	1a	1b	1c	1d	2a	2b	2c	2d	1a + 2a = 3a	1b +2b = 3b	1c + 2c = 3c	1d + 2d = 3d
From Table 4	Land needs for food	192,125	384,294	53,821	107,642					192,125	384,294	53,821	107,642
From Table 5	Land needs for feed					329,701	659,402	50,359	101,329	329,701	659,402	50,359	101,329
	Total land requirements									521,826	1,043,696	104,180	208,971
Current lan use													
Total area	3,303,280												
Total area non suitable for agriculture	1,746,815												
Total area suitable for agriculture	1,556,465												
Total area suitable but not used for agriculture	980,573		38,157				313,265			175,689	697,559		
Total area used for agriculture	575,892	575,892	575,892	575,892	575,892	575,892	575,892	575,892	575,892	575,892	575,892	575,892	575,892
Total land used for food crops	346,137	154,012	384,294	292,316	238,495	346,137	346,137	346,137	346,137	346,137	346,137	346,137	346,137
Total land used for cash crops	56,869	56,869	56,869	56,869	56,869	56,869	56,869	56,869	56,869	56,869	56,869	56,869	56,869
Other activities eg. grazing	172,886	172,886	172,886	172,886	172,886	172,886	172,886	172,886	172,886	172,886		172,886	172,886

Ya = actual yield for crops, Yt = attainable crop yield, CYa = actual yield for poultry, Cyt = attainable chicken yield, Pop1 = current population, Pop2 = future double population

In scenario 3a food will be produced in 192,125 ha and the freed-up land of (154,012 ha) can be used for feed production. An additional 175,865 ha is needed for feed production in the suitable land that is currently not used for agriculture. This amount of land is available.

Scenario 3b is most challenging, as not only additional land is needed for food production (38,157 ha) but even more for feed production (659,042 ha). This means that all agricultural land needs to be used and 697,559 ha of suitable land but not used for agriculture needs to be converted to crop land, when current land use is maintained.

When both crop and chicken production would reach attainable yield (Yt and CYt) and have to support the diet of the current population (scenario 3c), all food (53,821 ha) and all feed (50,359 ha) can be produced in land currently used for food production (as 292,316 ha of land is freed up compared to land used for food production under actual yields (Ya). There will even be some agricultural land freed up from food production which can be used for additional production of cash crops, maize for export and grazing.

Assuming attainable crop (Yt) and chicken CYt) production and double population size (Scenario 3d), the land freed from food production (238,495 ha) will all be needed for feed production within the land suitable for agriculture, to produce the remaining feed required. There could also an option to maintain the land for cash crops and grazing.

5.4. Discussion

The present study explored potential scenarios to provide sustainable diets to feed the population at the regional level and assess land requirements to produce sufficient food for the current and the anticipated double population size of the Iringa region by 2050 while minimizing land expansion.

5.4.1. Is there sufficient land to provide for future food needs?

The findings show that with the actual crop yield, about half of the current land used for food production is needed to produce a plant-based diet for the inhabitants of the region. The rest of the land is producing for export to other areas of Tanzania and neighbouring countries. Indeed, the Southern Highlands of Tanzania are known as the 'bread-basket' of the country, supplying food to other food-deficit regions of the country. Considering the attainable crop yield (80% of the water limited potential yield), only 16% of the current land used for food production is required to produce sufficient plant-based food for the population of Iringa and 32% for the doubled population size by 2050. There will still be 68% of current crop land available to produce for export which is still more than the 50% in the scenario with actual yield and current population. Producing food for the doubled population size with the actual crop yield, requires 38,157 ha additional to current food crop cultivated land, while considering no food export. As not all arable land is yet cultivated, this expansion is possible. Even when the same level of food production for export will be maintained, there will be enough arable land available for its cultivation.

Findings on the estimated land required for food production in the present study partly relied on the regional secondary data collected over the past decade and excluded food losses and wastes. In recent years actual yields may have increased due to better management practices and the use of improved maize varieties, but may also have decreased due to effects of climate change and more recently the high price of inputs (Shabani and Pauline, 2023). This study does not aim to provide absolute numbers. Rather, the scenarios explore differences based on a consistent data set which allows for a fair comparison. Our data excluded food waste at the level of consumers and food loss at the harvest and postharvest stage. Detailed data on these were not available, although ignoring them does lead to underestimation of land requirements in all scenarios.

5.4.2. Does a nutritious diet lead to food-feed competition for land?

The study findings show that adding one egg and consumption of 100 g of chicken meat per day may improve nutritional requirements in the individual's diet. Nevertheless, producing sufficient meat and eggs in the region requires sufficient quality feed. Considering the current population, the actual productivity of dual-purpose chicken and the actual yield of the crops used in formulating chicken feed (maize, soybean and sunflower), the current land used for food production must increase by more than two folds to produce sufficient meat and eggs. This implies that, with the actual crop yield and actual productivity of dual-purpose chickens, the amount of land needed for food and feed crop cultivation, will need an additional of 175,699 ha, which is equivalent to 31% increase in the current land used for food crop production. Considering the double population and the actual productivity of dual-purpose chicken and the actual yield of crops yield, the land used for crop production must increase more than two folds to produce sufficient food and feed. This is even without considering land currently used for livestock and cash crop production. Hence food -feed competition occurs as is also indicated at global scale by (Van Zanten et al., 2018). Assuming the attainable yield of crops and chicken, the region requires only 53,821 and 50,359 ha of land to produce sufficient food and feed, respectively, implying no further expansion of arable land. Furthermore, considering attainable yield and double population by 2050, the land needed for sufficient food and feed will be 104,180 ha, which is less than the current land used for food crop production. For a sustainable future, research recommended further agricultural intensification rather than expansion of arable land (Neumann et al., 2010). In the present study, we revealed the need for improving yield (attainable yield) to meet the dietary requirements for the anticipated double population by 2050 without further expansion of agriculture land in the region.

5.4.3. Can we meet the micronutrient requirements by adding animal-sourced food?

The micronutrients from ASF are readily available and its inclusion in the daily diet contribute to reducing malnutrition, improving growth, cognitive development and physical activities particularly for children (Leroy and Frongillo, 2007; Neumann et al., 2003). In the present study, we found that adding one egg and 100 g of chicken meat in the daily plant-based diet provide sufficient energy requirements, protein and some of the micronutrients i.e. Iron and Zinc (Table 4). Notwithstanding, adding chicken meat and egg in our scenarios could not meet the daily requirements for Calcium, Vitamin A and B12, and only slightly added the missing micronutrients. Alternatively, diets could be improved by adding sardines and fish, dairy products rich in Vitamin A, D, B1 and B2, as well as calcium, iron and phosphorous (Isaacs, 2016). The calcium rich sardines could be purchased from local market and retail shops throughout the country and its calcium supply is even higher and also more effective than from dairy products (Thilsted et al., 1997).

On the other hand, orange pale-fleshed potatoes and pro-vitamin A orange maize have been identified as possible solutions in reducing malnutrition problems in Tanzania (Kiria et al., 2010; Nkhata et al., 2020). This intervention could be an important entry point to achieve food and nutritional security at the regional level. We primarily considered chickens in our scenario analysis since it is the dominant livestock species, raised by 86% of the livestock keeping household in Tanzania (MLDF, 2019). A chicken is a unit fit for household consumption compared with ruminants. In Tanzania, chickens are owned by women who could decide on sales and consumption of chicken meat and eggs (Galiè et al., 2015; Shapa et al., 2021; Tavenner et al., 2019). Poultry products provide an enormous opportunity to improve the household nutrition as highlighted in the TLMP. The TLMP also highlights the potential of maize and soybean to improving access to adequate chicken feed, to improve the productivity of chickens to meet the increasing demand for chicken meat and eggs (Andrew et al., 2019; Nandonde et al., 2017).

5.4.4. How to reduce food-feed competition for land?

Innovations that embrace the whole food systems may improve access to diverse diet while reducing the environmental impacts and further expansion of the agricultural land (Rockström et al., 2009; Vermeulen et al., 2020). The sustainable innovations that can be applied to reduce further expansion of agricultural land include intercropping of some of the food crops produced in the region i.e. grain legumes with maize or sunflower (Mugi-Ngenga et al., 2021). This is of crucial importance given the additional land needed to produce poultry feed especially when population growth was included. By doing so, the farming household could diversify the diet by getting the dietary energy, protein and micronutrients through own production and consumption and/or purchasing food from the income generated from selling the surplus produce (de Jager et al., 2019). Furthermore, including grain legumes in the intercropping and crop rotations has significant advantage in replenishing soil fertility through biological nitrogen fixation, improving resource-use efficiency, weed, pest and disease control, and increase subsequent cereal yield (Iqbal et al., 2019; Rurangwa et al., 2018; van Vugt et al., 2018). Research in Tanzania shows that further improvement of crop productivity can be attained through the application of both organic and inorganic nutrient sources, efficient agronomic interventions i.e. soil conservation measures on steep slopes, optimizing plant density and weeding (Mugi-Ngenga et al., 2021). Our scenarios show that closing the yield gap to levels of attainable yield greatly reduced land requirements for food and feed.

Apart from the aforementioned advantages of maize-legume intercropping, including soybean has a dual advantage in providing edible cooking oil, soybean meal for chickens and other nutritious products (Martin et al., 2010; Mgeni et al., 2019; Wilson et al., 2021). Tanzania imports about 60% of edible oil and most of its soybean meal for poultry feed, partly due to low production and inefficient soybean processing facilities (Mgeni et al., 2019; Wilson et al., 2021). Considering the agroecological potential of the Iringa region (SAGCOT, 2015), there is a need for promoting soybean production and installation of efficient processing facilities to meet the increasing demand for edible oil and soy products for human consumption, and soybean meal for the rapidly growing poultry industry. Furthermore, with the increasing urbanization in the region (Africapolis, 2023) and the recent relocation of the national capital city from Dar es Salam to Dodoma (Msuya et al., 2020), the demand for ASF particularly that of chicken will increase enormously (Ngongolo and Chota, 2021), which requires efforts in improving local production.

5.4.5. Food waste and losses and use of by-products

Our study did not consider food losses in its calculations. When considering the post-harvest losses of maize i.e. 30% for example (Affognon et al., 2015; Brander et al., 2021), about 30% land increase will be required to produce sufficient food in the region. Similarly post-harvest losses in vegetables are often reported to be even higher but very dependent on how supply chains are organised and where losses are measured. For tomato 12% loss was found in the open market just before sale to final consumers, but losses before reaching those salesmen were not known (Dome and Prusty, 2017). Such losses call anyhow for initiatives to reduce the losses to prevent the need of further expansion of agricultural land. Food losses can be reduced by processing and treatment of the of food crops to increase preservation, but their effect can also be mitigated by utilizing the by-products as livestock feed. In the case of maize, the grain may be processed into maize flour and the by-product (maize bran) utilized as chicken feed. On the other hand, soybean can be processed into edible oil for human consumption, and the by-product (soybean meal) used in formulating chicken feed. In life cycle studies land allocation is divided between main and by-product for instance based on relative economic value or weight (Campos et al., 2020; Chen et al., 2010). In our study we did not go into such detail as the volumes of main and by-products were difficult to assess and losses and wastes for each component unknown. Currently, there are for instance inefficient soybean processing facilities in the country, limiting soybean utilisation as human food and animal feed (Wilson et al., 2021) but also making adequate assessment of volumes of main and by-product is difficult. For our study we could not quantify harvest losses, food waste etc. for each food item for Tanzania, and decided not to include them in our study, which means that our land requirement estimations are lower than in reality. On the other hand, we did also not account for use of a variety of by-products which will reduce land requirements allocated to the main products.

In Tanzania, most chicken farmers raise indigenous free-range chicken, particularly in rural areas (Michael et al., 2019). Most consumers in Tanzania prefer meat and eggs from the indigenous breed compared to the exotic breeds due to the perception that they taste good and are nutritious (Naggujja et al., 2020). Notwithstanding, it is challenging to meet the increasing demand for chicken meat and eggs while relying on the indigenous breed due their low productivity (Michael et al., 2019). Over the past decade, there has been increasing intensification involving the transition from keeping the low-input indigenous free-range chickens to keeping the improved dual-purpose and exotic breeds, driven by high productivity and potential for income generation (Mushi et al., 2020; Sanka et al., 2020; Wilson et al., 2023). In the present study, we calculated the land requirements to produce sufficient feed for the improved dual purpose crossbred chickens due to their potential productivity compared to the indigenous breeds. We assumed 1800 g actual body weight of a live chicken and 2,200 g attainable body weight, but this might not be the case. The dressing weight of chicken is about 75% of the live body weight. Nevertheless, in most developing countries including Tanzania, most parts of the chicken are consumed (Carron et al., 2017; Muhikambele, 2019), and therefore, the dressing percentage is higher than the reported values in the literature. A clear example on how contextual food waste and loss attributions are. We also assumed 1 kg of maize to be equivalent to 1 kg of maize flour which might hold for the whole grain maize flour. For the dehulled maize the processed flour may make up only up to 83% of the whole grain (Gwirtz and Garcia-Casal, 2014). Hence our assumption slightly underestimates land needs for supply of human food. As the maize bran is generally available as chicken feed, ignoring this resource may have led to some overestimation of land needs for supply of poultry feed.

5.5. Conclusion

With actual yields for crops and poultry and a doubling in population size by the year 2050, the land requirement must increase more than two folds to produce sufficient food and feed. When only utilising suitable land with the actual yields this leads to food-feed competition in most scenarios and with the increasing population, food export will be strongly reduced or no longer possible. To meet the increasing demand for food, the present study strongly recommends to focus on sustainable intensification options aiming to reducing the yield gaps in the region. Otherwise, with the current yield, producing sufficient food and feed will not be feasible without further expanding agricultural production in suitable and non-suitable land. Especially expanding in unsuitable land would require high investments in irrigation, energy use, labour, fertiliser etc.

Chapter 6

General discussion and conclusions

6.1. Introduction

Let us return to the main research objective of the present study which was to explore the potential of soybean-maize-chicken value chains to support the sustainable production of diversified diets and to identify important entry points for value chain integration in the Southern highland zone of Tanzania. The zone constitutes of the main breadbasket regions important for food production in the country (SAGCOT, 2015). The regions are endowed with rich soils and resources for food crops and livestock production for the growing population (CIAT and CARE, 2019). Surprisingly, the breadbasket regions have high rates of undernutrition and micronutrient deficiency, partly due to limited dietary diversity (Altare et al., 2016; Ministry of Health et al., 2016), which raised interest in choosing the Southern Highlands as our case study.

Chapter 2 employed fuzzy cognitive mapping (FCM) to understand the current soybean, maize and chicken value chains, highlight stakeholder relationships, and identified entry points for value chain integration to support nutritious diets in three regions in the Southern Highlands including Iringa, Njombe and Ruvuma. The fuzzy cognitive maps were constructed based on information gathered during household interviews followed by a participatory workshop with stakeholders involved in the three value chains. The study revealed the importance of networks of integrated value chains in domestic markets, whereby soybean-maize-chicken value chains are interconnected particularly at smallholder farming systems and at processing facilities. Chicken feed was an important entry point for integrating the three value chains, as maize and soybean meal are the main sources of energy and protein for chicken. Unlike maize, the utilization of soybean in chicken feed was very low, mainly due to inadequate processing of soybean grain into meal. As a result, the soybean grain produced is mainly exported to neighbouring countries for further processing, and soybean meal is imported at relatively high prices. The findings in Chapter 2 proposed enhancing local sourcing and adequate processing of soybean coupled with strengthening the integration of smallholder farmers with other soybean-maize-chicken value chain actors to improve access to nutritious food for people.

Considering the role of chicken in integrating the three value chains, in Chapter 3 we zoomed in on the farming systems to understand chicken farming diversity and explore the intensification gradient in the production systems in urban and rural areas based on a cross-sectional survey conducted in the Iringa region in 2018. In the next step, I conducted a problem tree analysis based on the survey data to classify the underlying constraints and their interrelations, and to identify common root causes, based on which we propose practical solutions to improve chicken production along the intensification gradient identified in urban and rural locations. This study is the first to explore the diversity of chicken farming and the underlying production constraints based on the subdivision of the production systems. The subdivision of poultry systems was refined by adding the size of the flocks to highlight variations in the scale of operations. On this basis we distinguished three main types: 1) subsistence small-scale free-range chicken production; 2) market-oriented small to medium-scale semi-intensive and 3) small to medium-large scale intensive systems.

The findings in Chapter 3 show that the degree of intensification of chicken production systems in the Iringa region was increasing with the number of improved crossbred and exotic chickens raised under the medium-large scale intensive systems, that were fed with homemade and/or commercial feeds in both urban and rural locations. We also found that intensive farms in urban locations raised quite a substantial number of indigenous chickens. This may be due to the assumed increased need for care for exotic breeds compared with indigenous breeds, because of their greater susceptibility to diseases or because of their higher management costs (Andrew et al., 2019). The farms under this typology were commercially oriented whereby most of the produce was for sale. These are typical characteristics of commercial mid-large-scale production systems in East Africa (Chaiban et al., 2020). The findings show that the more intensive the production system, the more the intensity and diversity of diseases identified by farmers as their main problem, which was partly attributed to the greater sensitivity of the improved breeds, poor veterinary measures, and the high chicken density facilitating disease spread. Furthermore, about 30% of households had more than one breed and/or rearing system combination. On one hand, the development of medium-large scale systems was particularly constrained by a limited supply of one-day-old chicks and theft, while on the other hand, the intensification of small-scale systems is constrained by limited access to quality feed, vaccines and medicines, capital, and lack of a reliable market, partly due to the absence of farmer organizations. These constraints can be addressed through the formation of producer groups and the promotion of outgrower and enterprise development models to enhance access of farmers to input-output markets.

Chapter 4 presents a feed gap analysis, where we explored the current feed gap and how the feed gap can be closed by comparing the actual feed quantity and quality supplied to dual-purpose chicken with the recommended standards. This study is the first to explore the actual production and feed quantity and quality (status quo) in the poultry industry in Tanzania. Recent studies have been conducted under a controlled experimental design focusing on on-station and on-farm performance evaluation of Kuroiler and Sasso chickens under the African Chicken Genetic Gain initiative in Tanzania (Guni et al., 2021; Sanka et al., 2020). In the study presented in Chapter 4, a mixed method approach was applied, including a cross-sectional survey, physical measurements of chicken bodies and eggs, quantification of feed offered to chickens during a farm visit and nutritional quality analysis of the feed using Near-Infrared Reflectance Spectroscopy and aflatoxin contamination using the

AccuScan Gold III reader. The results were compared with the recommendations for improved dual-purpose crossbred chickens, exotic layers, and broilers.

The results in Chapter 4 show that feeds were offered in insufficient quantity compared with the recommendations for laying hens (125 g/chicken unit/day), and indigenous chickens were fed less feed than the improved crossbred chickens in semi-intensive and intensive systems. Most feeds fed to dual-purpose chickens were of low nutritional quality, particularly lacking in crude protein and essential amino acids in both rearing systems and breeds. Maize bran, sunflower seedcake and fishmeal were the main sources of energy and protein in the study area. Furthermore, the findings show that the important feed ingredients, protein sources, essential amino acids, and pre-mixes, were expensive and were not included in formulating compound feeds by most chicken farmers. The results further show that only one farmer among the 101 interviewed respondents was aware of aflatoxin contamination and its effects on animal and human health. All feed samples analysed contained a detectable concentration of aflatoxins and 16% of them exceeded the allowed toxicity thresholds (>20 μg/kg). Based on the results, the chapter highlights the need for a stronger focus on feeding strategies and ensuring the availability of suitable and safe feed formulations.

In Chapter 5, we explored potential scenarios to provide sustainable diets to feed the population in the Iringa region, in the Southern Highlands of Tanzania by adding poultry products to the current diets. It does so by assessing land requirements to produce sufficient food of adequate nutritional quality for the current and the anticipated doubled population of the Iringa region by 2050 based on macro secondary data, and micro primary data collected in the region between 2018-2020. The actual and potential yield of the food crops grown in the region were extracted from the Yield Gap Atlas, a global open-access database. The region has about 1,556,465 ha of arable land suitable for crop and livestock production, of which only 37% is currently used for farming, providing an opportunity for the growth of the agricultural sector. With actual crop yields, half of the current land use is needed to produce a plant-based diet for the present population of Iringa. The rest of the land produces for export to other areas of Tanzania and neighbouring countries. Improved diets to be achieved with actual yields of crops and poultry for the current human population size in the Iringa region, would require about 521,826 ha of land for food and feed. This means that all land currently used for food crops needs to be utilized, plus an additional 175,865 ha of suitable land not yet cultivated. With actual yields for crops and poultry and a doubling in population size, a total land use of 1,043,696 ha is needed. Hence, even the total area used for agriculture is not enough to produce sufficient food and feed. An additional 697,559 ha need to be transformed from suitable land not yet cultivated when current land use for cash crop production and grazing is maintained. Such scenarios show that large food-feed competition will occur in the region, and then probably the poultry sector cannot be served with locally grown feed. Furthermore, in multiple scenarios, cultivation of food (maize) for export will be strongly reduced or no longer possible. To meet the increasing demand for nutritious food, the present study highlights the need for sustainable intensification options focusing on reducing the yield gap in the region. Otherwise, with the current yields, producing sufficient food and feed will not be feasible without further expansion of agricultural land.

In the next sections of this chapter, I explore the research findings of this thesis in the broader context, I highlight synergies between the chapters, and I draw conclusions from the main findings.

6.2. Integrated soybean-maize-chicken value chains for attaining diversified diets

The agri-food value chain involves all actors and activities from the point of production to consumption, including inputs, crop and livestock production, storage and processing, transportation and distribution, food retail and labelling, and consumption (Allen and de Brauw, 2019). Most value chain analyses use transaction cost economics to explain use of marketing channels and the functioning of the value chains. Value chains are often presented as a vertical linear framework with structured markets and organised value chain actors (Gibbon and Ponte, 2005; Tallontire et al., 2011). Value chains often have standards that producers have to comply with, which is often not easy for smallholders in developing countries (Lee et al., 2012; Tallontire et al., 2011).

In literature, value chain integration is often used to describe the integration between nodes within a value chain (Papazoglou et al., 2000), meaning for instance governance of flows of goods and information between producers, processors, retailers and consumers. Some authors emphasize the integration of smallholders into value chains (Barrett, 2010; Kissoly et al., 2017b; Ros-Tonen et al., 2019) as timely sourcing of sufficient volumes of products of adequate quality from multiple small scale producers is a challenge, which is especially highlighted in global value chain literature. In the present study, value chain integration is used differently. It is used to explain how different domestic value chains, notably soy, maize and chicken value chains, are connected with each other at one or more nodes e.g. production and processing. Using the value chain approach based on the fuzzy cognitive mapping method, in Chapter 2 we found that the soybean-maize-chicken value chains are integrated at different levels and hence reduction of transaction costs in one chain may not tell the whole story. The institutional environment often determines the transaction costs related to production and the involvement of stakeholders in a specific value chain development (Gereffi et al., 2005). Farm households are often engaged in different value chains for different reasons. In Mali, cotton cultivation provides households with access to fertiliser for cotton and maize and the nutrients remaining in these fields after cultivation become available for the next crop which is sorghum or millet (Dissa, 2023). These value chains serve different household objectives, with cereals providing food and their surpluses providing immediate cash when sold at spot markets throughout the year. Cotton provides once-a-year cash for investments, and cotton seed cake is a valuable source of cattle feed. Leonardo et al. (2017) stated that understanding smallholder farmers' sales arrangements by using transaction cost economics focusing on a single value chain does not make much sense in a smallholder context. The reason why this does not make much sense is that smallholder farmers usually produce different crops and participate in several value chains simultaneously, and allocate resources based on whole farm objectives (Leonardo et al., 2015).

In Chapter 2, we see that farmers in the Southern highlands of Tanzania are generally engaged in one or more of the following value chains i.e. soybean, maize and chicken. And up to 30% of the households had more than one poultry breed and/or rearing system combination with different outlets further emphasizing the engagement of smallholders in different value chains simultaneously. Chicken feed is an important entry point for integrating the three value chains, as highlighted in Chapters 3 and 4, where the medium-large scale farmers formulated chicken feed using maize and soybean meal as the main sources of energy and protein for chicken. Maize and chicken are mainly for household consumption with surpluses sold for cash while soybean functions entirely as a cash crop. After processing, both soybean meal and maize bran could come back to the farm as chicken feed. The processing level is where the value chains are most integrated. Furthermore, the value chain outputs are coming together at consumers' plates in the form of maize flour for energy and chicken meat and eggs, which are important sources of proteins and micronutrients. The integration of soybean into the farming system through intercropping and rotations with maize has the dual advantage of improving soil fertility and resource-use efficiency (Iqbal et al., 2019; van Vugt et al., 2018). Consequently, including soybean in the maize-based systems provides an opportunity to diversify diets.

Soybean could be part of consumers' diets but, the findings in Chapter 2 show that it's processing at the household level is seen as cumbersome in Tanzania due to limited knowledge of processing into soy oil and other soy products. Soybean flour is sometimes used in the fortification of maize flour with micronutrients for human consumption, mainly done by small and medium enterprises, while little is known about the processing of soybean into other nutritious soy products i.e. soy sauce, soybean curd, soy drinks and milk (Martin et al., 2010; Wilson et al., 2021). In our study, we found that inefficient soybean processing leads to low-quality soybean meal and soy products which hampers its utilization as chicken feed and as human food. The lack of proper soybean processing facilities, therefore, undermines the growth of soybean production in the country. As a result of the limited local processing of soybean, Tanzanian soybeans are exported to neighbouring countries for processing, and then soybean meal for chicken feed is imported again at high prices. Most animal feed manufacturers in Tanzania rely on imported soybean meal for the formulation of commercial chicken feed (Naggujja et al., 2020). Installing new soybean processing facilities requires high investment costs and will need a minimum quantity of soybean delivery to be feasible (Cheng and Rosentrater, 2019; Hichaambwa et al., 2014). However, this minimum quantity of soybean will only be produced if there is an assured market, which depends on the demand for soy oil and soy products for human consumption as well as soybean meal for chicken feed formulation. So where to start? This raises the question of the chicken or the egg; what comes first?

6.3. Bridging the gap between local food production and sustainable consumption

In Tanzania, achieving food and nutritional security is a major challenge as for most SSA countries. The breadbasket regions important for food production in Tanzania, the Southern highland in particular, are surprisingly most vulnerable, with high rates of undernutrition and micronutrient deficiency, particularly among women and children (Altare et al., 2016; Ministry of Health et al., 2016; Wang et al., 2022). The household diets in the region display high consumption of maize and other carbohydrate-rich staples, some legumes and vegetables, and little consumption of Animal-Sourced Food (ASF) (Ministry of Health et al., 2016). Research showed that, despite the high iron and zinc content of legumes and some vegetables, the bioavailability of these nutrients is weak due to the high content of anti-nutritional components limiting the uptake of these nutrients (Hurrell, 2003; Sandberg, 2002). On the other hand, the micronutrients from Animal-Sourced Food (ASF) are fully bioavailable. In Chapter 5, we therefore assessed the nutritional value of the most common food crops grown in the region and added two sources of ASF i.e. chicken meat and eggs, to the current diet and later estimated the impacts of these consumption scenarios on the crop and poultry production needs and land requirement for feed production. We found that adding one egg and 100 g of chicken meat to the plant-based diet provides sufficient minimum energy content, protein and some of the micronutrients i.e. Iron and Zinc (Table 5.4). Notwithstanding, adding chicken meat and egg to the diet could not meet the daily requirements for Calcium, Vitamin A and B12.

Considering the ecological potential of the region, sufficient ASF particularly chicken meat and eggs can be produced within the region, Chapters 2 and 3, highlighted different challenges limiting chicken production and envisaged opportunities to improve production based on the surveys and participatory workshop with stakeholders involved in the value chain. The stakeholders indicated that limited access to quality feed and feed ingredients is among the major constraints for chicken production in the region. Commercial feed is produced in the region packed in 50 kg bags, but it is expensive and not well affordable to most smallholder chicken farmers in the region. Other constraints include low genetic potential of indigenous breeds, limited access to one-day-old chicks, and the prevalence of diseases. Notwithstanding, the aforementioned constraints limiting chicken production have been continually reported over the entire country since 20 years ago (Buza and Mwamuhehe, 2000; Kibasa, 2020; Msami, 2000; Sanka et al., 2020), and we may wonder if it will it be possible to meet the increasing demand for chicken meat and eggs through local production for the anticipated double population by 2050. In Chapter 3 a subdivision of poultry systems in Tanzania was refined by adding the size of the flocks to highlight variation in the scale of operations where we revealed a range of underlying constraints in different production systems that requires different solutions as further explained in the next section.

6.4. One size doesn't fit all

Over the past decade, there has been increasing intensification of the poultry industry in Tanzania from keeping indigenous free-range chickens to keeping improved dual-purpose and exotic layers and broilers (Mushi et al., 2020; Sanka et al., 2020). In Chapter 3, we presented the findings on chicken farming diversity along the intensification gradient from semi-intensive to intensive systems and highlighted the linkages between constraints in different production systems in urban and rural areas and explored practical solutions. After a description of the systems found in urban and rural areas, this distinction was dropped in the remaining of the thesis as in further analysis the areas proved not to be significantly different. The subdivision of the farms in our study revealed differences in the degree of intensification from subsistence small-scale production to market-oriented systems where we came up with five farm types i.e. small-scale free-range, small-scale semi-intensive, medium-scale semi-intensive, small-scale intensive, and medium-large scale intensive farms. Based on the subdivision of the poultry systems, we revealed that different systems face different constraints that require different solutions. Understanding the diversity of chicken farming systems in the Iringa region allows a diagnosis of problems targeting interventions which come next.

The findings in Chapter 3 showed that the more intensive the production system, the more the diversity of diseases reported, partly due to the high density of chickens in the flock and low disease resistance of the improved and exotic chickens compared to the indigenous free-range chickens. The subdivision of chicken farm types in Chapter 3 revealed that the development of medium-large scale systems was particularly constrained by a limited supply of one-day-old chicks and theft. The commercial hatcheries installed over the recent years (i.e. Silverlands and Mkuza Chick), and the recent initiatives on genetic improvement of chickens, including the African Chicken Genetic Gain initiative and the involvement of Hendrix genetics, providing opportunities to improve the genetic potential and productivity of chickens in the region (Guni et al., 2021; Pius et al., 2021), particularly for the medium-large scale farmers. In contrast, smallholder chicken farmers produced their own chicks and/or purchased from the neighbours.

Risk-aversive farmers prefer indigenous chickens due to their resistance to diseases and high survival rates while raised with low production costs i.e. less veterinary drugs and feed. Risk-averse farmers are likely to refrain from investments when they are costly, irrespective of market prices for their produce (Andrew et al., 2019; Makhura, 2002). In Tanzania, most consumers prefer indigenous chicken meat and eggs rather than products from exotic broilers and layers. This is due to the perception that they taste good and are nutritious and that they come from chickens which are raised organically (Andrew et al., 2019; Muhikambele, 2019; Sanka and Mbaga, 2014). Despite the strong consumer preference of indigenous chicken meat and eggs and the change from free-range to more intensive systems with indigenous breeds highlighted in Chapter 3, it is challenging to meet the current demand through domestic production and supply (MLDF, 2019), because of the low productivity of the indigenous breeds. Considering the significant role of chicken meat and eggs in improving household dietary diversity, it is important to keep the production costs down to make the products attractive to improve diets of poor people. So, cost price and price at sale matters. Also, many farmers do not yet understand that investments need to be made to make a profit and often they do not have the capital to make the necessary investments upfront i.e. on quality feeds, one-day-old chicks and housing facilities as identified in the problem tree analysis (Figure 3.8) (Kadigi et al., 2017). Hence, training of entrepreneurial skills to farmers may be needed.

To summarize, smallholder chicken farmers in the Iringa region were constrained by high costs of inputs and limited access to quality feed, vaccines and medicines, capital, and lack of a reliable market. This limited their production. A partial solution may be found in models of farmer organizations as further explained in the next section. These organisations may also contribute to increasing farmers knowledge.

6.5. Farmer groups and business models

Chapter 3 highlighted the potential of the formation of producer groups and the promotion of outgrower and enterprise development models, both aiming to increase chicken production (Figure 6.1) and to reduce transaction costs through collective action (Markelova et al., 2009). Business models proposed for the growth of smallholder farmers in LMICs include the outgrower and enterprise development (Beesabathuni et al., 2018; Reji, 2013; Sanyang, 2012; Sikenyi, 2017; Thompson and MacMillan, 2010). The enterprise development model has been successfully implemented in Malawi whereby the input suppliers organised small-scale scale chicken farmers into small groups and organised them to set up and develop enterprises (Beesabathuni et al., 2018). The model appears to be the most promising business model for smallholder chicken farmers given that it allows farmers to access inputs i.e. feeds, day-old chicks or point-of-lay hens, housing, vaccines and medicines. Furthermore, in this model, farmers have more freedom in decision-making and management while strengthening linkages with input suppliers and output markets to ensure a viable and profitable business. On another hand, the outgrower model has high capital investments and contracts between a farmer/farmer group managing large flocks (≥5000 chickens) and a commercial entity (Beesabathuni et al., 2018). The model requires well-accessible organised farmer groups connected with dealers and distributors to ensure easy collection and transportation of eggs quickly.

Farmer organisations and business models may, however, also have problems to deliver the expected benefits (Francesconi and Wouterse, 2015; Liverpool-Tasie, 2014; Maghimbi, 2010). In Ghana a program that provided in-cash and in-kind support to farmer based organisations was confronted with farmer based organisations that were established for the sole purpose of benefitting from incentives offered by the program, and hence was counterproductive in promoting effective collective action (Francesconi and Wouterse, 2015). Similar problems of "fake cooperatives" were identified by Ruf et al. (2019) in the cocoa sector in Ivory Coast, where benefits for members were small or even inexistent. Providing incentives to foster farmer organisation apparently does not necessarily lead to the anticipated results (Francesconi and Wouterse, 2015; Liverpool-Tasie, 2014; Maghimbi, 2010). Hence the need for effective future programmes and policies to ensure transparency and effective accountability mechanisms to reduce dishonesty and corruption. Such programmes should facilitate efficient training and mentorship on entrepreneurial skills that would allow for effective participation of women and youth (Sikenyi, 2017), poor and rich (Mwambi et al., 2020) in collective action models, and enable fair benefit sharing (Liverpool-Tasie, 2014).

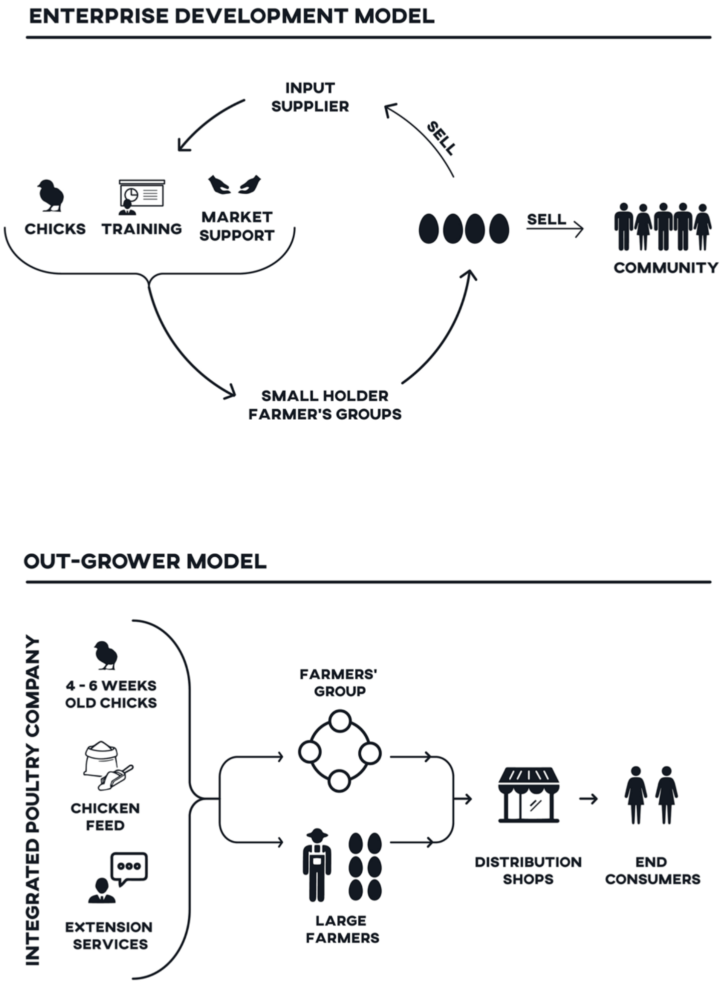


Figure 1. Enterprise development model and outgrower model (Beesabathuni et al., 2018)

In Tanzania, limited information is available on the efficient business models in the agricultural sector. Recent studies on rice, sugar cane and tea highlighted that there are many challenges to successfully implementing outgrower business models including national policies on the business environment in the agricultural sector particularly on land ownership, where women and youth have limited access to own land (Brüntrup et al., 2018; Sulle and Dancer, 2020). In Chapters 2 and 3, our findings show that smallholder farmers in the Southern Highlands of Tanzania are disorganised leading to inefficiencies in the soybean and chicken value chain. On one hand, soybean farmers in the region complained that there was no market for their produce, while on the other hand, traders could not collect the grains from disaggregated farmers due to the large transaction costs. Similarly, the chicken value chain is mainly informal, with disorganised farmers, partly due to a lack of farmer organisations.

In Chapters 2 and 3 we see that most farmers raised the indigenous breed of chickens in the Iringa region and that this breed was found even in the more intensive production systems. The productivity of indigenous breeds was very low resulting in a small amount of the products (meat and eggs) retained for household consumption and/or sold to generate income, mainly through the informal channel. We found that there were seasonal fluctuations in selling the products from the exotic breeds (layers and broilers) from January until August that affect mid-large scale farms. The increasing intensification from keeping a small number of free-range indigenous chickens to large flocks of the improved dual-purpose and exotic breed highlighted in Chapter 3 implies that there will be increased productivity which will drive the need for organized markets. The implementation of the business model i.e. the enterprise development and outgrower schemes will therefore require the organisation of farmers into groups to ensure input-output market access. In recent years, the outgrower development model has partly been implemented in the chicken value chain in the region where producers keeping 100-300 chickens were linked to input, extension services and market (Mugittu, 2016). Unfortunately, little is known yet about the progress and output of the project in the country.

Apart from economic issues such as high input costs we found in Chapter 2 that farmers lacked knowledge for efficient chicken production. To mitigate the challenges limiting chicken production, we already highlighted in Chapter 2 the need for government interventions as well as those of NGOs and international development organisations on improving knowledge of smallholder farmers about efficient management practices, feed formulation, and entrepreneurship. This plea has become stronger after findings reported in the subsequent chapters, confirmed the lack in knowledge on veterinary care and flock management (Chapter 3), adequate feed composition (Chapter 3 and 4) and entrepreneurial skills (Chapter 3). Adequate feeding strategies are also hampered by lack of nutrient composition on feed packages provided by the private sector (Chapter 2 and 3). Recent research in Ghana highlighted that shortage of veterinary officers partly contributed to insufficient knowledge and training of farmers on flock management and poultry health services (Enahoro et al., 2021). While farmer organisations may assist in overcoming access to inputs and markets, this creates the additional need to train farmers in skills and capabilities related to participation in and governance of farmer organisations. Hence apart from economic incentives such as availability of low-cost quality feed, and access to input and output markets, increasing farmer knowledge and skills is of essence to move the sector forward. There is clearly a role for government in terms of providing extension services but also for the private sector in for instance providing adequate product information.

What comes first? The chicken or the egg?

Improving access to quality feed is among the major priority areas highlighted in the Tanzania Livestock Master Plan (TLMP). The present study revealed that chicken feed is an important entry point for integrating soybean-maize-chicken value chains, where soybean and maize are the main sources of protein and energy for chicken, respectively (Chapter 2). From the sector we understood that opening improved processing facilities needs first a guarantee of sufficient soybean production, whereas farmers only produce soybean when there will be a guaranteed outlet. And at the same time the farmers need the processing to deliver the soybean meal for their poultry production. A typical question of what comes first? The chicken or the egg? In Chapter 4, we zoomed in on feed gap analysis, which is a comparison of the actual feed quantity and quality supplied to dual-purpose chickens with the recommended standards. Most authors reported limited access to high-quality feed and feed ingredients as the major constraint limiting chicken production and productivity in the country (Enahoro et al., 2021; Longo et al., 2019; Naggujja et al., 2020), but they did not describe local feeding strategies in different production systems in detail. Unlike most studies, the findings presented in Chapter 4, based on robust methods combining surveys, physical measurements of chicken and eggs, sampling of feed and laboratory analysis on micronutrient content and mycotoxin contamination, highlighted the need for a stronger focus on feeding strategies and ensuring the availability of suitable and safe feed formulations. In line with the TLMP, the chapter revealed a large gap in current chicken production and highlight the importance of closing feed gaps (both quantity and quality) to meet the increasing demand for chicken meat and eggs. The TLMP also highlighted the need for improving domestic production to meet the demand for chicken meat and eggs in the country by improving the genetic potential of the indigenous breed (MLDF, 2019). Improving chicken productivity requires capital investment in infrastructures and inputs particularly one-day-old chicks, feed, medicines and vaccines. Farmers could only make such investments while assured of good returns from chicken enterprises (Chaiban et al., 2020; Teklewold et al., 2006).

Over the past decade, Tanzania has passed through a period of prolonged drought, leading to increases in the prices of the major cereals (Randell et al., 2022; Shabani and Pauline, 2023). In the same period, the country has continued working on improving food security through domestic production despite the external challenges i.e. global economic downturn, and fuel, and fertilizer price hikes (Bumb et al., 2021; MLDF, 2019; URT, 2017). Consequently, the prices of chicken feed and feed ingredients have been increasing while farmers were still selling chickens and eggs at lower prices which subject them to enormous losses due to the high costs of production (Longo et al., 2019; TheCitizen, 2022). Unlike the red meat and pork value chain, the chicken value chain is less coordinated in Tanzania, dominated by informal value chain actors and with a lack of slaughtering and processing facilities

(Njombe and Msanga, 2009; Silva et al., 2017). The findings in Chapter 2 show that the chicken value chain is dominated by informal small traders and middlemen at the household level and primary markets. Live chickens and eggs from the farming household or primary market are sold to the informal middlemen/agents for further processing and supply to individual consumers, hotels, catering services etc. Chicken farmers spend several weeks or months raising and feeding chickens, but they have no power in deciding the final price of their produce; The market price for live chicken and eggs is entirely ruled by middlemen and other traders that act in their own interests (Mambile and Machuve, 2019). In recent years, the agricultural and marketing cooperative societies (AMCOS) has been successful in coordinating the production, processing, transportation and marketing of crops in Tanzania (Kibona and Yuejie, 2021; Shirima, 2022). The AMCOS could also be implemented in the poultry value chain and could further improve access to market information and the bargaining power of chicken farmers in price arrangements.

The continuing prolonged drought condition in Tanzania and neighbouring countries implies that there will be increasing prices of chicken feed and feed ingredients in the country. Therefore, the feed industries and farmers formulating their own feed rations should adapt by making adjustments in the feed formulation and using alternative feed ingredients to reduce the costs of feed (Doto et al., 2021). Chapter 4 highlighted the potential of BSF larvae as an alternative protein source that can be used as replacements for a fish meal while raised in a small area. Currently, some companies are investing in BSF production in major cities in Tanzania (Isibika, 2022; Limbu et al., 2022; Vernooij et al., 2019), but the scale at which it could contribute to the poultry feed industry is unclear.

6.6. Food and feed safety

Most farmers and consumers in developing countries are not aware of aflatoxin contamination and the associated health effects on humans and livestock (Shephard, 2008; Vipham et al., 2020). Some of the consumers in Kenya for example were aware of the harmful health effects of eating mould-contaminated food, but unaware of the risks of consuming products from animals fed contaminated feed (Kiama et al., 2016). The findings in Chapter 4 reported that all feed samples collected from the study area contained detectable aflatoxin contamination and 99% of the chicken farmers interviewed were not aware of its prevalence, associated health effects and control measures. Our findings show that maize bran and sunflower seed cake are the major feed ingredients in the Iringa region. The two crops are among the crops that are highly prone to aflatoxin contamination (Mwakosya et al., 2022), mostly occurring during crop production and storage (Agape et al., 2021; Suleiman et al., 2017; Temba et al., 2021). The aflatoxin contamination in chicken feed and feed ingredients, therefore, implies a high possibility of food contamination as highlighted in recent studies conducted in Tanzania (Jubeen et al., 2022; Mmongoyo et al., 2017; Mtega et al., 2020). Currently, the Tanzania

Bureau of Standards and Tanzania Veterinary Laboratory Agency are responsible for food and feed quality and safety regulations. Unfortunately, the latter organisation lacks equipment for feed safety analysis against mycotoxins and relies on outsourcing from other institutions (Doto et al., 2021). The outsourcing costs of the equipment are high and increase the costs of analysis to farmers and feed processors, and consequently might lead to skipping mycotoxin analysis to evade the costs and might increase risks of aflatoxin contamination, threatening animal and human health.

6.7. Exploring options towards sustainable diets: sustainable intensification and diversification

Over the past decade, Tanzania's population increased from 44.9 to 61.7 million people, with a growth rate of 3.2% per annum (NBS, 2022). By 2050, the population is anticipated to double, which implies that the demand for food will also increase more than two folds. The major population growth is projected in the growing towns and cities including the Southern Highland regions which call for sustainable options to improve food production. Chapter 5 explored potential scenarios to design food systems that provided sustainable diets to feed the current and the projected double population by 2050 while minimising land expansion in the region.

We found high-yield gaps in all food crops in the region. With the actual production, it will be challenging to feed the projected double population without further expansion of agricultural land. Research reported high yield gaps in the major cereals (Giller et al., 2021; Kwesiga et al., 2020; Ten Berge et al., 2019), and grain legumes (Van Loon et al., 2018), which are partly due to poor agronomic practices and soil fertility status. In practice, it is not possible to close the yield gap by 100% due to high economic costs and weather variability (Singh et al., 2015; van der Linden et al., 2018; Van Ittersum et al., 2013). Therefore, the results of the yield gap analysis presented in Chapter 5 were based on the difference between actual and attainable yield, the latter being defined as 80% of water-limited potential yield. And even achieving these yields would require massive investments in the agricultural sector in terms of farmer training, provision and application of affordable inputs, and efficient supply chains minimizing food losses and wastes.

In Tanzania, the demand for ASF chicken meat and eggs is already higher than the domestic production and supply mainly due to limited access to quality feed and the low genetic potential of the indigenous breeds (MLDF, 2019). With the actual production of dual-purpose chickens and the actual yield of the major feed ingredients used in the region (maize, soybean and sunflower), excess land will be required to produce chicken feed to meet the demand for meat and eggs for the current population. As a consequence, using the arable land intended for food to produce chicken feed ultimately results in food-feed competition (Van Zanten et al., 2018). The chapter highlighted the need for sustainable intensification options to improve crop yield (attainable yield) and chicken yield to produce sufficient food and feed without further expansion of the arable land. Including grain legumes in intercropping and rotations with grain cereal among others, has the advantage of improving soil fertility and resource-use efficiency (Iqbal et al., 2019; van Vugt et al., 2018). Consequently, including grain legumes in the maize-based systems provides an opportunity to diversify diets.

6.8. Concluding remarks

Over the past 14 years that I have been working in the Southern Highlands of Tanzania, I was wondering why the breadbasket regions located in this area have high rates of undernutrition and micronutrient deficiency. Indeed, the Southern Highlands of Tanzania is known as the 'breadbasket' of the country, supplying food to other food-deficit regions of the country. This thesis explored the potential of soybean-maize-chicken value chains to support the sustainable production of diversified diets and to identify important entry points for value chain integration in the Southern highlands of Tanzania. To meet the increasing demand for nutritious diets in Tanzania, soybean, maize and chicken value chains have an important role to play. The emerging chicken feed industry is an important market outlet for smallholders producing maize and soybean in the country providing them with an income to buy nutritious food items. Efficient processing of soybean has a great potential to increase the local availability of soybean products and by-products both for human food and animal feed. Further, domestic production and processing of soybean are expected to reduce the cost of chicken feed that currently relies on expensive fish meals. To realise the promising outlook in the functioning of the three value chains, addressing the inefficiencies identified in the soybean chain require both public and private sector partnership, value chain collaboration and promotion of innovation platforms.

My study revealed a large diversity of chicken production systems in Tanzania, beyond what had been described previously. The subdivision in production systems revealed different constraints limiting chicken production depending on the types which open the door to propose relevant packages for improving the production of meat and eggs for the household and other consumers. In line with the Tanzania Livestock Master Plan, our findings reveal a large feed gap in current chicken production.

My analysis revealed that with actual yields for crops and poultry and a doubling in population size, even the total area of land suitable for agriculture is not enough to produce sufficient food and feed. When utilising unused suitable or unsuitable land with the actual yields leads to food-feed competition in most scenarios and with the increasing population, food export will be strongly reduced or no longer possible. I hope that the findings from this thesis will inform the decision-makers from regional to national levels to implement sustainable intensification options aiming to reduce yield gaps and further expansion of agricultural land to produce sufficient diverse food for the current and future population.

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Appendix

Appendix A: Supplementary material for chapter 2 - Integrating the soybean-maize-chicken value chains to attain nutritious diets in Tanzania.

Appendix B: Supplementary material for chapter 3 - The diversity of smallholder chicken farming in the Southern Highlands of Tanzania reveals a range of underlying production constraints.

Appendix C: Supplementary material for chapter 5 - Scenario analysis towards sustainable diets and their land-use needs: the case of the Iringa region, Southern Highlands of Tanzania.

Appendix A:

Table A1. Crop production and utilization in the Southern Highlands of Tanzania

(a) Legume production and utilization in the interviewed households during the N2Africa survey[1]

	Bush bean	Soybean	Groundnut	Climbing bean	Cowpea
Number of farmers interviewed (n=448)	199	72	111	7	1
Farm area (ha/household)	0.7	0.9	0.9	0.5	0.4
Legume production; sole crop (kg/household/year)	493.4	525.4	376.3	317.5	-
Std. Deviation	693.2	547.3	263.6	306.5	-
Legume production in the intercrop (kg/household/year)	157.6	251.7	176.3	154.0	50.0
Std. Deviation	155.1	190.4	16.3	-	-
% consumed	30.2	1.0	-	-	-
% sold	50.5	99.0	-	-	-
% other use (seed, stored)	19.3		-	-	-
Crop processing and value addition (% farmers)	1.4	0.3	1.3	0.1	0.2

(b) Maize production in the SH regions of Tanzania based on the annual agricultural sampling 2016/17[2]

Region	Ruvuma	Iringa	Mbeya	Rukwa	Njombe	Katavi	Total (Southern Highlands)	Country's Total
Planted area (1000 ha/year)	169	113	376	186	135	72	1,050	6,068
Harvested area (1000 ha/year)	157	101	335	181	128	70	973	4,901
Quantity harvested (1000 t/year)	314	163	578	338	223	83	1,699	5,767
Average yield (t/ha/year)	1.9	1.6	1.9	1.7	1.8	1.2	1.7	1.2
Quantity sold (1000 t/year)	78	28	133	113	35	11	398	1,269

Data sources:

[1]N2Africa – Tanzania Annual Report (Baijukya et al., 2019)
[2]The United Republic of Tanzania. Annual agriculture sample survey. Crop and Livestock report (NBS, 2017).

Table A2. Characterization of chicken production systems in urban and rural areas, the case of Iringa region

		Farm location	
		Urban (n=48)	**Rural (n=73)**
Chicken breeds	Traditional (n=94)	0.34	0.66
	Exotic (n=18)	0.72	0.28
	Cross-bred (n=33)	0.58	0.42
	Multiple breeds (n=22)	0.59	0.41
Rearing system	Free range (n=40)	0.25	0.75
	Intensive (n=57)	0.54	0.46
	Semi-intensive (n=30)	0.17	0.83
Number of chicken per household (mean and range)	Layers[1] (n=21)	482.80 (9-5700)	278.00 (30-600)
	Broilers[1] (n=14)	378.00 (15-994)	220.83 (47-400)
	Dual purpose[1] (n=11)	106.27 (7-500)	51.10 (2-300)
Products for sale and household consumption	Egg production/week[1*]	550.45 (4-11970)[a]	74.91 (0-950)[b]
	Eggs sold per week[1*]	496.11 (0-11940) [a]	58.29 (0-900) [b]
	Eggs retained for home consumption/week[1]	11.89 (0-30) [a]	6.76 (0-30) [b]
	Chicken sold/month[1]	17.97 (0-167) [a]	8.29 (0-61) [b]
	Chicken retained for home consumption/month[1]	1.80 (0-18)	1.22 (0-5)
Main sources of feed	Commercial feed (n=35)	0.54	0.46
	Locally-made feed (n=68)	0.49	0.51
	Scavenge (n=36)	0.28	0.72

[1]mean and minimum and maximum number

Different superscripts (a,b) indicates a significant difference between urban and rural at p-value $\leq$ 0.05 level

Data source: Survey conducted in Iringa region (Wilson et al., 2021).

Table A3. Categorization of the value chain components categorised into different types based on indegree, outdegree and centrality of the components (summation of the indegree and out-degree) in the integrated soybean-maize-chicken value chain using FCM

Value chain component	Indegree	Outdegree	Centrality	Type
Research and development organisations (local and international)	0	9.5	9.5	driver
Large scale & local hatcheries	0	1.75	1.75	driver
Government policy, regulation	0	13	13	driver
Agricultural Development Bank	1	1.25	2.25	ordinary
Declining soil fertility	2.3	2.2	4.5	ordinary
Effects of climate change	0.75	1	1.75	ordinary
Export burn	1	4.5	5.5	ordinary
AMCOS, VICOBA, SACCOS	0.75	1.5	2.25	ordinary
Inadequate farm machinery	2	1.25	3.25	ordinary
Lack of quality inputs i.e. inoculants, seeds	1.5	0.5	2	ordinary
Farmer group & emerging platform	2.25	3.55	5.8	ordinary
Market uncertainties	1.8	2.25	4.05	ordinary
Limited access to finance	0.5	1.75	2.25	ordinary
High input costs	0.75	2.3	3.05	ordinary
Inadequate knowledge	2	2.35	4.35	ordinary
Lack of market information	1	2	3	ordinary
Soybean production	10.85	2.2	13.05	ordinary
Local consumers	2	1	3	ordinary
Disorganised farmers	1.75	2.25	4	ordinary
Local feed stores/home-made	1.75	1.75	3.5	ordinary
Maize production	9.75	6.75	16.5	ordinary
Imports (soybean meal)	0.5	3.75	4.25	ordinary
Chicken feed processors	2.35	2.35	4.7	ordinary
Inadequate supply of day-old chicks	2.25	0.5	2.75	ordinary
Disorganised market	4.25	1.25	5.5	ordinary
Cash	8.5	1	9.5	ordinary
Existence of diseases and pests	3	3.25	6.25	ordinary
Grain millers	1.75	4	5.75	ordinary
Lack of market infrastructures	1	1.75	2.75	ordinary
Extension & Veterinary services	1	6	7	ordinary
limited access to quality feed	3.35	1	4.35	ordinary
Chicken production (meat and eggs)	11.85	2	13.85	ordinary
Household food	7.95	0	7.95	Receiver

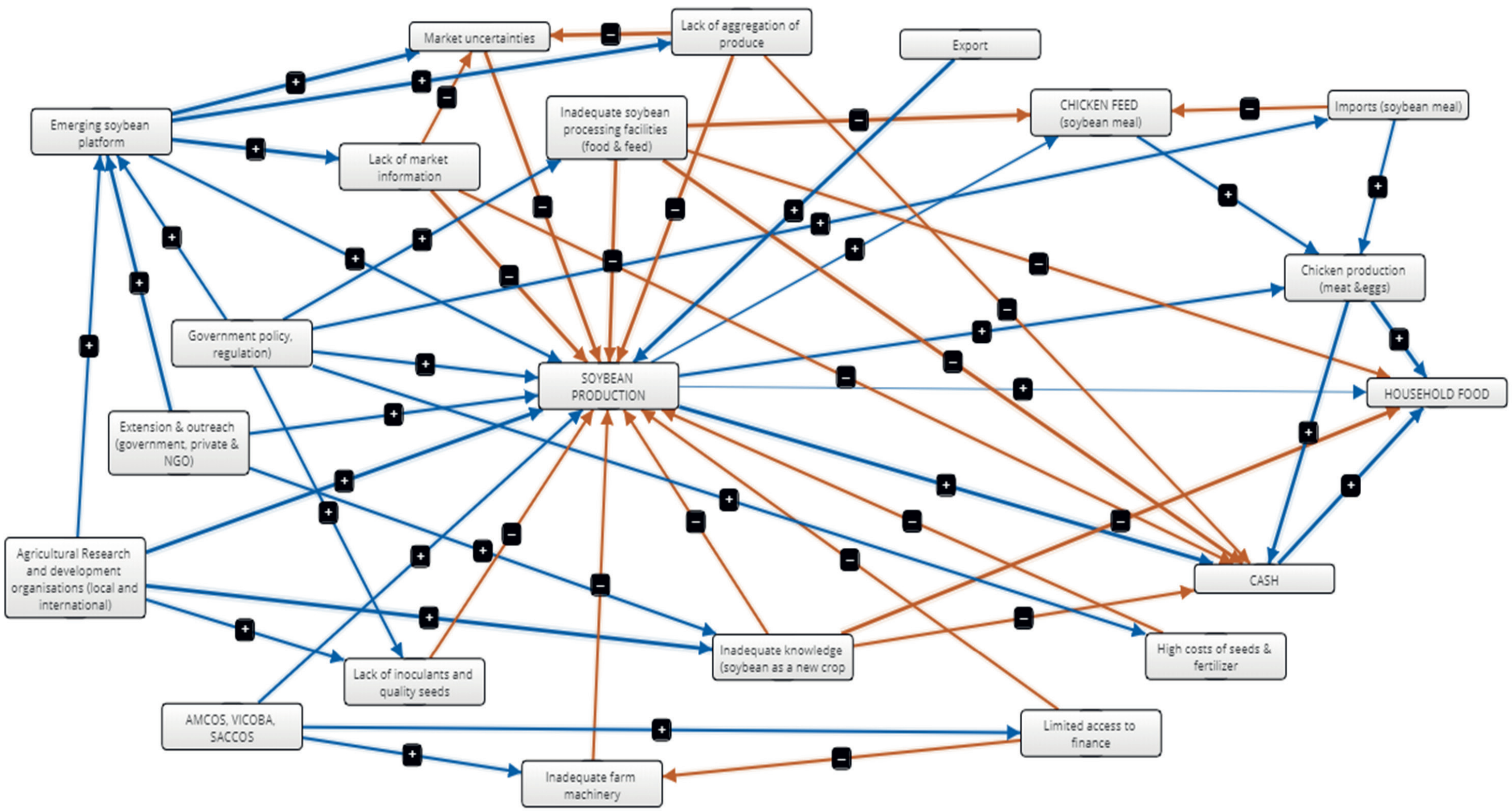

Figure A1. Stakeholders network and relation in the soybean value chain based on the FCM. The colour of the lines indicates whether the relationship is positive (blue) or negative (orange) whereas arrow thickness indicates the strength of the connection between the stakeholders i.e. the thicker the arrow the stronger the relationship. AMCOS stands for Agricultural and Marketing Cooperative Societies while VICOBA and SACCOS sands for Village Community Banks and Savings and Credit Cooperative Societies, respectively.

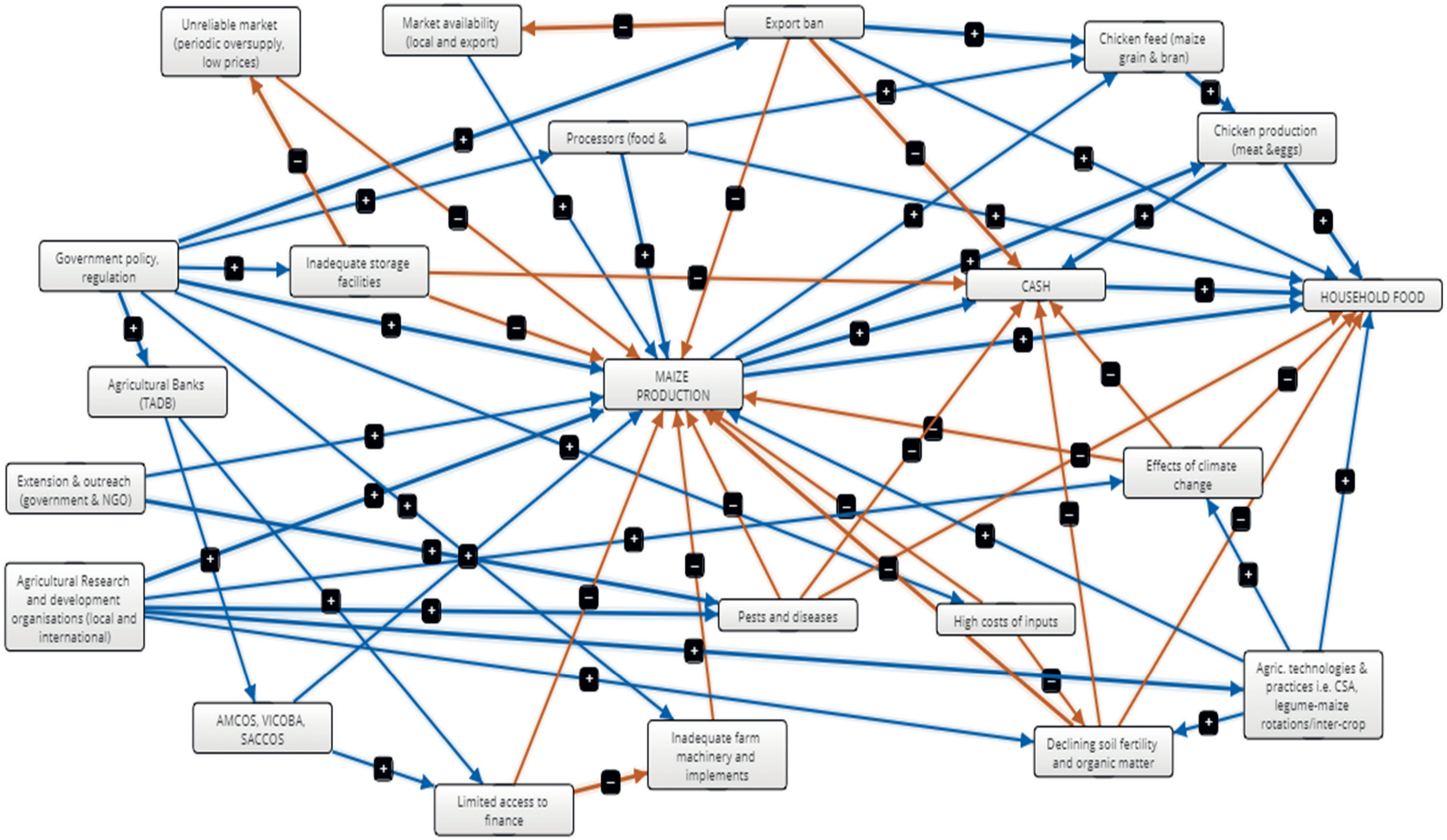

Figure A2. Stakeholders network and relation in the maize value chain based on the FCM. The colour of the lines indicates whether the relationship is positive (blue) or negative (orange) whereas arrow thickness indicates the strength of the relationship between the stakeholders i.e. the thicker the arrow the stronger the relationship. AMCOS stands for Agricultural and Marketing Cooperative Societies while VICOBA and SACCOS sands for Village Community Banks and Savings and Credit Cooperative Societies, respectively.

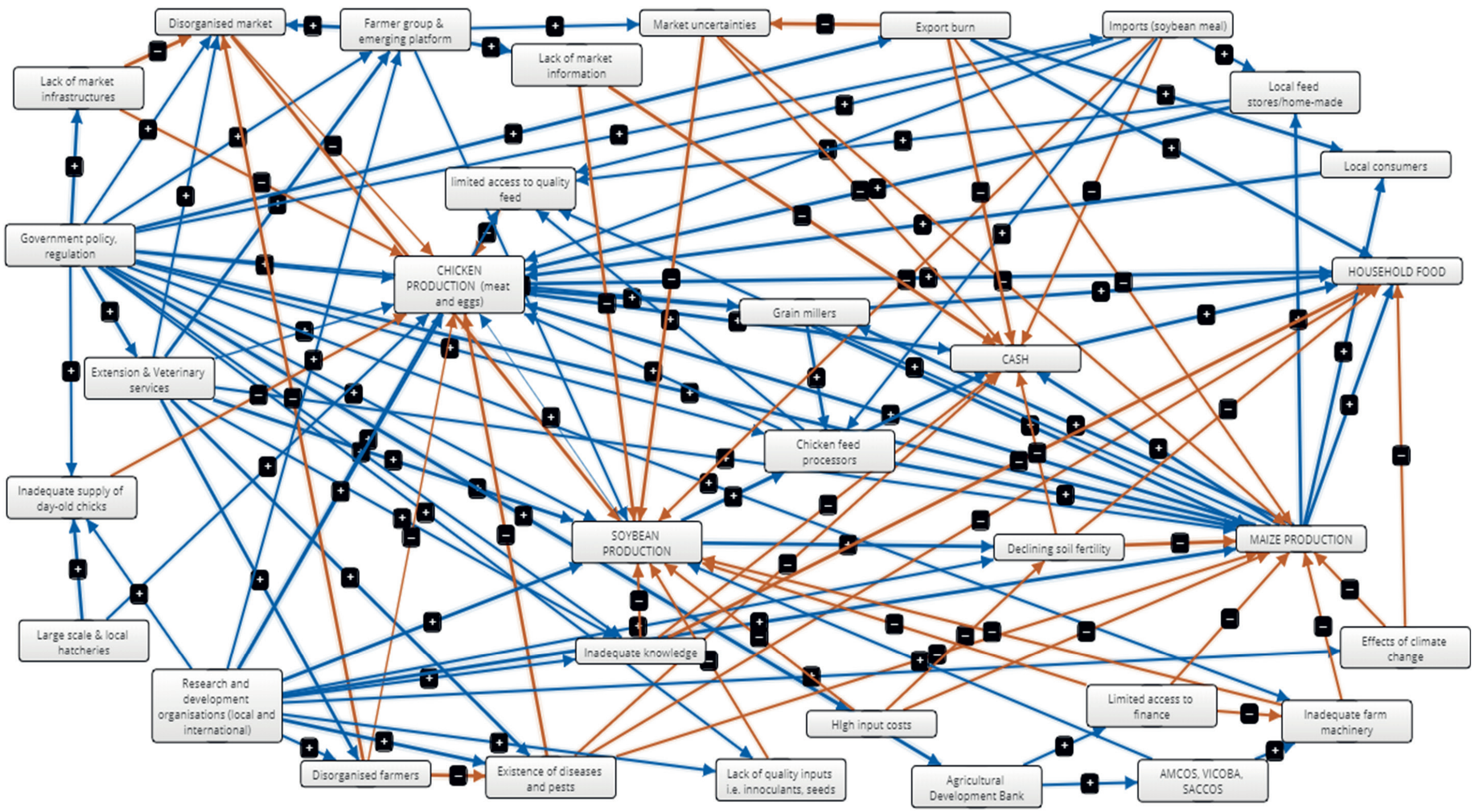

Figure A3. Stakeholders network and relationship in the integrated chicken-maize-soybean value chains using FCM. The colour of the lines indicates whether the relationship is positive (blue) or negative (orange) whereas arrow thickness indicates the strength of the relationship between the stakeholders i.e. the thicker the arrow the stronger the relationship. AMCOS stands for Agricultural and Marketing Cooperative Societies while VICOBA and SACCOS sands for Village Community Banks and Savings and Credit Cooperative Societies, respectively. AMCOS stands for Agricultural and Marketing Cooperative Societies while VICOBA and SACCOS sands for Village Community Banks and Savings and Credit Cooperative Societies, respectively.

Appendix B

Table B1. Number of chickens raised, chicken products consumed and sold in urban and rural areas of the studied study area

		Farm location	
		Urban (n=48)	**Rural (n=73)**
Number of chickens per household (mean and range)	Layers[1] (n=21)	482.80 (9-5700)	278.00 (30-600)
	Broilers[1] (n=14)	378.00 (15-994)	220.83 (47-400)
	Dual purpose[1] (n=110)	106.27 (7-500)	51.10 (2-300)
Products for sale and household consumption	Egg production/week[1*]	550.45 (4-11970)[a]	74.91 (0-950)[b]
	Eggs sold per week[1*]	496.11 (0-11940)[a]	58.29 (0-900)[b]
	Eggs retained for home consumption/week[1]	11.89 (0-30)[a]	6.76 (0-30)[b]
	Chicken sold/month[1]	17.97 (0-167)[a]	8.29 (0-61)[b]
	Chicken retained for home consumption/month[1]	1.80 (0-18)	1.22 (0-5)

[1]mean and minimum and maximum number

Different superscripts (a,b) indicates a significant difference between urban and rural at p-value ≤ 0.05 level

Appendix C

Table C1. Adult equivalent in East African countries, Source: WHO 1998

Years of age	Men	Women
0-1	0,33	0,33
1_2	0,46	0,46
2_3	0,54	0,54
3_5	0,62	0,62
5_7	0,74	0,7
7_10	0,84	0,72
10_12	0,88	0,78
12_14	0,96	0,84
14_16	1,06	0,86
16_18	1,14	0,86
18_30	1,04	0,80
30_60	1	0,82
60 above	0,84	0,74

Figure C2. Feed formulation formula for layers (a) and feed composition (b) based on the Feed Calculator App

(a)

Type: Standard Layer
LAYER Feed (For laying birds)
CP 16.5%
ME 2600 kcal/kg
Price: 811.51 / kg Date: 2023-02-16

Premix sachet 0.25% *All vitamin & trace elements*	2.50 Kg	7,072 TZS
Maize / Corn *CP 8% CFat 4.2% CFiber 2.1%*	634 Kg	466,182 TZS
Soybean meal, Standard *CP 43% CFat 3.2% CFiber 6.1%*	206 Kg	174,475 TZS
Sunflower seed cake *CP 29% CFat 11% CFiber 24%*	28.1 Kg	12,895 TZS
Bone ash *Ca 29% P 13%*	39.9 Kg	15,786 TZS
DL-Methionine (99,5%) *CP 58%*	1.14 Kg	16,085 TZS
Di-Calcium Phosphate (DCP) *Ca 24% P 18%*	56.7 Kg	112,331 TZS
Limestone *Ca 37%*	29.9 Kg	3,383 TZS
Salt	2.29 Kg	1,295 TZS

Total weight 1000 Kg

Total price 809,503 TZS

(b) Nutritional value of the feed

Type: Standard Layer
LAYER Feed (For laying birds)
CP 16.5%
ME 2600 kcal/kg
Price: 811.51 / kg Date: 2023-02-16

Nutrient		
ME	2596.9	Kcal/kg
Crude Protein	144.9	g/kg
Digestible Lysine	5.8	g/kg
Digestible Methionine	3.2	g/kg
Digestible Methionine + Cystine	5.2	g/kg
Ca	36.9	g/kg

Summary

The increasing human population in sub-Saharan Africa (SSA) implies that the demand for major cereals will increase three-fold while that of animal-sourced food (ASF) will double by the year 2050. Although initiatives are taking place to achieve SDG2 (zero hunger), food insecurity and micronutrient deficiencies are still alarming in SSA. Tanzania is among the SSA countries experiencing food insecurity due to high rates of malnutrition in many forms, largely attributed to a lack of dietary diversity among disadvantaged urban and rural households. Tanzania is a typical example of SSA country facing such challenges where limited dietary diversity has been reported among disadvantaged urban and rural poor households. Surprisingly, the breadbasket regions important for food production in Tanzania have high rates of undernutrition and micronutrient deficiency, partly due to limited dietary diversity. This thesis focused on exploring the potential of soybean-maize-chicken value chains to support the sustainable production of diversified diets and identify important entry points for value chain integration in the Southern highland zone of Tanzania.

The work presented in this thesis was part of the N2Africa project implemented in the Southern highlands of Tanzania between 2014 and 2018, aimed to improve household nutrition and cash income and to enhance soil fertility. Building from the N2Africa project findings, further research findings presented in this thesis was part of the "The Missing Middle project: Food system transformation pathways to link actions at multiple levels to Sustainable Development Goals (SDGs) particularly the SDG 2, 12, 13 and 15 in Tanzania" funded by NWO-WOTRO research program".

In Chapter 2, I employed fuzzy cognitive mapping (FCM) to understand the current soybean, maize, and chicken value chains, highlight stakeholder relationships, and identified entry points for value chain integration to support nutritious diets in three regions in the Southern highlands of Tanzania. The fuzzy cognitive maps were constructed based on information gathered during household interviews followed by a participatory workshop with stakeholders involved in the three value chains. The study revealed the importance of networks of integrated value chains in domestic markets, whereby soybean-maize-chicken value chains are interconnected particularly at smallholder farming systems and at processing facilities. Chicken feed was an important entry point for integrating the three value chains, as maize and soybean meal are chickens' main sources of energy and proteins. Unlike maize, the utilization of soybean in chicken feed was very low, mainly due to inadequate processing of soybean grain into meal. As a result, the soybean grain produced is primarily exported to neighbouring countries for further processing, and soybean meal is imported at relatively high prices. The findings in Chapter 2 proposed enhancing local sourcing and adequate processing of

soybean coupled with strengthening the integration of smallholder farmers with other soybean-maize-chicken value chain actors to improve access to nutritious food for people.

In Chapter 3, I conducted a cross-sectional survey to understand chicken farming diversity and explore the intensification gradient in the production systems in urban and rural areas in the Iringa region. In the next step, I employed a problem tree analysis based on the survey data to classify the underlying constraints and their interrelations, and to identify common root causes, based on which we propose practical solutions to improve chicken production along the intensification gradient identified in urban and rural. This study is the first to explore the diversity of chicken farming and the underlying production constraints based on the subdivision of the production systems. The subdivision of poultry systems was refined by adding the size of the flocks to highlight variations in the scale of operations.

The findings in Chapter 3 show that the degree of intensification of chicken production systems in the Iringa region was increasing with the number of improved crossbred and exotic chickens raised under the medium-large scale intensive systems, that were fed with homemade and/or commercial feeds in both urban and rural locations. Furthermore, about 30% of households had more than one breed and/or rearing system combination. The subdivision in production systems and the problem tree analysis in Chapter 3 revealed different constraints limiting chicken production depending on the types which opens the door to propose relevant packages for improving the production of meat and eggs for households and other consumers. Despite a greater management input, more intensive systems reported more disease problems implying that there should be training on improved housing and veterinary measures, particularly for the farmers intensifying to the medium to large scale production systems. Apart from the existence of chicken diseases in all the systems, the development of the medium-large scale systems is highly constrained by a limited supply of one-day-old chicks and theft, while the intensification of small-scale systems is constrained by limited access to quality feeds, vaccines and medicines, capital, and reliable output market, partly associated with lack of farmer organization. There is therefore a need for institutional support to organize producers into groups and/or cooperatives with an emphasis on training them on proper management, low-cost feed processing, group marketing and large-scale rearing of chickens. The enterprise development might be the most promising business model for the growth of smallholder chicken farming since farmers have more freedom in farm management and decision-making while they will be linked with the input suppliers and output markets to ensure a viable and profitable business.

In Chapter 4, I present the findings on feed gap analysis, where we explored the current feed gap and how the feed gap can be closed by comparing the actual feed quantity and quality supplied to dual-purpose chicken with the recommended standards. This study is the first to explore the actual production and feed quantity and quality (status quo) in the poultry industry in Tanzania unlike other studies conducted under a controlled experimental design. The findings presented in Chapter 4 highlight the need for a stronger focus on feeding strategies and ensuring the availability of suitable and safe feed formulations. The study was based on robust methods combining surveys, physical measurements of chicken and eggs, sampling of feed and laboratory analysis on micronutrient content and mycotoxin contamination. In line with the TLMP, the chapter revealed a large gap in current chicken production and highlighted the importance of closing feed gaps (both quantity and quality) to meet the increasing demand for chicken meat and eggs. The quality issues are not only related to low crude protein and essential amino acids in chicken feed rations but also to aflatoxin levels pointing at potential animal and human health risks.

In Chapter 5, I assessed land requirements to produce sufficient food of adequate nutritional quality for the current and the anticipated doubled population of the Iringa region by 2050 based on macro secondary data, and micro primary data collected in the region between 2018-2020. The actual and potential yield of the food crops grown in the region were extracted from the Yield Gap Atlas, a global open-access database. The findings of this Chapter revealed that with the actual yields for crops and poultry and a doubling in population size by the year 2050, the land requirement must increase more than two folds to produce sufficient food and feed. When only utilising suitable land with the actual yields leads to food-feed competition in most scenarios and with the increasing population, food export will be strongly reduced or no longer possible. To meet the increasing demand for food, the present study strongly recommends focusing on sustainable intensification options aiming to reduce the yield gaps in the region. Otherwise, with the current yield, producing sufficient food and feed will not be feasible without further expanding agricultural production in suitable and non-suitable land. Especially expanding in unsuitable land would require high investments in irrigation, energy use, labour, fertiliser etc.

To meet the increasing demand for nutritious food, the present study strongly recommends focusing on sustainable intensification options aiming to reduce the yield gaps in crop and poultry production. Otherwise, with the current yields, producing sufficient food and feed will not be feasible without further expanding agriculture on suitable and non-suitable land. Furthermore, access to poultry products alone will not allow consumers to have a micronutrient-sufficient diet thus more avenues need to be explored especially to increase Vitamin A and Calcium supply, which will also need land to be produced. I hope that the findings from this thesis will inform the decision-makers from regional to national levels to implement sustainable intensification options aiming to reduce yield gaps and further expansion of agricultural land to produce sufficient diverse food for the current and future population.

Acknowledgements

They say *it takes a whole village to raise a child*. One may dare to say that the process of fostering a PhD to completion is often like raising a child to school age, though it took a little bit longer for me. In my own case, I acknowledge that completing this PhD was not only possible with my dedication, but in large part due to the collective efforts of a lot of people who have in one way, or another contributed to this journey. I cannot acknowledge everyone contributing to this journey individually but will try to do my best.

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About the author

Wilson Charles was born on 7th July 1986 in a smallholder farming household in Babati district, Northern Tanzania where he obtained his primary and secondary education. He developed very early a marked interest in academia, travelling the world and farming, particularly livestock farming. He obtained his advanced secondary school certificate in chemistry, biology, agricultural science and applied mathematics from Karatu high school in 2007 and a diploma in animal production from Tengeru Livestock Training Institute, Arusha in 2009. Wilson moved to the Southern Highlands of Tanzania in mid-2009 where he started his career in providing agricultural extension services to smallholder farmers in the Njombe region. From 2014 to 2015 he worked as a cluster leader cum dairy production advisor for the East Africa Dairy Development project implemented by Heifer International before he was transferred to the Tanzania Livestock Research Institute (TALIRI) Uyole, Mbeya. Wilson obtained his BSc. degree in Animal Science from the Sokoine University of Agriculture in 2013 and an MSc in Animal sciences from Wageningen University and Research in 2017, specialising in Global and Sustainable production. Between 2017 and 2008 he worked as a Research Intern cum Consultant for the *Kb24* Resilience project implemented in the highlands of Kenya and Ethiopia while engaged with Wageningen Livestock Research. In April 2018, Wilson returned to Wageningen University to continue with PhD studies at Plant Production Systems and Animal Production Systems groups. His PhD research focuses on exploring the potential of integrating soybean-maize-chicken value chains in sustaining nutritious diets and assessing their contribution to achieving the Sustainable Development Goals (SDGs), SDG 2 in particular (Zero hunger) in the Southern Highlands of Tanzania. His research was primarily implemented under the N2Africa project, funded by the Bill & Melinda Gates Foundation, and the Missing Middle Project grant from NWO-WOTRO and the Netherlands-CGIAR Scientific Expert Programme while hosted by the International Institute of Tropical Agriculture (IITA). Besides, since 2019 he has been consulting Abt Associates Inc and coordinating the evaluation of the *AgResults* Dairy Productivity Challenge Project implemented in four coastal regions of Tanzania. Wilson is currently based in Tanzania, and he is looking forward to advancing his career in research and development in agri-food systems and value chains in the Global South. Email address: wilsoncharles018@gmail.com

List of publications

Selected peer-reviewed publications

Wilson, W. C., Dastoum, S., Oosting, S., Giller, K. E. Baijukya, F. P., & Slingerland, M (2023). Scenario analysis towards sustainable diets and their land-use needs: the case of the Iringa region, Southern Highlands of Tanzania. *In preparation.*

Wilson W.C, Slingerland M.A., Baijukya F, Giller K.E and Oosting S.N (2023). Feed gap analysis of dual-purpose chicken production in Tanzania: feed quantity and quality limited production. *Poultry Science,* Volume 102, Issue 5, *102574.* https://doi.org/10.1016/j.psj.2023.102574.

Wilson W.C, Slingerland M.A., Oosting S.N, Baijukya F, Smits Anne-Jo and Giller K.E (2022). The diversity of smallholder chicken farming in the Southern Highlands of Tanzania reveals a range of underlying production constraints. *Poultry Science,* Volume 101, Issue 10, 102062. https://doi.org/10.1016/j.psj.2022.102062.

Wilson W.C, Slingerland M.A., Baijukya F, Van Zanten H.H.E, Oosting S.N and Giller K.E (2021). Integrating the soybean-maize-chicken Value Chains to attain nutritious diets in Tanzania. *Food Security*, **volume 13**, pages 1595–1612 https://doi.org/10.1007/s12571-021-01213-4.

Other publications

Molina, P. B., D'Alessandro, C., **Wilson, W.C.,** Dekeyser, K, Msuya, J., Aiolfi, B., Maroson, M., Vaggi, G., Fontefrancesco, M.F and Zocchi, D.M (2021). Sustainable food systems through diversification and indigenous vegetables: Analysis of Tanzania's Iringa and Dodoma areas. Technical Report III. European Centre for Development Policy Management (ECDPM). Link: https://ecdpm.org/publications/sustainable-food-systems-through-diversification-indigenous-vegetables-analysis-iringa-dodoma-tanzania/.

Wilson, W. C. (2019). The Role of the Integrated Maize-Soybean-Chicken Value Chains in Sustaining Diverse Diets: the Case of Southern Highlands of Tanzania. *In* "N2Africa Podcast no. 57. PhD Student special". https://www.n2africa.org/role-integrated-maize-soyabean-chicken-value-chains-sustaining-diverse-diets-case-southern

Wilson, W.C., Nyokabi, S.N and Oosting, S.J (2017). Assessment of milk quality along the dairy value chain in Mbeya and Songwe region, Southern Highlands of Tanzania". MSc Thesis, Animal Production Systems, Wageningen University and Research, The Netherlands. Link: https://doi.org/10.5281/zenodo.4498357 or http://liquidprogram.net/index.php/related-theses-and-articles/.

Wilson, W.C., Van Reenen C.G and Lantinga, E.A (2017). Comparative evaluation of the behaviour of Jersey and Holstein-Friesian cows under European pasture-based management systems. MSc Thesis, Farming Systems Ecology, Wageningen University and Research, The Netherlands. DOI:*10.13140/RG.2.2.28686.92483. Ebook,* link https://edepot.wur.nl/477481.

Wilson, W.C and Jan van de Lee (2017). Tool selection for assessment of resilience in East Africa dairy farming. Project report, KB-22 Global Food & Nutrition Security. Wageningen Livestock Research, Wageningen, The Netherlands.

Wilson Charles Wilson (2022). Sustainability assessment of the integrated biological control of Tsetse fly (*Glossina spp*) in Sub-Saharan Africa. *Journal of Tropical Diseases & Public Health*. Volume 10, Issue 11, :358. DOI: 10.35241/2329-891X.22.10.358

Wilson Charles Wilson (2022). Control of zoonotic parasitic cestode (*Taenia solium*): sustainability assessment of potential vaccines. *A systematic review. Journal of Tropical Diseases & Public Health*. Volume 10, Issue 11 :356.DOI: 10.35241/2329-891X.22.10.356

Mwakilembe P.A.A., Mwambene P. L., **Wilson W.C** and Msangi A.A (2017). Improvement of dairy cattle productivity through genetic stabilization in the Southern Highlands of Tanzania: Enhancing Availability and Productivity of Dairy Cattle through Genetic Stabilization in Tanzania. Tanzania Livestock Research Institute (TALIRI – Uyole), Mbeya, Tanzania.

Wilson Wilson (2013). Assessment of dairy cattle production under a small-scale production system. The case of Wanging'ombe district, Njombe region. BSc Thesis, Supervised by Dr Stanley Israel. Department of Animal, Aquaculture and Range Sciences (DAARS), Sokoine University of Agriculture, Tanzania.

Conference, forum and symposium contributions

Wilson W.C, Nguyen Q, Oosting S.J, Baijukya, F.P, Brouwer I.D, Oosterveer P, Hoi P.V, Hernandez R, Giller K.E and Slingerland M.A (2023). The Missing Middle: Food system transformation pathways to link action at multiple levels to SDG 2, 12, 13 and 15 in Tanzania and Vietnam. Oral and poster presentation *In the Final symposium of the Joint SDG research programme "Tackling Global Challenges through Use-inspired Research (1st round).* KIT Royal Tropical Institute, Amsterdam, Netherlands. *Link:* https://www.nwo.nl/projecten/w-07303109-0

Wilson, W., Slingerland, M. A., van Zanten, H. H. E., Baijukya, F., Oosting, S. J., & Giller, K. E. (2019). The Role of the Integrated Maize-Soybean-Chicken Value Chains in Sustaining Diverse Diets in Tanzania. In E. Tielkes (Ed.), *Book of abstracts Tropentag 2019: Tropentag 2019 International Research on Food Security, Natural Resource Management and Rural Development:*

Filling gaps and removing traps for sustainable resources management (pp. 459-459). Cuvillier Verlag. Link: https://edepot.wur.nl/505784.

Wilson, W.C and Nyokabi, S.N (2018). Towards sustainable dairy value chains in Tanzania: the role of social networks on milk quality management. Poster presentation, CGIAR Science Forum (SF18 // 10-12 October 2018), Stellenbosch, South Africa.

Wilson, W.C., Nyokabi, S.N., and Oosting, S.J (2017). Assessing the influence of social networks on milk quality in the Southern Highlands of Tanzania. Poster and oral presentation, Wageningen Institute of Animal Sciences (WIAS day - February 6th, 2017), Wageningen, The Netherlands.

PE&RC Training and Education Statement

With the training and education activities listed below the PhD candidate has complied with the requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities)

Review / project proposal (4.5 ECTS)

- Exploring the role of the maize-soybean-chicken value chains in sustainable food systems: the case of Southern Agricultural Growth Corridor of Tanzania

Post-graduate courses (8.6 ECTS)

- Farming Systems and Rural Livelihoods: Pathways to sustainable development; PE&RC (2018)
- Meta-Analysis Using R - linear models and mixed linear models in meta-analysis; PE&RC (2018)
- International Advanced Course - Environmental Impact Assessment of Livestock Systems; WIAS (2019)
- Feeding a hungry planet: agriculture, nutrition and sustainability; WUR, EdX (2018)
- Sustainable food security: food access Sustainable food security: food access; WUR, EdX (2019)

Laboratory training and working visits (2 ECTS)

- N2Africa impact assessment study; International Institute of Tropical Agriculture (IITA) (2018)

Competence strengthening / skills courses (6.5 ECTS)

- Competence assessment; WGS (2018)
- Presenting with impact; WGS (2019)
- Project and time management; WGS (2020)
- The book publishing process; Elsevier (2020)
- The article publishing process; Elsevier (2020)
- Science communication; NWO-WOTRO (2022)
- Innovation and scaling; WUR & IITA (2022)
- The final touch: writing the general introduction and discussion; WIAS (2022)
- Writing grant proposals; WUR into Languages (2023)

Scientific integrity / ethics in science activities (0.6 ECTS)

- Scientific integrity; WASS (2018)

PE&RC Annual meetings, seminars and the PE&RC weekend (2.4 ECTS)

- PE&RC First years weekend (2018)
- PE&RC Midterm weekend (2019)
- PE&RC last year's retreat (2022)
- Artificial intelligence and sustainability (2022)

Discussion groups / local seminars or scientific meetings (7.1 ECTS)

- IITA IRSAF seminars and meetings (2018-2023)
- WaCASA and PPS lunch meeting seminars (2018-2023)
- Smallholder inclusiveness in the palm oil supply chain (2020)
- Advances in legume science and sustainability: association of applied biologists webinar (2021)
- Salmonella control measures in feed: world veterinary association webinar (2021)
- Sustainable Intensification of Agricultural Systems (SIAS) meeting (2022-2023)

International symposia, workshops and conferences (7.95 ECTS)

- WIAS Day poster presentation and pitch; WUR, the Netherlands (2017)
- SDG Conference Foodathon - Greenovators, Youth4Youth; WUR, the Netherlands (2018)
- Sustainable Agri-food Systems Strategies (SASS) workshop; Arusha, Tanzania (2018)
- The Missing Middle and N2Africa project meetings and workshops; Tanzania, Vietnam & the Netherlands (2018-2023)
- Tropentag Conference; Kassel, Germany (2019)
- Right Livelihood College and Biovision Africa Trust workshop; Nairobi, Kenya (2022)

Societally relevant exposure (0.3)

- N2Africa podcast (2019)

Lecturing/Supervision of practicals/tutorials (0.15 ECTS)

- Analysing sustainability of farming systems (2021)

BSc/MSc thesis supervision (6 ECTS)

- Why production does not meet consumption: poultry farming in the Iringa region of Tanzania
- Evaluation of the quantity and quality of the chicken feeds in relation to the performance of dual-purpose chickens in Tanzania

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